CRANFIELD UNIVERSITY

Mrs Emma S Sparks

FROM CAPABILITY TO CONCEPT: FUSION OF SYSTEMS ANALYSIS TECHNIQUES FOR DERIVATION OF FUTURE SOLDIER SYSTEMS

DEFENCE COLLEGE OF MANAGEMENT AND TECHNOLOGY

ENGINEERING SYSTEMS DEPARTMENT

PhD THESIS

Blank Page

CRANFIELD UNIVERSITY

DEFENCE COLLEGE OF MANAGEMENT AND TECHNOLOGY

ENGINEERING SYSTEMS DEPARTMENT

PhD THESIS

Academic Year 2006-2007

Mrs Emma S Sparks

FROM CAPABILITY TO CONCEPT: FUSION OF SYSTEMS ANALYSIS TECHNIQUES FOR DERIVATION OF FUTURE SOLDIER SYSTEMS

Supervisors: Dr CA Couldrick, Dr MJ Iremonger, Dr Derek Allsop

November 2006

This thesis is submitted in partial fulfilment of the requirements for the Degree of PhD

Blank Page

ABSTRACT

The intent of this thesis is to define a set of processes for use within UK Government dismounted soldier systems research that will provide stakeholders with auditable and traceable information to understand gaps in military capability and justify future procurement decisions. The need for this approach is linked to organisational shifts within the UK Ministry of Defence, and more specifically Government research with the move towards procurement of capability rather than equipment. In conjunction with reducing defence budgets and increased scrutiny, there is a need to prioritise spending to those areas that will provide the most significant enhancement to operational effectiveness.

The proposed process suite provides underpinning data to support Government decisions, from definition of military need through to concept design and prioritisation of future research activities. The approach is grounded in the field of systems thinking and systems engineering providing the logical and systematic constructs required for highly complex systems where the human is a central focus.

A novel fusion of existing systems tools and techniques enables both subjective data from domain experts and objective data in the form of operational analysis and field trials to be utilised for analysis across the five NATO capability domains, with output defining the relative importance of survivability, sustainability, mobility, lethality and C4I in the context of operational and strategic level military goals as well as wider challenges represented by the doctrinal defence lines of development.

Future developments should include alignment with developing pan-MoD initiatives in the form of MODAF, if required by the customer organisation. This would enable generic versions of the process suite to be applied to any defence domain and problem.

Blank Page

ACKNOWLEDGEMENTS

A PhD is intended to be a journey of self discovery and I feel that this has certainly been the case. It has confirmed to me the type of person I am, as well as showing a few others my true nature. Without the following people the journey would have been rockier or less enjoyable and for that I thank them.

Primarily, I thank Dstl as my former employer and initial funding stream for my research. If I had not taken the post at Fort Halstead things would have been very different, and it is unlikely that I would have realised my goal of doctoral research. Of particular note has been the support of Mr Alan Moss as a mentor, friend and sounding post, without which I would have lost my sanity and direction frequently. Mr Paul Cook for his support and advice on statistics and general hard work and diligence within the Operational Clothing and Textiles Programme, which provided the need for my research; and Mr Andrew Sims for his continued involvement even after I left the organisation to join the world of academia.

To my thesis panel, Dr Mike Iremonger and Dr Derek Allsop for their wisdom, support and encouragement; and especially to my supervisor Dr Chris Couldrick, for giving up his own time on several weekends and very late into the night to make sure I got to the finish. In the final stages thanks also goes to Mr Rick Adcock for providing the technical scrutiny I needed, and making me realise there are always people there to help.

To my colleagues within the Centre for Systems Engineering for providing normality during crazy times and giving me inspiration within my field; and to my boss for recognising my potential.

Finally to my family and friends for making me who I am and allowing me to chase my dreams, and my husband Simon for tolerating someone that is so driven, it sometimes scares even me.

Blank Page

CONTENTS

Blank Page

LIST OF TABLES

Blank Page

LIST OF FIGURES

GLOSSARY

Abbreviations & Terms

AHM	Analytic Hierarchy Method
ATDU	Army Trials and Development Unit
ATRA	Army Training and Recruitment Agency
C4I	Command, Control, Communication, Computing and Intelligence
CAEn	Close Action Environment
CAP	Capability Audit Plan
CHS	Centre for Human Sciences
DC IPT	Defence Clothing Integrated Project Team
DEC (ALM)	Directorate Equipment Capability: Air & Littoral Manoeuvre
DEC (AWB)	Directorate Equipment Capability: Above Water Battlespace
DEC (CCII)	Directorate Equipment Capability: Command, Control and Information Infrastructure
DEC (DTA)	Directorate Equipment Capability: Deep Target Attack
DEC (ISTAR)	Directorate Equipment Capability: Intelligence, Surveillance, Target Acquisition & Reconnaissance
DEC (NBC)	Directorate Equipment Capability: Nuclear, Biological, and Chemical
DEC (SP)	Directorate Equipment Capability: Special Projects
DEC (TA)	Directorate Equipment Capability: Theatre Airspace
DEC (GM)	Directorate Equipment Capability: Ground Manoeuvre
DERA	Defence Evaluation and Research Agency
DGR&T	Director General Research & Technology
DGSA	Director General Smart Acquisition
DLO	Defence Logistics Organisation
DMO	Defence Materiel Organisation
DPA	Defence Procurement Agency
Dstl	Defence Science and Technology Laboratory

ECC	Equipment Capability Customer
FBG	Future Business Group
FIST	Future Integrated Soldier Technology
HFI	Human Factors Integration
IA	Integration Authority
INM	Institute of Naval Medicine
IPME	Integrated Performance Modelling Environment
ITDU	Infantry Trials and Development Unit
JDCC	Joint Doctrine and Concepts Centre
JETL	Joint Essential Task List
MoD	Ministry of Defence
MOE	Measure of Effectiveness
MOP	Measure of Performance
NATO	North Atlantic Treaty Organisation
NEC	Network Enabled Capability
NGT	Nominal Group Technique
OA	Operational Analysis
QFD	Quality Function Deployment
R&PS	Research and Project Support
RAF	Royal Air Force
RAO	Research Acquisition Organisation
RIB	Rigid Inflatable Boat
RM	Royal Marines
SAM	Sweating Articulated Manikin
SME	Subject Matter Expert
SoI	System of Interest
SRD	System Requirement Document
SSDM	Sustainability System Dynamics Model
SSIA	Soldier System Integration Authority
SSM	Soft Systems Methodology
STT	Strategy to Task
TLB	Top Level Budget

UK	United Kingdom
UOR	Urgent Operational Requirement
URD	User Requirement Document
US	United States
Weltanshaung	German for 'World View'
WSoI	Wider Systems of Interest

Definitions

Boundary	Natural or artificial separations or divisions between adjoining properties to show their limits.
CADMID	UK Defence Procurement Agency acquisition lifecycle comprising Concept, Assessment, Development, Manufacture, In-Service and Disposal.
CATWOE	Part of Checkland's Soft Systems Methodology: mneumonic comprising Clients, Actors, Transformations, World view, Owners and Environment.
Customer 1	Central government budget holder for MoD research programmes.
Customer 2	Military customer (end user) for research and equipment.
Downey Cycle	UK procurement approach that pre-dated Smart Acquisition
Faster, Cheaper, Better	UK Defence Procurement initiative to ensure that the right equipment is procured on time and within budget.

Lifecycle	A course of developmental changes through which a system passes, from its conception to the termination of its use and subsequent disposal.
Lines of Development	Comprising of Training, Equipment, Personnel, Information, Doctrine and Concepts, Logistics, Organisation and Infrastructure.
MANPRINT	US study to understand catastrophic equipment failures caused by human attributes.
NATO Capability Domains	Comprising of Lethality, Survivability, Sustainability, Mobility and C4I.
Stakeholders	Individual or group that has an interest or influence in relation to the system of interest.
System	"A system is an open set of complimentary interacting parts with properties, capabilities and behaviours emerging from the parts and from their interactions" Hitchins.
Validation	Building the right system.
Verification	Building the system right

‘Twenty years from now
you will be more
disappointed by the things
you didn’t do than by the
ones you did. So throw off
the bowlines. Sail away
from the safe harbour.
Catch the trade winds in
your sails. Explore. Dream.
Discover.’

Mark Twain

Blank Page

CHAPTER 1: INTRODUCTION

1.1 AIM

To provide context to the pursuit of the research question.

1.2 OBJECTIVES

- Define the scope of the thesis
- Bound the problem
- Provide justification for pursuit of the topic
- Define the relationship between the thesis chapters
- Describe the shortfall in the current UK MoD research strategy with regards to Soldier Systems

1.3 THESIS DEFINITION

The intent of this thesis is to define a set of processes for use within Government soldier systems research that will provide stakeholders with auditable and traceable information to understand gaps in military capability and justify future procurement decisions. The need for this approach is linked to organisational shifts within the Ministry of Defence and more specifically Government research. Reducing budgets are forcing central fund holders to question what research is really needed and who should deliver it. Previously disparate Government research organisations are undergoing rationalisation as well as facing competition from industry system houses that are seen as single source providers. It is no longer the case that multiple pieces of equipment are conceived and made by multiple organisations, often with repeated effort. The new focus is what do we really need? Where are the gaps in our knowledge? How do we address these two key questions?

The processes and analysis devised supply underpinning data to answer these questions, from definition of military need through to concept design and prioritisation of future research activities. The approach taken is grounded in the field of systems thinking and systems engineering as this provides the logical and systematic constructs required for problems exhibiting high levels of complexity. In order to justify the pursuit of this topic there is a need to understand the fundamental premise behind 'systems thinking' and why application is required within the defence research context.

1.4 BOUNDING THE PROBLEM

Many subtly different definitions of what constitutes a system exist, (Weinberg, 1975, Flood & Carson, 1993, Hitchins, 1992) with overall consistency in the opinion that any system comprises a set of interacting elements working towards a common goal or purpose within a given environment (Skyttner, 2001). Further fundamental attributes must be displayed in order to classify a number of elements as a system, including boundary, holism, complexity and emergent properties (Flood & Carson, 1993). To illustrate some of these concepts based on a number of assumptions we can consider a modern motor car. The common goal that the system is working towards could be the transportation of people or goods around a road transport network. The car itself has a number of sub components i.e. the engine, transmission and steering which function in their own right, but only transport people and goods around the road transport network when placed together. The way in which the components/ sub-systems work together provides utility that is greater than the sum of the parts.

A modern motor car, with high levels of complexity born out of rapid advancements in technology is a good example of why systems' thinking has developed over the last twenty to thirty years. In early years of system design projects would often be controlled by one individual with concept design based upon knowledge and experience. This was possible as the knowledge required could be contained within one person's head and translated into a system through skilled individuals, usually working within the same building. With advancing technology, there has been a progression towards increasing numbers of components, with large teams, often geographically separated, and complexity of design that is beyond the capability of one individual to understand. When bringing together the ideas of many experts in order to design a system, there is a need to define an approach that ensures completeness and manages complexity to reduce the likelihood of poorly integrated or failed end-products. With the increasingly diverse nature of the specialisms that must be brought to bear, a common language such as systems engineering aids communication and understanding.

Public and private sector businesses and organisations are having to reduce expenditure on large scale systems due to a fluctuating economic climate. Using systems thinking and systems engineering enables whole life, system issues to be understood and managed through a logical and systematic breakdown of problems, with the intent of reducing risk and exposing long term cost implications. Governments and more specifically defence departments on both sides of the Atlantic are realising that these tools and techniques are equally applicable to design and procurement of high value military assets that continue to be plagued with time and cost overruns (Cordesman, 2005).

The world of defence is changing, driven in part by pressures from the wider environment (society, politics and money), but also as a consequence of shifts in strategic-level military doctrine. The face of warfare has and is different, with the dissolution of the Soviet Union in late 1991 (Suraska, 1998) and the start of the first Gulf War in January 1991 (Finlan, 2003). The Western Front and the Cold War do not provide the impetus for military equipment, with the likelihood of the 'front line' being far further from home, operating 24/7 and being far less distinct in nature.

In both 1999 (Director Infantry) and 2000 (Director Infantry) the Director Infantry issued pamphlets indicating the revised objectives of not only the Army, but all three forces. It states that the 2020 vision is to be able to 'carry out integrated, high tempo, combined, joint, multi national, inter agency, full spectrum combat operations, with a high degree of effectiveness, at short notice and with endurance, and be able to adapt through a seamless spectrum of conflict prevention, conflict and post conflict activities' (Director Infantry, 2000).

The level of flexibility described in the 2020 vision poses significant challenges not only to the Armed Forces, but to the organisations responsible for procuring military equipment, as it shifts the emphasis from platforms to people as the key enabler. The soldier becomes the lowest common denominator in the success of most other military hardware and software. In delivery of 'effect' the soldier will have to utilise skill in combination with equipment and platforms to bring about defeat of the enemy (Director Infantry, 2000).

Having often been an afterthought in the design of military platforms (Booher, 1990) the soldier has become integral to success. Examples of poor integration have pervaded the dismounted domain in both the fields of clothing and equipment (Vang, 1991) . To date the approach to R&D/ procurement has been piecemeal with optimisation of individual items, often at the expense of the effectiveness of the whole (Blackwell, 1993). This has led to undesirable emergent properties; an example of which is the incompatibility of body armour and helmet, with the soldier unable to sight the weapon in the prone position due to impingement caused by their personal protection (Haisman, 1975).

Although research organisations have long been aware that changes needed to occur in the scoping of future systems (Stephenson & Cross, 1995) it was not until the Strategic Defence Review (HM Stationary Office, 1998) that Government mandated reform. Formal recognition of reducing budgets and increasing levels of military intervention, most notably for peace keeping and peace enforcement meant that procurement objectives had to change. Replacement of platforms was out, ‘capability’ was in, scrutiny was up, and budgets were down; a trend that continues today. The challenge was and continues to be, how do we know what we need to provide in order that the Armed Forces can do their job more effectively, and how do we measure this thing called ‘capability’?

Taking the dismounted component of the three services in the context of the Armed Forces there is a strategic trend towards fighting unknown threats in diverse theatres with a reduced ability to move into theatre due to geographic location[1]. These dismounted forces have a number of goals at strategic through to operational level which they cannot achieve in isolation. Interfaces exist with other platforms to move around the theatre of operation, logistics support to re-supply provisions and training to make sure the job is done effectively. Personal protection to survive the environment and potentially enemy action as well as something to provide the ability to hold ground, in some instances with deadly force. Which element do we change to enhance soldier effectiveness? And how do we measure the level of effectiveness achieved?

By embracing a systems approach to soldier needs, whole system through life implications can be addressed through systematic breakdown and logical enquiry. The starting point is capability which forms the main Government focus with five domains defined by NATO (1999), consisting of lethality, C4I (command, control, communication, computing and intelligence), mobility, sustainability and survivability. These domains represent both technology and the human and can therefore be classed as socio-technical (Hitchins, 1992); fusing engineered, quantifiable elements with dynamic, unpredictable and un-quantifiable humans (Waring, 1996). Any approach must therefore account for the humans' ability to modify the behaviour of the overall system/s either positively or negatively as they are pivotal to success.

The United States have recognised for a number of years that the soldier is the key component within wider battlefield effectiveness, as their ability impacts the use of other systems critical for mission success. MANPRINT (Booher, 1990) looked at the impact of the soldier on the use of other pieces of military hardware and concluded that insufficient consideration had been given for human characteristics within the design cycle. This has led to the failure of a number of highly valuable pieces of equipment, in some cases with catastrophic effect (Wheatley, E., 1991). The UK are now following the American trend (Future Force Warrior) with the introduction of Future Integrated Soldier Technology (FIST), which has been heralded as the first time that systems engineering techniques have been employed within the context of soldier equipment (Dooley, 2000). It is intended that FIST will provide a holistic solution, without pre-conceptions of what should be procured and producing something that is properly integrated with other equipment. Wider implications have been explored in the areas of personnel and organisational impact (Bowyer & Martin, 2003) as well as the effect of any FIST system on social interaction and military team performance (Flower et al., 2001). Measurement of the success of any concept system in delivering increased

---

[1] www.jdcc.gov.uk Strategic trends paper on the Joint Doctrine and Warfare Centre website.

effectiveness has been a major thrust of the programme with measures of performance and effectiveness from component and sub-system, through to system and ultimately mission success or failure (Dooley, 2000). This is intended to provide an audit trail of decisions, and the way in which requirements have been addressed. It is believed that, by standardisation of the test methods, repeatability will be achievable and trade off analysis can be carried out.

Although the FIST programme has defined the five capability domains within which the soldier system should provide effectiveness, work to date has only investigated the lethality and C4I domains without full consideration of their wider impact. It is the author’s contention that this lacks the high level context that is carried out in the early stages of systems thinking to really understand the problem that needs to be addressed. Within the FIST programme rather than defining gaps based upon auditable and traceable data a number of assumptions have been made based on current operations. This has led to a lack of clear requirements for research and procurement of equipment across the domains underpinned by clear evidence of military need and supporting background information. With the intention of the Government to provide the Armed Forces with enhanced effectiveness through procurement of equipment that has been traded off across capability domains a clear front end understanding, with sound processes must be implemented to ensure completeness and an audit trail of decisions linked to military need.

It is the intention of this thesis to define a set of processes that are capable of producing clear direction for future soldier systems based on robust supporting evidence, as well as identifying gaps in current knowledge and capability.

1.5 THESIS STRUCTURE

The chapters have been devised to take the reader progressively through the development of the processes reflecting the logical and systematic way in which systems thinking should be applied. Several elements are broken out further in discrete chapters to reflect the novel application of systems methods and tools in answering the research question. Case studies are then explored to draw all of the chapters together and provide rigour before discussing the utility of the thesis output. Original knowledge is presented most specifically within chapters 5-9.

Chapter 2 provides the context for pursuit of the research question. Underpinning systems theory is discussed and the development of the field explored. This leads to the defence context and the perceived need for application of systems tools and techniques within this domain. The remainder of the chapter focuses on the tools and techniques that can potentially be employed for exploration of the problem space with a discussion of their relative strengths and weaknesses. This will identify the gap in knowledge that exists leading to the research aims.

Chapter 3 develops the research aims providing justification for the thesis approach/ methodology based on the shortfalls defined in chapter 2.

Chapter 4 is concerned with bounding the problem space, defining those areas that sit within and outside of the direct control of the stakeholder community. The task of managing complexity stems from understanding where and with whom responsibility lies. Even where direct control does not exist the identification of these areas ensures that external factors do not negatively impact successful delivery of a system of interest.

Chapter 5 constitutes the most significant portion of original contribution to knowledge with the definition of the process suite that has been devised to answer the research question. The next two chapters (6 and 7) break out specific elements of the process for further discussion.

Chapter 6 looks at the trade off approach and use of data collected as part of chapter 5 in carrying out this detailed task. The trade off represents one of the most complex areas of systems application with the need to develop a method that is robust and enduring against the desire for some stakeholders to skew results according to personal preferences.

Chapter 7 develops the area of measuring performance, which is central to determining if systems concepts meet the defined needs of the stakeholders. For soldier systems this presents a unique set of challenges with the decision on whole system versus sub-system test and the applicability of classic reductionist laboratory testing compared to field testing with difficulties in attributing outcome to specific variables.

Chapter 8 brings together chapters 5-7 by applying the processes to representative case studies. This exhibits the robustness of the processes when applied to the domain of interest in addition to identifying areas for future development across multiple fields of research.

Discussion of the work forms chapter 9 with conclusions and recommendations contained in chapter 10.

1.6 INTRODUCTION SUMMARY

System complexity has continued to increase with advances in technology leading to the need for systematic processes that can bring together large inter-disciplinary teams.

Within the defence context the use of systems thinking is new and the Future Integrated Soldier Technology Programme represents the first occasion that the soldier has been considered as pivotal in the use of equipment to deliver effect.

This change in thinking is partly driven by America who conducted a major study to determine the reasons for defence equipment failing catastrophically. Results concluded a lack of consideration for the skills of the operator as a root cause.

Within the UK the move towards procurement of defence capability rather than equipment is a step change in thinking. Whereas previously a more advanced version of an old system would be purchased the focus now is, ‘what is really needed to do the job more effectively’?

This thesis will provide a set of processes underpinned by robust evidence for definition of future soldier systems and associated research activities.

Blank Page

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 Aim

To provide justification for the pursuit of my research topic based upon exploration of existing literature.

2.1.2 Objectives

- Provide background to defence and more specifically the soldier as my domain of interest
- Describe the underlying premise of systems thinking
- Discuss the context and application of systems thinking to defence and more specifically soldier systems as my domain of interest
- Critically review literature relating to my domain of interest
- Articulate the gap in knowledge.

2.1.3 Setting the scene

The context of my study is the defence domain and more specifically defence research which has been a documented activity since the First World War (Bud & Gummett, 2002), but exhibiting largest growth in the 1950's and beyond (Working Party of the Council for Science and Society, 1986). Successes in the Second World War using operational analysis techniques to optimise bombing runs over Germany, as well as rapid technological development in weapons such as the atom bomb has led to Britain becoming one of the largest and most consistent international spenders in the area of defence equipment (Matthews & Parker, 1999). With technological advancement has come increasing levels of system complexity which has led to the development of new disciplines such as systems engineering to manage large defence and private sector programmes. Post-war, saw hardware as the focus; guns and tanks, planes and ships to stop an invasion from the western front (Dunnigan, 2003), with secondary importance placed on the role and impact of the soldier/ operator. This latter system component exhibits dynamic complexity and unpredictability, which may cause total system failure without due consideration of potential behaviour (Townshend, 1997). The statement, ‘your system is only as good as its weakest link’ still holds true today when considering human related systems, which are seen as open in nature (Patching, 1990). Unlike a manufactured system a human cannot be optimised as their response to situations is not consistent (Booher, 1990). The skills and ability of the soldier/ operator has a direct relationship with effectiveness of the engineered system with man and machine representing a socio-technical coupling (Hitchins, 1992).

To date, little success has been achieved in learning from the mistakes of the past when designing for the future, especially in the context of the dismounted infantry, as a soldier subset (Lothian, 2004). Taking the individual soldier as my specific system of interest, as the central component to defence system success, it appears critical to evaluate and understand the characteristics of the soldier as a system in order to subsequently optimise equipment for their use. There is a requirement based on Government need to capture operational lessons learnt and apply them in some logical and systematic manner to ensure the procurement of the most appropriate mix of equipment and support in order to carry out the tasks and activities associated with the dismounted infantry more effectively. This is grounded in a systems approach which considers the very widest implications of a problem and how to define it. The following chapter explores the development of system theory and practice as a discipline along with reasons for applying specific techniques to the systems of interest and the domain of defence within which it resides.

2.2 SYSTEMS THINKING

2.2.1 The rise of systems thinking

Central to any discussion on the application of systems thinking is the requirement to define the meaning of the term. There is no one universally accepted statement with a number of systems practitioners suggesting possible alternatives (Capra, 1997, Kauffman, 1996). However for the purpose of this thesis, Hitchin's, 1992, definition will be used as an appropriate expression of any form of system “A system is an open set of complimentary, interacting parts with properties, capabilities and behaviours emerging from the parts and from their interactions".

Systems' thinking provides the tools to make sense of a complex world through use of exploratory techniques. It is the rise in complexity (mostly due to technology) as well as gaps in scientific reasoning that have driven the expansion and subsequent proliferation of the discipline of systems thinking with a desire to reduce uncertainty and apply methods of enquiry that are rigorous and formalised (Flood & Jackson, 1995). The routes of change created by more classical scientific fields are investigated in the following sections to provide the context of applicability to defence and more specifically soldier systems as my chosen domain.

2.2.2 Philosophical standpoints

The philosophy of scientific reasoning provides the basis for the emergence of systems thinking, with debate over methods of enquiry for systems, spanning hundreds of years (Okasha, 2002). Two distinct schools of thought have existed within science. One is the mechanistic approach, believing everything that occurs is determined by something which preceded it. The other is the vitalist approach where mysterious forces are said to inhibit complex systems (Flood & Jackson, 1995). The majority of enquiry upon which these two approaches are based relates to human biological systems which have great parallels to the generic field of systems thinking as they are highly complex in nature (Senfelder, 1911). Over time the polarity of mechanistic and vitalist views has mellowed based on continued learning and enquiry, but staunch advocates of either group are still sceptical of the other's fundamental principles, causing the debate to continue (Hein, 1972). It is in the central ground between the two extremes that systems thinking finds support, with the notion of emergence (Broad, 1925).

A mechanistic approach adheres to analysis and reductionism, believing that the whole represents the sum of the parts enabling experimentation to break down variables to a point at which they can be measured (Flood & Jackson, 1995). Falsification of a hypothesis forms the basis of this testing where cause and effect can be attributed. Popper (2002) was a great advocate of this line of scientific enquiry where '*every* *genuine test of a theory is an attempt to falsify it, or to refute it. Testability is falsifiability.'* However this fails to account for many phenomena in biological sciences, such as cognition (Keleman, 1999). Furthermore it presents a very restricted and negative viewpoint, only reinforcing when something fails, or has an inability to perform, rather than documenting observations and inferring conclusions, a practice known as inductive reasoning (Okasha, 2002).

Equally, vitalism has potential difficulties in application due to the extreme opposite views, that also fail to adequately describe all forms of system behaviour (Emmeche et al., 2000). It is the contention of vitalism, that forces external to the system govern, and as such the notion of vitalism becomes irrefutable because it cannot be tested (Edwards, 1967). It applies objectivity to enquiry with reinforcement of concepts based on confirmative observations. However, Popper argues that it is easy to find confirmation or verification if you are seeking it, with speculation potentially leading to mistruths (Senfelder, 1911). At what point does confirmation/ verification transition the line of enquiry to fact? If you cannot determine direct cause and effect through test how can you ever know if something is true? Empiricism requires experiment or experience as a basis for credence and yet this very notion represents both vitalist and mechanistic tendencies based upon the values and beliefs of individuals that may vehemently oppose one another (Hein, 1972). Therefore consensus will never be reached on the suitability of one line of enquiry over another, a debate that will be revisited later in the chapter.

It is the concept of emergence that not only supports systems thinking in a generic sense, but also helps to explain characteristics of human complexity (the foundation of the systems of interest for this thesis), with many emergenist thinkers coming from the fields of chemistry and biology (Mill, 1843, Broad, 1925, Alexander, 1920). It was George Henry Lewes (1875) that gave emergence a philosophical standpoint stating that '*emergent entities (properties or substances) 'arise' out of more fundamental entities and yet are 'novel' or 'irreducible' with respect to them.'* The notion that the whole is greater that the sum of the parts (Smuts, 1973) became the foundation for new thinking in the form of general system theory (Bertalanffy, 1968) underpinned by Boulding (1964). In terms of the soldier as a system of interest this form of thinking recognises that the provision of optimised pieces of equipment will not necessarily lead to the same end result in every situation. Test of equipment, for instance a weapon and identification of performance characteristics, (accuracy as an example), does not mean that when used by the soldier the target will be hit on every occasion, as the behaviour of the soldier may not be consistent. The whole is greater than the sum of the parts because things will emerge from use as a whole system that would not happen in isolation. You cannot determine in advance what will happen when all system components are used as one in the context of an open system.

Recognition was given by the early 1920's that science and particularly biology as a discipline was imposing reductionist rather than systems thinking upon its very structure, with multiple disciplines and sub-disciplines with poor lines of communication and replication of effort (Bertalanffy, 1968). The concept of General Systems Theory is still driven by science, focusing on integration of scientific disciplines, concerned with measurement (Skyttner, 2001) but the intent is to create a framework of models, principles and laws that apply to generalised systems to overcome the previously poor communication between disciplines (Bertalanffy, 1968).

Although helping to found the systems approach movement, Bertalanffy's (1968) ideas are still very much towards a mechanistic standpoint which can be viewed as systematic in nature (Buede, 2000). It is the difference between the terms systematic and systemic that set apart the systems theories and practices that will be explored in the following section. General Systems Theory underpins a systems approach within which several distinct components exist including systems analysis and systems engineering (Skyttner, 2001). These areas are set apart by the methods that are applied, most of which are a legacy of the original creators. For instance systems engineering is generally very process driven focusing on systematically dealing with problem situations (Buede, 2000) with the desire to create a product at the end of the cycle. This has largely grown out of the aerospace industry, with foundations in the Second World War through mathematical optimisation and scheduling of bombing runs as discussed earlier in the chapter (Bud & Gummett, 2002). Systems engineering is systematic in nature and is mainly concerned with process and methodical application of tools and techniques to ensure delivery of a product within cost and time targets to a particular performance specification. In essence it looks to eradicate inadequacies in system design and implementation (McGraw Hill, 1998).

Systemic thinking links more to systems thinking and exploration of the 'problem space'; the pattern that holds together or integrates a phenomenon (Johanessen et al., 1999). The concept formally came into being during the 1950'and 60's at about the same time as a massive expansion in defence research (Bud & Gummett, 2002). It can be described as emergenist in nature (Weiner, 1947) with the emphasis on relations within and among systems (Harrington, 1991), with the need to continually view the parts and the whole in context (Maturana, 1981). Systemic thinking considers the widest implications of a system and the environment within which it exists, proposing that connections exist between systems and sub-systems causing impacts upon one another (Johanessen, 1996). As a concept it strongly supports the contention that you cannot understand emergence by means of reductionist analysis (Bateson, 1972), you have to look at the wider functions to explain the system in focus (Beer, 1981). In the context of the soldier there is a need to understand the equipment with which they operate in order to make judgements on the specific impact that this may have on them as the system of interest.

Investigation of the problem space from either a systematic or systemic viewpoint requires more detailed methodologies to be considered with associated tools and techniques (Waring, 1996). There are many options to consider with the need to narrow the field of discussion to specific tools for the domain of interest, in line with the author's experience. It should, however, be recognised that judgements or assumptions based purely upon knowledge and experience have created one of the downfalls of defence research and procurement, introducing risk into programmes (Controller and Auditor General, 1999). This can be translated further, to the consideration and development of theories and methods in general. Theory is based upon higher theory, which at its highest level is the theory of reality (Smith, K, 1984). Therefore any theory is based upon the world view of the person creating it, and the acceptance of that view by others, both of which are driven by knowledge and experience (Keleman, 1999).

This theme will be frequently re-visited within the thesis to understand the impact of imposing personal views upon decisions and application of concepts. The theory that will be discussed in the next section is a sub-set of what has been developed within the field of systems thinking based upon the author's world view, a component of Checkland's (1981) soft systems methodology. Similarly, the reader's belief or non-belief in the processes developed as part of this thesis will be based upon their world view, and so a fundamental challenge behind any defence or social problem under exploration is acceptance by the wider population, therefore highlighting the need for effective management of stakeholder expectation.

2.3 SYSTEMS THEORY

It is not the intent of this section to provide a detailed account of all systems theory that has emerged over a number of years. Furthermore it is not intended that 'hard' and 'soft' systems methodologies will be described in detail as these relate more directly to my area of interest. My focus is to understand the components of these approaches which reflect the challenges of my domain of interest and express gaps that my thesis is intended to fill through application to a specific problem.

2.3.1 Hard versus Soft Systems Methodology

In the previous section the emergence of systems thinking and systems engineering are described in the context of wider scientific exploration. Although both contribute to the understanding and scoping of complex problems and subsequent solutions, the underlying premises are distinctly different. It is the contention of some authors (Checkland & Scholes, 1990) that systematic thinking and the discipline of systems engineering uses processes and measurement applied to real world systems, whereas systemic thinking looks at the system through more abstract modelling and representation. The terms 'hard and 'soft' systems methods in their crudest sense could be applied to systems engineering and systems thinking or systemic and systematic approaches respectively. When defining a hard problem it tends to be well defined and quantifiable with the intent of improving or optimising performance, whereas soft systems are generally non-quantifiable and ill-defined with humans as a central component (Waring, 1996).

Systems thinking is concerned with scoping the problem space without preconceptions of what the solution may be, which fits well with Checkland's (1981) Soft Systems Methodology (SSM). The concept (SSM) is abstract in nature and is concerned with exploration of the problem space using diagrams and models to provoke discussion outside of the 'real' world (Checkland & Scholes, 1990). It represents problems that exhibit dynamic complexity in the form of humans and is linked directly to action research where progression of the methodology is through feedback from applied usage (Checkland, 1979). Conversely systems engineering is a 'hard' discipline in terms of the processes and measurement techniques employed to determine effectiveness. The focus is far more on the optimisation of systems and sub-systems with specific performance parameters determined at the outset. Models are analytic in nature concerned with real world measurable issues based on physical laws rather than abstract exploration (Ackoff, 1962).

However, even if a problem can be defined as 'hard' in nature it still has to be implemented (in general) by a company or organisation that exhibits all of the characteristics considered within soft systems thinking; therefore if a hard systems approach does not consider soft systems issues it is equally as likely to fail (Smith, A et al., 2004). An example given by Checkland and Scholes (1990) is the Challenger shuttle disaster where a technical fault caused catastrophic failure after launch resulting in the loss of the entire crew. This was seen as a technical fault which we could link to the need for a systems engineering approach, and yet it is likely that the real problem related to the political and social pressures to launch on time which were a consequence of soft systems issues (Presidential Commission on the Space Shuttle Challenger Accident, 1986) and (Vaughan, 1996) as cited in (Holloway, 1999). Similarly in a defence context, one can optimise a soldier system, but have changes dictated based purely on political and social pressures. An example is the optimisation of body armour based on the need to be mobile and therefore light, balanced against the unacceptability of soldiers being killed, consequently causing protection levels and weight to increase.

It may be a hard engineered system, but the pressures exerted on the fielded article have a number of more complex sociological elements applied to them, in addition to the perception from the user themselves (Nanson, 2000).

2.3.2 'Hard' and 'Soft' systems techniques

The techniques applied within a 'hard' and 'soft' context reflect the difference between achieving a pre-determined aim and defining options for improvement (Patching, 1990). Hard techniques tend to be quantitative in nature applying numeric values to a clear functional breakdown of the system. Decision analysis (Moore, 1976, Goodwin & Wright, 2004, Rivett, 1980) is one example where possible outcomes are represented with numerical values attributed to them. The impact of different outcomes and the critical path for success can then be analysed (Coyle, R, 1972). Conversely 'soft' techniques are exploratory in nature as the problem is ill defined and understood. Examples of 'soft' tools include brainstorming (Rawlinson, 1981, McLaughlin Hymes & Olson, 1992) and cognitive mapping (Ackerman et al., 2003) where subject matter experts are given an opportunity to discuss and diagrammatically represent issues surrounding an identified problem. Checkland (1981) goes further with a methodology that includes techniques such as rich pictures, forming part of a more detailed approach. Specifically relevant to organisations, it focuses on improvements to sociological issues rather than end product performance (Checkland & Scholes, 1990).

2.3.3 Finding the middle ground, fusion of techniques

Parallels can be drawn between hard versus soft and mechanistic versus vitalist in terms of the polarity in their extremes. Just as emergence as a concept bridges the divide between the far left and far right of mechanist versus vitalist viewpoints, fusion of hard and soft approaches would be beneficial in solving real world problems.

A difficulty that arises with fusion of hard and soft techniques is linked to the groups of people involved with their application. This is somewhat ironic as it forms one of the founding arguments for a soft systems approach. There is a tendency for the hard techniques to be applied by scientists and mathematicians whose natural tendency is towards reductionist testing where measures must be applied and cause and effect attributed (Pruzan, 1988), whereas the soft techniques tend to reside within the social sciences where qualitative, more subjective data is interpreted due to the ‘fuzzy’ and difficult nature of the problem space (Checkland & Scholes, 1990). This leads to debate over the validity of each approach based on the ‘world view’ of the analyst as described earlier in the chapter. Work published in the Operational Research Society Journal, which has a tendency towards ‘hard’ applications, has often looked at the shortfalls of soft systems methodology linked to the lack of validation of the models (Pala et al., 2003) as well as weaknesses of description in some of the central constructs (Ledington & Ledington, 1999). This standpoint can be understood based on the background of those involved, but in usefully applying techniques to real world problems it can lead to incomplete problem exploration and potentially failure, as seen in the Challenger shuttle example (Checkland & Scholes, 1990). Equally, blind acceptance of shortfalls is also not an acceptable route forwards as we should continually question whether improvements can be made to methodologies and constructs, as suggested in the action research cycle (Warmington, 1980).

Soft systems methodology is frequently challenged because it is based largely on interpretation and clarification of viewpoints from subject matter experts through qualitative means (Flood, 2001). The consultant or problem solving system can be the cause of bias which may provide misleading results (Ho & Sculi, 1994), and with difficulties in measuring of the validity of models (Pala et al., 2003) the resultant confidence in output may be low. Furthermore when basing decisions on input from subject matter experts there is an equally high chance that they will introduce bias to the mode of enquiry. As a person, one structures the world by means of what one knows; there is not a blank piece of paper upon which to scribe information (Checkland & Scholes, 1990). However this may be equally positive as well as negative, linked to the earlier statement on technical systems (in general) having to be built by humans or human related systems. Therefore by understanding the very nature of human decision making and the individuals’ ‘world views’ (as examples), those involved become far more empowered and confident in the completeness of their decision making process (Hindle et al., 1995).

Based on feedback from application, SSM has been refined over a number of years from a seven step process originally suggested by Checkland (1981) to a more flexible set of activities concerned with more generic applications (Checkland & Scholes, 1990), again showing conformance to the action research cycle where lessons learned are fed back into the process loop (Warmington, 1980). It is the ability to tailor, that forms the essence of systems thinking and systems engineering in the latter stages of development. Complex systems are often unique in some facet and as such the methods for defining and making sense of systems must have the inherent flexibility to deal with these specific needs as part of a larger architecture (Vencel & Sweetman, 2004). This is important as the team or individual must feel content that they have explored the scope fully, whilst not following a prescriptive path irrespective of whether a certain technique is applicable in a given situation or not. If every problem was 'painting by numbers' (an analogy for a problem that is well defined in both certainty of objectives and solution) (Obeng, 1994), there would only be a need for the process-driven component of a systems approach, not the explorative systems thinking to define the problem in the first place.

The strength of a systems approach is in the ability to manage large groups of stakeholders from differing backgrounds ensuring acceptance of the direction taken, or as stated earlier management of expectation (Connell, 2001). Organisational culture as a potential barrier to success will be revisited in the context of defence later in this chapter as well as in Chapter 5 when discussing the processes developed.

2.4 DEFENCE CONTEXT

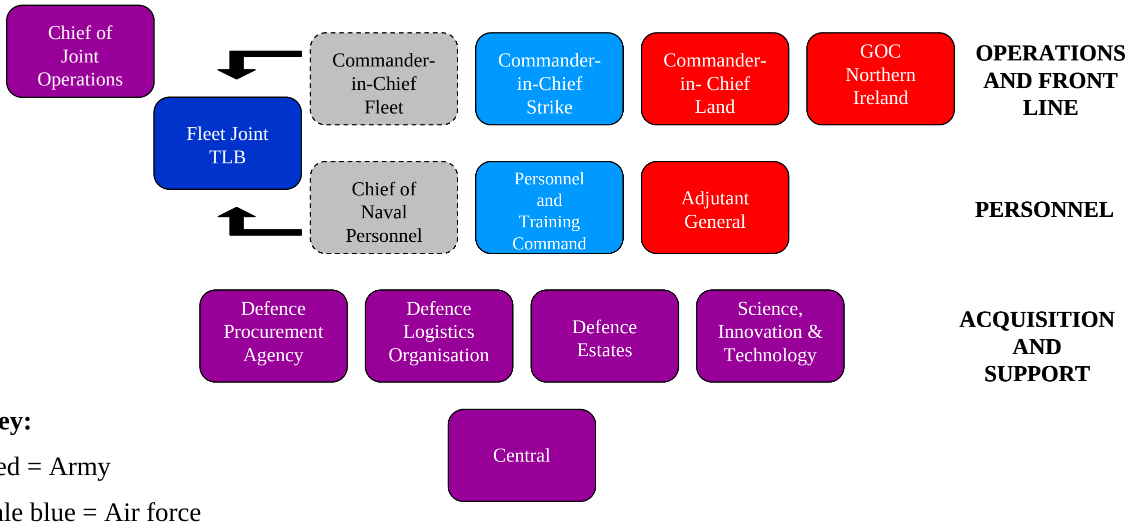
2.4.1 Research and procurement procedures within the Ministry of Defence

Systems thinking and systems engineering has clear application to organic (e.g. human related) as well as mechanistic systems. It therefore seems reasonable to deduce that such approaches should be used when defining high value systems that are socio-technical in nature with criticality in the effectiveness they deliver (Hitchins, 1992). Such a domain of interest that exhibits these qualities is the UK Ministry of Defence (MoD) and more specifically the procurement of equipment for the UK armed forces.

The intent of this department of state is ‘to deliver security for the people of the UK and overseas territory by defending them against terrorism; and to act as a force for good by strengthening international peace and stability’ (Joint Doctrine and Concepts Centre, 1996). It is however the very construct of this statement that signifies the importance of systems thinking within the defence arena, as in itself it has evolved due to significant changes in future threats and theatres of operation.

Within the last twenty years the MoD has seen significant changes in the conduct of its business, partly caused by diminishing defence budgets, but also through pressure to account for spending of public funds. New procurement processes in the form of Smart Acquisition (Defence Procurement Agency, 2005) define the application of a through life systems approach. Reports from the national audit office (Controller and Auditor General, 2004a) have questioned whether Smart Acquisition (introduced in the 1990’s) has to date been effectively applied to procurement and research, a point that will be justified within the subsequent paragraphs.

The Ministry of Defence receives vote funding, or guaranteed income from Parliament on an annual basis. It is supported by ministers for the armed forces, defence procurement and veterans with accountability for spending of public funds through the National Audit Office as well as parliamentary questions (Controller and Auditor General, 2004b). Five top level budget holders are responsible for delivering the defence aims, one for each of the armed services with the addition of Commander in Chief for Northern Ireland and Chief of Joint Operations. They are supported by delegated budget holders for each of the three services as well as the Defence Procurement Agency and the Defence Logistics Organisation.



Key:

Red = Army

Pale blue = Air force

Grey = components of Navy

Dark Blue = Navy

Purple = joint

Figure 1 Organisational structure for defence provision within Government [2]

The defence strategic guidance document underpins the direction of the department and dictates the procurement strategy. This paper is driven by future threat analysis, disposal timeframes of current equipment as well as research conducted by assigned research organisations. This creates one of the peculiarities of the organisational structure with entities funded to conduct research providing input to the topics for future research investment. Previously this would have been of little consequence as the majority of research was provided by Government agencies as part of the vote (Controller and Auditor General, 2004b) minimising concern for future security of the funding stream due to its guaranteed nature. However with changes to Government procurement practices and a drive to outsource research to industry and academia the vested interest in securing future work has increased: there is a danger that research is targeted to suggest further research, rather than fulfilling operational need.

The last thirty-five years have seen significant changes in Government process for the procurement of equipment and supporting research (MacDonald, 1999). This has

[2] www.mod.uk/NR/rdonlyres/27AE5C9A-5489-4137-9FEE032DDBA60D1310/departmental_framework_internet5.PDF

occurred as a response to rising cost and time over runs for a significant percentage of defence programmes (Controller and Auditor General, 1999). In 1962 the Downey procurement cycle was introduced as a method for bringing defence equipment into service (Fig 2).

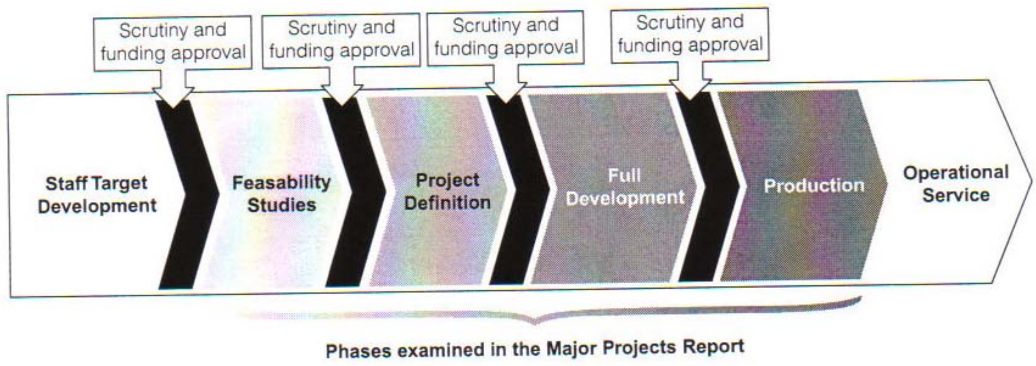


Figure 2 Downey procurement cycle (Controller and Auditor General, 1999)

The premise behind it was the ability of the treasury and ministers to monitor progress of the project team against targets and accordingly restrict the release of funds (Controller and Auditor General, 1999). The limitations of the cycle were twofold, firstly the duration between a decision point and release of funds (up to two years in duration) and secondly the subsequent effect of these time delays causing cost and time over runs. The cascade of problems spread to industry as well as Government due to the constraints placed upon platform/ equipment development. The models employed for technical delivery were centred on the procurement cycle decision points leading to a sequential delivery, where every stage was reliant upon completion of the last (Gabbai, 2000). This introduced a high level of technical risk to programmes, as changes to requirements would necessitate starting the entire process again or providing a platform/ piece of equipment with lower flexibility (Gabbai, 2000). With the perceived Soviet threat forcing many programmes through the early stages of development without properly understanding the technical risk of delivering them time and cost over runs were frequent when trying to fix problems retrospectively (Controller and Auditor General, 2005).

The Government had created a procurement cycle that magnified the very problems that it was trying to solve, and yet because of the relatively constant, predictable threat of the

Cold War, with the major focus on enhancing the equipment that was already in service, rather than pushing the boundaries of technology, it managed to continue unchecked for many years. Change was on the horizon, with the end of the Cold War (Simons, 1990, Armstrong & Goldstein, 1990) and the shift towards random and sporadic threats in a multitude of environmental conditions (Rogers & Dando, 1992). Government had a manifesto to act upon, and the Strategic Defence Review offered an opportunity to look at the entire defence procurement situation from first principles, and determine how a future process could support the fundamental restructuring of the Armed Forces in line with the emerging global threat picture. The study would be '*a foreign policy led strategic defence review to reassess Britain's security interests and defence needs and consider how the roles, missions and capabilities of our armed forces should be adjusted to meet new strategic realities*' (HM Stationary Office, 1998). Straight replacement or enhancement of existing platforms and equipment was no longer sufficient as the theatre of operation had moved geographically (Townshend, 1997). Adaptability in design was even more critical leading to the demise of the sequential and inflexible Downey cycle (Gabbai, 2000). The new term was 'capability' comprising lethality, mobility, survivability, sustainability and C4I when considered in the context of soldier systems [3].

McKinsey management consultants were commissioned in parallel to the strategic defence review (HM Stationary Office, 1998) to determine the strengths and weaknesses of the Downey cycle and propose a future direction (McKinsey & Co, 1998). By employing consultants, the Government could capitalise on the industrial viewpoint that would be applied to the problem with many of the recommendations falling in line with practices already used within the United States (Bourn & Controller & Auditor General, 2002). Two key themes came from the review; rationalisation of approvals and the application of a systems engineering through life framework (Controller and Auditor General, 2003). The age of complexity had been realised and with it the need for large inter-disciplinary teams that could bring a diverse set of skills for application to a number of problems. Figure 3 shows the Smart Procurement cycle with decision points rationalised from four to two and the addition of a disposal phase

[3] Outline NATO staff target for NATO soldier modernisation plan.

most likely as a consequence of costs incurred from programmes such as the Astute nuclear submarines (Controller and Auditor General, 1996).

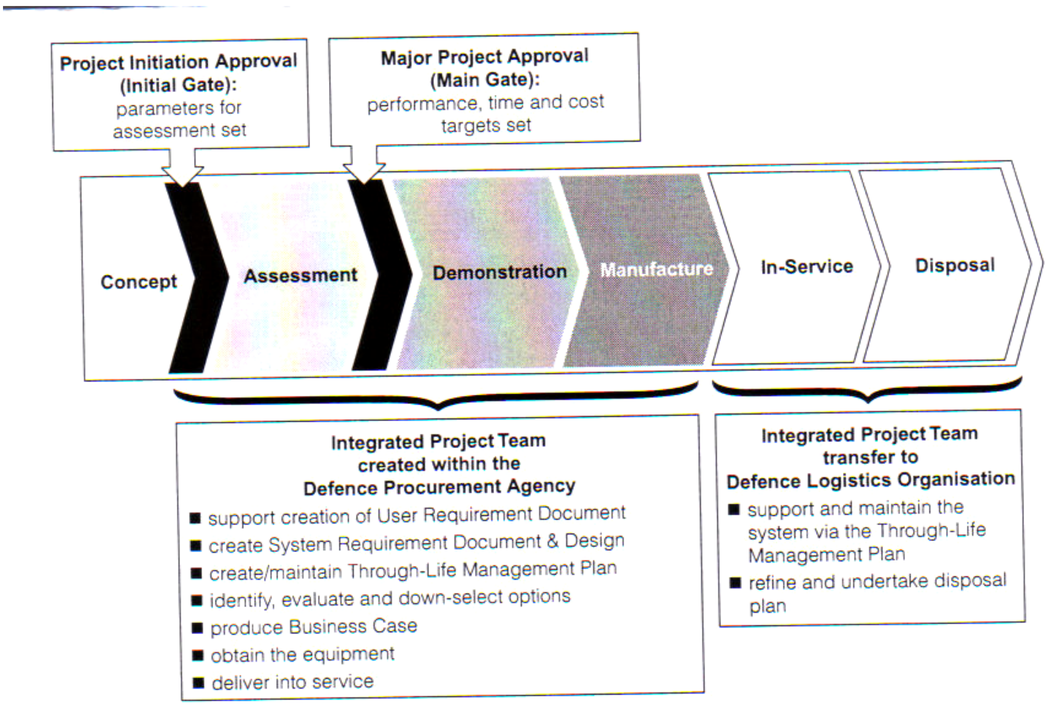


Figure 3 The CADMID cycle (Controller and Auditor General, 1999)

The McKinsey report (1998) highlighted the link between technical risk and time and cost over runs with an average of 37months slip between 1993-1997 and 7.5-8% average cost over-runs against estimate for the same period (Controller and Auditor General, 1999). The new model was focused on up front expenditure with approximately 15% of the total project cost to be spent reducing risk prior to full development approval (Controller and Auditor General, 2003). Although rational, this aspiration of the new process is still to be properly implemented with many projects unwilling or unable to spend such a large proportion of the budget upfront for fear of public reprisal if the project is subsequently scrapped. This issue will be discussed later, in the context of where shortfalls can still be found with current practices and whether risk is calculated accurately.

The Defence Procurement Agency (DPA) and the Defence Logistics Organisation (DLO) were formed in 1999 in support of the new process with re-assignment of approximately 10,000 staff to support the new procurement initiative (Bourn & Controller & Auditor General, 2002). The DPA now takes responsibility for the programme until the transition into service with the DLO subsequently taking on the through-life management and upgrade before disposal. The perceived wisdom of compartmentalising procurement and through life support has been a topic of continued debate (De Freja & Hartley, 1996) and, in part, is a legacy of the procurement executive structure which formed in 1972. The Australian model for procurement which is based almost exactly on smart acquisition (Defence Materiel Organisation, 2001) has only one organisation, the Defence Materiel Organisation, dealing with the entire system lifecycle. The dual organisations found in the UK model add to the cultural and organisational barriers to success discussed earlier in the chapter with increasing numbers of highly influential stakeholders, all with potentially different visions having to come together to achieve a common goal.

2.4.2 Applicability of systems techniques in a defence context

Much of Smart Procurement is based upon systems engineering processes and acknowledges the need for stakeholders and inter-disciplinary teams to solve complex problems (Controller and Auditor General, 2005). The acquisition hand book (Defence Procurement Agency, 2005), now in its sixth edition, characterises the aims and principles of smart acquisition with the aspiration for 'faster, cheaper and better procurement' practices. Based heavily on industrial practices as a consequence of lessons learnt (O'Keefe, 1964), systems engineering provides an opportunity to reduce risk by through-life management considering wider issues contained within 'lines of development' as expressed within the acquisition hand book (Defence Procurement Agency, 2005). '*Systems engineering consists of an over-arching set of activities which overlaps, interacts with and co-ordinates the inputs and outputs of other related processes and discipline*'(Defence Evaluation and Research Agency, 1999).

A number of paradigms exist that can be applied at various points within the lifecycle (which is characterised by CADMID within the UK MoD, Fig 3) or iteratively across the lifecycle as required (Stevens et al., 1998). This starts with the expression of need by the customer in the form of the user requirement document, requiring the problem to be understood and the scope and context discussed (EC MDU AD DEV, 2002). A systematic breakdown follows, to understand the more detailed system-level requirements (which define the delivered system to meet the user requirements) and then the architecture, or framework of the system itself. A frequently used model for this process is termed the 'Vee' diagram created by (Forsberg & Mooz, 1992). This expresses the lifecycle as decomposition from user requirements to detailed systems level requirements to components and then building of these elements back into a system in its operational context (Fig 4).

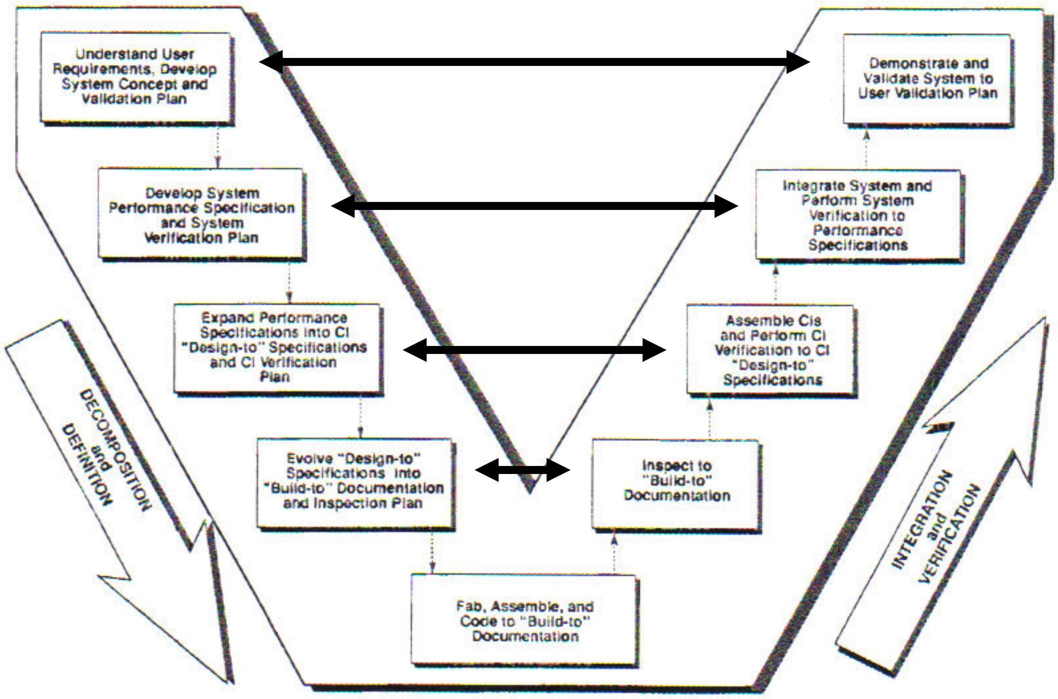


Figure 4 The Vee Diagram (Forsberg & Mooz, 1992)

Although forming a relatively simplistic model compared to others (Martin, 1997), it captures the essence of systems practice through identification of links right from the beginning of the process to the end of the process. Looking at the diagram (Fig 4) lines of validation and verification are drawn between the decomposition of the system on the left and the building of the system on the right. This is the underlying principle of systems engineering in that even at the very beginning you must be thinking about how you are going to prove if the delivered system meets the needs you have laid down.

Considering whether the right system has been built and whether the system itself has been built in the right way. As a model the Vee diagram is very systematic suggesting progressive steps to be carried out however it does hide some of the more subtle uses of systems techniques within the procurement cycle.

As well as being a tool to manage risk and integration it very much supports the front end understanding of the problem space during the concept and pre-concept phase where the user requirement document is produced (Defence Procurement Agency, 2005). Determining the need or user requirements in order to enhance effectiveness is partly an exercise in the management of expectation. Different stakeholders present different 'world views' based on their knowledge and experience as discussed earlier in the chapter (section 2.3.3). Each tends towards their perceived solution to the problem, which may be blinkered by the domain knowledge and experience that they have developed (Couldrick, 2005b). Engaging a diverse stakeholder group at the early stage of the lifecycle in conjunction with systemic lines of enquiry encourages wide debate on the possible routes to be taken, with the intent of creating a balanced output focused on capability rather than individually optimised pieces of equipment.

Characterisation of problem type helps to determine the strategy for solutions. Obeng (1994) describes four quadrants within which problems can be placed, based upon the level of uncertainty in the objective or solution. Fig 5 shows the analogies used for each of the problem types with the intent that progression through the lifecycle leads to movement of the problem from one quadrant to another for instance a 'foggy' problem once scoped fully, may transition to a more 'painting by numbers' problem.

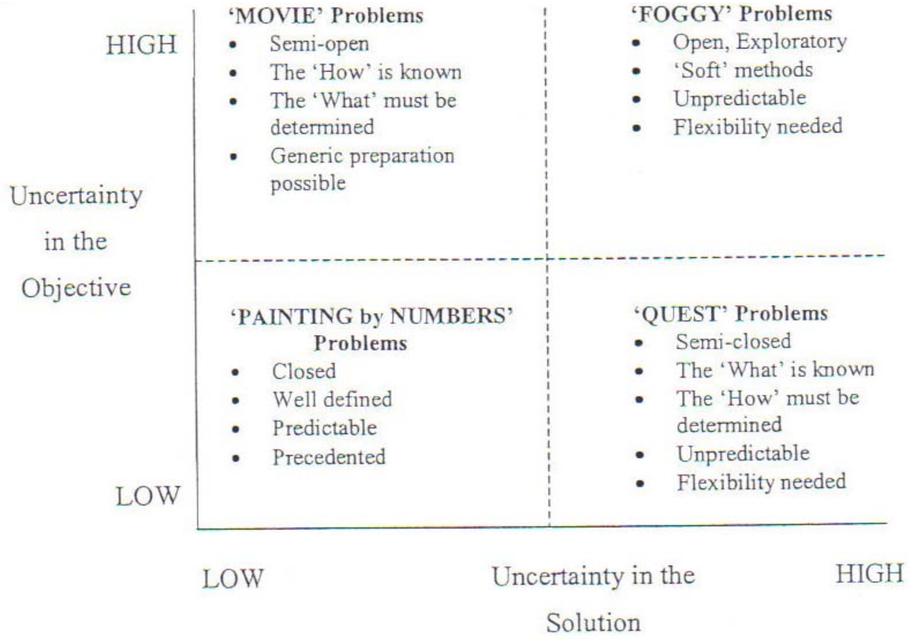


Figure 5 Obeng's problem types (Obeng, 1994)

One of the skills of the systems engineer is reconciling the opinion of different stakeholders to enable movement in a positive direction (Sheard, 1996). The systems engineer becomes the intermediary with the 'big picture view' drawing out knowledge and expertise from the stakeholders in order to create the system framework or architecture and define the subsequent steps in the lifecycle.

Therefore the applicability of systems tools and techniques in the defence environment spans every element of the system lifecycle whether it takes the form of systemic thinking or systematic application, from pre-concept through to disposal.

2.4.3 Current Government programmes using systems techniques

Because of the time taken between the definition of need, to a fielded platform or piece of equipment there are still a number of legacy projects that have not applied a systems approach to delivery under the auspices of Smart Procurement (Controller and Auditor General, 2004a). These projects have been segmented within the annual audit office reports to reflect the fact that 'you cannot retrospectively suddenly wave a magic wand over something which has been going since the late 1980's and turn it into what you think a Smart Procurement project would have turned out' (House of Commons

Defence Committee, 2003). For this reason a brief discussion on the range of projects using the Smart Procurement model will be discussed with specific focus on the Future Infantry Soldier Technology programme (FIST) due to the direct applicability to the thesis topic of dismounted close combat research.

All armed services have programmes that are using the Smart Procurement model, from the Type 45 destroyer for the Navy to the A400M for the Air Force strategic lift and Bowman communications for the Army (with connectivity across services) (Controller and Auditor General, 2004a). These represent complex platforms or pieces of equipment that have multiple integration and interface issues which must be effectively managed in order to successfully deliver capability. Bowman is a good example of a land-based system that has far wider utility as it provides secure communications between many different platforms (Pratt, 1994). A legacy platform that has already experienced difficulties with Bowman connectivity due to the lack of systems thinking is the Apache helicopter (AH64). The procurement of the Apache started during the Downey procurement initiative, which has led to numerous difficulties with retro fitting of equipment, one of which is Bowman with ground to air communication link problems (Controller and Auditor General, 2002). When designing the original system architecture the differences between the Downey cycle and the CADMID cycle are the consideration of how the framework may grow or alter and the need to create flexibility to accommodate this over time (Defence Procurement Agency, 2005).

Within the dismounted close combat context FIST has been heralded as the first programme to take a systems engineering approach to delivery (Dooley, 2000) pre-empting the formal introduction of smart acquisition by a number of years (Ministry of Defence, 1997). As previously discussed, the shape of warfare has changed and with it the vision of each of the armed forces in terms of future capability. The infantry vision states that '*by 2020 the infantry must be equipped, structured, manned, trained and sustained to fulfil its mission in accordance with its manoeuvrist doctrine. It must be able to carry out integrated, high tempo, combined, joint, multi-national, inter-agency, full spectrum combat operations, with a high degree of effectiveness, at short notice and with endurance, and be able to adapt through a seamless spectrum of conflict* *prevention, conflict and post conflict activities: in short a very useable infantry*' (Director Infantry, 2000). In response, the vision for FIST is '*to provide an integrated fighting system, encompassing improvements to lethality, C4I, survivability, mobility and sustainability. This is to be applied to individuals committed to dismounted close combat in order to enhance overall mission effectiveness of the battle group within the digitised battle space*' (Dooley, 2000). A number of studies have looked at the implications of changing fundamental working practices of the British Army in the context of FIST (Denton, 2001, Skinner et al., 1997, Gurr & Hampson, 1999). All lines of development defined as training, equipment, personnel, information, doctrine and concepts, logistics, organisation and infrastructure (Joint Doctrine and Concepts Centre, 2005) have been considered to ensure that personnel (Bowyer & Martin, 2003), and their interaction on the battlefield is not negatively impacted by the architecture of the final system solution (Flower et al., 2001). This recognises the human as the central component of the platform and largest potential modifier to system behaviour (ref Nick Beagley presentation). The programme is nearing the end of the assessment phase with Thales having been appointed as the prime contractor in 2003. The detailed architecture of the final system is not known at this time, but the intended in-service date is now standing at 2010 having slipped from earlier estimates of 2009. Although having made significant steps towards the aspirations of Smart Procurement and 'faster, cheaper, better', the majority of the programmes described including FIST have shortfalls in one or more of the areas be it in time and cost overruns or application of systems engineering techniques (Controller and Auditor General, 2004a).

2.4.4 Shortfalls with current Government programmes

The 2004 major project report (Controller and Auditor General, 2004a) highlighted significant shortcomings with the application of Smart Procurement to defence projects. Four key areas are identified from the evolving structure of data analysis, to major cost and time overruns linked to the achievement of key user requirements, principles of Smart Procurement not being applied consistently and changes being made to improve acquisition performance. The difficulty with some of these areas relates to the organisational culture still in existence within the MOD. New policies and procedures can be implemented, but it requires the staff to accept and adopt the process. A large organisational change that signifies a distinct shift away from previous practices may take a significant amount of time to implement successfully (Smith, A et al., 2004). The length of time reflects natural wastage of people that may be averse to changing their working practices to conform to new techniques as well as the introduction of 'new blood' in the form of graduates. Similarly, the problems brought about by improvements to acquisition processes tend to be linked to impatience to see results, whether from the individual team perspective or because of audit office scrutiny over the spending of public funds (Controller and Auditor General, 2005). This links again to Checklands (1981) view on organisations as systems, where humans within the system are driven by factors such as reward, rather than output for the greater good. Smart Procurement must underpin the team's good performance in order to get reward, with a belief that changes should be made if this is not evident. Without some period of continuity or consistency in the Smart Procurement processes it is difficult to measure the success of the approach.

The most concerning downfall to date is the poor application of acquisition principles and, in some cases, projects going wrong soon after progression through the main funding gate (Controller and Auditor General, 2004a). This potentially makes the Smart Procurement initiative little better than the Downey cycle that preceded it with cost for the top twenty defence projects 20% higher than estimated in the period 2003-2004 (Controller and Auditor General, 2004a). Systems engineering tools and techniques cannot produce instant results as expressed in a quote above when describing pre-Smart Procurement programmes. Success is reliant upon the knowledge and experience of the people applying the techniques as well as relevant tailoring to meet individual programme needs (Controller and Auditor General, 2005).

Some of the problems still relate to the technical risk of delivery, with requirements changing due to rapid advances in the private sector and subsequent re-definition of what is required by the end user, causing time and cost over-runs in the early project phases (Hedvall, 2004). Some, however, are still the result of insufficient scoping of the problem in the concept and pre-concept phase of the programme leading to ill defined architectures during the assessment phase and potentially beyond. An example of which is the Nimrod MRA4 aircraft which was intended to use an existing airframe, but at this moment is approximately 95% different to the original shell (Controller and Auditor General, 1999).

The use of modelling and simulation within these early project phases is one method by which potential system characteristics can be explored, with the intent of reducing risk in the latter lifecycle stages (Anderson & Marshall, 2000). Risk reduction is achieved through the ability to represent attributes of a system within a given environment without the need to physically build prototypes, but it does rely on the ability to measure and define the characteristics of candidate systems (Schmorrow & Kelsey, 2002) . It is the measurement of attributes that creates significant challenges particularly for human centred systems. The following section discusses not only the need for measurement, but current shortfalls particularly for the soldier as the system of interest.

2.5 MODELLING AND MEASUREMENT

2.5.1 The need for measurement

Measurement is used to validate and verify system suitability in meeting requirements as well as acceptability of what has been built (Forsberg & Mooz, 1992). In the context of defence, section 2.4.4 discusses shortfalls that are still impacting successful implementation of Smart Procurement practices determined by reports that are generated by the National Audit Office, who themselves apply measurement criteria to define success or failure.

In addition to measurement of system suitability, a link exists to release of funds for programmes as part of the scrutiny process. Measurement is used extensively within Government to test and check conformance and quality (Sage & Olson, 2001, Matthews & Parker, 1999) with initial and main gates used within the UK CADMID cycle as decision points for the release of further funds. However, it is the very nature of the terminology used within Government procurement and research that creates problems with the activity of measurement and its associated activities, including modelling and simulation- a point that will be revisited within this section.

There is a desire to define military need in terms of capability in line with the systems approach suggested by McKinsey (1998) which has led to the adoption of adjectives such as enhanced ‘effectiveness’ to describe the improvements required in defence capability. In doing so this introduces a far more abstract level of thinking that relates to many parameters and their interaction in order to create something that is ‘greater than the sum of the parts’ (Shalen, 1994) as cited by (Couldrick, 2005b); and yet the organisation is still driven by the need to procure equipment (Defence Procurement Agency, 2005). The difficulty arises in the ability to measure ‘effectiveness’ as it is a somewhat nebulous term. In order to make a decision on what is needed to be more effective there needs to be some form of measure attached.

Modelling, simulation and the activity of trading off use measurement to determine system performance and down select concept options to address customer requirements (Daniels et al., 2001). A lack of clarity of what constitutes effectiveness (Sproles, 1999) and how it is measured (Sproles, 2002) leads to difficulties in identifying the most appropriate solutions to a problem. This is further compounded when discussing dynamically complex systems such as humans that exhibit characteristics which may cause an aggregation of effect as discussed by Sproles (2002) making them hard to quantify. Dooley (2000) argues that without the ability to measure it is not possible to determine whether effectiveness has been achieved but, by the same token, dismissal of intangible parameters has led to the failure of defence projects in the past (Booher, 1990). This will form a significant part of the discussion in the following sections.

2.5.2 Benefits and drawbacks of modelling and measurement

With measurement comprising such an important factor within defence business, and dictating the suitability or otherwise of defence equipment and research opportunities, it is important to understand the methods currently employed and their potential benefits and drawbacks.

Increasing complexity of systems requires larger numbers of interactions, greater knowledge, and creation of inter-disciplinary teams leading to reliance on more effective communication and greater collaboration (Aughenbaugh & Paredis, 2004).

The difficulty arises in how to manage input from so many sources to create some form of meaningful output.

Modelling and simulation enable front end analysis as suggested previously, providing input for scrutiny and reducing the need for troop availability for field trials, which is increasingly more difficult. Simulation based acquisition (Johnson et al., 1998) is being used in the US to define a coherent strategy for modelling the through-life materiel needs of the US war fighter, but in itself should not be considered as a cheaper option or one that is void of difficulties. It is the perception within Government that fewer generic models with wide utility will minimise resource implications compared to individually optimised models (Johnson et al., 1998). However this does not consider legacy and the numerous models already in existence. This requires a detailed understanding of how models have been built and the cost/ benefit of consolidation or starting from scratch (Bratley et al., 1987).

Models are only as good as the information put into them with the phrase often used ‘rubbish in leads to rubbish out’. They are only representations of the real world, and as such must be relevant to the problem you are trying to answer (Wilson, B, 1993). Therefore the assumptions upon which modelling is carried out are vital to the level of confidence that can be associated with the output (Wang, 2001).

Modelling in one sense can be seen as a paradox. It is trying to reduce through-life project cost and risk in the early stages of the lifecycle by exploring different options and yet can be costly to develop, and introduce uncertainty and assumptions when parameters are hard to measure (Aughenbaugh & Paredis, 2004). The level of acceptable uncertainty and number of assumptions will often depend on the size of the programme that the data is associated with. For instance the level of scrutiny applied to input data for a programme with a value of £2 billion is likely to be different to that of a programme worth £1 million, although this in itself is an assumption. With the intent of any procurement programme to invest up to 15% of the overall through-life budget on front end analysis and risk reduction (Defence Procurement Agency, 2005) large programmes should in turn have the money they require for modelling and measurement in the early stages.

Funaro & Fletcher (1980) expressed the cost-validity trade-off very eloquently when they stated that 'analyses are resource intensive activities that span a significant period and their validity can always be increased by the addition of time or money.' The modelling becomes yet another area for trade-offs to be conducted, where the amount of time and money available will, to some degree, dictate the quality and confidence that can be attached to any output. If there is an unwillingness to engage in modelling, or shortage of time or money it may be necessary to temper the degree of credibility attached to decisions that are made. This becomes a potentially damaging cycle of lack of confidence fuelled by lack of credibility of results caused by insufficient time and resources, as a result of a lack of confidence in the output and so on and so forth.

This premise has in turn driven the types of modelling employed for large complex systems. The often dynamic and unpredictable nature of military systems which have the human at the core (although not unique to this domain) makes modelling and measurement very challenging (Curtis, 1996). Discussion later in the chapter will focus specifically on the human within the modelling domain, but more fundamental is the link between complexity, the scrutiny process and the ability to measure. The majority of scrutiny within defence is driven by cost, performance and time; or faster, cheaper, better as expressed in the Defence Acquisition Hand Book (Defence Procurement Agency, 2005). Improvements in effectiveness are balanced by the available budget and the expected in-service date of the equipment or platform. Before the advent of Smart Procurement and even to this day, for certain types of programme a balance of investment is carried out to look at where you get the most benefit for your money. This approach requires several characteristics in order to have confidence in the output, including a well understood problem space and a set of parameters for which you can apply cost measurements.

Walmsley & Hearn (2004) is a representative case study to illustrate the potential pitfalls of modelling and the difficulty of applying models to highly complex problems.

Walmsley & Hearn (2004) conducted a study to define the optimum mix of armoured combat support vehicles to fill a wide range of roles. The method was mixed integer programming that looks to optimise parameters based on customer input (an example of a 'hard' method). The optimisation process was based on the total number of compliant roles within the fleet (183 roles were identified). The difficulty begins with the number of assumptions that have been made. Rather than exploring the possible ways of addressing the combat support role the stakeholder community has automatically assumed that there are one hundred and eighty three roles, all using a vehicle of some description, therefore we must require a fleet of vehicles to replace them. Setting this aside there are a number of further issues.

Integer optimisation as applied by Walmsley & Hearn (2004) requires application of cost to all parameters in order that the appropriate algorithm can be used. A decision is made on this one parameter above all others that should be optimised, which in this case is the number of compliant vehicle roles that a concept will address. In applying this method it is not possible to appreciate intangible benefits, or non financial benefits. The only constraint is reducing cost to a minimum as conceded by the authors. As discussed in section 2.4.1 it is this form of assessment that ignores through-life implications and potentially escalates whole system costs.

A number of other studies have recognised the limitations of balance of investment activities and have looked at ways of enhancing the area of decision analysis[4] whilst maintaining robustness of output (Mathieson, 2002, White & Parker, 1999). The term cost-benefit analysis is an expansion of the intentions of the balance of investment to look at slightly less tangible parameters in complex systems. These techniques are still centred on elements that can have some form of measurement attributed to them by the stakeholders but move towards a fusion of hard and soft techniques as supported by Pruzan (1988).

[4] Structured way of thinking about how the action taken in a current decision will lead to a result, comprising: The decision to be made; the chance and impact of known or unknown events that can affect the result and the result itself. www.racteam.com/LANLRisk/Glossary.htm

Often improvements in hardware and software will reach a ceiling in the overall enhancement of effectiveness as there is a requirement for the skills and attributes of the operator to be considered (Lane & Strieb, 1980). This leads back to the question of whether you can include something if it cannot be measured (Dooley, 2000) because in acceptance terms you cannot be certain that the final system actually meets the level of performance required. An alternative is to recognise when a cost or benefit is intangible, or is difficult to quantify and then apply an assumption to them (White & Parker, 1999). The effectiveness of this approach would depend on the rigour applied by the person when interpreting the results, and the size of the study, and therefore potential number of assumptions. If the assumptions exceed a certain percentage of the parameters being measured is it a viable study? This poses a significant difficulty in moving forwards with modelling/ analysis techniques for complex problems, as on the one hand you have parameters that may impact the overall success of your system, but on the other hand you may have to make subjective judgements (Pruzan, 1988) about the level of impact that may have direct consequences to through-life cost and system choice. If it is necessary to include subjective measures or assumptions then further scrutiny should be applied to provide sufficient mathematical rigour.

This is the contention of Mathieson (2002) who discusses the use of a technique called benefits analysis. It can be considered a meta-discipline or approach as it fuses both qualitative and quantitative techniques that are already in existence to form a new robust tool for assessment, the middle ground between 'hard' and 'soft' techniques described earlier. The principal of the construct is to look at cause and effect which can then be linked to investment and value variables. The basis for the approach is a causal loop diagram that looks at interactions of different components and positive and negative relationships between them, a technique found in other forms of decision analysis (Charnes & Shenoy, 2004). However, there is still the difficulty of applying numerical values to non-tangible factors, creating uncertainty in the validity of the output (White & Parker, 1999).

Uncertainty is a product of analysis especially when inputs are subjective in nature (Grainger, 1997). The use of techniques is very much about tailoring, as different problems require different methods to examine them. An example is shown in a paper by White & Parker (1999) that looks at insensible munitions, which are resistant to accidental detonation. They discuss the difficulties of measuring benefit within a military context with issues such as collateral damage.

Often it is intangible benefits that drive the final decision on a system irrespective of quantitative input. As intangible benefits generally require input from subject matter experts SMEs (Mathieson, 2002), which is open to uncertainty and subjectivity, there is a need to ensure that studies are explicit in their methods for dealing with uncertainty and can demonstrate the impact that it may have on the decisions and conclusions (Grainger, 1997).

Challenges to modelling and measurement of intangible characteristics form one of the potential weaknesses of defence procurement and research (Yates et al., 1999), and yet they drive many defence decisions (Bailey & Baxter, 1990). The soldier as the central focus for this thesis encompasses both intangible and subjective characteristics (Duggan & Thachenkary, 2003) with the need to harmonise measurement and understanding of their attributes with the needs and constraints of Government processes.

2.5.3 Difficulties in characterising human performance

MANPRINT (Booher, 1990) highlights the catastrophic failures within defence programmes caused by the sidelining of human attributes. Although this insight comes from retrospective analysis it is one of the first instances where the gravity of human interaction as a component of the whole system has been considered. The six human factors integration (HFI) domains defined as part of the MANPRINT study (Wheatley, E., 1991) are used today by the UK MoD as part of the procurement process. Although significant steps have been made in the characterisation of certain human factors implications for defence equipment using techniques such as task analysis (Gillies, 1984) there are still extreme difficulties in producing a coherent modelling approach for human factors parameters (Lacey, 2001).

Laboratory testing of human attributes creates both positive and negative implications for modelling activities. Empirical data creates a body of evidence that can enhance validity of assumptions but, conversely, can create issues when trying to aggregate output. This links back to the reductionist nature of scientific testing to ensure that cause and effect can be attributed (Okasha, 2002). In breaking down the problem to such a low level of detail there is a tendency to lose the type of behaviour that is exhibited due to the dynamic complexity of the system. Because the procurement stakeholders are interested in gross measures of effectiveness such as mission success or failure as indicators of system suitability it becomes difficult to aggregate or in some instances extrapolate information that has been generated in a laboratory as there is no empirical evidence to support it and so confidence in output is reduced.

An attempt to aggregate human performance models has been made by QinetiQ Centre for Human Sciences, formerly part of the Defence Evaluation and Research Agency (DERA). IPME (Integrated Performance Modelling Environment) takes a number of models and data based upon laboratory trials and fuses them to create a meta-model of human performance (Wright, 1997a). The major application of this tool is the assessment of clothing and equipment on soldier performance most notably in the domain of survivability (Bunting, A.J & Kelm, 2002). What IPME fails to address in a satisfactory manner is the complexity of the aggregation of the models used with no validation of the assumptions made (Colthurst et al., 1999). The key to any meta-model is the development of correlation techniques which accurately translate between the levels of detail (Beagley, 1998) in addition to completeness of characteristics under investigation which IPME lacks in the areas of fear, confidence, personality and physical fitness as examples (Beagley, 1998).

Other combat models have tried to incorporate human characteristics, but struggle with the level of fidelity required, an example of which is CAEn (Close Action Environment) (Shepherd et al., 2003a). Part of the difficulty may be the retrospective inclusion of human parameters to models that have been designed for tasks such as lethality assessment which are not human-centred (Davis, 2000). When trying to add human characteristics it becomes a static rather than dynamic addition with ‘look up’ tables to determine performance characteristics at the beginning of a simulation run (Wright, 1997b) leading to inflexible, potentially misleading output. Retrospective inclusion of parameters including human factors issues can be very costly and may introduce errors due to incompatibility of the underlying software code (Garlan et al., 1995).

2.5.4 Current gaps in human modelling capability

Based on the above discussion there are a number of gaps in the ability to accurately model human attributes within the defence domain. This is not just evident with meta-models such as IPME, but wider in terms of assessing the human (Wheatley, E, 2001). The over-riding factor that makes representation of the soldier system so challenging is the complexity leading to issues of realism and also fidelity required in the modelling (Lacey, 2001). However modelling is still endorsed as the main tool for scrutiny of programmes including those within the soldier domain (Randall, 1997). This forms a constraint imposed by the environment and context within which soldier system research and procurement exists and as such must be addressed.

The soldier as a system has received increased attention with the initiation of the FIST programme (Dunlop, 1997). Previous development of operational clothing for the soldier has looked at the inclusion of human factors issues at the design level of the programme (Blackwell, 1993). Sometimes described as human factors engineering, the discipline looks at the application of human factors information to the design of systems to ensure safe, comfortable effective human use (Chapanis, 1996). However translating human factors issues, in conjunction with subject matter expert input into physical concepts that address high level military need is not widely documented (Burns & Vicente, 1996). It is not only the ability to model the human accurately, but to use the output to direct concept generation and measure effectiveness of the final product against the original need. Therefore any process devised, or technique used to deliver validated data must be capable of use at several levels of resolution (QinetiQ, 2001).

2.5.5 The use of Soft Systems Modelling (SSM) and fused techniques

Section 2.3.1-2.3.3 briefly described some of the techniques applied when considering ‘hard’ and ‘soft’ approaches to problems. Section 2.5.2 subsequently defines the soldier in generic terms as exhibiting ‘soft’ characteristics which are difficult to quantify, impacting the effectiveness when using equipment, which can be defined as 'hard' and capable of optimisation.

Pruzan (1988) discusses the need for fusion of 'hard' and 'soft' techniques to enable 'completeness' of view. With gaps identified in the current ability of Government to accurately measure and model soldiers and their related equipment (Wright, 1997a) it is appropriate to consider additional or alternative approaches from the field of systems thinking with the intention of incorporating subject matter expert opinion within a generic analysis framework.

Identification of relevant strengths and weaknesses of these alternatives and their potential application to the soldier system will lead to justification for pursuit of my research topic.

2.5.6 SSM and Fused tools and techniques

When considering the types of approaches that may be suitable for the system of interest (the soldier and their equipment) the boundaries and constraints should be considered at the outset to ensure completeness of the approach developed (Waring, 1996). This includes the defence context within which the system operates, as described in section 2.4, and the defence equipment procurement strategy (section 2.4.1). Drawing of system boundaries and potential constraints forms part of the 'soft' approach as described in section 2.3. Chapter 4 develops this further using rich pictures and context diagrams. The purpose of this chapter is identification of techniques that could be used rather than their subsequent application which is discussed in Chapter 5.

Before introducing suggested techniques for exploration it is useful to recap the major issues relating to the system of interest so that the applicability or otherwise of the approach/es can be determined.

- The system of interest includes the soldier and his equipment.
- The system can be classed as socio-technical in nature (where there is an interface of man and machine) (Hitchins, 1992).

- To date, soldier equipment has been individually optimised based on its performance, without consideration for impact on the whole, or the human (Vang, 1991).
- New Government procurement strategies require greater consideration for other lines of development (Controller and Auditor General, 1999).
- The procurement strategy requires relevant scrutiny to be carried out prior to release of funds for production (requiring measurement of concepts against some form of criteria) (Controller and Auditor General, 1999).
- To date, there has been no formal link between analysis and design for the generation of future soldier system concepts with designers using experience to determine specifications (Blackwell, 1993).
- There is no formal audit trail of design decisions made based on the user requirements and high level Directorate of Equipment Capability (DEC) and military strategy papers.
- A great deal of SME experience has been gathered over a number of years, but is difficult to utilise due to the quantity and form that it takes (Blackwell, 1993).

Therefore, the techniques considered need to bring together multiple strands of information, both in quantitative and qualitative form providing a clear audit trail of decisions made, and the ability to look at the impact of changes at varying levels of detail and with confidence in the data quality (Pipino et al., 2002).

Taking the Vee diagram (Forsberg & Mooz, 1992) Fig 4 as a simplistic representation of systems engineering activities, it can be seen that some form of decomposition is taking place from customer requirements, to systems requirements, to design and so on. At each stage there is also a forward looking element to understand how requirements will be tested and methods for system acceptance; but in essence the Vee represents a journey of increasing levels of detail and systems definition (Staker, 2000).
These characteristics are reflected in a number of techniques that centre on matrices and the collection of SME input. Quality Function Deployment (QFD) (Cohen, 1995), Analytic Hierarchy Method (AHM) (Lambert, 1991) and Strategy to Task (STT) (Bathe & Smith, 2002) can almost be used interchangeably in the context of deriving and

decomposing requirements and determining priority of potential concepts to address the customer need (Kim, K, 2002, Liu & Hai, 2005, Smith, J et al., 2002). All have in common the collection and interpretation of stakeholder views using numerical scoring and weighting to assign relative importance (Kim, Y et al., 2005).

Quality Function Deployment (QFD) was developed in Japan within the production industry to measure the relationship between design and need (Cohen, 1995). The approach allows formalisation of customer input through scores attributed to a number of statements. The strength of relationship between 'what it is you want to achieve' and 'how you can achieve it' is scored by relevant experts within a matrix structure (Fig 6) using 9, 3 and 1 as a non-linear prioritization scale (Franceschini & Rupil, 1999) . It is subjective in nature, but shows a clear audit trail of why decisions have been made. The technique recognises that stakeholders are often ignored within the design process and yet are the decision makers for system acceptance.

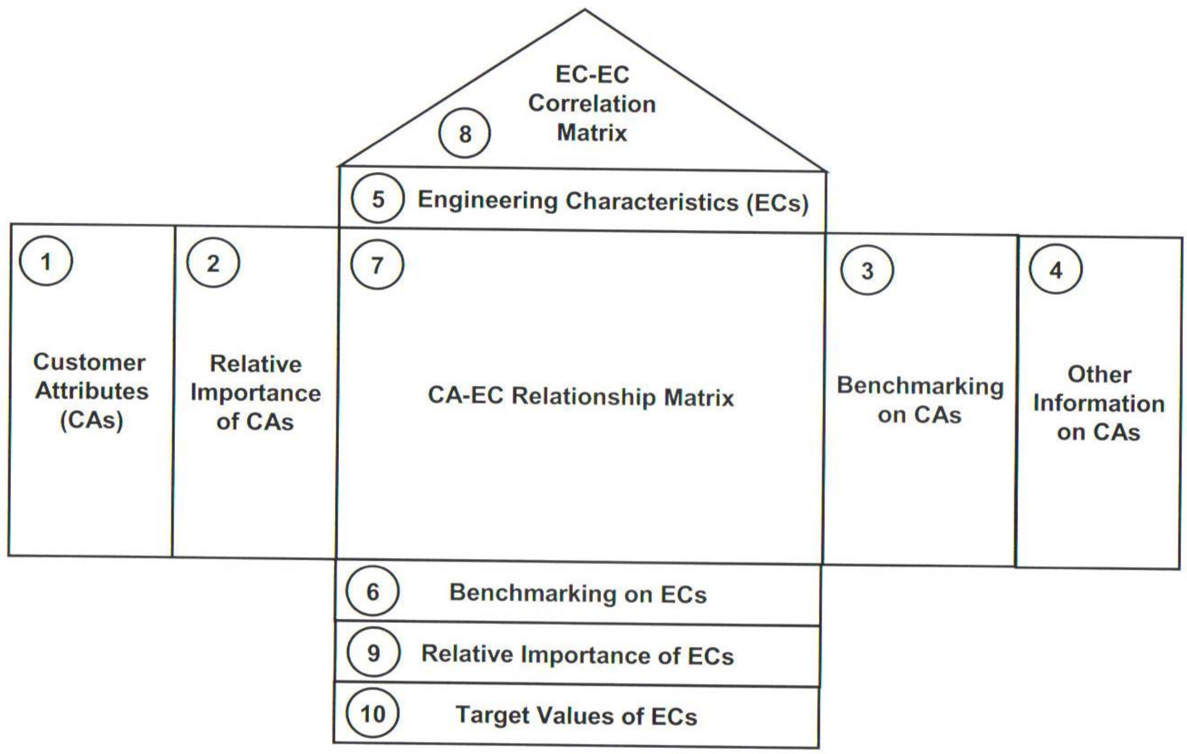


Figure 6 House of Quality; QFD matrix (Kim, K, 2002)

Over time the method has been adapted to many fields of enquiry such as risk in delivery of user requirements (Kenley, 2004) as well as actual derivation of user requirements (Weiss, 2004) and down-selection of technology options within the defence domain (Smith, J, 1993), however in essence the application of QFD is still centred on requirements derivation and potential solutions to address these requirements.

Strategy to Task and Analytic Hierarchy Method progress the utility of QFD for use in higher level strategy, specifically applied to defence (Bathe & Smith, 2002), but not exclusively tailored for this domain (Liu & Hai, 2005). A cascade of matrices is used to explore increasing levels of detail relating to customer requirements and potential ways of addressing them (Fig 7).

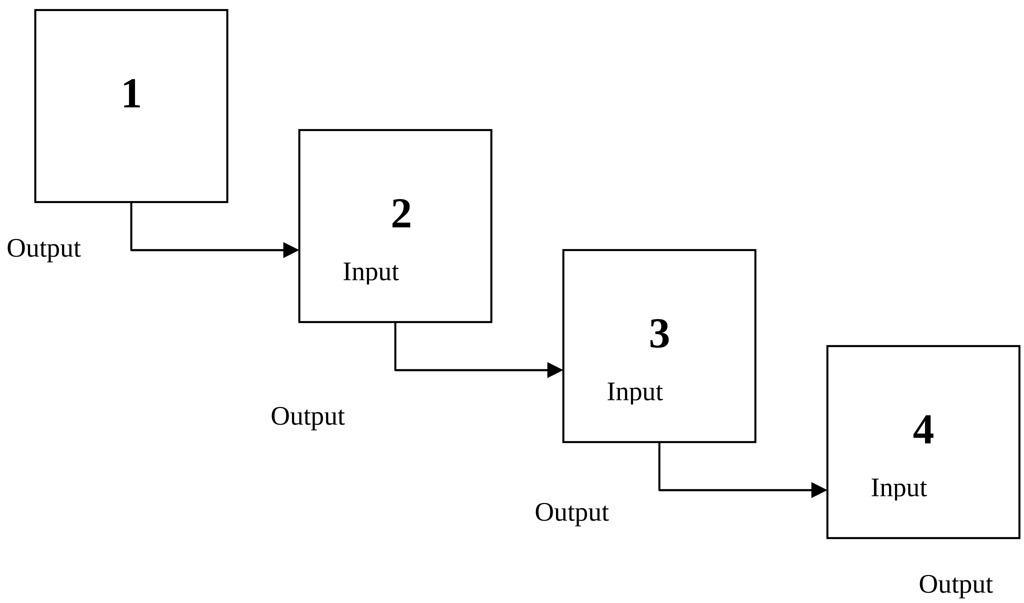


Figure 7 Strategy to Task/ Analytic Hierarchy decomposition

The data flow from one level of the matrix to the next reduces the level of subjectivity in the approach, as weightings are passed from one level to another with only the first matrix requiring decisions regarding the relative importance of input statements (Bathe & Smith, 2002). All of the scores are normalised (Frankfort- Nachmias & Nachmias,

1996) to reflect their individual relative importance in the context of the whole, with the intent of STT and AHM to apply objectivity to subjective input enabling sensitivity analysis to be conducted (Voorhees & Bahill, 1995, Karnavas et al., 1993) and robustness checked. The techniques are seen to have large potential benefits in bringing together stakeholders and eliciting their opinion (Zairi, 1995), however there is also strong criticism, that the nature of the scoring conventions applied lacks consistency (Mathieson, 2002) and can potentially cause skewing of results towards the higher orders and create mistakes in assessing a relationship/ correlation (Eum et al., 2001, Kim, K, 2002).

Underlying all of the techniques is the collection of SME opinion and the robustness that can be attributed to this form of data. The Delphi Technique (Sackman, 1975) and the nominal group technique (Delbecq et al., 1975) represent two distinctly different methods of data collection for subjective opinion, with inconclusive results on which is most effective (Rowe & Wright, 1999).

Delphi is intended to gather consensus of opinion from a group of experts through an iterative scoring exercise (Bolger & Wright, 1994). It has complete anonymity and can be completed from geographically disparate locations, but requires eventual agreement from all parties on one score for each statement pair (Dalkey & Helmer, 1963).

Nominal group technique brings together groups of SMEs to discuss issues prior to providing scores, with further iterations based on deepening understanding (Duggan & Thachenkary, 2003). Discussion of the utility of the different approaches focuses on group dynamics with some practitioners arguing that consensus is only reached using Delphi as a consequence of wanting to conform (Janis, 1982). However, equally the nominal group technique could introduce peer pressure due to the lack of anonymity of the participants (Hart, 1994). This may be particularly problematic within a military/ defence context due to the influence of senior officers on more junior ranks (Kramer, 1998). Furthermore there is a resource implication with both approaches whether located remotely or gathered for a meeting, multiple iterations become time intensive (Bowles, 1999).

With inconclusive data to support superiority of one or other approach (Rowe & Wright, 1999), relative merit should be considered in light of the domain needs. For instance when speed of collection is the driver NGT may be more appropriate, whilst geographically dispersed groups may benefit from the Delphi Technique (Rowe & Wright, 1999).

It should however be considered that classic Delphi is somewhat at odds with systems theory as although a group score is generated it is a non-interacting method (Rowe & Wright, 1999) with the final score representing the 'sum of the parts'. Whereas Nominal Group Technique encourages synergy through discussion, potentially leading to emergent properties that are 'greater than the sum of the parts' (Smuts, 1973). In both cases the validity of the output relies on the design of the study and should be treated with appropriate caution.

2.5.7 Strengths and weaknesses of SSM and fused tools and techniques

When deciding on the relative utility of matrix analysis to address stakeholder needs for defining future soldier systems concepts and research direction the key strengths and weaknesses of the approach should be defined. This provides the evidence to underpin justification for the research direction presented in Chapter 3 and subsequent development of the approach in Chapters 4-7.

Strengths

- Inclusiveness of the customer and stakeholder community which is considered an important part of acceptance of future concepts (Beagley, 1998)
- Ability to include the knowledge of SMEs in a manageable and focused format (Blackwell, 1993)
- Clear audit trail of decisions through the hierarchical cascade (Smith, J et al., 2002)

Weaknesses

- The methods have received large amounts of scepticism on their validity from 'harder' OA advocates (Mathieson, 2002)
- There are potential difficulties with varying interpretation of statements within the matrices depending on stakeholder understanding (Rowe & Wright, 1999)
- The techniques attribute numerical values to subjective opinion (Franceschini & Rupil, 1999)

It should be considered that the negative statements are the same for many forms of subjective data collection (Bertrand & Mullainathan, 2001), with the ability to manage uncertainty through sensitivity analysis which determines the impact of variations to given parameters (Voorhees & Bahill, 1995). Output from sensitivity analysis can be used for validation of models, improvements to subsequent iterations of models and warning of strange model behaviour (Karnavas et al., 1993), an example of which may be varying stakeholder interpretation of statements as described above.

Matrix analysis and associated sensitivity testing has wider utility, and a direct link to trade-off activities. Studies have been carried out to look at the application of different techniques for trade-off activities (Waddington, 1999), which often utilise some form of hierarchy, decomposing the issues at various levels (Daniels et al., 2001). When using hierarchical decomposition there is an ability to map how and why certain options will be of benefit for addressing the need (Bathe & Smith, 2002). It provides a defined level of confidence which can be provided to the customer based upon stated assumptions and it ensures effective communication between stakeholders by involving them from the beginning (Buede, 2004). At the stage of trading off between options there should be relatively few surprises to those involved as they will be aware of the output from each preceding stage.

When considering the application of techniques to new domains of interest such as the soldier as a system it is the ability to validate use that should determine application. Scheslinger (1969) characterised the process of enquiry aptly when he said 'analysis is not a scientific procedure for reaching decisions which avoid intuitive elements, but rather a mechanism for sharpening the intuitions of the decision maker… analysis is, in the end, a method of investigating rather than solving problems.' This contention will be revisited within Chapter 5 and 7 where the processes developed and their application is discussed.

2.6 LITERATURE REVIEW SUMMARY

System complexity has increased significantly over a number of years leading to a requirement for large teams of experts to deliver products.

The fields of systems thinking and systems engineering have been developed to address issues of complexity born out of shortfalls in scientific reasoning.

As with other scientific standpoints, systems theory has advocates of approaches that classify systems attributes at different ends of a spectrum. The major fields of study include 'soft' systems concerned mostly with people and organisations and 'hard' systems which define systems with clear parameters for optimisation.
The MoD as an organisation deals with large complex systems comprising of both man and machine. Therefore application of system tools and techniques would be applicable to scope defence projects.

Smart Procurement was introduced in the late 1990's in response to significant time and cost over runs of large defence projects. The basis for the new initiative was systems thinking/ engineering.

To date success of implementation has been variable. Reports from the National Audit Office have suggested organisational culture, poor application of Smart Procurement principles and technical risk of delivery as potential causes.

Part of the difficulty experienced by MoD relates to a fundamental shift from procurement of equipment to capability. Associated with this are challenges in measurement of candidate solutions leading to problems in the ability to accept items into service.

Tools and techniques traditionally used to determine solutions offering best value for money are difficult to apply to capability, which exhibits many intangible elements.

The soldier constitutes one such system element with the ability to cause success or failure of associated systems, but with significant challenges in measurement of characteristics.

To date attempts to replicate human attributes through use of models and simulation has been largely unsuccessful due to the complexity that individual's exhibit.

Many decisions relating to soldiers and their equipment have been based on knowledge and experience without consideration for the integration and interface issues which will impact capability.

From the literature reviewed there is a gap in the ability to define future soldier system concepts and research direction in line with Government requirements as part of Smart Procurement.

Chapter 3 articulates this gap, providing justification for pursuit of the research topic.

Blank Page

CHAPTER 3: RESEARCH AIMS

3.1 INTRODUCTION

3.1.1 Aim

To derive the research aims of this thesis based upon the rationale presented in Chapter 1, and supported by the presentation of current practice in Chapter 2.

3.1.2 Objectives

- Identify original contribution to knowledge in relation to scoping of future soldier systems
- Describe the activities that will enhance current practice in defence research
- Define the structure and progression of the activities
- Discuss the limitations of the research aims

3.1.3 Key drivers

Four key areas exist that drive the purpose of the study with a number of further sub-divisions providing greater detail. In addressing these areas in the subsequent chapters the research aims of the thesis will have been met.

1. The roles and responsibilities of the MoD as an organisation are changing:
   Therefore:
   - Methods are required that retain sensitive information within Government whilst outsourcing technology concept work to industry.
   - There is a need for transparency of the approach/es adopted in order to communicate ideas to multiple stakeholders.
   - The processes suggested as part of an overall approach must be able to persist through future organisational changes and be capable of growth.

2. There are fewer resources available for defence research:
   Therefore:
   - Duplication of effort needs to be minimised

- Decisions need to be robust
- Maximum value for money needs to be achieved

3. The military threat is changing and is unpredictable in nature:
   Therefore:
   - Solutions need to be flexible and/or enduring
   - The organisation must be able to respond to customer need at a faster rate
   - There is a need to understand the synergy between system and wider system entities

4. There is a need to understand the essence of ‘enhancing effectiveness’ (as a key Government driver)
   Therefore:
   - There is a need to determine ‘how much’ is enough
   - There is a need to determine limiting factors to success
   - There is a need to understand how to measure that which we cannot quantify

3.1.4 Background

Many of the current practices within the Ministry of Defence and more specifically the research and procurement sectors have been driven by private sector industry (Bud & Gummett, 2002). There are a number of parallels that can be drawn between large blue chip industries and military platform acquisition programmes, both in scale and complexity. Large teams of people working on high value projects with multiple elements to be integrated. Completeness is seen as one of the ways to minimise risk and manage complexity, reducing the likelihood of poorly integrated or failed end products (House of Commons Defence Committee, 2003). This is a goal of Government due to scrutiny for expenditure of public money and associated accountability to parliament (Controller and Auditor General, 1999). The application of systems thinking and systems engineering taken from private sector business can potentially answer many of the problems described, providing the common language that brings a number of diverse stakeholders together (Sheard, 1996).

Government research and acquisition organisations have suffered from a piecemeal approach to equipping the armed forces (McKinsey & Co, 1998). This has partly been caused by fluctuations in available budgets, but also through a lack of co-ordination and communication between different agencies and organisations. This has led to time and cost overruns leaving gaps in the capability afforded to our armed services and further deficits in research and procurement budgets (Controller and Auditor General, 2004b).

It has often been the case that military equipment is optimised for technical performance, a legacy of early research organisations formed after the two world wars (Bud & Gummett, 2002). This focus has been responsible for instances of catastrophic failure of military platforms (Townshend, 1997, Booher, 1990, Wheatley, E., 1991) based on a lack of consideration for human characteristics and behaviour.

To address these problems Smart Acquisition was introduced in the late 1990's (McKinsey & Co, 1998), replacing the Downey cycle in an attempt to bring programmes in on time and within budget by streamlining procedures and understanding wider issues such as people, training and support (Controller and Auditor General, 1999). Even though Smart Acquisition, as it is now known, (formerly Smart Procurement) has been implemented for approximately ten years it is still not possible to judge true success or failure as no programme or project has been through the entire cycle of concept through to disposal (Controller and Auditor General, 2005). Already several changes have been implemented to quell impatience to see results, which the author contends is one of the downfalls of processes facing public scrutiny. There is a need to have a period of continuity and consistency to determine if the processes are successful in delivering enhanced effectiveness in a timely manner, within budget and with the required performance.

It is this contention that shapes the techniques used within this thesis, as it is recognised by the author that Government and more specifically research organisations as a specific area of interest need tools and techniques that are enduring. Further to this, tools and techniques adopted to answer questions on where Government money should be spent for research, and which concepts should be pursued for procurement must also be sufficiently robust, and allowed a period of continuity without re-working to provide desired outcomes. Part of the constraint for this thesis is the environment within which the developed processes will be used and the stakeholders for which it is intended, all of which form part of a systems approach to problem solving (Waring, 1996).

3.2 CONSIDERATION OF THE SOLDIER AS A SYTEM

Within Chapter 2 a presentation of the foundations of systems thinking and systems engineering describes the benefits when applied to complex problems, particularly those involving both man and machine (Hitchins, 1992). FIST (Future Infantry Soldier Technology) is an example of a current programme specifically focused on the soldier and their equipment with the intent of enhancing combat effectiveness through advanced technologies (Dooley, 2000). The programme is currently in the assessment stage of the Smart Acquisition cycle as shown in Fig 3 Chapter 2. It is at this stage that concepts are down-selected based on their ability to meet the requirements laid down by the various stakeholder organisations. Similarly this activity occurs within the research organisation determining not only potential concepts for future systems before procurement, but also to decide where money should be spent to better understand how identified problems can be solved.

Understanding the system as part of a systems approach, drawing of the 'boundary' and defining what constitutes the 'system of interest' is of great significance for future decisions (Flood & Jackson, 1995). It helps to identify constraints dictated by stakeholders and the environment within which the system exists as well as reducing risk through completeness of viewpoint. In drawing the boundary there is a need to identify which elements are within the programme's direct control and which are outside, as well as the identity of associated stakeholders. This information will potentially constrain the system of interest, as important elements may be outside of programme control. An example of this is an existing military platform, which has fixed characteristics requiring a new system to interface with it, which dictates certain behaviours from the new platform.

Chapter 4 ('bounding the problem space') is an exploration of the soldier system as the domain of interest. This provides interpretation of what constitutes the system of interest, the environment within which the system resides and the impact of related systems both within and outside of programme control, on decisions. It forms the foundation for subsequent chapters as all processes and analysis are based on the definition of the system and related systems. This is further discussed within 'limitations to the research aims' later in the chapter where the inherent risks of drawing system boundaries are discussed and the implications of early decisions explored.

3.3 SYSTEM ANALYSIS OF THE SOLDIER SYSTEM

Considering the soldier as the system of interest creates challenges due to the dynamic complexity that humans exhibit (Chapanis, 1996). Analysis used within Government to choose between different concept options for future military equipment has insufficient resolution to cope with human dynamic complexity (Beagley, 1998). Modelling and simulation characterised as operational analysis is widely used for technology decisions based on optimisation of performance within certain operational and budgetary constraints (Smith, J et al., 1991). However, human involvement often increases the number of data assumptions made (Wilson, A. et al., 2000, Shepherd et al., 2003a), reducing confidence and robustness of output.

As the majority of complex problems involve the human to some degree or another, whether implicitly or explicitly, there is a need to understand their impact on successful delivery of combat effectiveness as a key military driver. This includes people's physical and mental attributes as well as the impact of their interaction with other pieces of associated equipment. Some meta-models have been created (Wright, 1997a), but have yet to be fully validated and are reliant upon the extrapolation of laboratory trials, which introduce further assumptions (Bunting, A.J & Kelm, 2002).

There is a gap in the tools and techniques available to understand dynamically complex systems as discussed in Chapter 2, section 2.5.3, particularly when related to soldier systems as a unique sub-set. Field trials have been used to gather data for interpretation as well as inform models, but this can never simulate the conditions of combat, providing limitations in the use of data. Post-operational reports are also in existence along with extensive past research carried out by subject matter experts, all of which have their strengths and weaknesses.

It is the author's contention that a fusion of information from both qualitative (e.g. subject matter expert (SME) input) and quantitative sources (e.g. Operational Analysis (OA)) within process/es is required to scope future soldier systems, providing appropriate levels of confidence and robustness in the output to satisfy stakeholder needs.

In taking this approach reliance upon one source of information will not be necessary, reducing the pressure for completion of operational analysis or field trials which are often heavily loaded as a resource or not available at all. In fusing different sources of information there is a greater opportunity to include lessons learned from operations (Shepherd et al., 2003b) as well as insight from SMEs. The important element within process development is the management of information, the time taken to generate concepts, research direction based on the diverse data sources and a method of collating all of the information so that it is readily available.

Chapter 5 describes the development of a set of processes to define future soldier system concepts as well as direct research to meet defined gaps in knowledge. In choosing the tools and techniques to develop these processes it is not the intent to evaluate all of the potential options, instead focusing on specific tools and techniques that have been chosen by the author to reflect the challenges of the domain of interest based on knowledge and experience within the field of defence research and systems engineering. The implications of tool choice will be discussed in the research aims limitations section.

3.4 FROM CAPABILITY TO CONCEPT- TRADING OFF

A process to decide which options will enhance operational effectiveness forms part of applying a systems approach to a chosen problem domain. At some point there will be a need to choose between possible alternatives- the process of trading off (Buede, 2004).

At first sight it might be concluded that if unlimited funds were available then the action of trading off would never be necessary as everything that was desired could be provided. However, the process of trading off is about understanding need and aligning solutions to meet those needs within certain parameters. It is often not desirable to provide everything that is technologically possible as this may produce undesirable systems behaviour or emergent properties (JSA AG1 Small Unit Land Operations, 2000).

Trade-off is seen by many as somewhat of a 'black art' with little definition of what techniques have been used or the method of application (Waddington, 1999). Most programmes create a bespoke trade-off process which has in the past been accused of providing output in line with the desires of the stakeholders through manipulation of figures (Felix, 2004). Although there is a degree of tailoring for different domains and stages within the lifecycle of the process (Buede, 2004) there are also a number of standard elements that can be exploited to make the process more transparent to those involved (Felix, 2004).

Chapter 6 discusses the methods applied to trade-off different options, whether for concepts or placement of research funding, based on the processes developed within Chapter 5. The stakeholders are heavily involved in the trade-off process, although the method discussed is robust to bias through comparison of technical versus customer input. Unification of customer need with technical feasibility and technology maturation has different consequences for research when compared to procurement. This forms part of the portfolio of evidence provided to the customer in order to make informed decisions.

3.5 MEASURING PERFORMANCE

Part of the trade-off process is dictated by whether concept options meet the requirements as presented by the stakeholders. Performance forms one of the measures by which different options can be assessed and is traditionally used within procurement as one of the constructs, with time and cost forming the other dimensions of the trinity (Defence Procurement Agency, 2005). The difficulty arises when trying to measure dynamically complex systems, as the level of consistency between individuals is low making aggregation of scores potentially meaningless (Wright, 1997a). The question of how to quantify something that you cannot measure with any accuracy has been a problem with human centred programmes already in existence such as FIST (Wilson, A. et al., 2000). This again highlights the shortfalls as discussed in section 2.5.3, with programmes either ignoring the human because they are too difficult to measure, or making certain assumptions with varying levels of validity (Colthurst et al., 1999). Part of the requirement for measurement comes from contractual obligations. It is unwise to pay for equipment or training if you cannot measure whether it addresses the problem that you set out to solve. Contractual acceptance is based on the ability to validate and verify that you built the 'right system' and that you built the 'system right'.

However, it is not appropriate to ignore system attributes or characteristics purely based on the difficulty of measurement. Instead it seems appropriate to provide performance bounds within which trade-off decisions could be made rather than exact technical measures (Sparks, 2004b). This not only provides greater flexibility for definition of the final system, but allows for change and growth if requirements change over time. Chapter 7 discusses the implications of measuring performance in the context of the soldier as the system of interest and defines a process for dealing with measurement in conjunction with the processes described in Chapter 5.

3.6 RESEARCH AIM LIMITATIONS

Several of the sections contained within the chapter have discussed potential limitations with the research aims, but in fact they are assumptions that are made based on supporting evidence of various descriptions. Section 3.2 discusses drawing a boundary to define the system of interest and associated entities in the wider environment. This is a fundamental task within a systems approach and will help to define all of the subsequent decisions made about the form and function of the system.

Chapter 4 specifically looks at drawing the boundary for the soldier as the system of interest and the implications for the programme and related programmes in drawing that line. It may be considered a weakness of the research aims that multiple boundaries have not been drawn and investigated. This is an activity that could be carried out formally, but in doing so it would take a lot more time and resources which is contrary to the objectives set out at the beginning of the chapter. Additionally, the impact of putting something inside or outside of the direct system boundary is considered as part of the exercise from the beginning. Detailed questioning of why elements/ entities should be placed inside or outside of the system boundary form part of the problem scoping and incorporate stakeholder identification and other activities making duplication of effort unnecessary.

Chapter 4 provides the rationale for boundary definition providing robustness through supporting evidence for the decisions made. With boundary definition forming one of the tailored aspects of a systems approach there will always be a need to make decisions based on assumptions from a knowledgeable team (Sparks, 2004a). As with any assumptions that have to be made within the thesis, the strength of adopting a systems approach is in stating the assumptions clearly and transparently, providing evidence to support the assumptions wherever possible and ensuring they are auditable and traceable over time (Sparks, 2004a).

Drawing the boundary locks in expenditure as time progresses helping to shape the system concept or the requirement for further research. Time spent at the beginning of the programme helps in risk reduction, but can be time consuming and resource intensive. One of the potential weaknesses with a systems approach for any system is knowing how much time should be expended in the early stages before moving on to more rigorous processes for scoping the problem. As with drawing the boundary it relies upon the knowledge and experience of the practitioner as well as supporting evidence from various sources wherever possible. This is known and accepted within the field and is dealt with openly in conjunction with stakeholders to ensure that all parties are happy with the approach to be adopted.

This discussion can similarly be applied to the choice of tools and techniques applied to explore the problem space once the boundary has been drawn. There are numerous methods that can be applied when analysing dynamically complex systems (NATO, 1992). However, as with drawing of the boundary a great deal of time and resources can be utilised dismissing options after attempted application to the system of interest. Based on the system boundary that is drawn, the stakeholders involved, the system constraints and desired behaviours within a given environment an experienced systems engineer can rationalise tools and techniques (Sterman, 2000). As with the boundary, supporting evidence for the choice of tools is provided and in the field of human related systems there are some accepted constructs within which multiple tools and techniques have been validated (Checkland, 1979).

The other potential weakness with the research aims related to tools and techniques is the use of subjective data to make system decisions. One of the key objectives of the thesis is to introduce methods that provide robust evidence which is capable of validation and verification. Using subject matter experts can be flawed if using these criteria, as they will be biased according to their world view (Checkland, 1981) a point that is discussed in Chapter 2, section 2.2.2 However the rebuttal for use of SMEs within the processes that are developed as part of Chapter 5 relates to non-reliance on any one source of information to carry out systems analysis. It is the fusion of qualitative and quantitative techniques that is the contribution to knowledge of this thesis. Understanding viewpoints produced from both SMEs and operational experience tempered by modelling and field trials provides a central ground for comparison and unification of direction. This also links to the discussion earlier in the section about assumptions and their implications when using systems techniques. If you fully understand the potential limitations they can be equally as positive as they are negative, and with techniques such as sensitivity analysis to prove the robustness of subjective data there is no reason why it should not be used to enrich qualitative input.

3.7 RESEARCH AIMS SUMMARY

The aim of my research is to develop a suite of processes that can be used by Government research departments specifically concerned with dismounted soldier systems to aid the definition of future concepts and potential research direction. In order to achieve this the following objectives apply to the proceeding chapters:

Chapter 4: To define the problem space and the implications of drawing a systems boundary. This provides the context to the later analysis and highlights the complexity of the problem to be addressed.

Chapter 5: To discuss the tools and techniques used to address the problem identified in Chapter 4. This identifies the requirement for a unique fusion of techniques based on the shortfalls of currently available approaches, when concerned with dynamically complex systems such as the soldier.

Chapter 6: To identify a method by which trade-off activities can be carried out in order to prioritise soldier system concepts and research direction. The customer requirement is for prioritisation as it is not affordable to provide everything, or indeed necessarily beneficial. This chapter builds on Chapter 5 by creating a bespoke, but generic trade-off process to directly answer this customer need.

Chapter 7: To discuss the implications of measuring performance and effectiveness for dynamically complex systems and suggest application to the problem defined in Chapter 4. The challenge of measurement is discussed in Chapter 2 with the objective of Chapter 7 to define a way forward in the context of the soldier as the system of interest. This has significance in the wider procurement community as the transition of research to procurement currently requires contracts with measurable requirements.

Chapter 8: To use case studies to test the validity of the approach devised within Chapter 5. By using a control and then more challenging data set the utility and robustness of the process suite can be judged in order to enhance the confidence of the customer and justify the method and approach adopted.

Chapter 9: To critically analyse the output from the chapters and consider any areas for future work. This reflects the need to identify if the key drivers identified at the beginning of this chapter have been addressed as well as identification of shortfalls and how these may be addressed in the future.

Blank Page

CHAPTER 4: THE PROBLEM SPACE

4.1 INTRODUCTION

4.1.1 Aim

The aim of this chapter is to provide the bounds for the problem space (the soldier as a system) using a systems approach.

4.1.2 Objectives

- To define the problem space and the entities within it.
- To draw a boundary around the system of interest, wider system and environment and justify its position.
- To check for completeness of the problem space definition using soft systems methods.
- To build conceptual models to understand the scope of the processes to be developed in Chapter 5.

4.1.3 Background

Chapter 2 discusses some of the techniques that can be applied to systems problems. The specific system of interest for this thesis is the soldier and his or her kit which can be described as socio-technical in nature (Hitchins, 1992) as it includes both man and machine. This type of problem is difficult to bound as it is dynamically complex in nature with high levels of unpredictability in behaviour (Ackoff, 1969). The intent of this chapter is to explore the problem space within the context of the thesis intent, reflecting the fact that certain constraints exist from the outset due to stakeholder requirements.

Socio-technical problems are often centred on humans impacting the functions of an organisation, for example process implementation or technical output (Checkland & Scholes, 1990). Therefore scoping of the problem space is often carried out when something has already gone wrong with the current system or approach, introducing the need to understand how things can be done more effectively (Checkland, 2002). The problem to be dealt with is not new and there are elements of legacy, both in equipment and practice which require new techniques to integrate with old or where necessary replace them completely. These characteristics can be attributed to the soldier as a system with current problems relating to procurement and research strategies (Controller and Auditor General, 2004b) and legacy in the form of current and past equipment.

Identification of the soldier system as socio-technical suggests the application of more exploratory techniques in the early stages of problem and system definition, taking on board multiple viewpoints and building some level of 'completeness'. This aligns with the soft systems methodology (Checkland, 1981) discussed in Chapter 2 where diagrams in the form of brainstorming or rich pictures and more formal context diagrams are used to determine the boundary for the direct system of interest (SoI) the wider system of interest (WSoI) and the environment. These terms are used to describe, in the first instance the elements without which the system will not operate. The wider system of interest defines the directly related systems, which the SoI must interface or integrate with in order to be effective and the environment dictates some of the constraints placed on the system, such as political climate, available resources and legislation as well as the physical environment.

Drawing these boundaries significantly impacts the shape of the final system as it relates to control in decision making, a factor that will be discussed later in the chapter.

4.2 THE PROBLEM SPACE

The context of the thesis provides certain constraints that influence the boundaries of the system of interest. The process of defining these constraints, identifying stakeholders and creating initial context diagrams of the system of interest are developed as parallel activities as they help to inform the creation of each other. In trying to understand the problem space there is a need to understand what elements it consists of, which requires identification of stakeholders. This helps to grow the picture of what the system is and leads to further stakeholder identification. As stakeholders are identified, so are constraints on the shape of the system, as influence is exerted from different parties.

Fig 8 diagrammatically represents the analysis carried out to determine system context as well as stakeholder needs and constraints. It identifies that embedded within the approach is more subjective (represented by the upper circles) and objective (represented by the lower circles) input. As with the process suite described in Chapter 5; there is an element of judgement and of uncertainty even in definition of the system boundaries. This reflects the breadth and variability of the soldier as a system, with the need to potentially flex boundaries depending on the specific context. It also recognises the subjective and objective influence of stakeholders, who may be driven by legislation and policy on the one hand, whilst introducing personal preference and bias on the other.

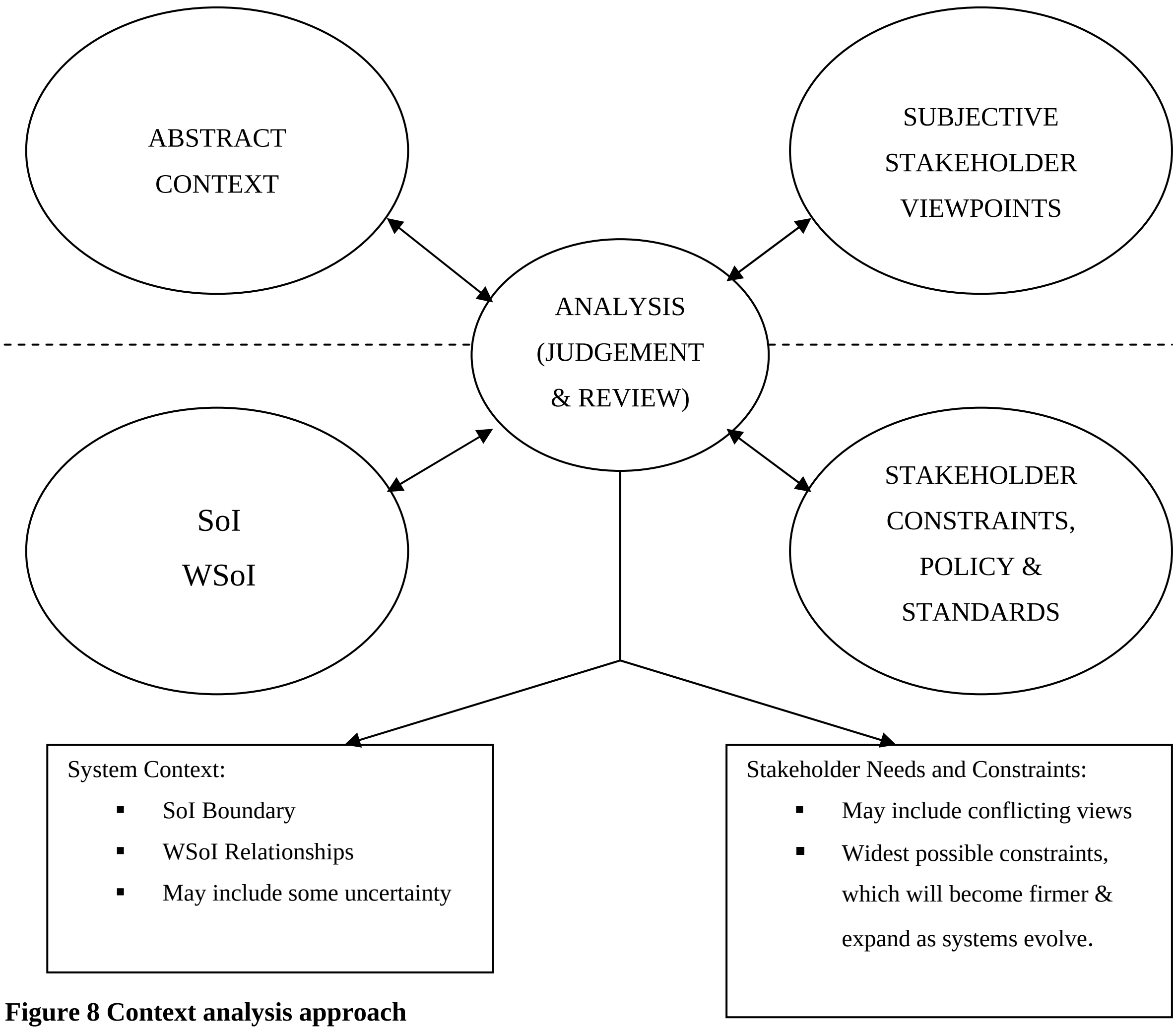


Figure 8 Context analysis approach

Creating a process suite to answer a specific customer need represents an applied problem. Utilising techniques such as Soft Systems Methodology (Checkland & Scholes, 1990) within the analysis context (Fig 8) provides a tailored approach to a specific problem. In defining the problem space the analyst is observing how and with what the system operates in order that potential shortfalls can be identified and remedial action taken. The following sections use tools and techniques from Soft Systems thinking (Checkland, 1981) to progress the analysts understanding of the soldier as a system, to a point where conceptual models can be built; upon which, the process suite (Chapter 5) is defined. This evidence forms part of the audit trail that helps to ensure completeness and increases confidence in the robustness of subsequent output.

4.2.1 The domain of interest

Fig 9 represents a high level view of the domain of interest with the soldier forming the centre and other components radiating out from this point. This is a second iteration diagram taken from a brain storm containing general thoughts drawn onto paper without any formal structure. The derivation of the elements is based on stakeholder input formalised by the author. It includes mandated categories in the form of the defence lines of development comprising training, equipment, personnel, infrastructure, logistics, doctrine and concepts, organisation and information (Joint Doctrine and Concepts Centre, 2005) as well as the organisations involved in the delivery of soldier system output and the environment within which they operate.

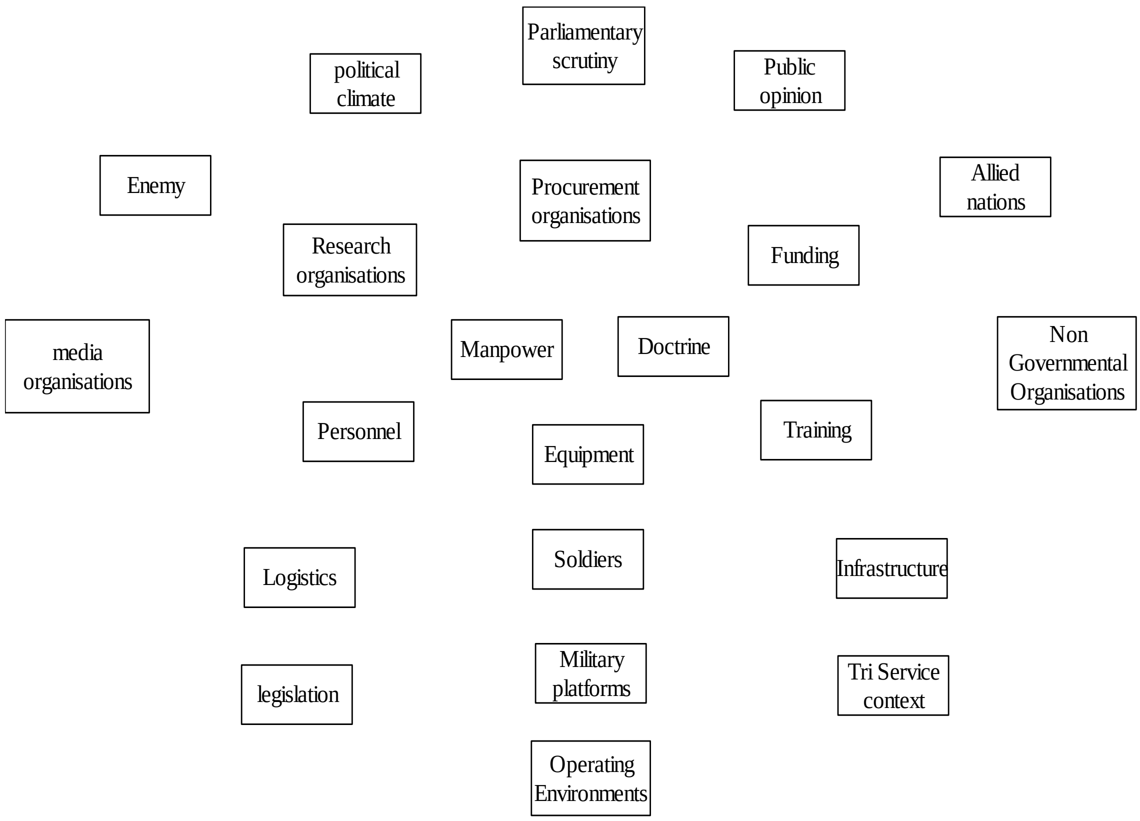


Figure 9 High level view of the domain of interest

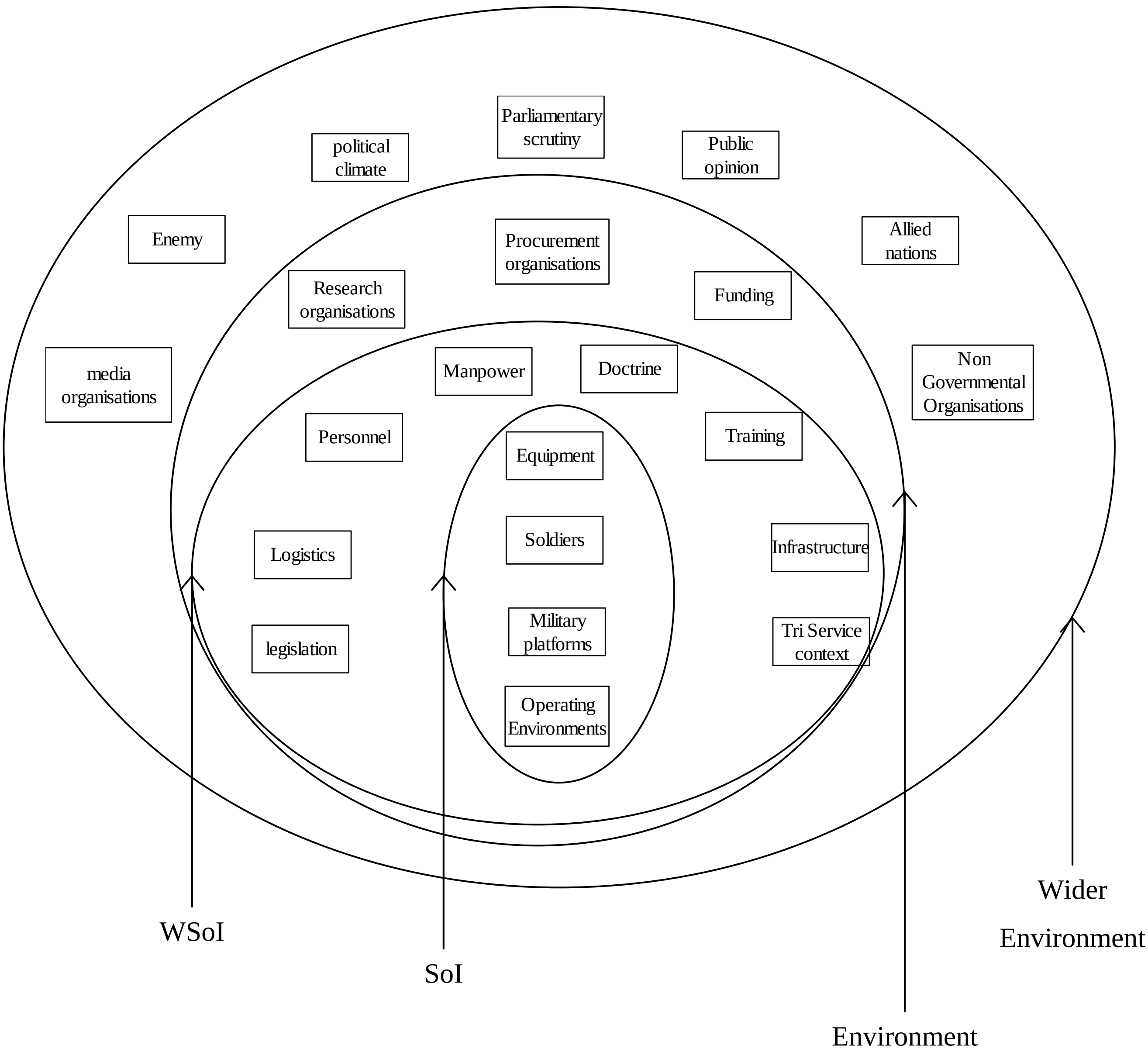


Figure 10 Context diagram first iteration

Fig 10 shows how these can be grouped at the highest level into the system of interest within the centre ellipse, the wider system as the next ellipse from the centre and so on with the environment and the wider environment as the final two ellipses. These boundaries have been drawn as a consequence of the thesis context in addition to stakeholder input. The following paragraphs provide the rationale for these high level boundaries before exploring sub-sets of Fig 10 in more detail.

As defined in Chapter 1, Government soldier system research is the driver for this thesis. More specifically, the thesis responds to the need for the 'provision of information that is auditable and traceable to understand gaps in military capability and justify future procurement (and research) decisions' as stated by the Equipment Capability Customer (ECC).

The system of interest boundary includes soldiers, equipment, operating environments and military platforms. This may require amendment with further investigation of the problem space as it represents a wide scope. Before drawing the final boundary it is necessary to explore the sub components of the system of interest as well as areas of control currently held by the stakeholders.

Having defined the context, further supporting evidence can be identified to help populate more detailed context diagrams. An example is the specific focus on infantry, as dictated by the high level stakeholder. The infantry have a future vision as set out by the Director Infantry (2000) which provides guidance on the types of operation and equipment that are perceived necessary or desirable within the 2020 timeframe. This helps to clarify some of the potential parameters such as the importance of logistics and evolving doctrine, both of which have been captured as components of the soldier system context diagram (Fig 10)

Further supporting documentation comes from existing programmes that relate to our system of interest, for instance FIST (Future Integrated Soldier Technology). As a development programme, FIST has already scoped the problem space and made decisions on the system boundary, which impacts on future soldier system research, through the need to interface with existing programmes and equipment. The FIST programme has been instrumental in the development of the NATO capability domains (survivability, sustainability, C4I, lethality and mobility) which are recognised as descriptors within many international programmes. To ensure consistency between current and future approaches as well with international partners, commonality is encouraged wherever possible leading to the use of the NATO capability domains when exploring the problem space in more detail.

Taking these further pieces of information in conjunction with the context of the thesis described above it is now possible to break out specific portions of the context diagram for further population (Fig 11).

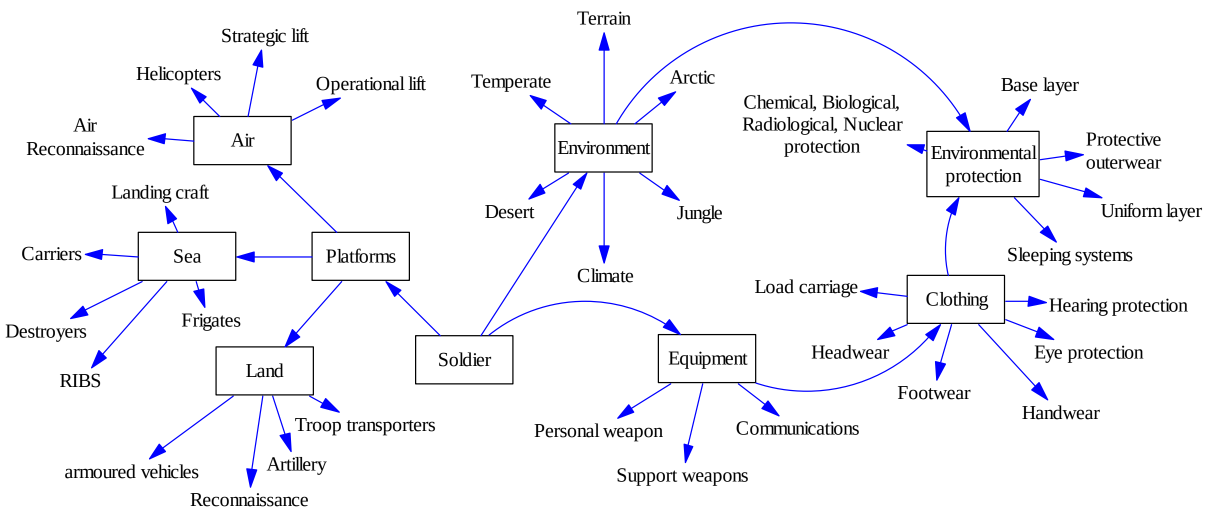


Figure 11 Soldier specific context diagram

This diagram takes the soldier as the central focus and looks in more detail at the other components within the system of interest. This does not show every platform or variation of environmental conditions. Instead it is intended to be a representation of the breadth of elements to be considered for each area. When interpreting the diagram and the inter-relationships, questions are raised on the original interpretation of the SoI boundary. If we are considering the infantry and more specifically the dismounted infantry as the central focus, the platform sub-set should form the wider system of interest. Although it is necessary for the soldier to be transported both to and around the battlefield, responsibility for research and procurement of this area falls outside of the dismounted component. In addition to this, the soldier is capable of achieving combat effectiveness without platforms in certain scenarios and therefore is not within the direct SoI. Therefore, it is essential to have an interface with platforms, but as they are not imperative for soldier effectiveness and they are outside of the direct control of the programme they should form part of the WSoI (Waring, 1996).

In terms of equipment and clothing the soldier is not capable of carrying out his required tasks ‘throughout the spectrum of conflict with a high degree of effectiveness, at short notice (Director Infantry, 2000) without these elements. This requires them to be included as part of the SoI as the soldier system cannot achieve the stakeholder requirements without their inclusion. In terms of the environment, this presents more of a constraint than a direct element of the system of interest. You do not have to have the environment in order to carry out soldier-related tasks; in fact the environment can provide a constraint to carrying out required tasks and as such must be given due consideration when scoping any system component. A revised context diagram considering these changes is shown in Fig 12.

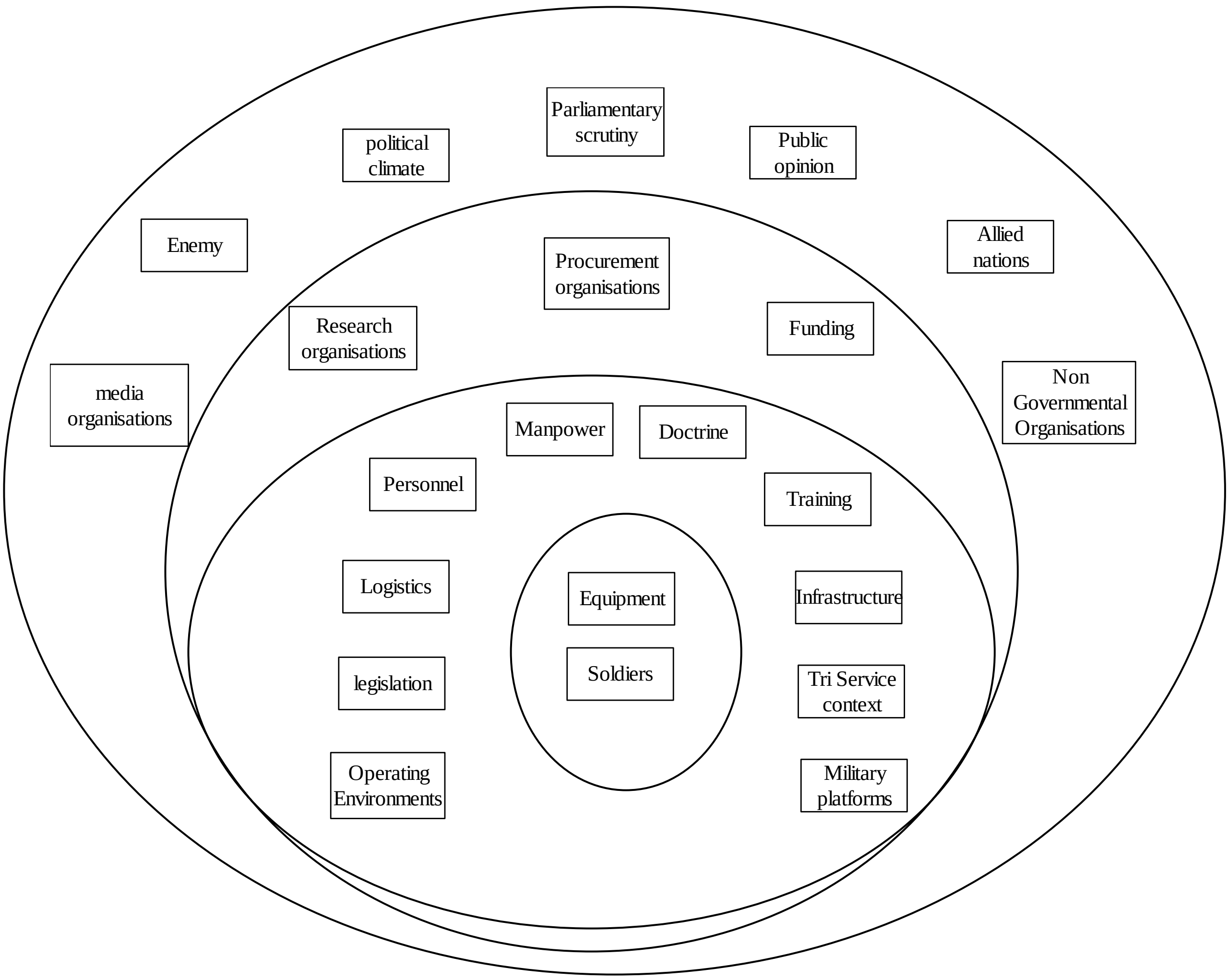


Figure 12 Revised context diagram

To cross check the system of interest and wider system of interest, a further context diagram has been constructed to look at soldier effectiveness as the major driver for future soldier systems. This is expressed using the NATO capability domains, as these groupings are used by the high level stakeholders to define capability gaps and future systems for example FIST. This will help to clarify the role of the elements presented in Fig 11 and Fig 12 context diagrams.

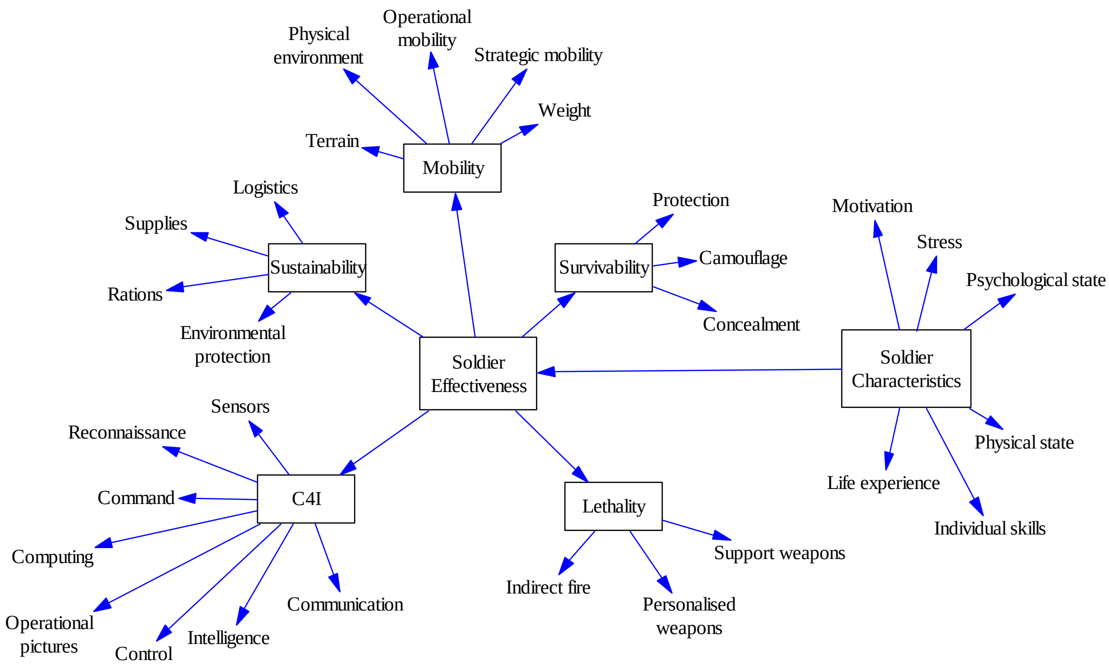


Figure 13 Soldier effectiveness specific context diagram

Many of the lines of development from Fig 12 are represented in this diagram (Fig 13), in addition to soldier states which are recognised as modifiers to system behaviour. This diagram highlights the relationship between the SoI and the WSoI as platforms are integral to wider soldier effectiveness especially within the domain of mobility. From this viewpoint areas such as doctrine and infrastructure are less obviously represented. This fundamental difference between the diagrams supports the notion of looking at differing viewpoints to achieve completeness of diagrams (Sterman, 2000).

Within the authors' MSc thesis (Westwood, 2003), which focused on the FIST programme, further models were used to check for completeness of context diagrams. This included the whole system model (Mackley, 2005) and the generic reference model (Hitchins, 1992). The whole system model provides an external perspective of the system. Figure 14 diagrammatically represents the five areas that are considered.

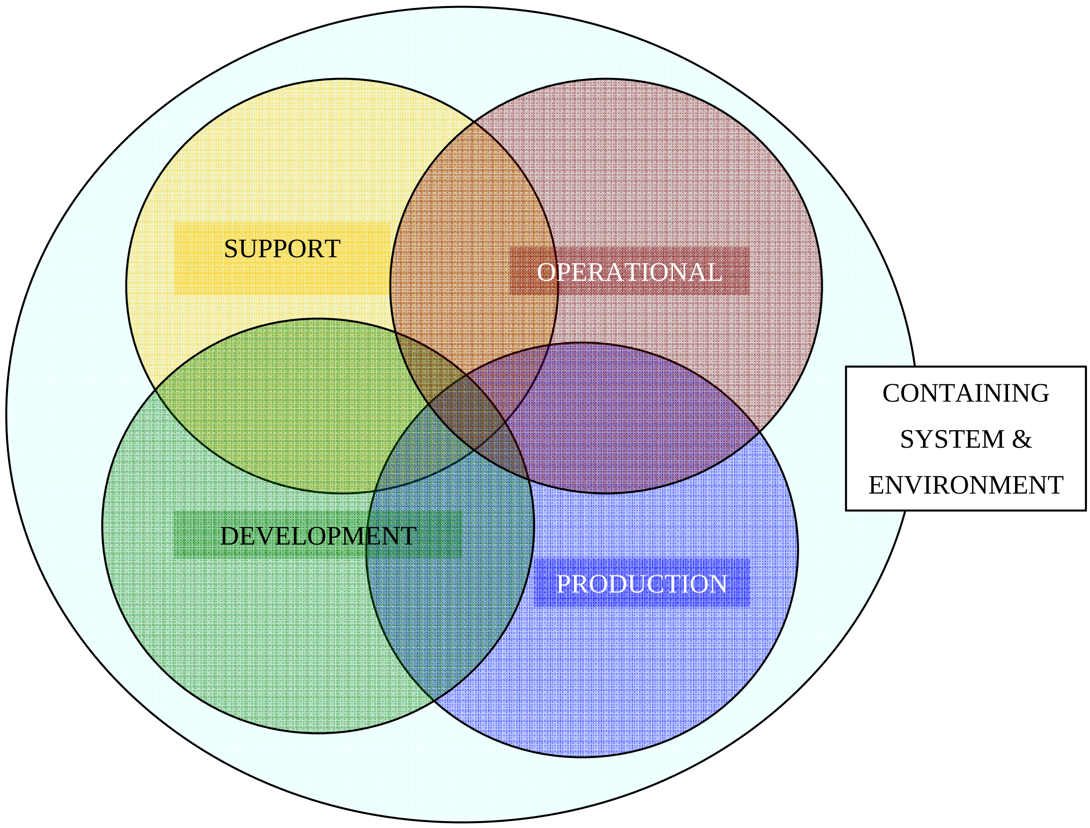


Figure 14 Whole system model

It is more commonly applied to systems where a functional breakdown has been completed as it is concerned with the system that will go into service and the elements that will support this goal in the form of development, production and support, all of which exist within an environment. It relies on an understanding of what the system comprises of in functional terms and what it is trying to achieve, which are not attributes of a ill defined problem (Davies, 1989) such as the soldier system at this stage of enquiry. Having carried out this process in direct relation to FIST it is the author's contention that some benefit can be gained from the exercise, but in the context of human related systems it has limited utility as you have to make the technique fit the domain of interest rather than it providing additional insight into the problem domain.

Similarly the generic reference model (Hitchins, 1992) takes an internal view of the system describing the 'function' in terms of mission, resources and viability, and the 'form' in terms of structure, influence and potential. This model is specifically concerned with socio-technical systems such as the soldier system where man and machine interact to bring about the desired output. However, as with the whole system model it has questionable utility at this stage of problem exploration. When applied to FIST (Westwood, 2003), the model has been used to understand the high level missions of the system; what it is trying to achieve and the resources that it will need to achieve this. A simplified expression of these terms is the identification of input, output and the relationships between them. This is equally as applicable to the generic soldier as a system, but having carried out the technique for the FIST system the author contends that alternatives are equally if not more appropriate for the system of interest. The justification for this contention relates to the importance of stakeholder identification as part of the thesis context.

The intent of this thesis is to create a set of processes that will provide information on gaps in military capability (specifically relating to the soldier) as well as justifying procurement and research decisions. Rather than understanding one soldier system as with FIST, the output from the systems approach in this instance relates to an enduring ability to scope future soldier systems. The success of the process relies on accurate identification of stakeholders to understand where delegated authority exists for delivery of programme elements. Furthermore it is the willingness of these stakeholders to accept and act on output from the processes developed that will indicate success or failure, requiring them to be involved from the very early stages of the approach.

Therefore, there is a need to understand the domain and the boundary of what falls inside and outside of programme control, without focusing on specific decompositions of this. In effect the process created must provide a framework within which decisions can be made. This requires an understanding of the domain, and over time a detailed understanding of components within that domain, but not specific instances of use. The detail forms part of the criteria within the process; for instance what are the implications of carrying out X tasks, in Y environment, with Z level of enemy force.

Scoping of a specific system such as FIST or a future equivalent is the output of the process, but the process itself must be capable of re-use in a consistent manner, using different input parameters. In essence the combination of processes can be classed as a generic ‘method’ to define future soldier systems based upon identified capability gaps.

4.2.2 Stakeholder identification

Having identified the importance of the stakeholders, a parallel activity to creation of the context diagrams is stakeholder identification. Creation of a stakeholder list is iterative in nature and relies on knowledge and experience of other stakeholders to help with progressive expansion. For each of the stakeholders identified, a point of contact is established so that questions and progress can be appropriately directed. Some stakeholders will have a far greater input and impact than others, with further sub-division of the list reflecting this over time.

The stakeholders and their respective interest/ involvement are listed in the Table 1 below.

STAKEHOLDER	INTEREST	LEVEL OF LIKELY INVOLVEMENT
Army Trials and Development Unit (ATDU)	Involved in soldier testing and research	Low to Medium
Army Training and Recruitment Agency (ATRA)	Involved in research related to selection of army recruits	Low to Medium
Directorate Equipment Capability- Air Literal Manoeuvre DEC (ALM)	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
Directorate Equipment Capability – Above Water Battlespace DEC (AWB)	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
Directorate Equipment Capability – CCII	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
Directorate Equipment	Cross DEC implications with	Low to Medium

Capability – Deep Target Attack DEC (DTA)	soldiers needing to integrate with other platforms	
Directorate Equipment Capability – Ground Manoeuvre DEC (GM)	Direct customer and instigator of the approach	High
Directorate Equipment Capability – (ISTAR)	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
Directorate Equipment Capability – Nuclear, Biological and Chemical DEC (NBC)	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
Directorate Equipment Capability – Special Projects DEC (SP)	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
Directorate Equipment Capability – (TA)	Cross DEC implications with soldiers needing to integrate with other platforms	Low to Medium
DGR&T		Low to Medium
DGSA		Low to Medium
Directorate Land Warfare	The directorates are the high level representation of the end user, or military community	Low to Medium
Directorate Operational Requirements	The directorates are the high level representation of the end user, or military community	Low to Medium
DLO	Specific IPT's within DLO will have knowledge of legacy equipment	Medium
DPA	Knowledge of current programmes and potential synergy with output from the process work	Medium/ High
Defence Science and Technology Laboratory (Dstl)	Research provider and preferred Government supplier	High
Fleet	Lead organisation for the Naval branch of the armed forces	Low
Future Business Group	DPA based organisation involved in scoping future programmes and technology watching	Low/ Medium
HQ Infantry	Lead organisation for the Army branch of the armed forces	Medium
Industry	Various contractors will have an interest in delivery of concepts and research work	High
Institute of Naval medicine (INM)	Research organisation specifically concerned with the Navy and Royal Marines	Medium
Integration Authority (IA)	Part of the DPA responsible for understanding all of the linkage between development programmes	High

Infantry Trials and Development Unit (ITDU)	Responsible for co-ordination of army trials	Medium/ High
NATO working groups	Interested in international programme developments	Low/ Medium
NBC Defence Centre	Test and research centre for specialist NBC equipment	Low/ Medium
Research Acquisition Organisation (RAO)	Responsible for placing research contracts based on requirements identified by the DEC	High
Research and Project Support (R&PS)	Government research organisation currently responsible for most soldier system research	High
Soldier System Integration Authority (SSIA)	Formed as a sub branch of the IPT responsible for delivery of FIST	Medium/ High
Strike	Lead organisation for the air force branch of the armed forces	Low
Universities	Currently responsible for a number of research projects linked to soldier systems	Medium/ High

Table 1 Process Stakeholders

4.2.3 CATWOE analysis

The mnemonic CATWOE forms part of Checklands approach to soft systems problems (Checkland, 1981). The letters have the following meaning:

- Clients – Those that will benefit from the system or output
- Actors – Those involved in carrying out the system intent
- Transformations – What happens to the input to create the desired output
- Weltanschauung – German for the world view of a specific stakeholder
- Owners – Generally the stakeholders that have authority over the output
- Environment – Constraints imposed by external elements

CATWOE is a way of formalising context diagrams, drawing out the key stakeholders and the desired output of the system. From the CATWOE analysis the root definition is derived which captures what the system of interest 'is', in preparation for modelling of the system to determine what it must 'do' to achieve the desired output (Wilson, B, 1993). There are several benefits in applying CATWOE as a technique. Firstly it explores the roles of various stakeholders and their perception of the system output. Secondly, it reconfirms constraints identified as part of the context diagram and helps to check for completeness.

For the soldier as a system, CATWOE can be used in place of techniques such as the whole system model (Mackley, 2005) and generic reference model (Hitchins, 1992) described in section 4.2.1 CATWOE analysis enables high level exploration of the problem domain, whilst focusing the context diagrams and checking for completeness by shifting the stakeholder viewpoints.

Before completing the analysis it is necessary to define the context and drivers for the problem space. This is a strength in a systems approach and in particular soft systems methods for complex problems (Hindle et al., 1995) as there is a constant recourse to the problem that is trying to be addressed. This discourages a loss of sight of the original problem which can often occur as further analysis is carried out. With this approach there is a constant questioning of ‘what is it I am really trying to achieve?’

Therefore, as stated earlier in the chapter, the driver for the thesis and analysis is soldier system research, with the more specific context based on high level stakeholder need to provide ‘information that is auditable and traceable to understand capability gaps in military capability and justify future procurement (and research) decisions.’ This provides the focus for the CATWOE analysis.

The stakeholders are listed in Table 1 with their respective level of involvement and interest in the problem space. From this the CATWOE analysis can be carried out from a number of perspectives to explore the effect on the problem space. Those stakeholders with a high level of interest or involvement are considered directly within the CATWOE process and subsequent conceptual model building, with the full list of stakeholders considered at some level of detail for one or more of the models shown in Fig 19-22.

Fig 15 takes the high level stakeholder perspective, the customer for the work, DEC (GM).

Customer focus

Clients	DEC (GM) as the beneficiary of the output from the processes
Actors	Dstl as the providers of the process
Transformations	Data into processed information to support research and procurement decisions
Waltanschaung	The clients want a process/es that will satisfy parliamentary scrutiny
Owners	The RAO are responsible for contracting the work and are interested in cost as well as measurement of success against requirements
Environment	The defence budget, political climate and economic stability of the defence sector will directly impact delivery of the output

Figure 15 CATWOE – Customer Focus

Root Definition:
'A process/es to provide scrutinised information that will support Government research and procurement decisions for future soldier systems.'

This root definition has importance when defining the processes to provide scrutinised information as it shows the very specific remit of two of the high level stakeholders, the RAO and DEC (GM). To some degree they are less concerned with the findings of the process and more concerned with the ability to pass scrutiny and be capable of contracting work. This will become more evident when looking at the process from the perspective of the user community- the armed forces (Fig 16).

User focus

Clients	The British Army and Tri-service personnel that will benefit from future systems
Actors	RAO with DEC (GM) having responsibility for placement of contracts and concept development
Transformations	Information from the process/es into concept equipment
Waltanschaung	The clients are interested in receiving improved equipment to enhance effectiveness
Owners	Central Government budget holders who provide delegated authority to the RAO and DEC
Environment	The direction of concepts will be constrained by current and future threats, theatres of operation and media as examples

Figure 16 CATWOE – User focus

Root Definition:
'A research driven soldier system to enhance combat effectiveness of the dismounted soldier.'

This root definition reflects the user's desire for a physical output from the information provided by the process/es. They are less concerned with the workings of the process and more focused on an output that will improve the ability to carry out their roles and responsibilities. This will be explored further when the root definitions are translated into conceptual models.

As the intent of the process is to provide information that will dictate research and procurement decisions based on recognised capability gaps another important viewpoint is that of the organisations that may be responsible for delivery of either product or service. Fig 17 looks at this viewpoint using CATWOE.

Supplier focus

Clients	DEC (GM) as the co-ordinator for the equipment, in conjunction with the DPA longer term
Actors	Industry or academia responsible for delivery of the products or services
Transformations	Information from the process/es into concept or research output
Waltanschaung	Profit and kudos for the organisation
Owners	Central Government budget holders who provide delegated authority to the RAO and DEC
Environment	Economic stability of the defence sector, political climate relating to placement of defence contracts with certain providers. Stability of the research environment with long term commitments to universities

Figure 17 CATWOE – Supplier focus

Root Definition:
'A profit driven system/ problem solution to satisfy the clients need whilst enhancing the organisations position in the defence or research community.'

This root definition highlights the distinct difference between stakeholder viewpoints that must be born in mind when creating the system process/es. External organisations are more likely to be driven by profit and kudos than Government, but will also require certain levels of support to be able to carry out the desired tasks. This is an important consideration when developing the processes as they will have to used not only by internal stakeholders, but external stakeholders with different needs and drivers.

A final viewpoint is that of Dstl who have responsibility for delivering the process for DEC (GM) and the RAO. Fig 18 defines their viewpoint.

Process provider focus

Clients	Dstl will benefit from the output of the process through increased funding and workload
Actors	The teams within Dstl and associated organisations
Transformations	Resources into research output
Waltanschaung	To increase business through completion of research programmes for Government
Owners	The RAO and DEC (GM) as research contract partners
Environment	Competition from other research providers, industry, academia, consortia. Reducing defence budgets. Public opinion

Figure 18 CATWOE – Process provider focus

Root Definition:

'A programme to deliver required research output to the customer organisation.'

This viewpoint is interesting as it shows a distinct gap between the people involved in delivering the output and the organisation that has control of the programme. As a research provider, Dstl are concerned with research market share. Therefore, they must deliver on contracts in order that the customer has confidence in their ability to provide output. This will lead to future contracts being placed and so on and so forth. Dstl in many ways mirrors the supplier focus in Fig 17 managing resources to provide output for maximum kudos and 'profit', or surplus in Government terms. The difficulty for the organisation is matching specialist resource to need, in effect, having the right people with the right skills to do the job. This places a constraint on the way that the process is developed as there will need to be simplicity, auditability and traceability to make the process robust to changes in team dynamics. This is a desire as expressed by the high level stakeholders, but for reasons of scrutiny rather than organisational changes. The difference between the needs of the two should be duly considered when creating the process/es.

4.2.4 Conceptual model building

The intent of CATWOE and the root definitions as defined by Checkland (1981) is to create a basis for conceptual models to be built by the analyst to represent a viewpoint of what the system must do in order to achieve its purpose (as stated in the root definition) (Waring, 1996). The conceptual model shows the minimum number of actions that must exist in order that the transformation described in the CATWOE analysis can be achieved. It is important that only one transformation is considered for any one conceptual model for the sake of clarity in understanding. The rationale for this approach relates to the intent of the conceptual model to reduce complexity and provide a model for comparison against the real world. It is about the analyst's exploration of the problem space, which can subsequently be compared with the real world and debated with the stakeholder community (Checkland, 2002).

The building of conceptual models enables the analyst to take the different viewpoints described in section 4.2.3 and build on these, iterating both the model and the root definition as knowledge increases (Checkland, 1979).

The following conceptual models have been developed from the root definitions in section 4.2. taking each of the stakeholder views as a unique conceptual model. The 'monitor' and 'control' functions expressed on the diagrams have been placed outside of the specific activities ellipse as they underpin the actions that occur. Both the monitor and control function pervade all of the activities that exist within the conceptual model ellipse.

Customer focus

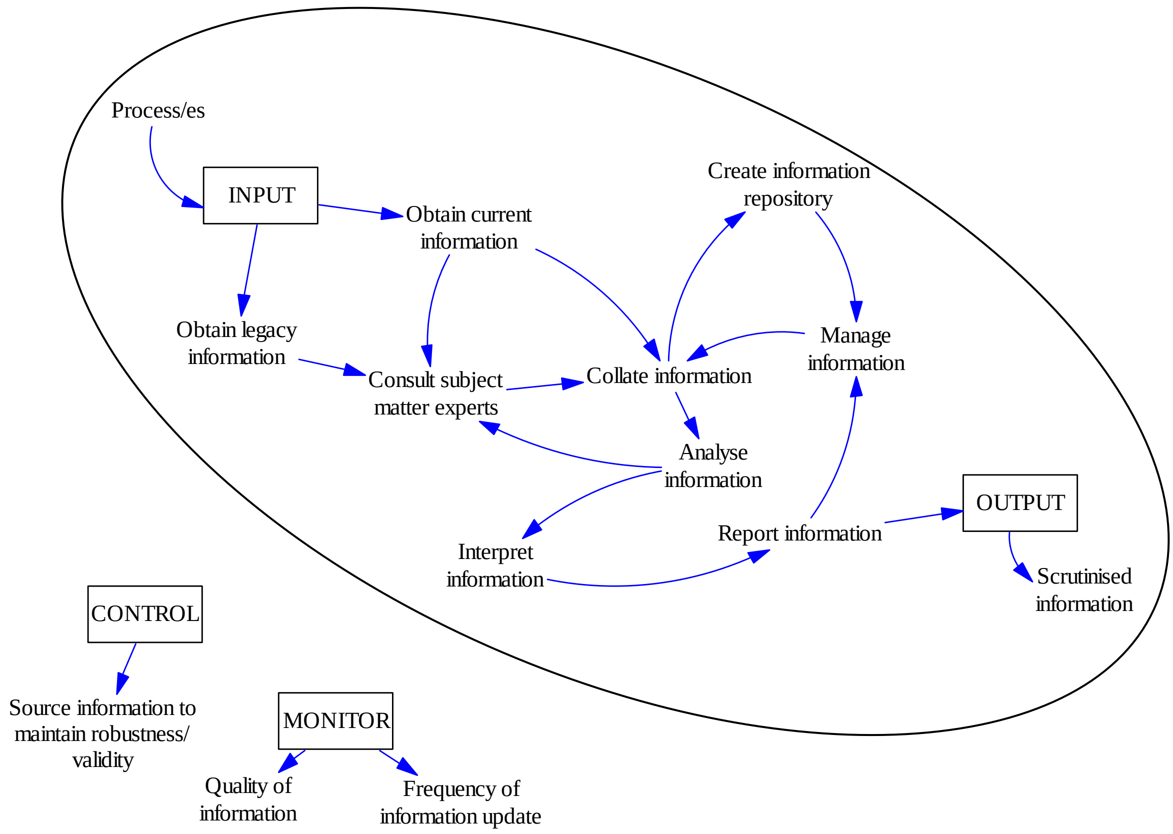


Figure 19 Conceptual model- customer focus

When creating the conceptual models for the different stakeholder views it becomes apparent that they are inextricably linked in many ways. This provides reassurance that there is a common goal with differing perspectives; however it also reaffirms the power and control of certain stakeholders.

The customer focus shapes the processes required to define future soldier systems. It confirms the need for robustness of information and some way of managing information that is gathered and analysed. Furthermore, it expresses the iterative nature of any process developed so that subsequent interrogations of the information are current.

User focus

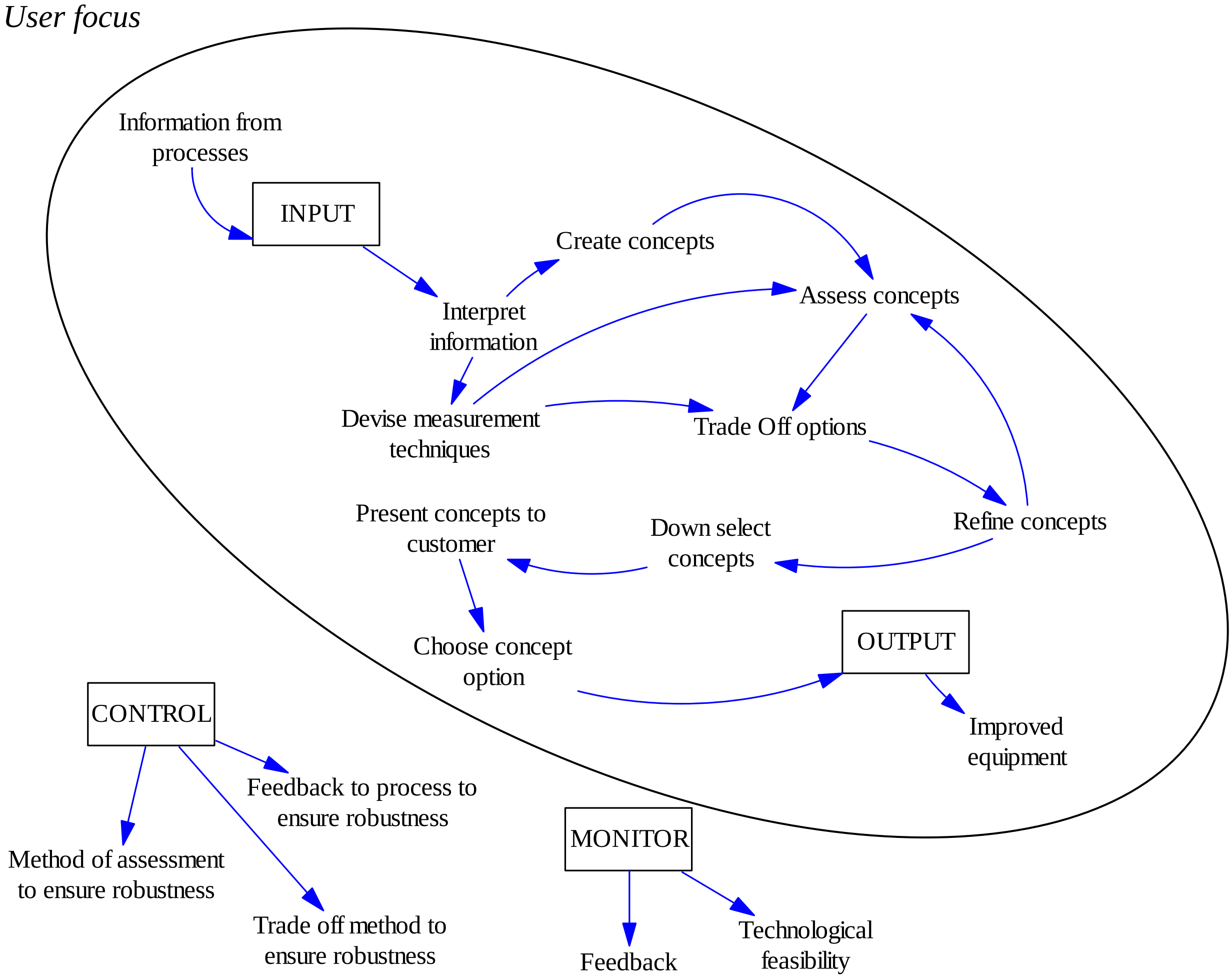


Figure 20 Conceptual model – User focus

The user focus is concerned with the physical output from the process work, an example of which would be equipment. The activities within this view integrate with the customer view as they expand upon the requirements for a process to define future systems. This view is far more concerned with understanding how we can measure system concepts and down select them to provide enhanced effectiveness. Technical feasibility and measurement are key drivers which link closely to the supplier focus.

Supplier focus

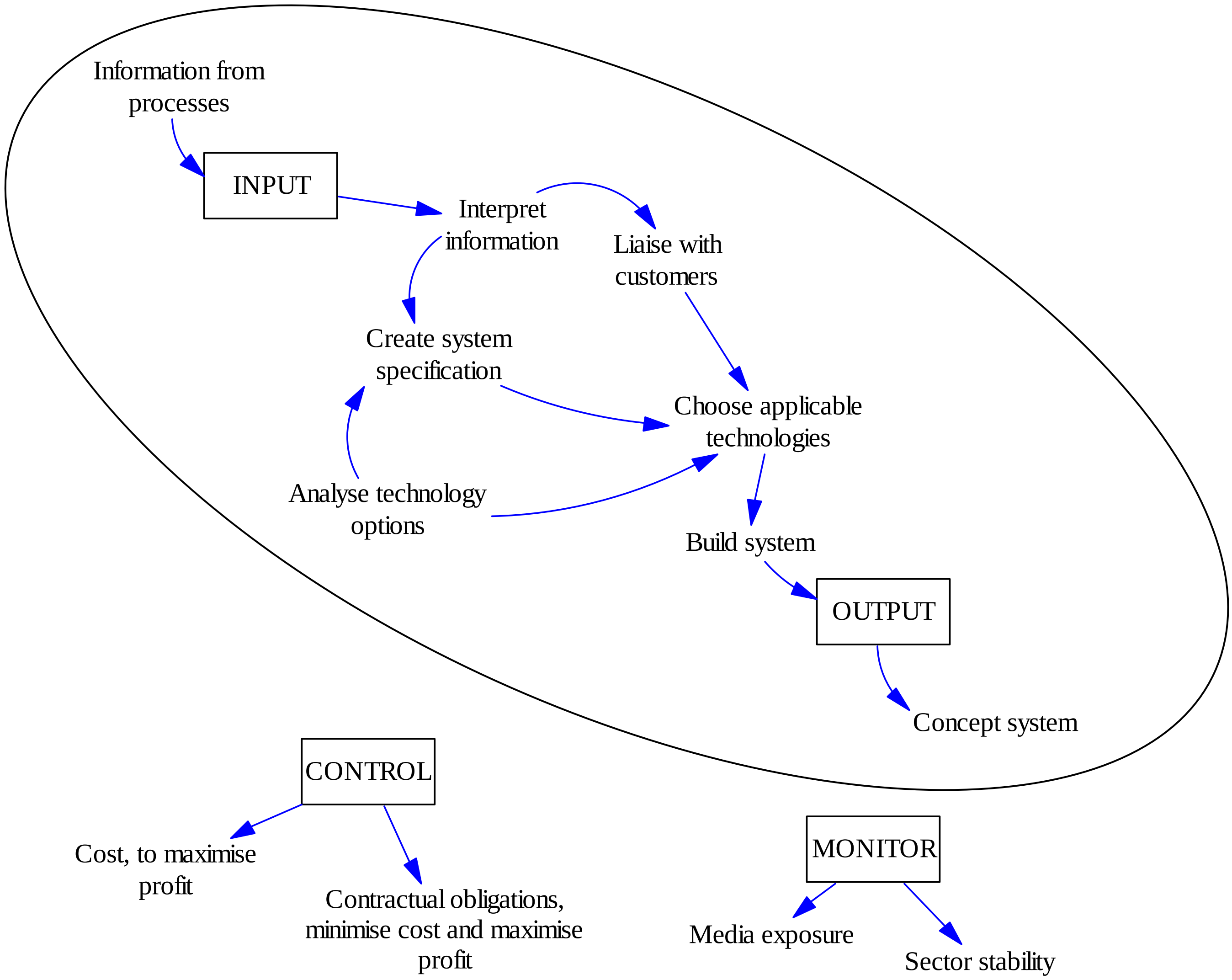


Figure 21 Conceptual model – Supplier focus

As with the user focus, the supplier is concerned with concept delivery as the output rather than the specifics of the process that will direct what the concept should contain. The difference between the two is the monetary driver for industry compared to the product suitability for the user. Of importance for process development is the action of interpreting the information provided by the process. This requires clarity in the information provided to industry and wherever possible early involvement to enhance this group of stakeholders' awareness of what the system is trying to achieve.

Process provider focus

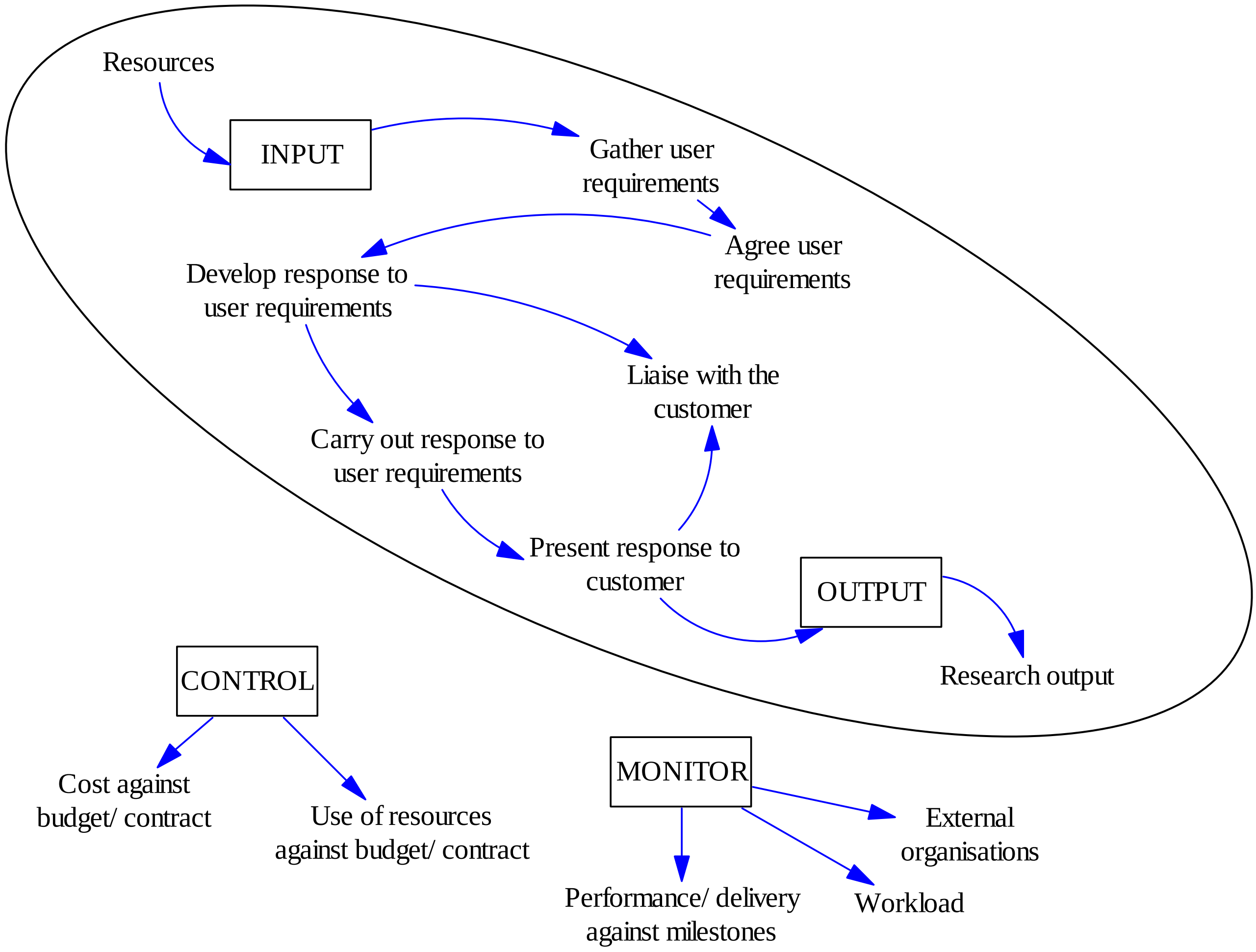


Figure 22 Conceptual model – Process provider focus

The process provider view conforms more directly to project management functions and process driven systems engineering practices. Looking at the customer and user conceptual models, the synergy between the three views can be seen more strongly. In essence the customer and user are both high level stakeholders, one controlling the budget and one utilising the resultant capability. Therefore, where the conceptual model for the process provider has actions such as 'gather', 'agree' and 'response to customer user requirements' the actions from the first two conceptual models (Fig 19 & 20) are utilised. In breaking down the viewpoints to manage the complexity of the problem, multiple activities have been exposed for inclusion within the resultant process. As the process is developed in Chapter 5, the output from the CATWOE and conceptual models will be used to check for completeness and determine where further iterations and refinements are required.

4.3 CRITIQUE OF THE TECHNIQUES USED

4.3.1 Justification for use of the techniques

The context diagrams, CATWOE analysis and conceptual models are all elements of the soft system methodology proposed by Checkland (1981). It has been established in Chapters 1 and 2 that considering the soldier as a system is a dynamically complex problem and, as such, lends itself to techniques such as those proposed by Checkland. Justification for use of these techniques is further supported by the work of Obeng (1994) who described certain problem types and potential approaches for dealing with them. If there is uncertainty in what the problem truly is, the ability to define a system in detail becomes difficult, as there is little evidence to base decisions on.

Further differences exist between human related systems, often classified as ‘soft’ and engineering/ technological problems often classified as ‘hard’. This relates to the aim of the approach, which in turn affects the detailed methods applied (Checkland, 2002). Hard systems are frequently looking for optimisation based on a single criterion, the result of which will enhance performance (O'Keefe, 1964). Soft systems are still concerned with making improvements but recognise that human related systems have multiple values associated with them, many of which are conflicting in nature. The outcome is not optimal, instead it is the process of learning that occurs from carrying out the exploration of the problem that leads to actions being taken and re-assessment of subsequent situations (Checkland, 2002). It may take several iterations of a soft approach to get to a point of efficient action to a problem, something that may only have taken one attempt for a hard system to optimise (Smith, J et al., 1991). This underpins the action research cycle where implementation is the foundation for subsequent improvement (Warmington, 1980).

In using a highly iterative and flexible approach including the opinions of stakeholders, soft systems methods realise the importance and power of people. As discussed in

Chapter 2 section 2.2 most systems have human influence in some form, from production to use. Therefore acceptance is important for any system both contractually and in everyday use. Part of acceptance is driven by perception as well as physical measurement of performance. An individual’s perception is developed through their experience of the world and will be shaped by the environment within which they reside. Soft systems methods explore the impact of different stakeholders’ views on the shape of the problem and potential ways of resolving it. If the stakeholders are not prepared to accept the proposed process to address their identified needs it does not matter how brilliant the solution, it will not be accepted. Soft systems methods allow for front end analysis outside of the real world situation with comparison to the real world enabling more abstract interpretations to be explored.

4.3.2 What insights do the techniques provide?

The continued growth and revision of the problem space has been shown within the context diagrams, CATWOE analysis and conceptual models. The final element is to compare the conceptual models to the real world situation to determine where shortfalls exist.

Each of the diagrams and models brings greater clarity to the thought processes of the analyst. They form the basis for decisions on how to address the problem and will be revisited in Chapter 5 when the system process is developed. When comparing the conceptual models to the real world situation, a number of conclusions can be drawn from the analyst’s interpretation of the problem enhanced by the stakeholder viewpoints:

- The customer (RAO and DEC GM) have the most significant power to dictate the content of the processes developed to address the problem.
- The customer requires processes to be developed that will stand up to scrutiny from their customer (central Government) which will impose certain constraints.
- The customer does not currently have a method to address the problem that will stand up to scrutiny. In fact, identification of candidate future soldier systems is highly subjective with multiple assumptions.

- The approach to the problem at this time has insufficient monitoring and control functions associated with it, which has led to duplication of effort and poor integration.
- The user is still only concerned with equipment, with little interest in the processes that will provide direction on what should be procured.
- Industry is motivated by profit and to-date has been accustomed to detailed specifications being supplied by Government. They are not used to taking on developmental risk and will need to be engaged at an early stage, to ensure a clear understanding of what is trying to be achieved.
- The process providers are concerned with delivering against contract and securing future work. They appear to be focused on meeting customer and contractual requirements above the intellectual challenge of resolving the problem.

4.3.3 Checking for completeness

When determining completeness of view, consideration must be given to the intent of a soft systems approach. As discussed in section 4.3.1 the method is intended to be iterative, and as such refinement continues throughout the derivation of the process and beyond to subsequent iterations of the approach. In terms of drawing a boundary and feeling content with the scope of the problem to be addressed, use of context diagrams, CATWOE and conceptual models provides a basis for discussion. Stakeholders are consulted, diagrams drawn and redrawn after debate, and greater clarity is achieved. Is it ever possible to say that something is 100% complete? It is the enquiry that instils confidence in the output through justification and reiteration in debate. Soft systems as a methodology is about learning, it is not about application of a prescriptive tool, so tackling this type of problem in itself is about learning (Checkland, 1981). It establishes a basis for debate (Patching, 1990) where more detailed knowledge is being gained through each iteration of a diagram or model.

In drawing a system boundary, elements are included and excluded but not ignored. There is possibly more danger in drawing a boundary that is too wide where control is minimal for large portions of the potential system. The boundary may flex over time and with changes to the environment within which the system exists. However, it may be contended that as long as the entities are represented, their impact upon one another can be investigated and stakeholders engaged. It is of more concern to ignore entities that may cause integration or interface issues at a later date.

4.4 PROBLEM SPACE SUMMARY

The soldier as a system has been defined as the problem space with the specific requirement of the customer for a process that will provide auditable and traceable information to direct future procurement and research of soldier systems. This, in conjunction with relevant military visions for the next twenty years, provides the constraints within which the process must be developed.

The context diagrams in conjunction with the stakeholder listing have enabled a boundary to be drawn around the direct system of interest, containing the soldier and his personal equipment. This constitutes the areas within direct control of the programme. Vital interfaces are then shown within the wider system and constraints are expressed as part of the environment.

CATWOE analysis, in conjunction with conceptual models, has been used to check for completeness. Stakeholder identification and subsequent exploration of their viewpoints enables the analyst to more fully understand the major drivers for future systems. It also clarifies the power balance within the problem space and identifies further constraints to the development of the system processes in Chapter 5.

Root definitions developed from the CATWOE analysis form the basis of conceptual models, representing the analyst’s view of the problem. When reconciled with the real world view shortfalls can be identified which will be addressed as part of the process in Chapter 5.

Blank Page

CHAPTER 5: THE PROCESS SUITE

5.1 INTRODUCTION

5.1.1 Aim

The aim of this chapter is to define the process suite that has been devised to answer the research question presented in Chapter 3.

5.1.2 Objectives

- Describe the organisational functions based on output from Chapter 4
- Discuss techniques for development of the process suite
- Define the process suite
- Examine the completeness of the process suite when compared to the output of Chapter 4

5.1.3 Background

The aim of my research as defined in Chapter 3 is to develop a suite of processes that can be used by Government research departments specifically concerned with dismounted soldier systems to aid the definition of future concepts and potential research direction.

Development of these processes is a progression from the conceptual models described in Chapter 4 (Fig 19- 22). Derivation of the conceptual models and root definitions provides the analyst with an understanding of different stakeholder perspectives and drivers, in addition to the activities required to transform (in this case) data into scrutinised information, as required by the customer. In order to transition from the conceptual models to the process suite a more functional view (Sage, 1992) is required focusing on delivery rather than problem definition.

Chapter 4 defines the boundaries of the soldier as the system of interest in addition to the environmental and stakeholder constraints that will shape the processes described in this chapter. The problem to be dealt with has legacy and as such cannot be addressed without certain criteria being met. The customer has already stated requirements: 'a process that will provide auditable and traceable information to direct future procurement and research of soldier systems' and there are strong stakeholder views, all of which must be addressed within the processes. Furthermore, certain activities, such as scrutiny to receive funding, are mandated, and so must be incorporated, along with the existing delivery organisations in the form of the Defence Procurement Agency and Defence Logistics Agency with alignment in practices wherever practicable.

The following sections describe the process suite development using the output from the conceptual models as a foundation, in conjunction with tools and techniques described in Chapter 2 section 2.5.6. Application of the process suite is carried out using case studies within Chapter 8 to determine if the customer requirements have been met.

5.2 PROCESS DEVELOPMENT

5.2.1 Assumptions

There are a number of assumptions or in some cases constraints that will shape the developed processes. In line with the requirement for auditability and traceability these are stated in advance of the process diagrams:

- The SoI has been defined as the soldier and their personal equipment.
- The focus of the processes is the dismounted infantry from either the land, air (RAF Regiment), or sea (Royal Marines) domain.
- The capability domains are consistent with those used by Government, at this time comprising survivability, sustainability, mobility, lethality and C4I (NATO LG3, 1999).
- The customer for the work is DEC GM (Directorate Equipment Capability, Ground Manoeuvre) and the RAO (Research Acquisition Organisation) whose requirements dictate the content of the processes
- The processes will align with other tools and techniques used for Governmental scrutiny, more specifically operational analysis.

- Definition of future operational threats and representative scenarios for test and evaluation purposes are the responsibility of military subject matter experts in conjunction with Government intelligence agencies.

These assumptions are discussed in context within the subsequent chapter sections.

5.2.2 Organisational functions

The organisational functions bridge the gap between the conceptual models and the process suite, forming a high level representation of the activities required to deliver the desired customer output. It is an allocation of the key activities from each conceptual model to the appropriate organisational entities. To achieve this allocation, the following refinement and grouping of activities into coherent functions for each organisation is summarised below:

- The conceptual model for both the customer and the user has had their activities transposed into the process provider's box as the group responsible for delivering the stakeholder requirements.

- The 'process provider' conceptual model activities are subsumed into the role of project management which compliments the delivery of product against requirements.

- The supplier focused conceptual model is captured within the supplier box in Fig 23, with many components of the user conceptual model reflecting the desire of both groups to have physical output. As suggested in the root definition, the user is most interested in output, not how that output has been achieved, and is therefore focused on operational capability within the organisational functions.

- Finally there is the customer whose main driver is the use of scrutinised information provided as output from the process; this is reflected in the documentation within the Customer 1 box.

The arrows between the boxes represent the inter-relationships between the stakeholders, and act as a reminder that communication is of importance when defining the more detailed analysis approach described in section 5.3.3 In conjunction with the conceptual models it provides the basis for checking completeness later in the chapter as well as indicating areas of stakeholder responsibility and authority.

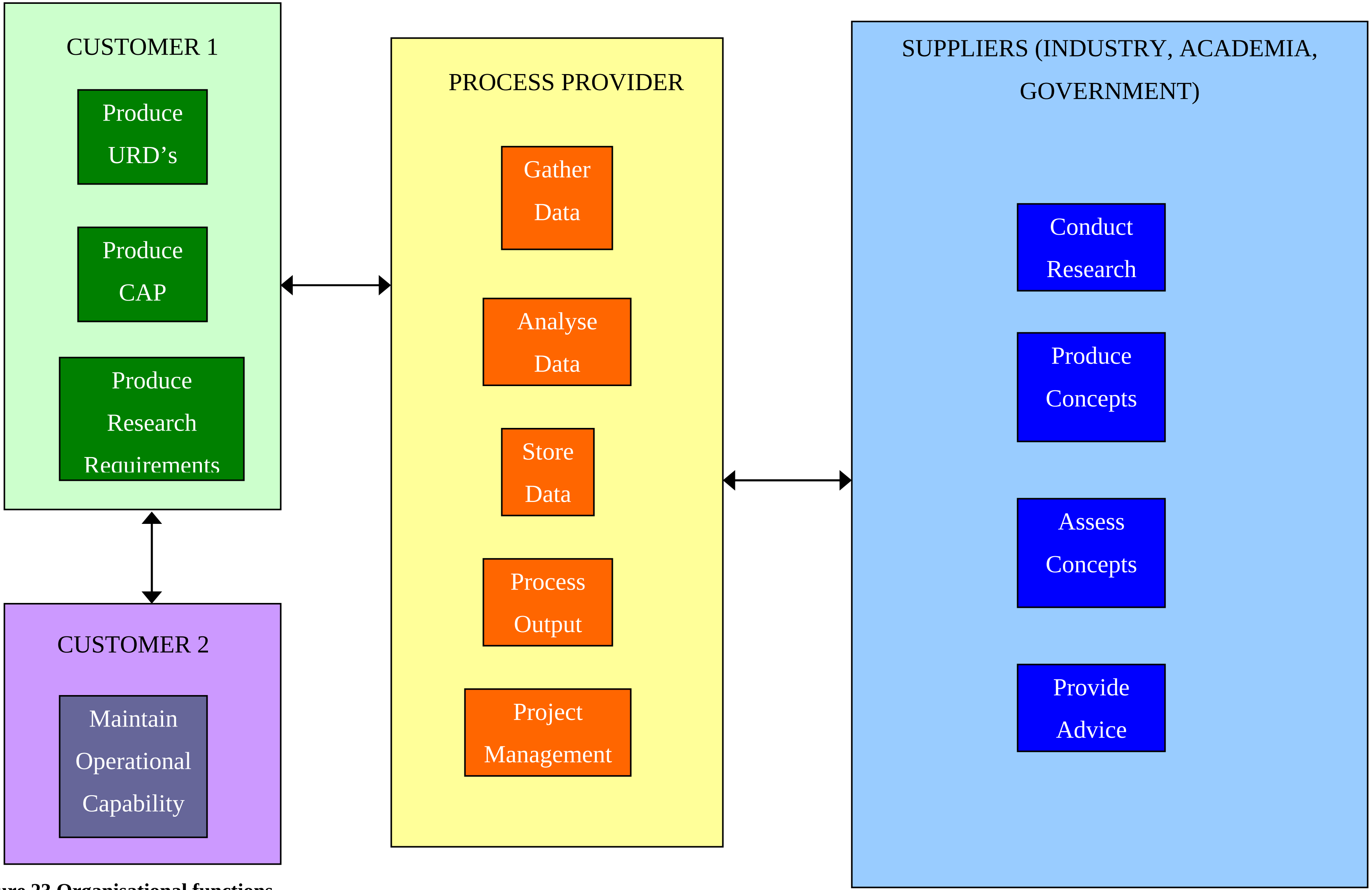


Figure 23 Organisational functions

5.3 THE PROCESS SUITE

The organisational functions defined in Fig 23 form the starting point for the process suite which is intended to provide the scrutinised information required by the customer. Four key functions are shown with the activity of project management over arching all activities. The four of interest are:

- Gather data
- Store data
- Analyse data
- Process output

In addressing these functions and their interface with the other grouped functions shown in Fig 23 the process suite provides the output required by the customer. This is tested using case studies in Chapter 8.

The following sections take each of the four functions in turn describing the more detailed activities and their associated tools and techniques.

5.3.1 Gather data

As with many studies the starting point is to gather information in order to understand the type and scale of the problem to be addressed or within academic pursuits to determine who has studied what in order to form a current opinion (Frankfort-Nachmias & Nachmias, 1996). With the desire of the customer to enhance the combat effectiveness of the soldier there is a need to identify what is currently being used and whether this is sufficient, or not, for the future. As with experimentation, (Miller, 1989) a baseline creates a standard against which alternatives can be measured, with the activity of ‘gather data’ capturing this need.

Brainstorming is a tool that enables large groups of stakeholders to provide input, drawing on diverse backgrounds (Rawlinson, 1981). Fig 24 is the product of a facilitated brainstorm using a number of SMEs with suitability of output ratified by the customer as the key decision maker.

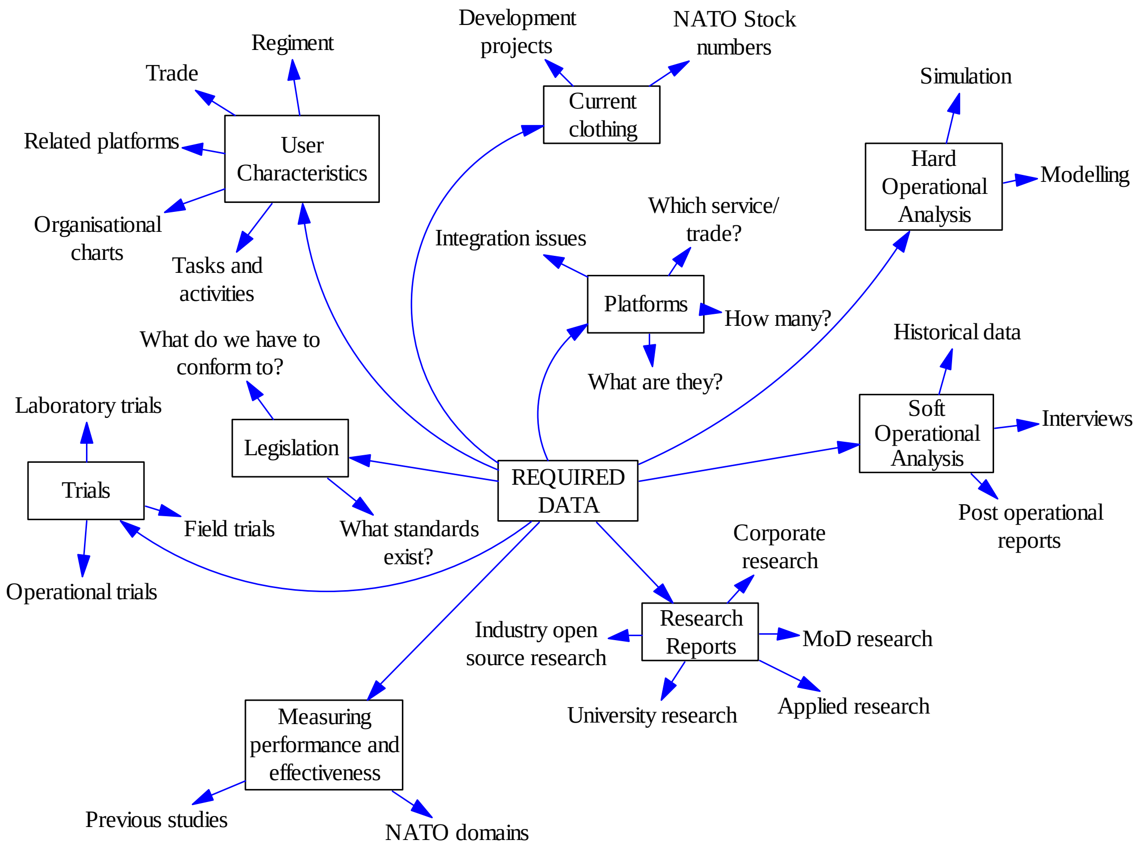


Figure 24 Input data brainstorm

A number of questions were posed in the context of the problem, guided by the customer requirements and the assumptions described on section 1.2.1.

- What is in existence at this point in time?
- What development projects are already in existence?
- Who is the user?
- How is the user organisation structured?
- What research has been conducted before?
- How have systems/ equipment been tested?
- What capability does current equipment provide?

- What mandatory requirements will Government be required to meet?

In essence there is a need to understand:

- What there is at this time and what is planned for the future.
- Whether it provides the right capability to meet the identified or projected threats.
- What mandatory requirements (e.g. legislation) Government must conform to.
- Whether any research or testing has been carried out that might support any of the above assertions.
- What testing and measurement criteria can be used to determine whether what we have meets requirements or what we propose will meet requirements.

The brainstorm (Fig 24) is a tool to explore the function of ‘gather data’ in the context of the customer needs. Output from the brainstorm identifies a number of areas needed in order to understand current capability and potential shortfalls. It provides evidence of a tight coupling with the function ‘store data’ as there is a need to bring together data from a number of stakeholders and organisations to understand current and future needs. This has associated with it configuration control issues in the management of data as control of the data rests outside of the organisation, but also potential benefits through collation of diverse sources within a single controlled repository, linking to the customer need for auditability and traceability as well as reduction in response time to queries.

Part of the problem with the fragmentation of Government research over a number of years has been the lack of knowledge of what has already been investigated (Bud & Gummett, 2002). By consolidating past research there is an opportunity to identify relevant supporting information; an activity that has been mandated by the Defence Science and Technology Laboratory (Dstl) through an activity called knowledge integration (Defence Science and Technology Laboratory, 2004).

Conversely, there are difficulties associated with the management of data that has been generated by external sources, not only in terms of validity, but as mentioned previously, the configuration control to ensure consistency.

The breadth of the input data sources reflects the necessity to consider the system in a through-life capacity, but also as an enduring and iterative activity that will be updated and expanded as the process suite is applied over time. This links to the ethos of the action research cycle, where one adopts methods to address a problem, apply them, refine them, apply them and so on and so forth (Flood, 2001, Warmington, 1980), a premise that will be revisited in Chapter 8..

The next section specifically addresses the need to store data as part of the process suite, and explores the coupling with the function of 'gather data'.

5.3.2 Store data

The need for storage of data satisfies several of the criteria laid down not only by the customer, but as part of applying systems techniques to a problem (Martin, 1997). From a systems standpoint there is a desire to attribute decisions to evidence and to provide the ability to do this easily over time. This is not only viewed as good practice, but with requirements potentially changing or being refined over time it is important to identify what has been done to date and the impact that changes will have (Buede, 2000).

From a generic and enduring process perspective, data storage is critical for iteration and configuration control with the need to create a structure that can expand over time (Sparks, 2004b). As analysis is carried out and research is conducted the information that is stored will grow. Capability gaps will be identified and then addressed requiring updates to the current knowledge to reduce the likelihood of repetition. External providers of information such as the current list of clothing and equipment (Defence Clothing IPT, 2003) will update their inventory, which in turn will require the data store to be updated. This management and update ensures currency and provides the customer with an almost single source for answering queries. This may open further opportunities for other stakeholders to use the information by request through the process provider, fulfilling the desire of the organisation to create kudos and attract future business, as defined within the conceptual models (Chapter 4, Fig 19- 22).

The method by which data is stored is described in detail by Sparks (2004b). This is an aside from the process suite, although the architecture for the data storage conforms to systems principles (Buede, 2000). The function of 'analyse data' discusses both gathering and storage of data in more detail. It is the 'analysis of data' that forms the working element of the process suite consolidating the other functions to provide the process output described in section 5.3.4 and forming the basis for the case study (Chapter 8).

5.3.3 Analyse data

Having identified the potential sources of data to support any decisions made, the largest component of the process suite is derivation of an analysis process to enable scrutinised information to be supplied to the customer. This requires data from the identified sources to be used in some structured way to provide the required output.

Fusion of qualitative and quantitative data is necessary due to the socio-technical nature of the soldier system as described in Chapter 2, section 2.3.3. It is not possible to optimise human related systems in the same way as engineered systems (O'Keefe, 1964) and as such the analysis must balance the human and their characteristics with the needs of the Government in terms of scrutiny and procurement. What are the gaps in current capability? And how can we provide enhanced combat effectiveness for the future? What do we not have? Or not know?

It is the fusion of approaches that represents the most significant contribution to knowledge as it has not been achieved within defence before, for either research or procurement.

Chapter 2, section 2.3.3 discusses the bias that can be introduced if only one source of data is relied upon. This is considered to be a greater problem when using purely subjective input (Bertrand & Mullainathan, 2001) due to the lack of objectivity, but equally it is beneficial to limit reliance on just one source of data in case of non-availability (Pruzan, 1988). This provides justification for fusion of techniques, particularly when considering the dynamically complex nature of the soldier as the systems of interest.

The intent of the analysis is to identify the relative importance of different parameters for enhancements of combat effectiveness, to allow the customer to prioritise where resources should be directed. This is necessary because of the environment and constraints within which the system of interest exists, as shown in Chapter 4, fig 12.

Chapter 2, section 2.5.6 specifically describes some of the techniques to create a coherent approach to addressing customer requirements. Of particular interest is the use of decompositional matrices, with techniques such as strategy to task (STT), and quality function deployment (QFD). These have been used in previous studies for technology down-selection (Smith, J et al., 2002) as well as commercial applications such as production (Zairi, 1995). The perceived benefit of using decompositional matrices for the defined research question (Chapter 3) is the ability to capture subjective input, in a more formalised and structured way, as discussed within Chapter 2, section 2.5.7 whilst comparing and inputting more objective data from OA.

Strategy to Task/ Analytic hierarchy (Smith, J et al., 2002, Lambert, 1991) is of particular interest within the analysis process (Fig 26) as the matrices flow from one system level to another using the output from one as the weighted input to the next. The high level matrices are therefore shaping the significance of the scores in the lower matrices linking decisions back to the top, potentially reducing the ability for subjective skewing (if coupled with sensitivity analysis). Fig 25 diagrammatically represents this relationship which distils from one level to another.

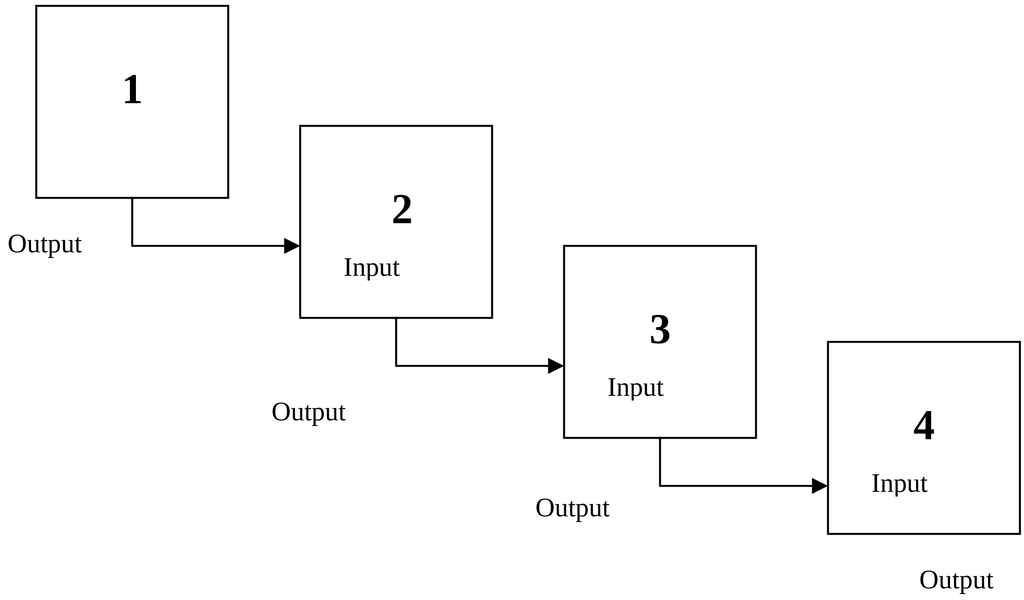


Figure 25 STT decompositional relationship (Bathe & Smith, 2002)

In the paper by Smith et al (2002) the very top level of the matrix relates to military doctrine with subsequent levels decomposing this to lower and lower levels of detail. This can similarly be achieved for the soldier system process to provide the auditability and traceability of need, with the high level doctrine feeding down through to land requirements and then more detailed, but generic, system level requirements/ implications. No solutions are described, instead focusing on the areas that will help to deliver the high level doctrine and military tasks and activities.

This type of decomposition also relates to a system-oriented, systematic breakdown of the problem with stakeholder needs and constraints at the capability level, linking to more specific land domain needs and then generic system level requirements.

To reflect the breadth of input data required to make decisions as shown in the 'gather data' function, the 'analysis function' uses the decompositional matrices in conjunction with more objective data sources including OA and trials, with concurrent activity on both areas as shown in Fig 26.

The breakdown and application of these elements are discussed within the context of the process in the following sections.

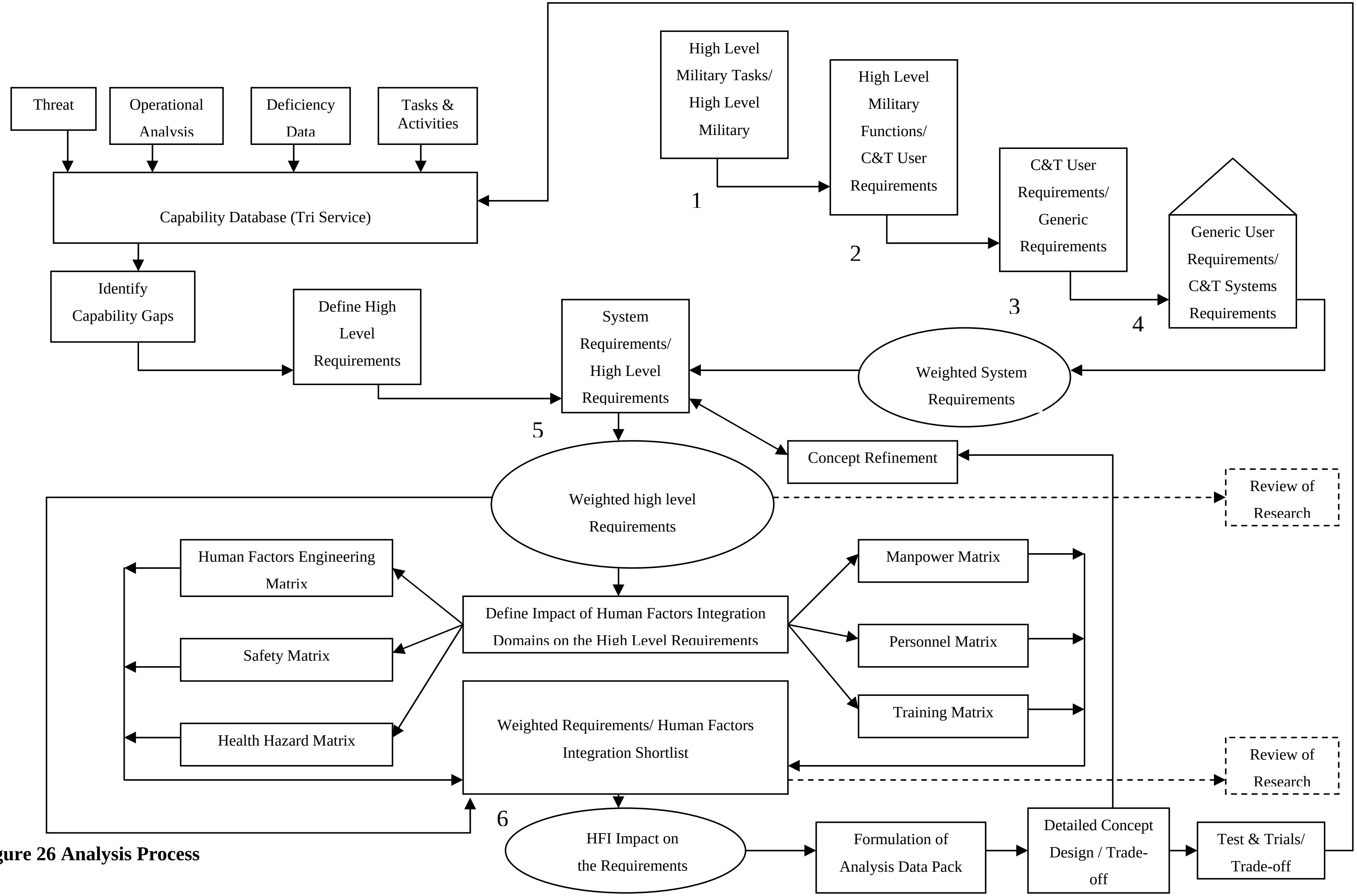


Figure 26 Analysis Process

The analysis process (Fig 26) comprises a number of activities that turn input data into scrutinised and prioritised information to underpin decisions made by the customer. The structure of the analysis process is a further reflection of the conceptual models presented in Chapter 4 using key themes to shape the contents of the decompositional matrices. The influences of the customer (Fig 19, Chapter 4), user (Fig 20, Chapter 4) and supplier (Fig 21, Chapter 4) on the analysis process components are used as a basis to describe the process breakdown in the following paragraphs. The overall structure of the analysis process is a reflection of the process provider conceptual model (Fig 22, Chapter 4) concerned with delivery of customer requirements on time and within budget.

The customer (Fig 19, Chapter 4) requires scrutinised information to underpin decisions and direct research. This is reflected in two main ways within the analysis process (Fig 26). On the top left hand side of the diagram within the capability database and on the top right hand side of the diagram within the decompositional matrices (level 1-4 boxes).

The capability database reflects the fact that data is required in order to carry out an analysis. If the desire is to enhance soldier effectiveness current capability must be understood to identify if a gap exists. Numerous sources exist to help in the decision making process as discussed in section 5.3.1 with the need for storage of data described in section 5.3.2. Four specific inputs are shown within Figure 26 as follows:

Threat	Current and future challenges are identified by government analysts, which helps to forecast gaps in capability.
Operational analysis	Input from war games including CAEn help in the understanding of the impact of future threats.

Deficiency data	Post operational reports and in theatre end user feedback detail the positive and negative attributes of current equipment.
Tasks and activities	Doctrine and standard operating procedures in specified environment and scenarios help to understand the impact of shifting future threats.

In addition to the historical sources of information contained within the capability database there is a wealth of experience available in the form of SME's. These may be individuals within research organisations, the customer community, industry and academia. They provide currency and uniqueness of thought, but must have their input captured in such a way that it is manageable and meaningful.

The decompositional matrices (Level 1-4 boxes and latterly 5-6) use an approach similar to that of STT Bathe and Smith (2002) in order to formalise SME opinion in the context of the domain of interest (soldier systems). The matrices reflect customer needs as they provide an audit trail of perceived importance of different factors from defence doctrine at the highest level to system and sub-system considerations at the lowest level. The statements within each of the matrices are concerned with identifying importance of relationships at progressively lower levels of fidelity. Weightings cascade from one level to the next appropriately skewing statements to reflect some form of ordering. This creates priorities at each of the matrix levels as well as overall drivers which drop out from the bottom. The sets of statement pairs for each level are identified below with justification for their inclusion:

Level 1	Looks at the relationship between the defence missions (Joint Doctrine and Concepts Centre, 1996) and the operational and strategic level tasks for the three services(Joint Command Headquarters, 2001). These statements underpin the roles of the three services at the highest level with the defence missions reflecting tasks such as peace time security and the operational and strategic level breaking this down to actual

delivery, for example conduct tactical movement. This sets the context for the lower levels of detail that look at the land domain specifically and then the role of the soldier within that.

Level 2 Takes the operational and strategic levels tasks from the level 1 matrix (along with the weightings that have been generated from the scoring) and compares these statements to land domain user requirements as the specific domain of interest. The land domain user requirements i.e. ability to conduct operations at a faster rate than baseline, reflect specific needs in relation to dismounted infantry. By scoring these in the context of higher level operational and strategic level tasks key relationships can be identified which in turn may influence concepts at the lower levels.

Level 3 Compares the land domain user requirements with generic requirements based on legislative performance bounds and constraints for future soldier systems. Level 2 shows which land domain user requirements are key, with level 3 identifying relationships between these statements and the more system focused considerations i.e. I need to carry loads appropriate to mission completion, but there is legislation that limits the allowable weight carried, therefore there is a strong relationship between these statements. This information will be sued when making design level trade-off decisions.

Level 4 Compares generic requirements with generic system level requirements, identifying challenges in delivery of the final system. The generic systems level requirements include statements such as ‘energy cost to wearer’ with scores reflecting the difficulties or otherwise of meeting generic legislative constraints when designing the physical systems and sub-systems to satisfy prioritised requirements from earlier matrices.

Level 5 in the centre of the diagram (Fig 26) represents the point at which data is fused from the top left of the diagram (representing more objective input) and the top right of the diagram (representing more subjective input). High level statements of need i.e. enhanced fragmentation protection are generated from interrogation of the capability database, combined where available with output from operational analysis, which is capable of representing future environments virtually to look at the impact of changing threats. These high level statements are generated for each of the five NATO capability domains (NATO LG3, 1999), which creates a separate analysis process output ready for fusion into one comparative matrix as part of the trade-off process (Chapter 6).

The high level statements are scored in relation to the system level requirements cascaded from level 4, with the intention of identifying the generic challenges in trying to deliver the high level requirements that will enhance effectiveness. An example of which is the level of relationship between increased fragmentation protection and the energy cost to the wearer. This will have a greater or lesser impact depending on the design decisions that are made.

Level 6 in the centre bottom of Fig 26 is intended to consider the wider related issues associated with the soldier as the systems of interest. It reflects the fact that equipment may not be the only solution to enhancing capability with changes to doctrine and logistics as examples providing the same benefits.

The Human Factors Integration (HFI) Domains represented in the latter matrices are taken from the Defence Procurement Agency (Rowbotham, 2006) and are intended not only to help in the consideration of related issues such as manpower and logistics, but to encourage cross-agency and department commonality and communication. Having identified at level 5 the potential systems challenges to delivery of high level requirements the HFI domains provide the wider challenges and risks of trying to deliver the requirements.

Pick lists have been created to allow tailoring of the process to suit particular applications, the contents of which are described in more detail in Chapter 8 using several case studies. The statements are generated using the HFI framework from the Defence Procurement Agency (DPA) in conjunction with SMEs, an example of which can be found in Appendix A. The ability to choose different statements depending on the domain and customer requirements supports the iterative nature of the analysis process. When using the process at the capability level, or first pass, the statements that are chosen relate to areas within the wider environment that will impact design. For example, are there safety issues we must address in terms of potential solutions in a given environment? Is there legislation that we must adhere to?

For a second or subsequent pass through the process when it is more clearly understood which high level requirements have been down-selected, it is possible to explore areas that design will influence, but still in the wider context. Can we instil confidence in the wearer, increasing the likelihood of acceptance? Can we reduce the heat burden on the wearer?

The output from this part of the matrix analysis provides potential risks in the ability to deliver the high level requirements based on related systems and components as shown in the system context diagram (Chapter 4, fig 12). An example is the risk associated in enhancing mobility when there are critical interfaces within the wider system in the form of logistics.

Output from every level of the matrix is then consolidated to form an analysis data pack for industry where the key drivers are identified ready for concept generation, which is described in section 5.3.4. The generation of the analysis data pack links to the user (Fig 20, Chapter 4) and supplier (Fig 21, Chapter 4) focused conceptual models. In order to generate concepts for testing there is a need to provide information for industry to interpret. Similarly the link to measurement and testing is important to both the user and the supplier, contractually and in proving that overall effectiveness has been enhanced. Section 5.5 and Figure 27 show in more detail how the analysis process achieves this.

The concept refinement box reflects the fact that the process can be used for numerous iterations to gain a more detailed understanding of concepts that can address the high level requirements. The process shows a concept refinement box that loops back round to level 5 of the analysis process. It is suggested that the top level decompositional matrix on the right will remain consistent for each iteration, using the same high level requirements. The intent of iterating with greater levels of detail from level 5 is to identify the wider risks of and challenges to delivery of the high level requirements. As an example, increased fragment protection has been suggested to enhance effectiveness (Shepherd et al., 2003a) and the wider issues of achieving this have been explored. The process output is provided to relevant industrial and Government parties to suggest concepts to address the issues. A number of concepts are drawn up with varying characteristics, not considering performance at this stage. These can be substituted for the high level requirements at level 5 and then filtered down through the subsequent matrices. A concept may address several high level requirements with the ability to explore the implications on paper prior to physical demonstration. In carrying out this paper analysis it reduces the resources needed at the early stages, potentially reducing cost and time burdens.

5.3.4 Process output

The process output is the scrutinised information required by the customer not only to inform their decisions, but to form the basis for contracting of concept work to address identified shortfalls. Although not a detailed specification, it forms the foundation for discussion with contractors without unduly stifling their creative and technological ideas on how to solve the problem. The intent with new programmes as part of the Smart Acquisition initiative is to include industry from an early stage and allow them to exercise their knowledge and experience on the problem (within bounds) rather than assuming that Government knows best through heavy specification and subsequently receiving an inferior end product (McKinsey & Co, 1998). The 'data pack' shown on the analysis process diagram (Fig 26) consists of interpreted information for industry to use in development of future concepts, with a summary of what is contained within it in Appendix B. As with the soft systems methods used in Chapter 4 to explore and define the problem space, the data pack is intended to open up debate between a customer and industry on how to address the issues raised. The relative importance of certain elements over others forms part of the trade-off activity that will be discussed in more depth in Chapter 6, and links directly to the data pack.

The activity of trade-off and down selection of concept options for future soldier systems requires measurement. A decision on the level of effectiveness required and the associated performance will dictate, in conjunction with technical feasibility which systems will eventually be taken forwards. The analysis process in general and the process output specifically has been deliberately partitioned from measurement of performance and the need to make decisions on which concepts will address the customer needs. The reason for this decision relates to the desire for solution independence within the high level decisions. When making decisions on which capability domain to focus on, or which concept to down select there begins a negotiation often dictated by the cost of the different solutions or the current political or media induced climate. The shift focuses from what will truly enhance effectiveness to what is achievable within the budget and taking on board external pressures and constraints.

In terms of the process there is a realisation that constraints will be placed on the system solutions. However, as stated in Chapter 2 section 2.4, things change: both threats and budgets are fluid and as such there needs to be flexibility in potential solutions to reflect lifecycle options of a given system. It may be that procurement in an incremental manner over a number of years will allow for technology to be inserted when it becomes sufficiently mature, providing progressively enhanced capability (Defence Procurement Agency, 2005), rather than unduly constraining concept options which have not yet passed into equipment procurement projects.

It is however recognised that measurement is a critical component to validate and verify requirements derived from the process suite. Having summarised the key elements of the four functional areas (section 5.4), section 5.5 describes specific supporting measurement components, with Chapter 6 & 7 describing trade-off and measurement in greater detail.

5.4 SYSTEM ANALYSIS SUMMARY

The process suite provides the scrutinised information required by the customer to make decisions on future research and soldier systems concept priorities. It addresses the organisational functions identified in Fig 23 of:

- Gather data
- Store data
- Analyse data
- Process output

Data sources from a number of contributors help to identify:

- What equipment is currently in existence
- The characteristics of the users
- What research has already been conducted
- Current military capability
- Future threats

This enables potential gaps to be identified in both capability and research.

Having gathered the data it is necessary to store it, to ensure auditability and traceability of decisions. Data can also be updated as knowledge grows, reducing the likelihood of repetition in future research contracts. Gathered data is analysed to provide scrutinised output. This uses a combination of qualitative and quantitative input from both SMEs and tools such as operational analysis.

Decompositional matrices similar to the strategy to task technique (Smith, J et al., 2002), identify relationships between elements at a number of levels of resolution. Defence missions are considered at the highest level, down to generic system implications and other lines of development.

The fusion of techniques is unique and enables large quantities of information and knowledge to be distilled in a meaningful, yet useable way.

The widest possible implications are considered aligning with other procurement practices with the inclusion of the HFI domains (Rowbotham, 2006).

Output from the analysis process defines high level requirements for enhancing effectiveness for a specific capability domain, linked to future threats and activities, whilst identifying potential challenges in their achievement and the impact on the wider environment including logistics and training.

The analysis process can be layered to look at the implications of one domain or all five of the NATO domains (NATO LG3, 1999), which is discussed in Chapter 6. The analysis data pack provides the customer with information on the key areas to focus effort, forming the basis of contract negotiations with industry.

The detailed concept/trade-off activity can be completed at several levels of resolution providing greater and greater detail, by iteration of ideas around the lower portion of the process. Detailed concept design and trade-off activities are supported by measurement and trade-off discussed in more detail in section 5.5 and Chapter 7. This provides the tools to understand performance implications to help in concept down selection.

Iterated and refined concepts using defined measurement and trade-off characteristics can subsequently undergo test and trials for final down selection, with output providing further evidence for inclusion into the capability database. This update prepares the data store for subsequent interrogation and identification of capability gaps, conforming to an action research approach (Coghlan & Brannick, 2004, Warmington, 1980).

5.5 MEASUREMENT AND TRADE-OFF

The measurement activity provides the detailed characteristics by which trade-off can be carried out, enabling the selection of possible alternatives (Buede, 2004). This part of the process relates to design level trade-off which is based on relative importance scores from the decompositional matrix analysis.

Fig 27 shows the analysis process with an expansion of the bottom right hand corner to include the supporting activities of measurement and trade-off. The partitioning of measurement from the analysis is discussed in section 5.3.4 with the desire to minimise constraints on concept design until absolutely necessary. Fig 27 has two boxes labelled internal and external, relating to areas of control in relation to output. The inclusion of the measurement techniques within the internal box reflects the desire to control the criteria by which concepts will be accepted. It should be the responsibility of the process provider to dictate the level of performance that any concept must have and how this will be proved. Allowing this task to sit within the supplier organisation may lead to acceptance tests that only reflect what industry can measure or wish to measure. The supplier functions box has been taken from the organisational functions diagram (Fig 23), with some or all of the activities required.

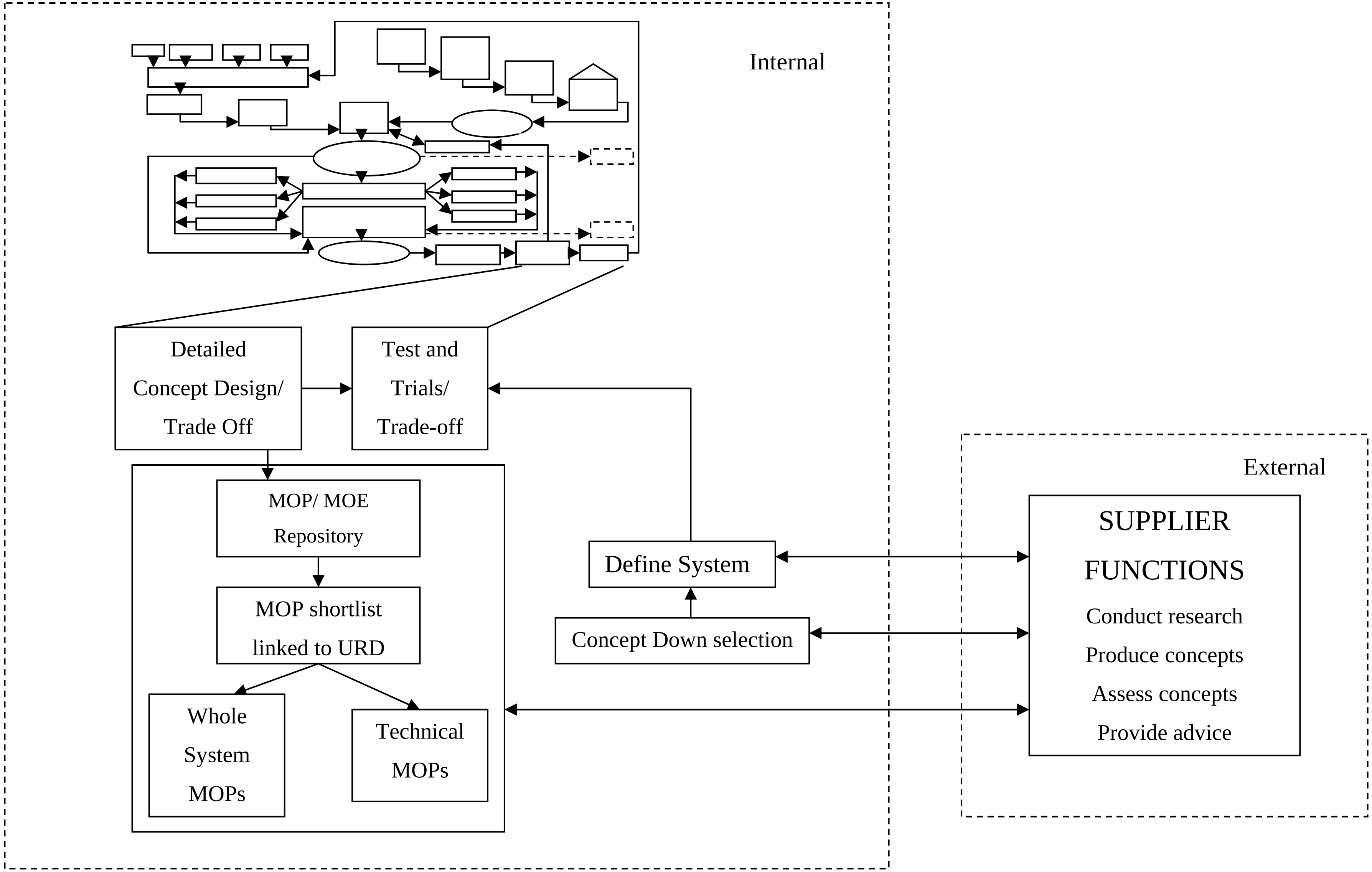


Figure 27 Measurement and Trade-off

The intent of the measures of performance (MOP) and measures of effectiveness (MOE) repository (Fig 27) is twofold. There is firstly a desire to standardise test and measurement criteria and procedures to ensure consistency over time (Mackley, 2005). Secondly, it reduces time for down selection of concepts and potentially contract creation as there is a body of information to refer to, rather than having to consider each instance on a case by case basis. Creating a repository allows time for stakeholders to be consulted across a number of different programmes both in research and development to see what has been done and what is currently being done. As with the HFI domains within the main body of the process (Fig 26) the repository can be used to create a pick list appropriate to the capability gap under consideration. The repository also reflects different measurement needs from more focused technical performance measures to whole system tests where overall functionality is being considered, all of which is discussed in more detail in Chapter 7. Both whole system and sub-systems test are important to create a balanced understanding, with technical MOPs indicating specific characteristics of sub-systems with causal behaviour, and whole system tests identifying emergent behaviour only exhibited when all parts are fused, but harder to attribute cause and effect.

Some of the measures used will be dictated by things such as legislation, for instance we must conform to this level of sound attenuation because of British Standard X. Other performance bounds will be guided by tools such as operational analysis where the impact of different levels of performance may have been investigated, or possibly through data gathered from field trials. In terms of trade-off the most desirable situation is to provide upper and lower bounds within which performance can fluctuate (Felix, 2004) rather than rigid pass, fail measures. The reason that this is desirable is linked to the highly inter-related nature of many of the concept attributes. By providing a performance envelope different options can be explored with the customer. An example may be that you can have X performance, with Y weight penalty (which is undesirable), however for only Q% less performance you can have L% less weight penalty which will provide R% more mobility. The customer can then make an informed decision of how much of any one characteristic they want, whilst understanding the impact this may have on other parameters. If you design to a singular measure, for instance, must have a range of X, there is little flexibility in the system if the future threat environment changes, as well as potentially causing significant resource implications due to technical difficulties in achieving the requirement.

The measurement and trade-off component completes the process suite for delivery of the customer requirements as stated within the Chapter 3 research aims, with subsequent Chapters (6 & 7) providing further detail of specific components and application within a number of case studies (Chapter 8).

5.6 DISCUSSION

5.6.1 Completeness of processes compared to conceptual models

The conceptual models in Chapter 4, Fig 19- 22 define the minimum activities required to achieve the stated transformations from the CATWOE analysis, and root definitions. Therefore the process suite developed should include those activities as a minimum in order to be assured of relative completeness. By using the organisational function diagram Fig 23 as the basis for the subsequent processes, activities have been captured throughout the various stages.

Both the customer focus conceptual model (Chapter 4, Fig 19) and the user focus conceptual model (Chapter 4, fig 20) have had all activities encapsulated within the process suite. The supplier focus conceptual model has activities to be understood rather than directly incorporated in some instances. It is noted that some of the supplier functions are outside of the direct control of the process provider, although this realisation led to the measurement and acceptance criteria being included within the control of the process provider (Fig 27) as a potential conflict of interests was identified. It would not seem wise to have the organisations responsible for building concepts also responsible for setting the criteria by which they will be accepted as this may lead to unrepresentative testing based on the organisations ability to test certain characteristics. The supplier focus also helped in the development of the contents of the analysis data pack (Appendix B) with the need for clarity without stifling creative input.

The process provider conceptual model (Chapter 4, Fig 23) has all activities considered within the process suite, although the project management function has not been discussed in any detail as it is outside of the direct remit of the research question.

Stakeholders have engaged with the process suite at a number of levels providing continuity and completeness of view through their wide and varied knowledge and experience. Formalisation of their views using the decompositional matrices helps to manage expectation and encourage ownership of output at a later stage, with a detailed discussion on the success of the processes when applied within Chapter 8.

5.7 PROCESS SUITE SUMMARY

Using the contextual models and current 'real world' practices the organisational functions for each of the main stakeholder categories have been devised.

The organisational functions represent the minimum activities required to transform data into scrutinised information, meeting customer need and answering the research question posed in Chapter 3.

Analysis uses decompositional matrices with fusion of qualitative and quantitative input providing the most significant contribution to original knowledge.

It is recognised that by using the techniques in this way subjective knowledge from stakeholders can be tempered by objective input from trials and operational analysis. This overcomes issues of bias as no one source of information is relied upon.
Output from the analysis informs the customer and provides a basis for contractual negotiation with industry to provide concepts.

Measurement and trade-off to enable the down selection of candidate solutions is controlled by the process provider, using a consistent set of criteria contained within a separate repository.

Compartmentalisation of measurement and trade-off from the main analysis activity is instigated to ensure that unnecessary constraints are not imposed too early within the lifecycle.

The process suite in its entirety has been developed with maximum flexibility to meet user needs in an enduring manner. It can support single or multiple domain investigation as well as numerous levels of design iteration, with the intent of continuous improvement with use over time in line with an action research ethos (Flood, 2001, Coghlan & Brannick, 2004).

Chapter 8 uses case studies to apply the process suite in order to test utility and robustness.

Blank Page

CHAPTER 6: TRADE-OFF

6.1 INTRODUCTION

6.1.1 Aim

To define the process for trading off within and between capability domains using analysis output from the process suite discussed in Chapter 5.

6.1.2 Objectives

- Define the process that will enable decisions to be made on the balance of capabilities required in order to enhance soldier effectiveness
- To describe how trade-off will be used in conjunction with the process suite discussed in Chapter 5 to aid the definition of future soldier system concepts
- To discuss the link between the system processes (Chapter 5), design activity and other stakeholders, and the method by which final concept decisions are made

6.1.3 Background

Chapter 5 describes the process suite that enables quantitative and qualitative data to be fused in order to prioritise future soldier system concepts and research. In making decisions about the relative importance/ priority of one element over another the analyst is effectively 'trading off'.

Trade-off is a form of decision making where options or attributes are chosen, one over another; the selection of possible alternatives (Buede, 2004). Systems engineering links customer requirements to the process of trading off, with measurement of system performance identifying those concepts or options that most closely meet the defined need (Daniels et al., 2001). However, this relies on the ability to accurately define and measure both requirements and potential concepts, which represents a significant challenge for human centred systems, which is discussed in more detail in Chapter 7. Therefore the trade-off process for a human centred problem must exhibit sufficient flexibility to account for high levels of dynamic complexity in addition to other trade-off needs.

Some components of the trade study will be dictated by external, environmental parameters, for instance the need to conform to legislation or the technical feasibility of different options (Middleton et al., 2000). These form part of the study constraints, which should be identified within the scope of the trade study, in addition to the statement of need and the expected consequence of doing nothing at all (Felix, 2004). This provides the necessary justification for embarking on the trade-off activities.

At an early stage the criteria upon which decisions will be made must also be clarified, as the benefits of one option over another form the focus of the study. This is discussed in more detail within section 6.3 relating directly to the processes discussed in Chapter 5.

6.2 TYPES OF TRADE STUDY

The conduct of the trade study very much depends on the type of output required. Buede (2004) defines six types of trade study ranging from identification of system concepts to system architecture and sub-systems. This is reflected in the context of the dismounted soldier with trade-offs being made at a number of levels from capability through to detailed design. The intent is to understand the most appropriate balance across capability domains (mobility, lethality, C4I, survivability and sustainability) (NATO LG3, 1999) that will maximise enhancement to combat effectiveness. This in turn will drive subsequent more detailed system and design level trade-offs dictated by required system performance levels.

6.2.1 Specific soldier system trade-off considerations

Conducting trade-off at different levels of resolution both within a capability domain and between capability domains provides the customer with flexibility of application. This is necessary as it may not always be desirable to replace the entire soldier system. It may be that the customer needs to upgrade specific elements, which requires an understanding of the impact this will have on the soldier and their wider systems characteristics. The processes described in Chapter 5 provide the necessary framework and data to underpin decisions at a number of levels with detailed discussion in section 6.3.

The output from the analysis process (Chapter 5, Fig 26) identifies key areas within a capability domain (but looked at in the context of all five) that will enhance soldier effectiveness. This highlights challenges in meeting domain specific high level requirements, but is two-dimensional in nature as it considers the requirements of one domain in the context of user and system level requirements.

The following sections discuss how the output from the five capability domain analysis can be layered to enable a multi-domain trade-off to be carried out. This allows the analyst to explore the most appropriate balance of high level requirements across all capability domains in order to enhance combat effectiveness, with the need to determine the relative importance of one domain in relation to another, filtering from high level doctrine to detailed systems design. This can be used not only to prioritise research direction, but also in the specification of soldier systems concepts.

6.3 THE TRADE SPACE

6.3.1 Defining the trade space

Few papers discuss a generic approach to trade studies (Felix, 2004, Buede, 2004), with most designed for a specific domain or problem (Ashby et al., 2004) if reported at all. General agreement can be found in the need to apply measures against which attributes can be judged (Mackley, 2005) with weightings applied to parameters to determine a ranking of importance. Output is looked at in the context of whole system performance and in the case of detailed concepts allows different options to be down selected based on the number of desirable functions/ attributes each option possesses compared to the requirement (Bathe & Smith, 2002).

The decompositional matrices described in Chapter 5 use scores to reflect the relative importance of one characteristic/ function or parameter in relation to another. The intent is to use the information already gathered as part of the analysis process to provide input to the trade-off activity. This has two primary benefits as it not only provides a clear flow down of information within the matrix, but also ensures that the trade-off has sound underpinning and is relatively impervious to data skewing from the stakeholder community (Waddington, 1999). This is because the weightings to determine the relative importance of one parameter over another will have been derived directly from the decompositional matrix, rather than subjectively from the stakeholders. This addresses one of the key criticisms of carrying out trade studies, where weightings are often derived in a subjective manner by the stakeholders. The use of existing data coupled with techniques such as sensitivity analysis and impartiality of the trade-off analyst help to provide greater robustness and enhance confidence.

A further strength of using data gathered as part of the systems analysis is the generic applicability, flexibility and endurance to meet the changing requirements of the customer community. Because there is a clear audit trail of inputs and decisions these can be revisited or amended in line with need (Sparks, 2004b). This is a powerful trait within the procurement cycle as it provides a through-life tool and input for scrutiny procedures when research passes into the equipment programme.

6.3.2 Drivers

In order to derive relative importance between parameters within the trade-off, the ultimate intent of the system of interest (the soldier) must be understood. Within the context of this thesis the key driver is identified as:

- Enhancing the combat effectiveness of the dismounted soldier.

Implicit within this statement is the need to improve over the current baseline, for either equipment or changes to the other lines of development[5] (Joint Doctrine and Concepts Centre, 2005) as defined by output from the trade-off.

6.3.3 Constraints

Generic constraints imposed by the environment include the need for customers to provide and endorse trade-off weightings to ensure acceptance of the approach.

---

[5] Lines of development are defined as training, equipment, personnel, information, concepts & doctrine, organisation and logistics.

Specific constraints imposed by the environment within which the system of interest resides are:

- The need to minimise the negative impact on the wearer
- The need to conform to appropriate legislation
- The need to accommodate customer/ political needs
- 'Cost' which forms an indirect constraint as it should only be applied at the detailed systems trade-off level

These statements are distilled from Chapter 4 and 5 sections 4.2 and 5.2.1 respectively, based on the system context and system intent.

6.4 LEVELS OF RESOLUTION

There are several levels that need to be addressed within the trade-off process from capability through to detailed design as it is desirable to understand the key domain issues and the potential concepts to address them in order that the customer can prioritise if budgetary or political constraints are applied during the system lifecycle.

6.4.1 The capability level

The highest level of trade-off requires an understanding of capability level issues both within the five NATO domains (NATO LG3, 1999) and between the five domains: What is the relative contribution of the domains in relation to enhancing combat effectiveness? Direction from the customer is needed at this level as many of the weightings will be driven primarily by political and legislative implications, an example of which is media coverage of troops being killed on operations due to perceived shortfalls in specific pieces of equipment (Chamberlain, 2004). This is balanced by the output from the original systems analysis using quantitative and qualitative input in relation to threat, scenarios and tasks and activities (Sparks, 2004d).

What is created is a new set of focused matrices in the same hierarchical flow down as the analysis process described in Chapter 5, Fig 26. The original data from each of the capability domain analyses is used providing the audit trail of decision making and the input of a wide pool of stakeholder knowledge. Rather than having five individual sets of matrices (one for each capability domain) one matrix with multiple levels is created by taking the key statements from each capability domain systems analysis and consolidating them (Fig 28). The specific breakdown of the various layers of trade-off will be discussed in more detail within section 6.5.

Amalgamation of data allows for a cross domain analysis to be carried out with identification of key areas across the domains for consideration within concept design. The level of improvement to combat effectiveness has to be confirmed using tools such as operational analysis when potential concepts have been defined. This reflects the fact that aggregation of benefit derived from isolated domains would potentially fail to account for emergent properties of complex problems. As an example it would not be valid to assume that because increased fragmentation protection has been assessed to enhance combat effectiveness through increased survivability, that this will automatically reduce combat load and so improve mobility. An example that will be pursued again in Chapter 7. In fact it is likely that increasing fragmentation protection will, at some point have a detrimental impact on mobility (Ashby et al., 2004).

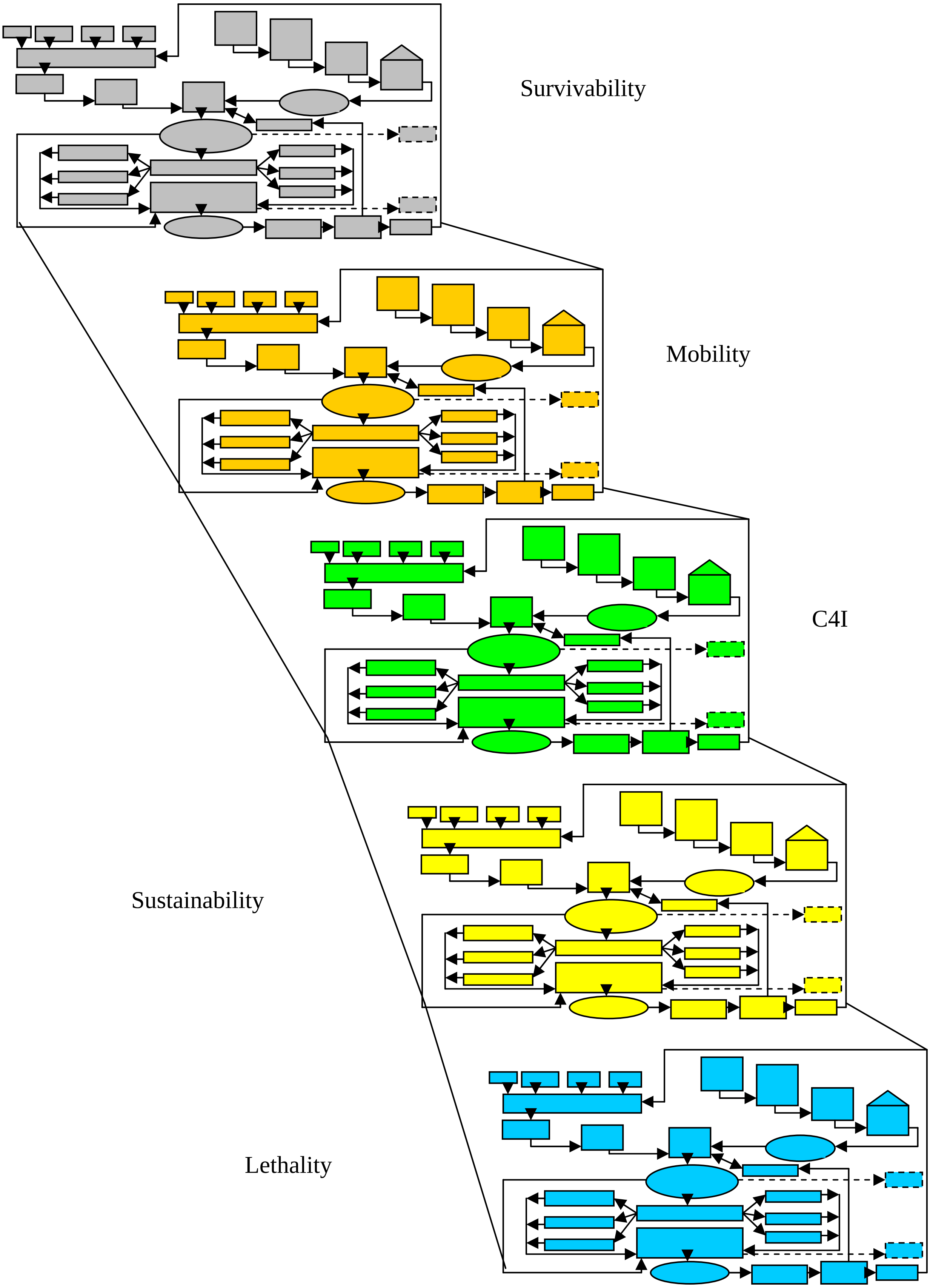


Figure 28 Five domain trade-off matrix consolidation

In addition to using the existing data there is a need to create a new matrix to provide the customer perspective that will be used to define the relative importance of the various capability domains. The new matrix gives the customer the opportunity to indicate their perception of the relative importance of the domains, which will include political and other constraints imposed on the system of interest. Creating this additional matrix allows the analyst to compare the input from OA and SMEs from a technical perspective, with the politically driven customer focus to identify the level of disparity. This recognises that the customer has a large influence on the shape of the final system, but retains the more technically focused data from SMEs to open up lines of discussion if large differences are found. When designing any system it may be proposed as ideal to design for the optimum technical solution but this is rarely feasible. By creating the matrix flow down for the trade-off based on the reality of the environment within which the system of interest resides the final concept should meet not only the performance criteria, but also the customer and stakeholder criteria.

The output from the refined matrix analysis provides a focused list of the key areas across all capability domains for enhancing effectiveness. It identifies the most important high level requirements as well as the wider impact of trying to deliver such requirements in relation to the human factors integration domains. The output from this phase of the trade-off has two areas of significance. Firstly it provides a new analysis data pack to the design entity that reflects the whole soldier system requirement across all capability domains. Secondly it provides the evidence that can be used in conjunction with the capability database (Sparks, 2004b) and feedback from the design entity to derive the future research direction based on potential gaps in knowledge. An example would be that the first stage of the trade-off has identified hearing protection as a critical component in enhancing combat effectiveness. The design entity has raised the issue of integration of any such protection with other related equipment. The technology research SMEs subsequently found legislation that we cannot currently conform to; indicating a gap in our ability to deliver the future system requiring research to be directed accordingly. All of this is based on the identification of hearing protection as a key requirement across the capability domains.

6.4.2 The design level

The design level is where the detailed trade-off decisions are made; dictated by the levels of performance required to achieve enhanced effectiveness. The capability level trade-off is concerned with balancing the customer needs with high level requirements, whereas the design level trade-off is focused on delivering a system that will provide, as far as possible, all of the desired attributes, whilst minimising negative emergent properties.

In order to trade-off at the design level, supporting documentation is required from several sources. There is the original set of analysis data packs for each of the capability domains that provide the full audit trail of SME and OA input (Annex A), along with the capability level trade-off across all of the domains that focuses this information further (Chapter 8, section 8.3, Table 4). There is also output from the MOP/ MOE repository detailing how the desired requirements will be measured and the final concept accepted with detailed discussion in Chapter 7, in addition to the capability database with all supporting documentation available for query.

Within the data packs and the capability level trade-off there are generic requirements that help to shape the concept options at the design stage. They represent the key generic performance requirements that should be achieved in order to satisfy the high level need. The ten statements are as follows:

1. Protection from environmental categories as defined in DEF-STAN 00-35 Pt 4
2. Protection from defined biological and chemical agents
3. Protection from a defined level of fragmentation and bullet type
4. Conformance to legislation and standards (hearing)
5. Conformance to legislation and standards (Vision)
6. Conformance to legislation and standards (flame)
7. Protection against defined levels of directed energy threat in relation to the eyes
8. Protection against detection within the thresholds for thermal imaging
9. Protection against detection within the thresholds for infra red
10. Protection against over loading (man)

These statements are an amalgamation of legislative constraints, environmental issues and specific scenario issues. They have been taken from the context diagrams in Chapter 4 (Fig 11 & 13) and the process development in Chapter 5, section 5.3. They cross all capability domains and are specifically focused on the soldier as the system of interest. Greater detail on the scope of these parameters can be found in Sparks (2004c).

The key generic performance criteria form the design envelope with upper and lower bounds dictated by either legislation or a combination of threats and tasks and activities used as part of the operational analysis for each of the capability domains. The design level trade-off then becomes a detailed consultation and negotiation process between the supplier and the customer to determine what is technically feasible whilst conforming to the drivers and constraints of the system as described in section 6.3.2/ 6.3.3.

The design entity has all relevant pieces of information passed to them to guide the design process, in an iterative manner so as not to constrain ideas too early in the process. A combination of individual capability domain analysis data packs, the focused data pack based on the capability level trade-off and the research concept system requirement document (Sparks, 2004c) provides a detailed picture of what is trying to be achieved, the implications of trying to achieve it and the required levels of performance.

Having derived a concept or number of concepts based on this process, operational analysis can be used to confirm if there is an increase in combat effectiveness of one or more of the detailed systems prior to physical demonstration. As was stated in section 6.4.1 the cross capability prioritised requirements are not -until this stage- tested for their cumulative effect. It should not be assumed that there will be a linear aggregation of positive enhancement to effectiveness without modelling to check this.

The detailed design level trade-off activity completes the analysis loop, providing input to the capability database. It also creates a second opportunity to direct future research based on technological shortfalls. It may be that certain system characteristics will dramatically improve combat effectiveness, but are not sufficiently mature to be used in large scale production. An example is the requirement for electrical power and the way that it is generated. Many soldier systems and sub-systems require electrical power (Lakeman, 2000), which, depending on how it is provided, has weight and bulk penalties associated with it. Fuel cells and other generators can potentially decrease these negative emergent properties, but require further research (Browning, 2003, Green, 2003, Slee, 2001). As mobility and power have been identified as high level requirements (Chapter 8, Table 3), and design level trade-off has highlighted shortfalls in the ability to provide lightweight power sources, it is appropriate to conduct further research. The output can then be fed into the next iteration/ generation of soldier systems concepts.

At whatever level of detail the loop never stops with research and technological advancements answering the future questions and needs driven by the evolving threat, and captured as part of the capability database.

6.5 DETAILED PROCESS BREAKDOWN

This section describes in detail the process to amalgamate individual capability domain data into one set of matrices for use within the capability level trade-off. The analysis process from Chapter 5 forms the basis for trade-off activity and is provided (Fig 29) to help clarify the subsequent paragraphs.

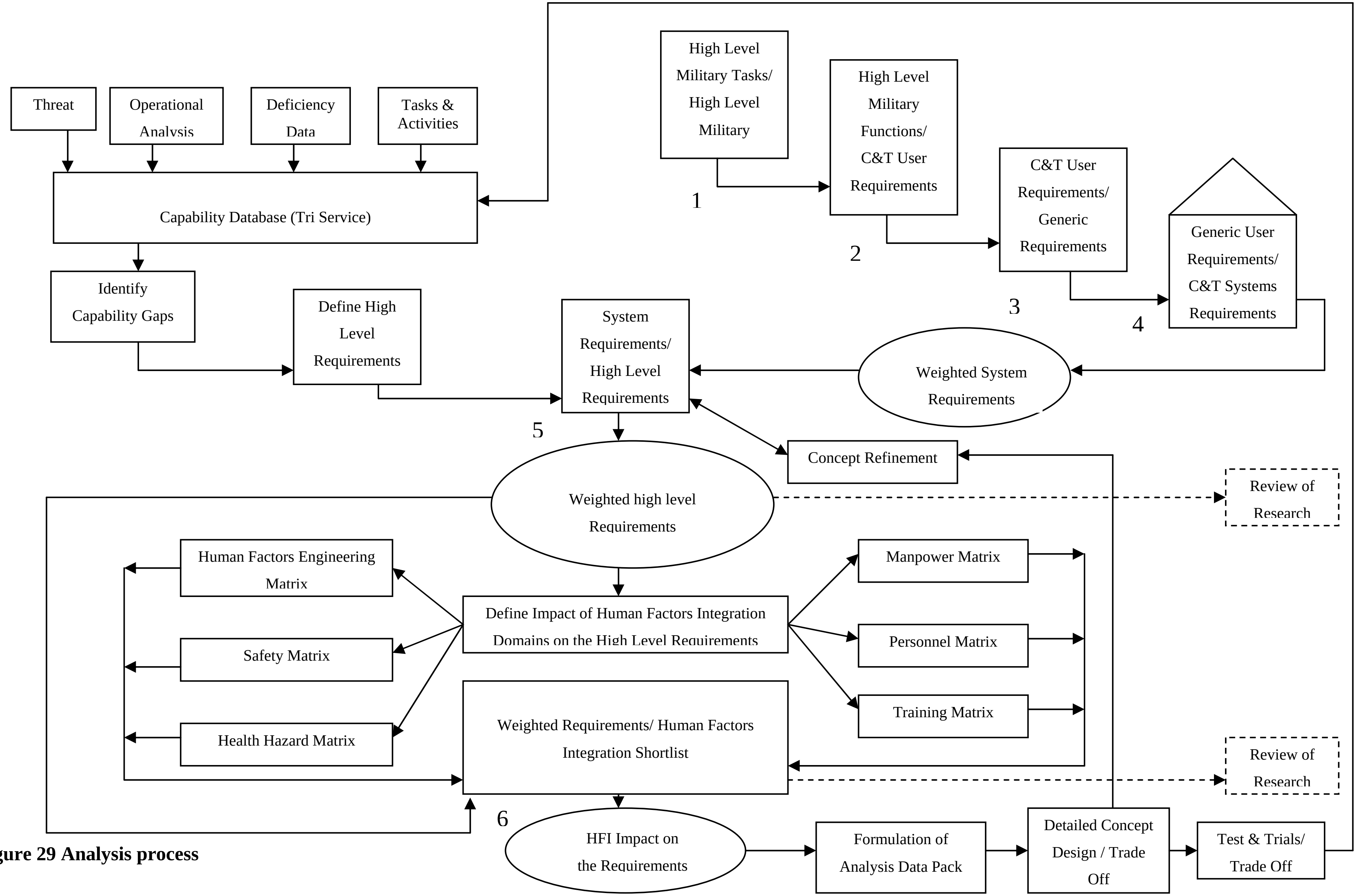


Figure 29 Analysis process

6.5.1 Use of the systems analysis output

The underpinning component of the trade-off approach is the systems process described in Chapter 5. A decompositional matrix flows down weightings from one level to another working from defence doctrine at the top to generic systems requirements at the bottom. The following paragraphs define how this output is used for trade-off decisions and what supplements are needed to complete the process.

6.5.2 Stage 1

The original set of matrices at level 1, Annex A and Appendix D looks at the relationships between the high level defence doctrine taken from the joint essential task list (Joint Command Headquarters, 2001) and the operational and strategic activities from the same list. This is scored by various military experts[6] and remains consistent for all of the capability domain analysis. Within the trade-off this can be used directly to provide the weightings for the level 2 matrix.

6.5.3 Stage 2

The level 2 matrix has the operational and strategic statements weighted from the level above and then looks at the relationship with land domain user requirements. These reflect the five NATO capability domains using the Future Infantry Soldier Technology (FIST) programme as a basis. Systems analysis provides five sets of data at this level having used various groups of SMEs to reflect differences in perceived importance depending on the capability domain of interest. For the trade-off these scores are consolidated into one figure for each box to define the key relationships once the weightings have been applied.

To cross check the output at this level, the matrix is also scored by the customer community taking into consideration the constraints and drivers placed upon them as discussed in section 6.3.2 – 6.3.3 Once scored, a comparison is made between the two sets of scores and the relative frequency of statements (once normalised) within each of

[6] Input provided by Lt Cmndr Clive Carrington Wood, Squadron Leader Jed Yarnold and Major Nial Moffat

the capability domains considered. This begins to identify if a particular domain is perceived as providing a more significant contribution to overall effectiveness than another. This premise can be ratified or refuted as the trade-off progresses.

6.5.4 Stage 3

Stage 3 deviates from the decompositional flow-down as it relates to level 5 of the analysis process shown in Fig 29 (levels 3 & 4 will be addressed later). It is described at this point to reflect the link to the user requirements from level 2 of the matrix. Stage 3 requires that a new matrix is compiled and scored by the customer organisation. The matrix consists of the high level requirements from the operational analysis and their relative importance in relation to the land domain user requirements from level 2 of the matrix flow down. The intent of the additional matrix is to understand the customer's perception of high level requirement importance across all of the capability domains, in relation to land domain user requirements. The output will be used later in the trade-off, and is compiled to balance technical desire with Government constraints and feasibility.

6.5.5 Stage 4

Level 3 of the matrix takes the weightings from the land domain user requirements (these are consolidated to take account of the customer and SME perspectives) and looks at the relationship to the generic requirements. As with stage 2, five sets of data exist reflecting the five different capability domains. As before these need to be consolidated into one figure for each box to determine the relative importance in relation to the weighting. At this level the scoring will only be used as guidance in determining relative importance of the generic requirements with the main intent to provide the SME perceived weightings to the next matrix level. The reason for this relates to the research concept system requirement document and the definition of performance parameters. In the design level trade-off the statements contained within level 3 of the matrix will be driven by a combination of the customer and legislation. They will provide the space within which the designers can manipulate concepts to best meet the overall need as described in section 6.4.2. This is outside of the intent of the matrix, which is concerned with flowing down perceived importance based on knowledge and experience. With this in mind it is important to maintain the continuity of matrix use as well as utilising SME experience rather than a purely customer driven perspective.

6.5.6 Stage 5

Level 4 of the matrix looks at the strength of relationship between the generic soldier system requirements and the more design driven system requirements. The weightings for the generic requirements in the trade-off context flow down from the level 3 matrix. As with previous matrices there will be five sets of data to reflect the five domains scored, all of which will require consolidation to one number for each box. The output identifies the strength of relationship between the generic requirements and the system requirements.

The ‘hat’ that appears on the top of this matrix further aids the design team through identification of inter relationships between the system requirements showing the wider dependencies within any future concept, this forms part of the analysis data pack.

6.5.7 Stage 6

The next stage is to understand the design challenges in meeting the key high level requirements across domains. At this point the new matrix (stage 3) is revisited and drawn into the trade-off process. The matrix from stage 3 helps in the definition of ‘key’ high level requirements which represent the most important elements to be addressed. This requires that a cut off score is identified (having subjected the matrix to sensitivity analysis) that determines ‘key’ from the other high level requirements. Figure 30 pictorially represents how high level requirements are taken from the matrices constructed for each of the five capability domains (based on the cut off described above) and placed into a final matrix that has a selection of the high level requirements. The darker shading represents when a specific statement is chosen from a number of alternatives. The intention of using a prioritised list of high level requirements is to make the analysis manageable and increase the validity of the output scores as large numbers of parameters can dilute the final weightings. This is an area of the trade-off that may be refined once it has been conducted for the first time. This is due to uncertainty of the benefit of excluding any of the high level requirements at this stage, a matter that will be discussed further within the case study chapter (Chapter 8).

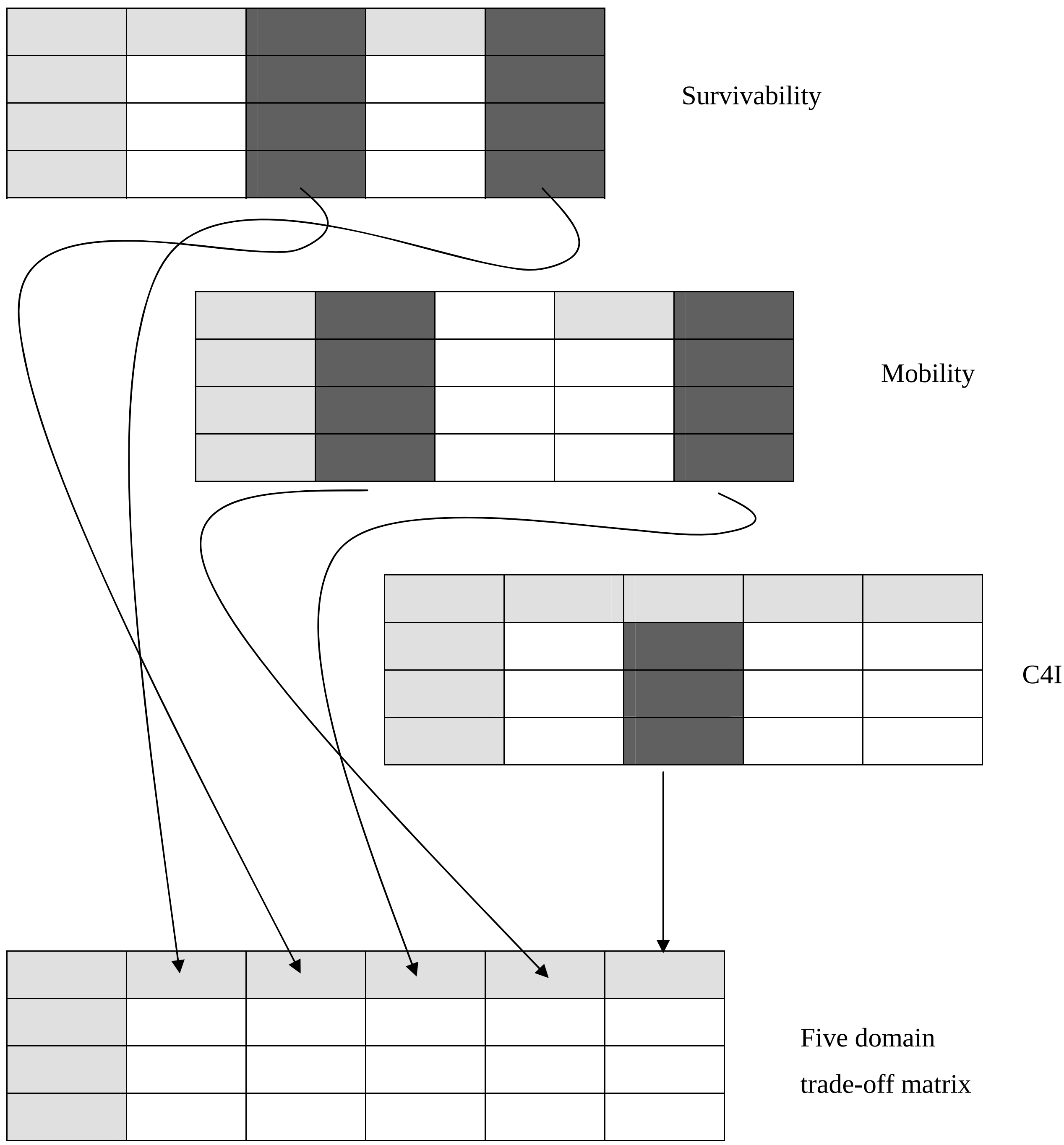


Figure 30 Matrix amalgamation showing a representation of the five capability domains

The relationship between the key high level requirements is looked at in relation to the level 4 system requirements. The flow of weighting from level 4 ensures that the customer and SME scores continue to be considered at this level.

Having identified the key high level requirements across all of the domains the original scores from the individual domain scoring can be transferred into the final matrix. With potential changes to the scores from the matrix flow down due to consolidation the final output may vary significantly from the individual domain scoring. In effect the use of the original scoring with the addition of the customer focus and the multi-layering of the domains provides a form of 'capability balance of investment' (Sharp et al., 1999).

The output from this matrix will be the identification of the most challenging system requirements to meet, along with the most challenging high level requirements to meet. This builds a focused summary for design purposes across all of the domains.

6.5.8 Stage 7

This represents the last matrix (Level 6) for scoring with the identification of the wider human factors implications of trying to meet the high level requirements. This level presents a unique challenge for the trade-off as the human factors integration (HFI) matrices use pick lists with variations for each capability domain. The consolidation across domains should not present a problem; in fact the consolidation of scores can potentially highlight the areas that have applicability to multiple domains. Identification of statements that have applicability across domains is carried out using a colour coding to identify how many domains it relates to. With the down selected list of high level requirements the exercise becomes more focused, although care must be taken due to the potentially large number of statements which will dilute score sensitivity. The output defines the wider challenges and risks of delivering the high level requirements in the context of the human factors integration domains.

6.5.9 Outputs

The trade-off activity provides one data pack for the design entity to use in production of a whole system to meet the high level need. Having identified potential concepts these can pass back through the analysis loop again to determine their impact on the wider HFI issues. The next phase is the design level trade-off which is dictated by required system performance parameters. This is likely to lead to further modelling of final concepts prior to physical concept creation.

6.6 DESIGN LEVEL TRADE-OFF

As discussed in section 6.4.2 the design level trade-off is far more fluid than the capability level trade-off. At this level the process is more concerned with dialogue between the design entity, the customer and the process provider. Previous sections have described the space within which the design level trade-off can be made based on constraints imposed by legislation and wider political drivers. Different concept ideas can be iterated through the process as required to investigate feasibility, and as down selection occurs, further operational analysis can be carried out to look at the impact on overall combat effectiveness. The capability database provides underpinning information to supplement the analysis, guiding decisions on the performance envelope within which concept choices can be made. However, it is ultimately the end user that dictates final system choice.

By independently conducting the capability trade-off to include the customer perspective the analyst responsible for trade-off activities can reduce the potential for bias. This is achieved by cross-checking the customer output from stage 3 with more detailed decisions within the design trade-off phase. This will indicate consistency and can be used to open up dialogue and discussion if large discrepancies are found.

A benefit of developing the trade-off process in a generic and flexible manner using output from the analysis is the ability to expand and adapt as required. It allows the suppliers to consider the widest -yet focused- set of high level requirements and define concepts that address as much as possible whilst providing the required performance. At the design level the trade-off forces the customer to take ownership for decisions and maintain an active role in the delivery of the final concept.

6.7 TRADE-OFF SUMMMARY

The use of the original analysis within the trade-off activities is a powerful and robust method of continuing the auditability and traceability of information and decisions. It provides a decompositional flow from defence doctrine through to systems requirements whilst encapsulating both SME and customer perspectives without the ability of either stakeholder group to skew results to suit desired outcomes.

Measurement of the desired performance attributes of the system are driven by legislation as well as customer need which provides flexibility over time through setting of upper and lower bounds rather than specific figures. This allows the designers greater freedom to define concepts that have balance within given tolerances. The intent is not to optimise one component, but explore the whole system attributes and positive emergent properties.

The loop is completed through secondary testing of concepts with further operational analysis if appropriate. This not only provides the final underpinning evidence for scrutiny, but a final opportunity to direct research if further technical issues arise.

Application of the trade-off will be discussed further within Chapter 8 with case studies used to explore the process and trade-off activities. This will show the detailed output from the activities prior to a detailed discussion in Chapter 9.

Blank Page

CHAPTER 7: MEASURING PERFORMANCE

7.1 INTRODUCTION

7.1.1 Aim

To understand the challenges of measuring socio-technical systems and establish a method for overcoming this within the bounds of the thesis.

7.1.2 Objectives

- Discuss the challenges in defining measures of performance and effectiveness for socio-technical systems
- Describe methods that have been adopted in other related studies
- Define the method to be adopted for measuring performance and effectiveness in the context of the thesis area of interest

7.1.3 Background

Chapter 2, section 2.5.1 discusses the importance of measurement within a systems engineering framework, forming the basis for acceptance of requirements. Without the ability to measure desired attributes of the system, it is questionable that confidence can be achieved in system suitability (Dooley, 2000). However, measurement is not always straightforward, particularly when the system of interest is dynamic in nature. This coupled with a lack of standardisation of approach (Mackley, 2005) leads to a fundamentally required activity that has little agreement in its conduct (Sproles, 1999).

The terms ‘measure of effectiveness’ (MOEs) and ‘measure of performance’ (MOPs) are used frequently in defence documentation as tests of system attributes (Hitchins, 2003), and yet there is no one universally accepted meaning (Sproles, 2002). There is however, a commonly held view that MOEs are external in nature and MOPs are internal in nature (Willis, 1982, Sproles, 1999). What is meant by the term ‘internal’ and ‘external’ relates to the level of detail that the two types of measure apply. It is suggested by Sproles (2002) that an MOE is external as it can be applied to any number of solutions for a given problem, whereas MOPs are internal as they are specific to an entity. However the fact that MOPs and MOEs both have the term ‘measure’ at the beginning may question Sproles’ more simplistic and purist view.

The term ‘measure’ does not have to be literally translated into some form of quantification, instead representing a standard or quality to be achieved, with effectiveness indicating that the system provides the intended results (Sproles, 1999). Therefore in the context of the soldier as the system of interest, it is the ability of concepts to meet the stakeholder requirements, or needs. This may be achieved in a number of ways and as such the measures of effectiveness should be solution independent, conforming to an external view. However, in order to understand whether you have achieved the ‘intended results’ it would appear that some form of measurement of required performance is needed, suggesting a tight coupling of performance and effectiveness.

MOEs are concerned with whole systems issues, the concept of emergence and the whole being greater than the sum of the parts (Shalen, 1994) cited in (Couldrick, 2005b). An example of this in the context of the soldier as the system is the loss exchange ratio. For a given mission was there success or failure, and with how many losses? This relies on systems level attributes rather than specific components of the system. MOPs relate to lower levels of detail specific to concept options with less emphasis on the impact of putting components and sub-systems together. An example is the performance of body armour, measured as likelihood of perforation. Optimisation of this performance measure might be viewed as enhancing survivability, but in the context of the whole system may cause undesirable emergent properties such as reduced mobility.

The difficulty arises in understanding the relationship between MOEs and MOPs, and whether lower level performance measures can be aggregated to understand effectiveness. This links to the discussion in Chapter 2, section 2.5.3 regarding whole system versus sub-system test. In measuring and optimising performance at the sub-system level is it possible to directly aggregate output to understand whole system performance? Or in fact will the whole system behave differently due to emergent properties exhibited only when all of the elements are placed together?

The MOEs must have the ability to be measured in order to validate the capability to the customer, and yet it may not be possible with any level of certainty to understand which elements of performance make one solution more desirable than another. There is a fundamental problem with the validity of aggregating effect, which is magnified when dealing with systems that cannot be optimised due to their dynamic complexity. An area that will be explored further in the next section.

7.2 GENERIC CHALLENGES IN MEASURING PERFORMANCE AND EFFECTIVENESS

7.2.1 The shift from procurement of equipment to capability

Since the Strategic Defence Review (HM Stationary Office, 1998) the focus for procurement has shifted from military equipment to 'capability'. This is discussed in detail within Chapter 2, section 2.5.3 highlighting the difficulties of measuring intangible elements such as personnel as well as the issue of attributing cause and effect. It is the complexity exhibited by the term 'capability' that makes test and evaluation difficult. If you adopt reductionist techniques to understand cause and effect of certain parameters you may alter the very characteristics you are trying to understand and yet whole system test also introduces uncertainty as you do not necessarily understand what is providing the enhancement to effectiveness (Hitchins, 2003). Replacement of equipment is more straightforward in a number of ways as you are looking for performance improvement over the current baseline, and integration of various sub-systems into a final solution (King, 2004).

Capability requires multiple systems to work successfully together having also considered the training, manpower and logistics implications as examples (Joint Doctrine and Concepts Centre, 2005, Parry, 2005). In procuring capability the risk shifts from mostly technical to service delivery. The other lines of development that are frequently less tangible can dictate success or failure. It raises the question of whether capability is something that we can contract against as it may never be possible to validate operational capability. Instead, it may be necessary to devise progressive assurance throughout the lifecycle of a system, where different forms of testing are considered in the wider context of capability. The customer in conjunction with other stakeholders provides the high level strategic framework to test within providing a common view of what constitutes success to a myriad of different systems projects.

Current activities carried out by the Integration Authority (IA), part of the Defence Procurement Agency could support this framework approach through identification of system and platform interfaces and related integration issues. Although not involved at the detailed measurement level the IA have an overview of all programmes and projects within the DPA and their intended output. This is formalised within a number of tools that produce charts showing inter-relationships and synergies between different systems and platforms (Masterman, 2005). This information could be used in support of more detailed measurement to understand the wider implications of delivering capability considering all lines of development (Joint Doctrine and Concepts Centre, 2005, Parry, 2005).

7.2.2 The link between measurement and systems engineering

The major driver for measurement of solutions/ concepts is the ability to determine if the necessary requirements have been met. From a systems engineering standpoint it stems from contractual implications providing criteria against which contract adherence can be determined (Boardman, 1997). If you cannot measure the conformance of a system or sub-system, how will you be able to judge which solution meets the requirements you have specified? How can you judge the technical feasibility of one solution/ concept over another if you cannot measure the characteristics? This is not only an issue for Government, but also for industry. The less detail a contract contains the greater risk the company will bear. This is because the company will be unable to prove to the customer (Government in this instance) that they have provided what has been specified. This could potentially work in the favour of the customer as flexibility in the specification will allow the customer to make changes over time. However, this can equally work against Government as it may allow greater openness in interpretation by industry, which does not meet with customer expectation. Therefore weak or loose specifications without the appropriate systems architecture and framework as part of a systems approach increases risk for both the customer and the supplier making it an unsatisfactory position for both.

7.3 MEASUREMENT OF SOCIO-TECHNICAL SYSTEMS

7.3.1 Validity of measuring dynamic and unpredictable variables

When measuring humans in particular there are a number of considerations related to the unpredictability of response. Human behaviour has a number of modifiers, for instance fear and fatigue,[7] which are caused by a number of contributing factors including physical effort expended and available energy resources as examples (Curtis, 1996). The measurement becomes complicated because the relationship between parameters is not linear or even quantifiably cumulative as individuals will respond differently. Through extensive testing it may be possible to hypothesise expected behaviour, but as with whole system test, the level of certainty may not be high. In the defence context it becomes harder to extrapolate human behaviour based on laboratory trials as soldiers often experience extremes of situation that cannot be recreated within trials and modelling (Colthurst et al., 1999). Even in field trials the level of fear or impact of fatigue will be different from when there is a true belief that their life is at risk, or there is a fear of operational failure (Woolford & Randall, 1997). As it is recognised that these problems will never be fully overcome, a certain number of assumptions will be required (Wright, 1997a); supplemented where possible with operational data to ensure completeness of view.

It is the customer as the primary stakeholder for the soldier system domain that acts as the driver for both measurement and trade-off activities leading to the requirement for the proposed process suite. Accuracy of measurement of human attributes will partly be dictated by available resources, as modelling and simulation can be expensive when creating new tools. Secondly it will be dictated by the amount of risk that the customer

---

[7] Presentation given by Dr Nick Beagley, DSTO Land Operations Division, Edinburgh, South Australia to Dstl Land Systems Fort Halstead, Sevenoaks, Kent (2004).

is prepared to accept, as inaccurate modelling will potentially lead to higher uncertainty and therefore higher risk. The next section discusses the current approach taken within Government and the perceived shortfalls.

7.3.2 Approach of existing programmes in this domain

Soldier equipment programmes have traditionally been scrutinised differently from their larger platform counterparts (Taylor, 2005). This has been partly due to the significantly lower budgets for soldier equipment, which has a reduced level of scrutiny associated with it, and partly because of the difficulty of applying modelling and simulation techniques which are based on optimisation of given parameters (Walmsley & Hearn, 2004). The result of these factors has been measures of effectiveness dictated purely by customer expectations. Although the views of the stakeholders form a critical component of defining measures of effectiveness (Sproles, 1999) this represents a very subjective and potentially biased outlook on system characteristics. Tools and techniques such as modelling and simulation can help to formalise or make stakeholder input more objective by looking at measures in relation to the mission or purpose of the system of interest (Sproles, 1999) suggesting a benefit in the fusion of techniques.

The Future Integrated Soldier Technology (FIST) programme represents one of the first instances where modelling and simulation in the form of operational analysis has been used to determine the effectiveness of solutions for a dismounted role (Wright, 1997b). The FIST programme uses the combat model CAEn (Close Action Environment) to investigate potential concepts. CAEn is capable of modelling the effect of threat weapon systems looking at an infantry company up to the battlegroup or higher using a set of assumptions which have been validated over a number of years through field trials and SME input.

Measurement of effectiveness for the FIST programme focuses on the number of losses sustained and achievement of the mission objective within a given time. These two parameters combined provide the loss exchange ratio, with the least casualties during a rapidly executed mission proving desirable. CAEn is used for scrutiny of many projects that are not confined to the dismounted close combat area. Originally developed as a lethality model, CAEn has several shortfalls when measuring socio-technical systems, as it was not designed with this in mind. Static data files represent the greatest problem, with a singular 'look up' at the beginning of a simulation run to determine percentage degradation or improvement in performance for parameters such as fatigue. This fails to account for dynamic and cumulative effects that would occur within the simulation run depending on the activities carried out, and as such is not an accurate representation.

Other meta-models in the form of IPME (Integrated Performance Modelling Environment) have been developed to try and address the shortfalls and interface with combat models such as CAEn, but they have yet to be successfully validated (Colthurst et al., 1999). If misinterpreted, human characteristics such as fatigue and fear may invalidate the output from combat models. For example, if fatigue is not appropriately modelled there may be fewer men available in the combat phase, or their effectiveness may be lower, which could result in failure to complete the mission, or greater time to complete. This may alter which options are most effective, and in the extreme lead to sub-optimal solutions being chosen.

This observation questions the validity of the FIST approach if models such as CAEn have these shortfalls. However, in the context of FIST, many field trials have and are being conducted in support of the modelling, which can be used for validation purposes. This is achievable for the FIST programme due to the size of budget available, but reliance on field trials as discussed in Chapter 2, section 2.5.2 is costly and not always achievable due to troop availability. For this reason it is beneficial to have accurate models and simulations with utility across applications, something that has been recognised within the NATO working parties in this area.

The NATO measurement framework (NATO LG3, 1999) has been created as a repository of performance and effectiveness measures for use in soldier related research and procurement activities. This creates a standardised set of measures (Mackley, 2005) to promote commonality between nations in both trials and modelling. Metrics are grouped at a number of levels from battle group to company and at the lower levels the individual soldier. It provides a useful structure within which to categorise measures, but suffers from the same challenges as IPME and CAEn in relation to a lack of understanding of how performance aggregates to effectiveness and in how to measure ‘whole system’ issues associated with the soldier. Many of the measures included in the framework are derived from the work within the FIST programme, which is optimised for measurement of equipment performance, rather than the impact of human modifiers to overall effectiveness.

The NATO Land Group 3 responsible for the measurement framework (1999) have identified the need for further work to understand the impact of the human on the measures adopted. However, at this time it is still a shortfall of the existing documentation.

The approach discussed in section 7.4 utilises the framework suggested within the NATO documentation, expanding the utility by inclusion of a far more comprehensive set of measures at a number of different levels. This provides commonality with the NATO framework (1999) and the ability to integrate the two sources as required, over time, benefiting a number of stakeholders.

7.4 PROCESS SUITE APPROACH

Discussion within the chapter and in Chapter 2, section 2.5 describes the current problems with the activity of measurement for dynamically complex systems and the standardisation of measurement for said systems.

Chapter 5 defines a suite of processes to be used for definition of future soldier systems and direction of future research. Measurement compliments this activity, and is vital in choosing between possible alternatives (Buede, 2004). Fig 31 diagrammatically represents the measurement activities to support the process suite. The intent of a repository to aid standardisation fulfils the ideas of the NATO measurement framework (NATO LG3, 1999) in addition to other related papers on the topic (Mackley, 2005, Sproles, 2002).

Based on the same principles as the capability database described in Chapter 5, section 5.3.2 and in detail within (Sparks, 2004b) the MOE/ MOP repository consolidates information from a number of sources. Appropriate configuration control and regular updating ensure that current practices and thinking are reflected, maintaining the iterative nature of the systems approach within an action research cycle (Warmington, 1980).

As with the system process ethos (Chapter 5), commonality should be achieved with other departments where possible to aid lines of communication and encourage wide acceptance of ideas. Therefore the framework presented by NATO (NATO LG3, 1999) will form the basis of the categories within the repository, but not restrict the content within them.

The NATO framework (NATO LG3, 1999) mirrors the other elements of the systems process in the fact that it is decompositional in nature from campaign level to component level. This will enable measurement in both a performance and effectiveness context to be included and aid completeness of the view. The following section describes the composition of the MOE/MOP repository as shown in Fig 31.

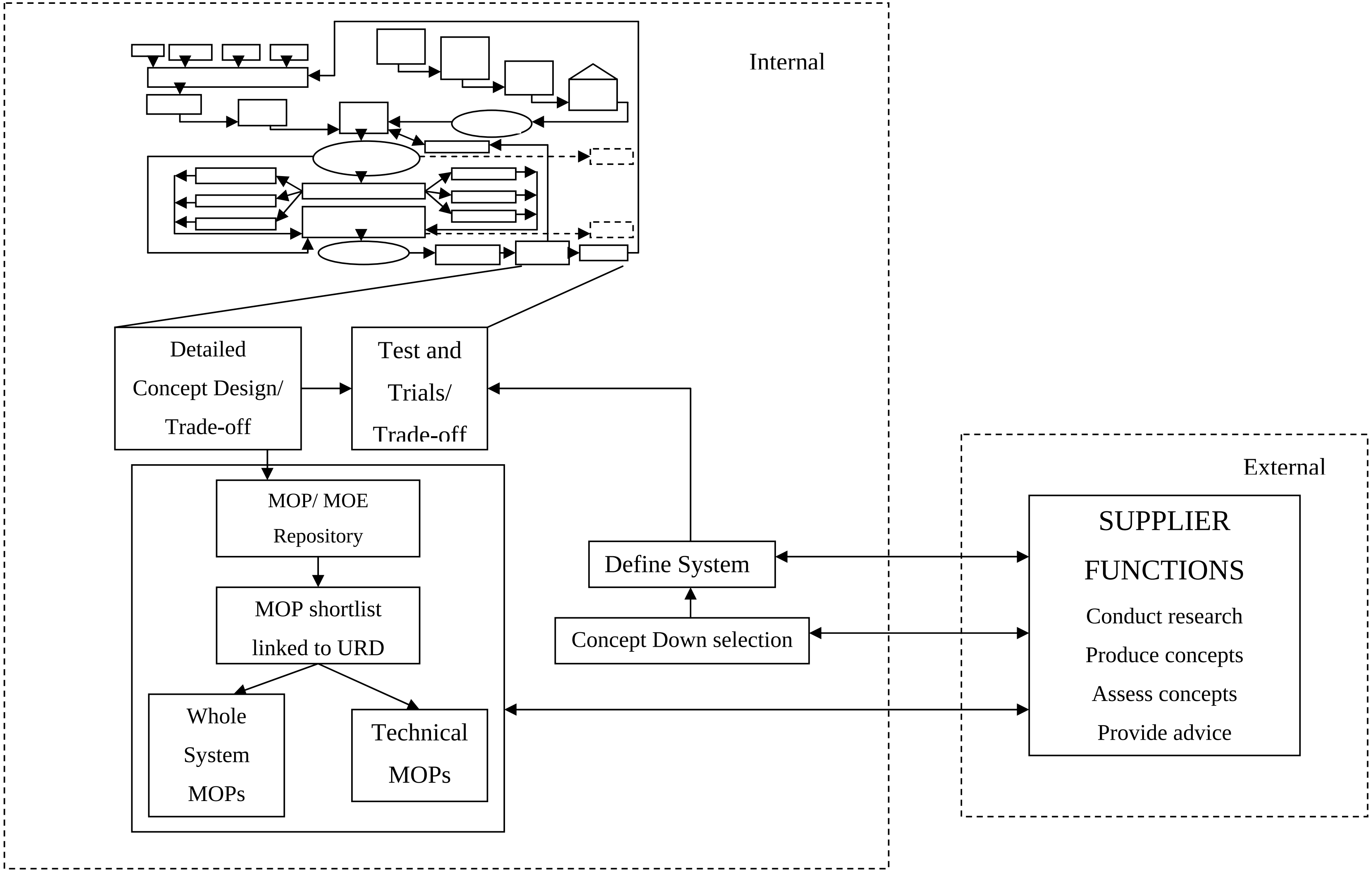


Figure 31 MOE/MOP Repository configuration

7.4.1 MOE/MOP repository composition

The repository characterises the measures of performance and effectiveness in three ways to provide the flexibility to answer system questions at different levels of resolution within the process suite:

- The measure
- The ways of measuring
- The level of performance required (when dictated by external elements such as legislation)

An applied example of these categories in relation to a soldier system issue is as follows:

The Question

The key high level requirement of environmental protection has been identified within the analysis. In this instance some initial concept designs have been generated, but there is a necessity to understand which concept will enhance effectiveness whilst minimising impact across the capability domains. For example, how much protection is enough?

The MOP/ MOE repository is consulted to determine the measures that can be used at various levels of resolution:

- Environmental protection is the area of interest
- Specific fabrics can be measured for their properties within the laboratory
- Whole system tests can be used such as the sweating articulated manikin (SAM) to look at the impact of layers of clothing on the soldier
- Field trials could be instigated to gain direct user feedback
- Historical data from research programmes could be used to form an opinion on experimentation already carried out in relation to environmental protection

All of these tests have associated measurement techniques taken from sources such as the measurement framework (NATO LG3, 1999) or British standards in terms of wear testing and durability (British Standards, 1999) allowing the level of performance to be determined. Whole system tests such as those using SAM would be interpreted using past physiological testing parameters to determine desirable levels of venting and other characteristics as examples (British Standards, 1990, Higgenbottam, 1996, Satsumoto & Ishikawa, 1997).

This is just one specific application at one level of resolution to indicate the flexibility that is desired from the framework and related database. It is not intended to address the shortfalls within the modelling and simulation of human attributes which have been identified in Chapter 2, section 2.5.3- 2.5.4 and within this chapter, section 7.3.1 as this requires a longer term research programme. The analysis process described in Chapter 5 is intended to address many of the shortfalls within human related modelling by use of SMEs in conjunction with more objective data sources. The introduction of an MOE/MOP repository is intended to continue the theme of auditability and traceability with commonality across domains and organisations wherever possible. As with the process it is intended to be iterative in nature and grow over time.

7.4.2 The link between measurement and trade-off

Section 7.3.2 discusses how the measurement framework provides choices on what is being measured, how it can be measured and the level of performance that is required. It is the level of required performance that links the contents of the repository to the activity of trading off, completing the cycle from requirements to options, to down selection. For some measures the level of performance will be dictated as there is legislation that the Government must conform to. In all other instances the level of required performance will be dictated by a combination of the threats and tasks and activities to be encountered, tempered by the customer and their particular expectations.

In order to maintain flexibility it is desirable to have a range within which performance and effectiveness is acceptable. This is discussed in Chapter 6, section 6.4.2 in relation to trade-off activities, but is tightly coupled with measurement. The current measurement framework (NATO LG3, 1999) used by the FIST programme looks at specific performance for a given measurement parameter. This can be hard to define when you are identifying enhancement to effectiveness rather than performance. How can you be sure that in conjunction with a number of other performance parameters changing one by X percent may not impact another by Y percent producing less overall effectiveness?

By separating the performance measure and ways of measuring performance (as reflected in the MOE/MOP repository breakdown) it allows far greater flexibility when performing the trade-off. If you have tested a component or whole concept within given parameters that have upper and lower acceptable bounds, rather than against one specified level of performance you can trade within and between capabilities looking at the impact that such a decision will have on overall effectiveness.

It also allows for responsiveness to changing requirements and auditability of decisions at a later date. If you have defined that you require the system to protect the soldier from temperatures of 40° C you can fail to understand what the system might be able to achieve. If you then come to the point of trade-off and it is decided that it would be preferable to have a fabric that will protect to 30° C, but also have certain other characteristics it is possible that you will not have collected the supporting evidence that you need.

The systems process suite is concerned with application of a consistent and flexible framework. Options can be explored at varying levels of resolution without placing unnecessary constraints on performance requirements in the early stages of scoping the problem. As concepts are developed and traded off, the output is incorporated into the capability database, in order that subsequent iterations can identify when and if capability gaps have been addressed.

In combination, the process suite and the supporting components such as the MOE/MOP repository and the capability database provide a flexible, multi-level, multi-domain tool for addressing soldier system issues, with Chapter 8 applying two specific case studies to test the utility of the process suite.

7.5 MEASURING PERFORMANCE SUMMARY

Measures of effectiveness and measures of performance are used to determine whether a concept or solution has met the stakeholder requirements.

MOEs/ MOPs form part of a systems approach in terms of test and acceptance to ensure that the system is built in the right way and can be accepted against a specification and associated contract.

There is no universally accepted meaning of the terms MOE and MOP, which can lead to misunderstandings and incorrectly constructed measures.

MOEs can be considered as whole system tests as they are solution independent, with MOPs constituting sub-system tests as they are specific to solutions.

The Government desire to procure capability rather than equipment has lead to challenges in measurement terminology as it is difficult to measure intangible characteristics.

It is usual to exclude requirements that cannot be measured due to contractual difficulties; however this raises many questions in relation to human-centred systems as excluding elements due to difficulty of measurement may undermine confidence in the final output.

It is important to balance whole system and sub-system tests to ensure a completeness of view that recognises different levels of detail and helps to provide confidence to the stakeholders.

Because of the difficulty in measuring socio-technical systems, it may be necessary to make a number of assumptions that should be carefully documented for stakeholder consideration.

It is the customer that dictates both the measures applied to a system and the trade-off criteria in all instances other than those governed by legislation.

Current soldier modernisation programmes (FIST) have been instrumental in development of measurement frameworks (NATO LG3, 1999), but have continued to apply these in a technically focused way.

The approach expressed in this thesis expands upon ideas already in existence, but ensures completeness and separation of the performance measure and the measurement of performance to create a more flexible, generic method for dealing with effectiveness and performance.

The approach expressed in this thesis encourages standardisation and continued growth over time to aid communication and promote commonality.

Blank Page

CHAPTER 8: CASE STUDIES

8.1 INTRODUCTION

8.1.1 Aim

To apply the suite of processes described in Chapter 5 to a representative problem and discuss the validity of the output.

8.1.2 Objectives

- Define a representative problem to explore the use of the process suite defined in Chapter 5
- Apply the process suite tools and techniques to the identified problem
- Report the results of the process suite analysis, including the validity of the approach
- Discuss the analysis output and identify strengths and weaknesses within the process suite

8.1.3 Background

In taking a systems approach to the research question presented in Chapter 3 the next phase within an action research cycle (Flood, 2001) having provided a potential solution to the problem in the form of the process suite is to test the effectiveness and validity of the approach. The intent of this chapter is to use two representative case studies to determine the applicability and ease of use of the process suite. The two case studies chosen form part of the operational clothing and textiles programme run by Dstl Land Systems based at Fort Halstead. The data gathering and interpretation of these case studies was carried out during the course of this research whilst working for the organisation, hence there is a need to separate the raw data from the thesis due to the restricted nature of the content (Annex A). This does not affect the utility of the case studies as it is still possible to discuss the interpreted output with accompanying summary information. The importance of the case study chapter is not restricted to the specific input data, with the intent to explore use, applicability and validity of the process suite.

The first case study looks specifically at one capability domain to test the use of the decompositional matrices (Chapter 5) and the general method. Survivability has been chosen as it represents a mature domain with a clear understanding of the problems and challenges. As such it can be considered a control for the study as the output should conform to SME expectation.

The second case study looks at all five of the capability domains with the intent of exploring the trade-off activities discussed in Chapter 6. By using this case study it is possible to discuss the relative importance of one capability domain over another and make observations on the areas where future research should be directed. This is done with data collected over the period 2004-2006 with output reflecting the challenges and gaps of that time.

8.2 CASE STUDY 1- SURVIVABILITY

8.2.1 Introduction

Consideration of the single domain of survivability in relation to the operational clothing sub-set of the soldier system is intended to act as a control for case study number 2 which looks at all five of the NATO capability domains (NATO LG3, 1999), trading-off to identify the key areas. The challenges and requirements relating to soldier protection and survivability are well known by the relevant subject matter experts (Couldrick, 2005b, Ashby et al., 2004). In using this domain to test the process suite described in Chapter 5 a certain level of confidence in the validity of the processes can be established. If the output from the analysis confirms the beliefs of the SMEs and is found to be insensitive to changes in the scoring using recognised techniques (Voorhees & Bahill, 1995) it would suggest that further applications with less certainty in the results can be explored including the five domain trade-off.

By using the process for one domain as well as across all five NATO domains it exhibits the intended flexibility of the process suite. It is the intention of the process to be capable of analysing small scale issues within the wider framework and understanding the impact that this will have on the other lines of development (Sparks, 2004a) as well as full scale, whole system changes.

8.2.2 Method

The input for the analysis is a combination of operational analysis and SME scoring as part of a decompositional matrix. Fig 32 shows the analysis process as described in Chapter 5 to aid the reader in the following paragraphs. The scoring of the matrices follows a convention used in many studies (Kim, K, 2002). The figures of 9, 3 and 1 are used as arbitrary indicators of a strong relationship, medium relationship and weak relationship between statements (Franceschini & Rupil, 1999). Traditionally the scoring is used to identify uni-directional relationships between the statements in the matrix (Cohen, 1995), however, within the system analysis process (Fig 32) this is not the case as the figures are of secondary importance. The scoring convention has been used for clarity in processing the input data, but equally a traffic light system (Christley & Witty, 2001) or other method of indicating strong, medium and low relationships could be adopted. The intent of the analysis is for SMEs to indicate in either direction, if a relationship exists between two statements within the matrix, and if 'yes' how strong that relationship is. The figures are not used as absolutes, instead it is an opportunity to flag issues and aid communication.

Many potential drawbacks have been associated with scoring conventions if the raw figures are used to make decisions on systems or concepts (Cole, 1989); one of the main reasons for reducing the significance of the scoring for this study. The classic 9, 3, 1 scoring has been found to potentially skew results towards the higher order scores as well as exhibiting bias and subjectivity based on the knowledge, experience and motives of the people involved (Haysman, 1998). The case study for both the single domain of survivability and the multiple domain trade-off addresses this using sensitivity analysis (section 8.2.4) which is designed to test robustness of input data to ensure that it could not have been generated by chance alone. Section 8.2.4 discusses the methods applied to check the sensitivity of data to change including alterations to the scoring convention. The results of this are discussed in sections 8.2.5 and 8.3.3.

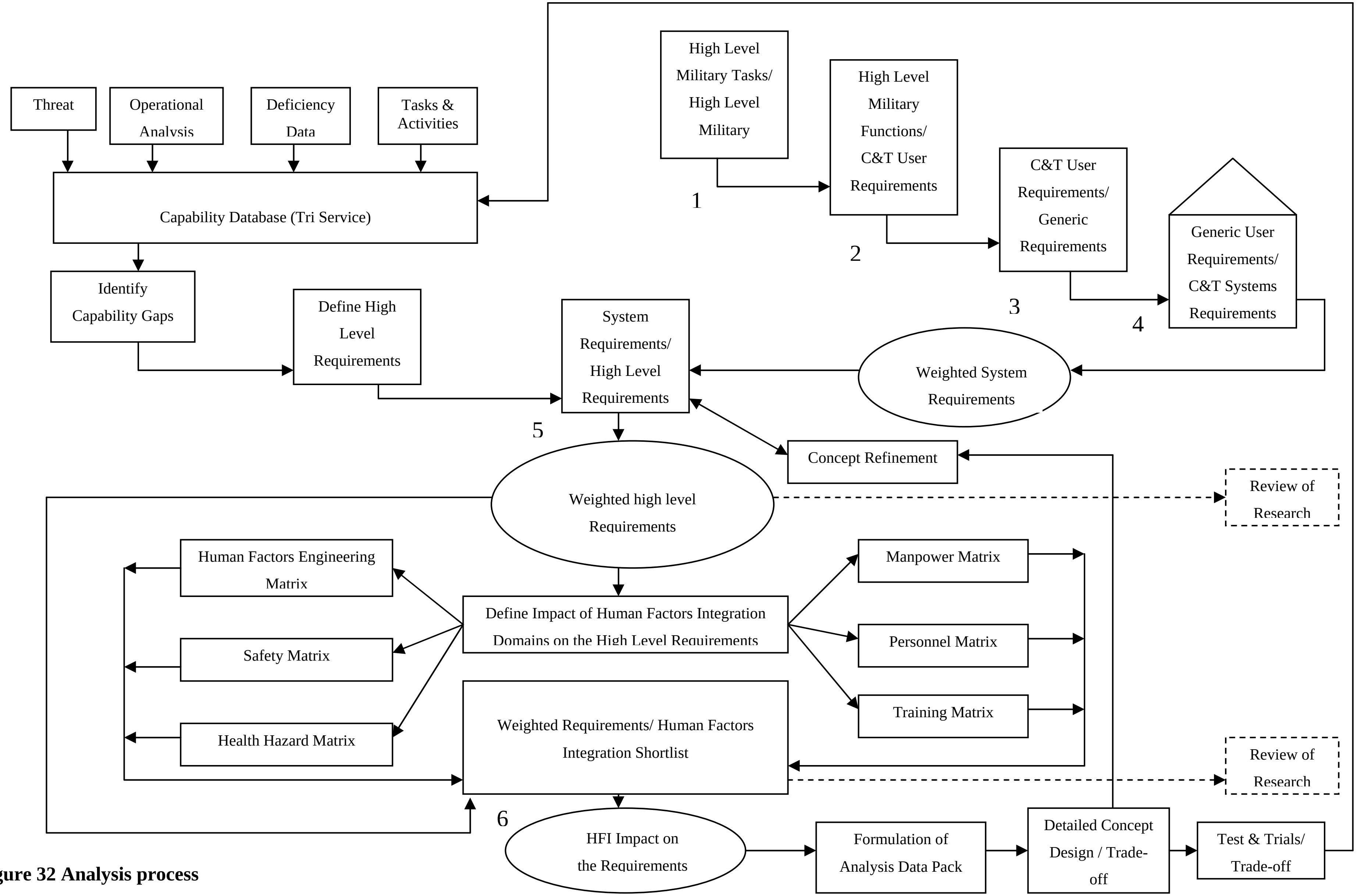


Figure 32 Analysis process

Microsoft Excel spreadsheets are used for collection and management of the data in order to allow for ease of change and also manipulation for application of techniques such as the sensitivity analysis where weightings are altered to determine the impact further down the matrix chain. In using spreadsheets any changes can be made quickly and with linked tables will cascade through all of the levels automatically. This allows for a rapid turn around of data and ease in managing multiple iterations of the analysis, all conforming to the aims of fusing data in this way to look at the problem space. The raw technical importance for each column is generated by multiplying each score by the corresponding row weighting and then adding these together to provide the column total. Normalisation is achieved by taking the sum of each of the columns and dividing it by the total sum of all of the columns. This provides a figure that reflects the relationship to all other scores within the table. It is the normalised figures for each of the columns that become the input weighting for the next level of the matrix.

For the survivability analysis the SMEs met to complete the matrices during one informal meeting. This allows questions to be asked with guidance documentation issued in advance (Appendix C). Facilitation by the thesis author as a systems engineer and creator of the matrices helps with issues of interpretation and general understanding of the scoring convention. Use of more than one SME for the scoring requires that multiple matrices are amalgamated to provide one score for each of the statement pairs as unless all scores are the same (e.g. all three's providing an average of three), using an average leads to non-alignment with the standard QFD scoring of 0,1,3,9. To overcome this problem it is necessary to understand the scoring convention behind QFD to ensure consistency. Franceschini and Rupil (1999) describe the scaling of different scoring conventions, with 0,1,3,9 representing an example of a logarithmic interval scale where judgements are related to one another in a ratio such that m(high)/m(medium) = m(medium)/m(low). This has led to the creation of groupings to translate the averaged scores back to the 0,1,3,9 QFD scale whilst maintaining the appropriate ratios between the scores.

This provides the following alignment of averaged scores that do not conform to the 0,1,3,9 convention when calculated using the ratio convention described in Franceschini and Rupil (1999).

- Zero scores are translated directly as a 0
- Average score of all SMEs below or equal to 0.5 = singular matrix entry of 1
- Average score of all SMEs above 0.5 and below or equal to 1.5 = singular matrix entry of 3
- Average score of all SMEs above 1.5 and below or equal to 4.5 = singular matrix entry of 9

The scores entered into the matrix are cross-checked against the mode for each statement pair. This can also be used to check for levels of agreement between SMEs and groups of SMEs and for potential validation of the matrix and the statements within the matrix. If a polar response is found it may indicate two things:

- A potential misunderstanding of the statement
- A difference in the 'world views' of the person taking the test.

Very strong disagreements require that the data is revisited, although this was not necessary for the case studies presented.

Summary results are grouped into a tabular format within Table 2, and, due to the security classification of the raw data, contained in full within Annex A. The content of each matrix level is described in section 8.2.5 in addition to discussion of the results. Table 2 divides matrix statements into 'key' and 'important' indicating some level of segregation for trade-off purposes later on. The division of the statements has an element of subjectivity associated with it and is related to the expert interpretation of the analyst. It is necessary as part of the trade-off to down select from possible alternatives (Buede, 2004) until one or more appropriate solutions can be identified in later iterations.

For the single domain of survivability a percentage gap was used to identify which statements were key and which were important. The figure of 10% minimum between the top statements and the next grouping of statements is applied. Any statements falling close to the 10% margin are identified as key. This was based on a visual inspection of the data which showed distinct clusters. This was developed further for the five domain trade-off, which is discussed in section 8.3. It is noted that this is a subjective decision relating to the cut-off for data; however the clustering of output with agreement of parameters with the customer is the same as used for other elements of the trade-off activity and reflects the need for SME input to ensure robustness.

8.2.3 Input data

The input data is primarily from two strands, quantitative and qualitative; operational analysis and SME scoring. The operational analysis used within this case study was commissioned by DEC (GM) as the customer for Soldier Modernisation research. It was initially intended to test if current models in the form of CAEn can be used effectively for clothing-related analysis (Shepherd et al., 2003a). The work was commissioned in advance of the process suite described in Chapter 5 and as such has certain shortfalls for the purposes of systems analysis that are discussed later. Further OA in the form of user perceived deficiencies from operational experience supplement the model-based OA and help to reflect end user needs and expectations. The results from both of these studies are contained in the following reports (Shepherd et al., 2003a, Shepherd et al., 2003b).

The OA study uses subject matter experts to define potential systems that could be tested within the CAEn war game to look at the impact on operational effectiveness compared to the baseline of what is in existence. Each of the systems have performance parameters that are characterised by a number of measures within the model, an example of which is speed over ground, which may be impaired if the system is a certain weight. Each of the concepts is tested in relation to a scenario that dictates the threats to be encountered, the terrain and climatic conditions and the scale and ability of the enemy force, all of which are dictated by intelligence documentation.

From this study the concepts tested are grouped to indicate those that have the greatest positive impact on operational effectiveness (Shepherd et al., 2003a). These are supplemented by key issues from the user perceived deficiencies to provide a list of the key requirements to be achieved in order to enhance effectiveness within the domain of survivability:

- Enhanced high velocity bullet protection
- Enhanced fragmentation protection
- Enhanced camouflage
- Improved body coverage
- Full integration of components
- Fully integrated with personal kit
- Accommodate 5-95th percentile
- Training
- Issuing policy

This provides the high level requirements for the decompositional matrix on the left hand side of Fig 32 (identify capability gaps/ define high level requirements boxes). As discussed previously there are certain limitations with the OA input data relating to the number of assumptions made and lack of traceability of some of the degradation measures used (Sparks, 2004d). For the purposes of this case study it does not impact the validity of the results as the assumptions are known, but in terms of acting upon any output for direction of future work the customer should consider the assumptions that have been made and decide if further OA is required to validate the output.

In addition to the OA input data for the systems analysis, SMEs are used for the decompositional matrix on the right hand side of Fig 32. The survivability analysis uses a cross-section of SMEs to carry out the scoring. Levels 1 and 2 specifically focused on high level military tasks and activities are scored by high ranking members of each of the armed forces[8]. The lower levels are scored by a combination of body armour

[8] Lt Cmndr Clive Carrington Wood, Squadron Leader Jed Yarnold and Major Nial Moffat were used for this analysis

specialists, research scientists, a systems engineer, several designers and a human factors expert to provide the necessary balance of domain expertise.

The focus of the scoring is survivability and its link to land domain issues, as we are concerned with dismounted troops and their operational clothing needs for this case study. The SMEs are provided with the matrices and scoring profile (Appendix C provides a copy of the guidance notes for SMEs). Each of the matrices is scored in turn with breaks or explanation of content as required. The HFI pick lists (level 6 within Fig 32) are considered in advance of the matrix scoring session with the SMEs providing opinion on which statements are most relevant for inclusion within the matrix analysis. When the scoring takes place the HFI matrices have already been focused to the statements that are considered appropriate saving time when scoring. The content of each matrix is discussed within the results section 8.2.5, with a blank matrix in Appendix D.

8.2.4 Sensitivity analysis method

The issue of validity has been discussed within earlier Chapters (2&5). It constitutes an important component of a systems approach with the need to test if the right system has been built to meet customer requirements. In this instance it asks the question of whether the specific techniques used within the process suite provide the auditable and traceable information required to make decisions on the direction of future research and soldier system concept design.

There is no specific format for sensitivity analysis, mirroring trade-off activities in many respects, with different projects using different techniques (Karnavas et al., 1993). In order to test robustness fully, several variations of sensitivity analysis are applied to the process suite. The desirable outcome is for the sensitivity analysis to show that matrix scores are insensitive, indicating that SMEs input is providing robust opinion, therefore increasing confidence in the validity of the approach.

Three specific trade-off activities are used:

1. Changes to the scoring convention
2. Analysis of the sensitivity of key and important statements to change
3. Impact of changes to the high level weightings on the flow of matrix scores.

Changes to the scoring convention

The classic 9,3,1 can be amended to 7,3,1, 5,3,1 and 9,3,0 as examples to see if differences appear in the statements that are considered important (Kim, K, 2002). This has been used for a number of studies and can be applied generically to this study with results shown in section 8.2.5.

Analysis of the sensitivity of key and important statements to change

With relatively large numbers of SMEs and statements used within the matrix scoring, it is possible to dilute the output and potentially miss important links (Phillips et al., 1994). When defining key requirements compared to less crucial requirements as described in section 8.2.4 above there are subjective judgements made based on the difference between the output scores. To test the robustness of this judgemental split (set at 10% clearance for the survivability case study), sensitivity analysis is carried out to understand the changes in output score that would be required to move a non-key requirement to a level of being a key requirement for that particular matrix level, and conversely a key requirement to a level of being a non-key requirement for that particular matrix level. This can be achieved by looking at borderline requirements statements for each matrix level as these will be, potentially, the most sensitive to change. The higher the percentage of change required to move the position of the key requirement, the higher the confidence in the data split point.

Impact of changes to the high level weightings on the flow of matrix scores

The level 1 matrix is concerned with the high level defence missions as defined within military doctrine (Joint Doctrine and Concepts Centre, 1996). All seven statements are given an equal weighting to reflect the diverse range of both peace and war operations that ground troops are involved in. However, alterations can be made to the weighting to reflect a skewing towards either war or peace to look at the impact on the statements in proceeding matrices. By altering the weightings within the very top matrix it is possible to explore differing needs related to type of operation. When designing, there is a tendency towards war fighting as the potentially most demanding scenario. However, with the ease of changing input data more extensive checks of the data can be carried out. The output from this is discussed in section 8.2.5.

8.2.5 Results

Due to security classification, the raw data from the analysis is contained within a restricted annex, which can be obtained with appropriate clearances (Annex A). The following results table represents the key statement summary for each of the matrix levels that will be used within the data interpretation.

Fig 32 shows the location of the matrix levels with specific statement headings described in the following sections. A blank version of the matrices used within the analysis process is contained in Appendix D.

Level 1		Level 2		Level 3		Level 4		Level 5		Level 6	
Key	Important	Key	Important	Key	Important	Key	Important	Key	Important	Key	Important
Plan & direct own force disposition		The user shall be able to conduct operations within defined notice periods	The user shall be able to carry loads appropriate to completing the mission	To protect from environmental categories as defined in DEF STAN 00-35 part 4		Accommodate 5-95 percentile anthropometric range		Enhanced high velocity bullet protection		How important is the system to overall operational effectiveness?	Will the system weight impact the likelihood of injury?
Implement information operations		The system shall have a high level of operational availability		To protect from defined biological and chemical agents		Allow access to equipment whilst carrying out mission essential tasks		Enhanced fragment-ation protection		Does the system affect the user's ability to thermoregulate?	Will the system restrict movement, which may affect the way in which tasks are carried out E.g. manual handling
Co-ordinate with other national/ international organisations		The user shall have significantly improved survivability		To protect from a defined level of fragmentation and bullet type		Reduce the energy cost to the wearer		Improved body coverage		Could the system contribute to the onset of heat stress?	Will the system add a substantial amount of weight or bulk to a specific area?
Provide personnel support						Minimise impedance of range of movement					
Conduct medical support						Minimise impedance of speed of movement					

Table 2 Matrix results table

Level 1

Level 1 looks at the relationship between high level defence missions as described in military defence doctrine (Joint Doctrine and Concepts Centre, 1996) and the strategic and operational level tasks from the joint essential task list (Joint Command Headquarters, 2001) to encompass the tri-service land context. As discussed in section 8.2.4 the defence missions are given an equal weighting to reflect the broadest operating challenges of the dismounted soldier, with alternative weighting applied as part of the sensitivity analysis later within this section.

Independent military officers provide the input for this level of the matrix with air, land and sea representatives ensuring a balanced view of the relative importance of the statements[9] .

The key and important statements identified as a result of the analysis are listed in Table 2 and show a strong grouping towards operationally focused tasks not only for our own forces, but including the need to interoperate with other nations and organisations.

Level 2

Level 2 looks at the relationship between the operational and strategic level tasks (with the weighting cascading from the output of level 1) and land system user requirements in the context of the soldier and their equipment. The latter information is taken from the FIST user requirement document[10] as a representative example of future dismounted soldier equipment direction. This has been supplemented to reflect further challenges identified within the NATO capability domains (NATO LG3, 1999) in the soldier system context as described in Fig 13, Chapter 4, section 4.2.1.

Level 2 is also scored by military experts due to the operational and strategic statements that are included. User requirements are characteristically compiled by the customer and so the individuals scoring this matrix come from that organisation.

---

[9] Lt Cmndr Clive Carrington Wood, Squadron Leader Jed Yarnold and Major Nial Moffat were used for this analysis.

[10] D/DCC/20/1/06/01 14 Jul 2003. Originator DCC IPT Abbeywood.

Table 2 shows the land domain user requirements that have the strongest relationship across all of the strategic and operational tasks. This matrix is applied in nature as it relates to operational implications within the land domain and in the context of survivability. Key areas identified by the analysis include operational availability of systems (which relates to wider system issues of logistics) as well as the need for combatants to survive in order to execute the defence and land domain tasks and activities.

Level 3

Level 3 looks at the relationship between the land domain user requirements (with the weighting cascading from the output of level 2) and the generic soldier system requirements. The generic soldier system requirements represent the performance bounds that are applied to the system as further resolution is achieved and later within the design level trade-off activities. Level 3 and 4 of the matrix expose more detailed issues associated with delivering the high level need, but are still solution independent at this stage of the analysis.

Strong relationships at this level may indicate where significant challenges exist in delivery of future concepts. Some of the statements are driven by legislation at this level which becomes mandatory in defining performance criteria as well as for trade-off activities, in subsequent iterations of the analysis.

This is the first level of the matrix where technical SMEs provide the input, reflecting the shift from wider capability driven issues to more specific, but solution independent system issues. The intent of level 3 and 4 of the matrix is not to define a specific system to meet high level need, but explore the potential implications of trying to deliver any system to address the problem domain, which in this case is survivability.

Table 2 shows the generic requirements that have the strongest relationship across all of the land domain user requirements, in the context of survivability. It indicates significant need and, potentially, challenges in the delivery of environmental protection, nuclear biological and chemical protection and protection from fragmentation and bullets.

Level 4

Level 4 looks at the relationship between the generic soldier system requirements (with the weighting cascading from the output of level 3) and the system level requirements. The system level requirements are solution independent as with the level above, but represent a lower level of fidelity than the generic soldier requirements. In subsequent design iterations of the analysis, these statements have performance measures associated with them (Sparks, 2004c) as part of any specification that is agreed with industry when delivering concepts. However, at this stage of the analysis they are purely used to look at design challenges and inter-relationships of system elements.

Level 4 of the matrix has a unique feature in the form of a ‘hat’ that sits above the matrix (Appendix E). This identifies the inter-relationships between the system level requirement statements. These are not scored but provide a check that informs the designers of the wider impact of decisions. An example may be that impedance to range of movement has been identified as a key issue. The hat on the top of the matrix shows that in addressing this, there is also a relationship with speed over ground and access to equipment. If you are considering one, then the others must be considered as well. This underpins the complexity of the domain, highlighting the multiple integration and interface issues that exist. Furthermore it acts as an additional cross check to stop important factors from being missed.

Table 2 shows the system level requirements that have the strongest relationship across all of the generic soldier system requirements, in the context of survivability. It indicates the importance of access to equipment as well as fit and potentially negative physiological implications in relation to addressing survivability issues.

Level 5

Level 5 looks at the relationship between the system level requirements (with the weighting cascading from the output of level 4) and the high level requirements obtained from the operational analysis (OA). Level 5 specifically focuses the matrices towards survivability statements that have been deemed to enhance operational effectiveness as part of the operational analysis. Until this point the matrices have been generic in nature with SMEs considering solution independent implications of delivering high level defence missions and tasks.

Although level 5 of the matrix is still solution independent as it does not state solutions, it has defined areas such as fragmentation protection and high velocity bullet protection. The level of detail of these requirements starts to dictate certain systems and later design implications in order to meet the need. This is where the unique fusion of information is most evident.

When looking at level 5 of the matrix in relation to the levels above, feasibility of achieving the high levels requirements in relation to the doctrine and land domain tasks and activities start to become apparent. An example may be that mobility has been highlighted in the upper matrices as vital, with the need for higher amounts of protection potentially impinging this depending on the types of material available for the final system concept.

Table 2 shows the high level requirements that have the strongest relationship across all of the system requirements, in the context of survivability. It indicates the importance of, or greatest challenge in delivering enhanced fragmentation and high velocity bullet protection in addition to degree of body coverage. This is placed in the context of wider systems issues using the HFI pick list and level 6 of the matrix.

HFI Pick list

The level 6 matrix requires that appropriate HFI statements from the six domains have been chosen by the SMEs (Appendix A) ready to be scored in the level 6 matrix. The first iteration of the analysis as presented in the results is concerned with those HFI statements relating to areas that drive the overall design of the system concept/s. The second iteration of the analysis, used when potential concepts have been derived, focuses on areas within the HFI pick list that design can influence. These would be desirable to achieve, but are not driven by compulsory elements such as legislation.

Level 6

Level 6 looks at the relationship between the high level requirements derived from OA and the HFI pick list. This level of the matrix cascade identifies the wider through life implications of any potential concept system. It helps to identify any HFI related risks in achieving the OA driven high level requirements acting as a completeness check, and adding to the portfolio of evidence to be passed to industry.

This level of the analysis is still solution independent although more focused because of the high level OA driven requirements. The intent is to provide sufficient evidence to guide industry in the creation of concepts, but not stifle creativity. Level 3 and level 6 of the decompositional matrix provide statements that will be capable of applying performance bounds and measures as concepts are refined and specifications produced. This again reflects the through life systems approach towards dealing with the problem space, and is discussed in more detail in Chapter 6.

Table 2 shows the HFI pick list statements that have the strongest relationship across all of the high level requirements, in the context of survivability. It indicates the greatest potential risk in the physiological impact of achieving the high level requirements along with the consequences operationally of not providing sufficient protection to the user.

Sensitivity analysis

Section 8.2.4 discusses the methods applied to test the sensitivity of the results to changes in score. The intention is to check the robustness of the SMEs input as well as the implications of statements shifting from ‘key’ to ‘important’ and vice versa. Appendix F has the full results tables for the three methods applied within the analysis. A summary of the results is as follows:

Changes in the scoring convention

- Key statements were found to remain constant irrespective of the scoring convention used (as defined in section 8.2.4)

- In some cases, additional statements were found to fall within the 'important' criteria based on the % margins described in section 1.2.4 when scoring conventions were changed

Number of scores that would need to change for the outcome to be affected

- It was found that in most instances at least half of the SMEs involved in the scoring would need to alter their score to affect the final outcome, indicating that scores could not have been achieved by chance alone. Insensitive scores provide confidence in the output.

Impact on 'key' and 'important' statements depending on war or peace weighting

At level 1, a significantly lower proportion of the statements related to peace when compared to war. In later matrices the statements were relatively unchanged whether war or peace was given higher precedence. Therefore, with a customer focus towards war fighting (with a perception that this is more challenging) it is likely that most peacekeeping needs and challenges will also be captured.

8.2.6 Discussion

The output from the analysis indicates that survivability has significance in relation to the operational effectiveness of the soldier. Of particular importance is the availability of equipment as supported by recent operational difficulties (Chamberlain, 2004) in addition to the challenges of achieving appropriate levels of survivability in a range of environmental decisions.

More specifically, at the system level the fit of systems is found to be key, which is also reflected in the output from the operational analysis. In addition to that, impedance to the range and speed of movement as well as physiological impact are all seen as key design drivers. This output conforms to current challenges relating to protection of the soldier as a sub-system of survivability (Couldrick, 2005b, 2005a). Current technologies have weight and bulk penalties associated with them depending on the level of coverage and area of coverage required. This impacts the individual in a number of ways due to the rigidity of the sub-system and the lack of breathability of the composing fibres.

As well as being supported by stakeholder experience, the output is robust in terms of the sensitivity analysis which indicates that results could not have been obtained by chance alone.

Results for the single capability domain of survivability show that the analysis is capable of fusing different data sources with feedback from stakeholders expressing positive views on the utility of the matrix analysis. Key statements reflect what is currently known by SMEs within the field, and yet is shown to be impervious to scoring bias having applied the sensitivity analysis. The next section applies the analysis process across the five capability domains in order to carry out the trade-off that identifies the key capability domain and characteristics for future research and development as described in Chapter 6.

8.3 CASE STUDY 2- FIVE DOMAIN TRADE-OFF

8.3.1 Introduction

The five domain trade-off looks at how the analysis process can be used to make whole system decisions. What is the optimum balance of capability to deliver enhanced soldier effectiveness? It uses data generated for individual capability domains, as represented for survivability in section 8.2 and fuses this information to make decisions on key areas to enhance effectiveness using the trade-off technique discussed in Chapter 6. The output is intended to prioritise future research direction as well as soldier system concepts to obtain maximum benefit from diminishing resources, as per customer requirements.

The results from this analysis are contained within Annex A as for the survivability case study. The consolidated output is provided in Tables 3 & 4, providing all of the information required to discuss the meaning and implications of the analysed data. The input and output is validated using the same techniques as described in section 8.2.4.

8.3.2 Method

The method for the five domain trade-off is described in detail within Chapter 6. The base matrices used within the trade-off are generated using the same method as the survivability case study. The only difference relates to the domain that is being scored with sustainability, lethality, C4I and mobility adding to the domain of survivability described in section 8.2. Therefore when scoring lethality SMEs from that domain would be used in conjunction with design, HFI and systems SMEs (Smith, R, 2005).

Operational analysis and/or trials data is collated for each of the five-domain analysis providing specific domain high level requirements, which are subsequently amalgamated for the five-domain trade-off.

Amalgamation of the data within the matrices is achieved using the same techniques as described in section 8.2.2 for survivability, which is latterly used for the five-domain trade-off matrix set. The source of the OA data for each of the domains high level requirements is briefly described below with discussion of their relative importance in section 8.3.3. Further detail can be found in (Smith, R, 2005). A summary of the high level requirements for each of the five capability domains can be found in Table 3 below.

Survivability	Mobility	Sustainability	Lethality	C4I
Enhanced High Velocity Bullet protection	Training	The scale of issue should be appropriate to operational tasks and activities	Integrate with other pieces of personal equipment	Minimise cognitive workload on the individual
Enhanced fragmentation protection	Issuing policy	To reduce replacement time of kit in theatre (mean time to repair)	Enhanced effectiveness against structures	Minimise bulk and weight penalty
Enhanced camouflage	Accommodate 5-95th percentile	To provide correctly sized clothing and equipment	Increased area effectiveness	Minimise loss of spatial awareness
Improved body coverage	Accommodate mission essential equipment	To improve guidance to commanders on scale of provisions required for all operating environments	Reduced system weight	Minimise impact of system on 24hr operations
Full integration of components	Fully integrated with personal kit	Supply adequate resources to meet mission need and levels of expenditure (prior to and during combat)	Improved system ergonomics	Optimise man machine interface
Fully integrated with personal kit	Minimise injuries sustained in a mobility context	Minimise degradation in human performance from carriage of load (prior to and during combat)	Increased probability of hit (reduced firer error)	
Accommodate 5-95th percentile	Minimise degradation in human performance	Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)	Increased suppression effectiveness	
Training	Reduce/Minimise marching order weight		Increased probability of incapacitation given a hit	
Issuing policy	Reduce/Minimise combat order weight		Ability to identify friend or foe	
	Reduce/ Minimise assault order weight			

Table 3 High level requirements for each of the capability domains

Mobility

As with the domain of survivability described in section 8.2 the input for the high level requirements in the domain of mobility are constructed using a combination of operational analysis and user-perceived deficiencies. Simulation, in the form of CAEn (Close action environment) wargame, assesses the impact of certain equipment weights carried by the soldier when involved in specific tasks and activities within a number of scenarios. These mirror the conditions modelled for the domain of survivability to ensure consistency wherever possible. Detailed output for the mobility analysis can be found in Hayworth & Shepherd (2005).

Sustainability

The domain of sustainability represents a significantly different challenge as it relates to higher order issues such as logistics. CAEn as a wargame and simulation can model to company level and below which represents approximately 100-250 men. Furthermore, analysis of sustainability encompasses many factors which to-date is unsupported by unified quantitative data. Although human performance data is available from laboratory trials there is a significant shortfall of validated data when aggregated (Bunting, A.J & Kelm, 2002, Wright, 1997a). This has led to the creation of a new system dynamics model (Durrant, 2005) as part of the Operational Clothing and Textiles programme (Dstl Land Systems) to provide the required objective data input to the process suite. Sustainability System Dynamic Model (SSDM) is a meta-model using a combination of data sources from both laboratory and field trial in a novel format.

Of consideration when used as a tool for derivation of input data for the process suite is the need for validation of (SSDM). This is noted as an assumption, with execution of validation trials falling outside of the direct remit of this thesis.

Lethality

The CAEn wargame was originally developed for lethality studies, examining the effect of different weapon systems when carrying out representative missions (Eyre & Syms, 1994). The lethality input for the high level requirements and subsequent matrix analysis is distilled by SMEs from a number of previous studies (Hammond, 2006, ,

2005) looking at both the weapon effect and the impact on the soldier as the system of interest.

C4I

The domain of C4I presents a problem for generation of input data as there are few if any simulations within the domain currently available to manage the complexity of the interactions. Looking at the soldier as a system, the major focus of investigation for the C4I domain is the impact of carrying and accessing additional equipment. The benefits of enhanced situational awareness and other command and control issues are captured within the FIST development project (Rook, 1998) and fed into research through mediums, such as the capability database. For the purposes of the case study the input data for the high level requirements and matrix analysis are distilled by a subject matter expert from a number of trials reports generated as part of the FIST programme (Skinner et al., 1997, Woolford & Randall, 1997, Randall, 1997). This reflects the psychological and physiological impact that C4I elements can impose upon the soldier.

8.3.3 Results

There are two key tables that contain the summary of results for the five-domain trade-off with detailed tables contained within the restricted annex to this thesis (Annex A). Further ranked summary tables are contained in Appendix G providing further detail for each of the matrix levels. The trade-off process that has been adopted is discussed in detail within Chapter 6, with only the output of the analysis described in this chapter.

Table 4 shows the ranked requirements from each level of the matrix analysis. Key requirements are shown shaded grey, and important requirements are included but not shaded. The following paragraphs describe the output from each level of the five domain trade-off with discussion and interpretation of the findings.

Rank	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
1	Plan and direct own force disposition	Operational availability of the system	Protection from defined biological and chemical agents	Potential heat burden to the wearer	Fully integrated with personal kit	How important is the system in the overall operational effectiveness?
2	Implement information operations	Ability to conduct operations within defined notice periods	Protection from a defined level of fragmentation and bullet type	Take into account the impact of being worn for prolonged periods of time	Minimise degradation in human performance	Will the system instil confidence in the wearer?
3	Co-ordinate with other national/ international organisations	Individuals level of performance in all environments	Protection against overloading (man)	Allow adjustment to create a 'best fit' for the wearer	Minimise degradation in human performance from carriage of load (prior to and during combat)	Will the systems size and weight impact the end user?
4	Provide personnel support	Survivability of the individual		Speed of movement	Reduce/ Minimise marching order weight (4^{th} = to) Reduce/ Minimise combat order weight	Will the system add a substantial amount of weight or bulk to a certain area of the user?
5	Conduct medical support	Ability to move over ground at a rate commensurate with the tactical situation		Range of movement	Reduce /Minimise marching order weight (4^{th} = to) Reduce/ Minimise combat order weight	Will the system weight impact the likelihood of injury?
6		Ability to conduct operations at a faster rate than baseline		Physical limits beyond which injury will be caused to the wearer	To provide correctly sized clothing and equipment	Will the wearer see the system as an improvement to overall effectiveness?
7		Ability to carry loads appropriate to mission completion		Creation of sweat whilst being used	Minimise injuries sustained in a mobility context	Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling
8				Energy cost to the wearer	Reduce/ Minimise assault order weight	Will the combination of sub systems have an impact on

						musculoskeletal loading rate?
9					Accommodate 5-95th percentile	Does the system need to work within or in conjunction with other systems?
10					Accommodate mission essential equipment	Will the system negatively impact the ability to carry out the task?
11					Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)	
12					Training	

Table 4 Ranked requirements across the matrix analysis

Level 1

Although rankings have been determined for this level they are applied with some caution as the level 1 matrix is intended to provide context for the lower matrices. It provides the auditable link right back to the highest level of doctrine, but has limited direct significance for the more detailed land domain issues. Within the survivability case study, alternative weightings are given to the seven defence missions as part of the sensitivity analysis. This can equally be applied across the five domain trade-off if desired by the customer. When trading off between alternatives, the likelihood of occurrence is a major factor in making decisions and so looking at differences between heavily weighted importance towards either peace or war can provide an insight into potential changes in key requirements.

Level 2

Level 2 looks at the relative importance of the land domain user requirements in terms of delivering the operational and strategic level tasks.

Within the ranking there are some strong disagreements between the SMEs and the customers on the relative importance of the statements. There are several reasons why this may have occurred:

- The customer is only providing one score compared to SMEs who are responsible for providing a score in their specialist domain with five scores considered.
- The operational and strategic statements are skewed more towards support operations and planning with fewer statements for execution/combat which would impact the strength of relationship at the next level down (this could explain the low score for survivability for the customer).

Level 3

Level 3 looks at the relative importance of the generic system level requirements in relation to (or causing challenges to delivery of) the land domain user requirements.

This level of the matrix is harder to interpret than others as high rankings are likely to signify challenges or difficulties rather than beneficial importance. Therefore it is unsurprising that chemical, biological, radiological and nuclear protection (CBRN) ranks most highly as it represents a challenging operational environment. Similarly the second rank for survivability is likely to be a function of the operational context exhibited by the land domain user requirements. Whereas the operational and strategic tasks are far more planning focused the land domain user requirements are operational combat focused. If the soldier does not survive then they are not able to perform the functions stipulated, causing a high survivability ranking. The customer does not weight this level of matrix as it requires detailed SME domain knowledge to make the connections between statements.

Level 4

Level 4 looks at the relative importance of the generic system level requirements in relation to (or causing challenges to delivery of) the system level requirements.

The output from this level aligns closely with the out put from level 5, for instance heat burden links to minimising human degradation and so on for the majority of key requirements, which is a positive re-enforcement of the trade-off activity.

It is important to note at this level that there are strong inter-dependencies between statements that will need to be provided as part of the analysis data pack (Appendix B). These inter-dependencies may also contain further research areas for consideration having identified the major drivers as part of the analysis, as discussed in the first case study.

Across all of the domains physiological impact to the wearer is a key driver in addition to the importance of fit.

Level 5

Level 5 looks at the high level requirements derived from OA and trials across all five of the NATO capability domains. This level of the matrix is a key driver for concept generation and down selection of high level requirements across the capability domains.

Results show a number of areas where there is good agreement between stakeholders. However, there is strong disagreement between the SMEs and the customer in several other areas. These have been broken out into the following categories:

<u>Agreement between SMEs and customer</u>:

- Fully integrated with personal kit
- Minimised degradation in human performance
- Minimise degradation due to carriage of load

<u>Areas where customer rank and single domain rank was high, but not when ranked across domains:</u>

- Survivability
    - Integration of components
    - Integrated with personal kit

- Training

- Sustainability
    - Scale of issue
    - Replacement time
    - Guidance to commanders
    - Availability

- Lethality
    - Integration with personal kit
    - System ergonomics

- C4I
    - Minimise impact on 24hour operations
    - Optimise man machine interface

The survivability statements scored relatively highly within the individual domain but not in the context of the five. However, ‘fully integrated with personal kit’ is a key requirement in the domain of mobility. There are two issues. Firstly the commonality of some statements across domains (such as integration) as shown above, which may require consolidation of results for the level 5 matrix. Secondly, integration is a more general issue that has relevance to a number of domains, not just one in particular, which is likely to increase its relative importance.

In terms of sustainability, the statements that score highly in the individual domain but not across domains are all captured subsequently in the level 6 matrix. They represent the wider design issues and are captured as part of the user perceived deficiencies report conducted by the OA group within Dstl Land Systems (Shepherd et al., 2003b).

An interesting general trend is for SMEs to rank reduction in weight carried, as well as systems weight in the case of lethality as highly important. Stakeholders are also concerned with minimising weight and bulk penalty and incapacitating injuries, whereas the customer ranked these as relatively low priority. This trend is something that should be looked at when the customer is making subsequent judgements to check consistency (it may partly explain the problems that are occurring with current programmes if true desire to reduce weight over increased technology is not paramount in the customer's eyes).

Having ranked the level five requirements statements it is possible to group them into themes which can be considered within the design phase of the process. Some of the themes are a consequence of design decisions whereas some will drive the actual components of the final design. Suggestions are as follows:

1. Integration of kit
2. Minimising degradation in human performance
3. Reduce load carried
4. Optimise sizing of clothing and equipment (within 5-95th percentile range)
5. Accommodate mission essential equipment
6. Training provision

Looking at the full list of twelve factors that have been identified as key for level 5 the most significant theme is mobility, which is heavily supported by level 2, 4 and 6 of the matrix.

Level 6

Level 6 of the matrix looks across the HFI matrices to understand wider system implications. It acts as a check for completeness for areas that may otherwise be neglected. Of greatest importance is the link to achieving operational effectiveness with the less quantifiable measure of instilling confidence in the wearer ranked second. This reflects the need for acceptance of system solutions by the user community: can a system be deemed as successful if it meets the performance requirements, but the user will not wear it? The high ranking nature of this statement re-enforces the need for fused techniques where wider issues will impact success.

Sensitivity analysis

Each of the individual domains has sensitivity analysis applied using the techniques described in section 1.2.4, with all showing that output could not have been achieved by chance alone. The five domain trade-off has a further sensitivity analysis applied as it includes customer input in matrices not previously created. The focus is on the impact of changes in the scoring convention to the key and important statements with detailed output in Appendix H. This is supported by a visual representation of the output at each level of the matrix due to the tight groupings that were experienced for the five domain trade-off case study. Allocation of key and important sub groups is based on visual interpretation of the graphs, with sensitivity analysis of the various scoring conventions showing that no statements were missed as a consequence of using the 0,9,3,1 convention.

8.3.4 Discussion

Using the evidence provided by the matrices (which are supported at multiple levels) the major driver for concept definition and research direction is mobility, encompassing all of the key requirements that have been identified. In terms of the system concepts, there is a desire to encompass as many of the issues from across the domains as practicable, but for trade-off purposes the key driver should be mobility as this links right back to the land domain user requirements as well as the operational and strategic tasks.

The need for a "trade-off" process arises because each "community" of experts will have different opinions as to how a set of higher level requirements will be best fulfilled. The technical SMEs assess the strength of relationships between requirements in each of their domains to establish where the design may have some significant influence. The customer likewise also has a view as to the strength of relationship between requirements from their own perspective, informed by their experience in the programmatic and political domain. These differing views must be combined to form a single coherent set of requirements. The five-domain trade-off allows this to be balanced with an understanding of constraints imposed on the system either due to the environment (political) or customer (budgetary).

Although more challenging to fully validate, the finding that mobility is a key driver is well supported within the dismounted domain (McMillan, 1995). For many years, decades and possibly centuries (Cathcart et al., 1923) the plight of the infantry has been documented. Current shortfalls in load carriage equipment (Vicary, 2005) are compounded by advances in technology as part of a networked battlefield (Secretary of State for Defence, 2005, Bunting, A et al., 2001).

Output from the process suite provides the underpinning evidence from doctrine through to design that formalises years of domain specific research and conjecture by SMEs regarding mobility and load carriage. Further validation using modelling and simulation will allow exploration of load carriage options in the context of enhancement to operational effectiveness.

8.4 CASE STUDIES SUMMARY

The case study chapter is intended to test the utility of the process suite described in Chapter 5. A representative data input set has been used from work completed whilst working for Dstl Land systems. Although suitability and validity of the input data has been discussed within the chapter, the analysis output is considered secondary to the testing of process suitability.

Both a single domain (survivability) and multiple domain analysis are used to test the flexibility and utility of the process suite with the single domain acting as a control for the more complex multiple domain analysis.

Survivability, when analysed individually, is found to make a significant contribution to operational effectiveness with factors such as impedance to movement having high significance at a system level.

Sensitivity analysis for both survivability and across all five domains indicates that results could not have been achieved by chance providing confidence in the validity of the fused matrix approach.

Across all capability domains, mobility is found to most significantly impact operational effectiveness, a finding that is strongly supported by other defence research literature (Vicary, 2005, Bunting, A et al., 2001).

Trade-off activity shows strong agreement in output between stakeholders in most instances, with variances resolved through effective communication and discussion.

Sensitivity analysis uses the same method as for the domain of survivability; focusing on the impact of changes in the scoring convention on the key and important statements, with a summary table in Appendix H.

Output confirms that the scores are insensitive to change based on alterations to the scoring convention. Cut-off points to distinguish key from important statements based on visual interpretation of the data use a 5% margin between scoring clusters for levels 2-4 of the matrix, and the first three and proceeding nine requirements as ‘key’ and ‘important’ for level 5 and the first five and following five respectively for level 6.

For the five domain trade-off, score clustering was found to be closer than for individual domains, with graphical representation in Appendix H used to support cluster decisions.

CHAPTER 9: DISCUSSION

9.1 INTRODUCTION

9.1.1 Aim

To describe how the research question defined in Chapter 3 has been addressed.

9.1.2 Objectives

- To re-iterate the key elements of the thesis in the context of the research question presented in Chapter 3
- To critically analyse the output of the thesis chapters in answering the research question, in the context of wider research
- To identify shortfalls in the proposed approach and areas for future work

9.1.3 Background

The intent of the thesis as defined in Chapter 3 research aims is to ' develop a suite of processes that can be used by Government research departments, specifically concerned with dismounted soldier systems, to aid the definition of future concepts and potential research direction.' Derivation of the research question is a direct result of customer requirements leading to a highly applied thesis.

When creating the process suite there are a number of constraints and requirements that are enforced by the customer based on legacy and resource implications. In general processes such as the ones described in Chapters 4 & 5 are not developed unless current practices are seen as unsuccessful or lacking in one or more areas (Boardman, 1997).

In the context of soldier systems research, the problem has arisen because of changes to the organisation and the business practices that are being adopted (HM Stationary Office, 1998). Although the processes developed involve the gathering and interpretation of data in order to make decisions; it is the organisation that both requires this information and must accept the output. Therefore, success is reliant upon understanding, and acting on organisational requirements, which in turn dictate the tools and techniques used for process derivation.

Defence research has traditionally received secured funding from Government on an annual basis (Controller and Auditor General, 2004b) with decisions on what should be pursued based on negotiation between subject matter experts and the customer organisation. With changes to procurement practices through the introduction of Smart Procurement (Defence Procurement Agency, 2005), and the Strategic Defence Review questioning MoD contracting procedures (HM Stationary Office, 1998) the last fifteen years has seen significant organisational and procedural change. The impact within the research community has been greater scrutiny of the work that is carried out, with the need to define clear lines of application to capability and the end user, linked to accurate test and measurement.

The application of systems tools and techniques has been accepted within Government for some time (House of Commons Defence Committee, 2003), although it can be argued whether it has been successfully implemented to date (Controller and Auditor General, 2004a). Considering the soldier as the system of interest within a systems context is relevant from both a consistency viewpoint, in line with other Government departments, but also due to the complexity that the system exhibits representing a dynamic socio-technical problem (Hitchins, 1992). The following sections consider the summary information from the thesis chapters, with a progressive discussion on pursuit of the research topic and the developed processes.

9.2 ADDRESSING THE RESEARCH QUESTION

9.2.1 The application of a systems approach to the soldier

Systems complexity has increased significantly over a number of years leading to the requirement for larger teams of experts and potentially more geographically disparate working practices. The field of systems engineering and systems thinking, originally adopted within defence and more specifically the air industry (Gabbai, 2000) has, over a number of years been developed and refined to deal with these large, multi-disciplinary projects, where many elements have to work together to ensure success. This is based upon a through life, whole system perspective where multiple factors are considered in combination to bring about a desired outcome. This is supported by a number of fundamental scientific theories including vitalism, mechanism and emergence as discussed in Chapter 2, section 2.2.2.

Vitalism and mechanism can be considered as two ends of a spectrum with vitalism concerned with strange forces dictating the behaviour of the system (Flood & Jackson, 1995) compared to refutation of hypotheses and detailed low level test and optimisation used to identify mechanistic characteristics (Popper, 2002). Somewhere in the middle is the concept of emergence where a number of elements come together, and in doing so exhibit behaviour that would not otherwise be achieved if working in isolation (Boulding, 1964).

Lewes (1875) was a founder of emergence describing emergent entities as those that arise from more fundamental entities and yet are novel and irreducible with respect to them. The concept of the whole being greater than the sum of the parts (Smuts, 1973). This is followed more recently by general systems theory (Boulding, 1956, Bertalanffy, 1968) which is cited in many systems texts, an example of which is (Skyttner, 2001). The applicability of emergence to the soldier as the system of interest links to the dynamic complexity that they exhibit (Waring, 1996) and the realisation within defence that the human as a system component can be a direct cause of system failure if not taken account of (Booher, 1990, Wheatley, E., 1991). Humans have many attributes which are non-linear and often cumulative (Chapanis, 1996, Coyle, J et al., 1999); and so in reducing them to test how they might behave in a given situation you change the very behaviour that you are trying to understand. The difficulty arises with how you test the soldier as a system if reductionism is undesirable, an area that continues to split different sectors of the systems movement (Bateson, 1972) and is discussed in the following sections in the context of application to the thesis research question.

Reductionism as described in Chapter 2, section 2.2.2 is concerned with testing at a level where cause and effect can be attributed (Okasha, 2002). This requires that a system is broken down and tested against some form of hypothesis with the intention of disproving the statement (Frankfort- Nachmias & Nachmias, 1996). This is attractive as it suggests that a specific parameter is responsible for certain behaviour and that control mechanisms can be introduced to ensure the output is as desired (Miller, 1989). However, as discussed previously it may change the very behaviour that you are trying to understand because it neglects the concept of emergence. If the whole is greater than the sum of the parts and is irreducible, as previously suggested (Lewes, 1875), then breaking it down will create meaningless data. However by not breaking systems down into parts that help us to understand cause and effect it is not possible to determine what is providing the desired behaviour. This introduces uncertainty and means that criticality of certain components to overall system success will not be understood.

Attributing cause and effect relates to the desire of humans to compartmentalise and define the world in which we live (Angyal, 1969). There is a certain element of discomfort in not being able to label why something happens, with most organic systems requiring control in order to survive (Okasha, 2002). When applied to defence, the desire to test and measure relates to acceptance and contractual obligations. In the past when Government was concerned with the procurement of equipment, testing was relatively straightforward as it consisted of requirements with performance measures, which concept systems would either pass or fail. This would enable Government to place contracts with suppliers and test whether the systems that they built met those requirements. The introduction of capability and effect introduces difficulties of measurement as it is not just focused on performance. Capability represents a step forwards in terms of appreciating emergence and how complex systems are composed of a number of systems and attributes in delivery of required behaviour (Boardman, 1997), however in terms of test, evaluation and acceptance it introduces complexity, which in the past has not been considered.

In terms of the soldier as the system of interest, the customer wants to understand what specifically will enhance effectiveness of the individual in the context of achieving larger mission goals. What is needed in terms of equipment and supporting lines of development so that UK land forces can be successful during combat operations? To date, few Government programmes have used a systems approach to deal with this type of problem due to a lack of maturity in the tools and techniques to support it. The Future Integrated Soldier Technology programme (FIST) uses a systems engineering framework with associated measurement tools and techniques to understand performance characteristics, but it is still very technology focused and does not consider human characteristics as a central modifier (Chapanis, 1996). This may relate to the boundary that has been drawn around the system (Dooley, 2000) or it may be due to the difficulties and uncertainty associated with less quantifiable measures.

In proposing a systems approach to the soldier as the system of interest there are benefits as well as drawbacks for the Government as the customer. A benefit and justification for pursuit of this research topic is the fact that to date there have been failings with the way in which concepts are developed and research contracts assigned. Projects have encountered difficulties and military capability has failed to be optimised due to a lack of understanding of whole system, through life issues (Controller and Auditor General, 1999, , 1998, , 2004a). Therefore with the complexity exhibited by soldier systems it would seem appropriate to apply systems tools and techniques as mandated by the Smart Procurement initiative (Defence Procurement Agency, 2005). However, there is also a risk that MoD as an organisation is not ready to accept or adjust to systems engineering at a capability level with the need for significant restructuring in order to implement it effectively. When introducing a new initiative on the scale of Smart Procurement there is a curve of acceptance and learning. It is suggested, that cultural change within an organisation can take up to ten years to implement (Smith, A et al., 2004) with a need for consistency when radically new ideas are introduced, and yet changes have been made continually since the introduction of Smart Procurement in order to see results faster. If insufficient time and money is spent on the ‘enterprise’ that is the MoD, the long term strategy and direction will fail to be realised, as working practices will continue to encourage segmented groups with ineffective lines of communication (Boardman, 1997).

MoD certainly appears to be increasing in competence with design level systems engineering tasks, endorsing clear processes and procedures within the Acquisition

Management System[11]; but strategic level coherence, other than the introduction of the Integration Authority within DPA is still lacking. It is this perceived lack of strategic view that pervades other areas of defence capability including activities such as modelling and measurement which impacts soldier system research, as discussed in the next paragraph.

Having considered the benefits of a systems approach (described in detail in Chapter 2, section 2.4.2), the main challenge is in selection of appropriate tools and techniques that will be applicable to the soldier as the system of interest. Fusion of techniques within a defence context has been relatively limited to date as advocates of either whole system or sub-system tests are loath to consider a middle ground (Pruzan, 1988). Scrutiny, which is formally carried out at several points within the project lifecycle often relies on operational analysis to look at the costs and benefits of pursuing certain system options (White & Parker, 1999). This is based on tangible measures and shows a disconnect that still exists between the shift towards capability and the focus on performance to distinguish between alternative solutions (Curtis, 1996). With scrutiny forming such a fundamental component of the funding criteria for projects it would appear that commonality of approach across departments would be beneficial, and yet formation of a DEC to look at analysis and measurement has only been instigated within the last two years (Ferbrache, 2003). In addition to a lack of centralised control over modelling activity, little has been done to understand the synergies that can be achieved using modelling and simulation from different defence sectors, including pooling of resource for validation trials, even if they are understood (Anderson & Marshall, 2000). The problem is not unique to defence with the appreciation that measurement -which is used extensively for acceptance as well as validation and verification activities- has no single interpretation or centralised framework (Mackley, 2005). NATO has started to develop a measurement framework specifically focused on soldier systems, but it would appear that a longer term Government aspiration should consider a more generic approach.

With measurement enforcing a significant constraint on the way in which the soldier as a system can be viewed, any process that is developed must consider the critical

[11] Acquisition Management System Website- www.ams.mod.uk

interface with wider Government and scrutiny. This requires both objective and subjective input to bring together the two distinct data groups that have been used in the past, for concept derivation (subjective) and which will be required in the future for scrutiny purposes (objective). In development of the process suite, use of these two data sources represents a unique fusion of elements that considers the dynamically complex nature of the soldier as a system. From the subjective data source arises the opportunity to explore the human and their related attributes, and from the objective data an opportunity to look at performance and effectiveness characteristics. When these are brought together using systems tools and techniques as described in Chapter 2, section 2.5.6 and Chapter 5, section 5.2 the output not only has supporting evidence from a number of domains, but has considered the wider implications of delivering capability.

Fusion of data sources in this novel way accepts the fact that the current processes are not perfect, and that modelling of the human has many difficulties and shortcomings. However, when there is an applied problem to solve, it seems unacceptable to do nothing just because it is difficult and uncertain. It is likely that the environment within which defence and more specifically soldier related research exists will continue to have constraints and assumptions imposed. If appropriate exploratory techniques are chosen for the problem, such as soft systems methodology, success is measured in whether the customer is satisfied with the output, and that the original problem situation has been improved, with refinement over time as knowledge increases.

9.2.2 Development of a process suite to address the research question

Based on the customer requirements as defined in Chapter 5, section 5.2.1 and the key drivers for the research question in Chapter 3, section 3.1.3, the intent of the process suite is to provide auditable and traceable information to help prioritise future Government research and concept generation for soldier systems. Section 9.2.1 discusses the challenges associated with socio-technical systems and the need to fuse different data in order to utilise the existing skills and attributes of the subject matter experts in conjunction with the needs of other Government organisations in the form of scrutiny and measurement.

This has not been achieved within defence before this thesis, even with the introduction of systems engineering techniques as part of the FIST programme and as such the processes described within this thesis have required testing in the form of case studies (Chapter 8 and section 9.2.3 below) to check validity.

In addressing the problem from a systems perspective, and more specifically as a soft system including the human as a central focus (Checkland & Scholes, 1990), there is an opportunity to apply validated tools and techniques in the early stages of problem definition. The benefit of this is the amount of published data and varying applications over time that will help to enhance customer confidence in the approach. Although the process suite constitutes a new approach to the problem using existing tools and techniques through novel application, there are still research papers that can support the generic ideas (Bathe & Smith, 2002, Smith, J et al., 2002). This is important within an organisation that is still within a transitionary period in terms of their culture (Smith, A et al., 2004). There must be a balance of taking a new approach with familiarity and conformance to needs of other Government departments, otherwise there is likelihood that the approach will not be accepted. This is characterised within soft systems methodology and more specifically CATWOE (Checkland, 1981) through the 'world views' of the stakeholders. MoD still has many influential people that have seen various new initiatives introduced and replaced over a number of years. They may be resistant to change based on their knowledge and experience as well as other external constraints as discussed before in the form of resources, budget and political drivers (MacDonald, 1999).

Of particular importance, if the process suite is to be implemented, are the lines of communication between the operational analysis community and the system analysis community. From personal experience over five years of working within defence research, it is the job of the systems analysts to act as facilitators in bringing diverse stakeholders together. Direct experience has shown that each stakeholder must consider their input to be important within the big picture, with equal credence given to subjective and objective data. Chapter 4, section 4.2.3 helps to clarify and understand this organisational trait through CATWOE analysis and derivation of conceptual models and root definitions (Checkland, 1979). Different stakeholders have different expectations and needs, with the management of this promoting stakeholder acceptance from an early stage. In deriving the functions and activities required of the process suite from the conceptual models and root definitions in Chapter 4, section 4.2.3- 4.2.4 it is intended that all stakeholders will be appropriately represented and utilised. This highlights the progressive scoping of the problem, channelling into more detail as issues and concerns are understood (Waring, 1996).

Having identified the organisational functions based on the output from Chapter 4 the subsequent activities within the process suite look specifically at how auditable and traceable information will be provided to the customer, and the methods by which measurement and down selection will be achieved. The intent is again to look at the application of existing tools and techniques in a novel way to satisfy customer requirements.

A major component of the process suite is decompositional matrices, which have been used extensively within defence and other sectors (Lambert, 1991, Bathe & Smith, 2002). The relevance to the soldier as the domain of interest links to ‘useability’ of input data and manageability of diverse data sources and stakeholders (Tajino et al., 2005). By capturing opinion and data within a matrix it is possible to examine different levels of fidelity as well as formalising what has, in the past been large quantities of SME reports (Westwood, 2001a, 2001b, Clarke, 1995).

It is recognised that matrices are not without problems, including the scoring conventions that are used (Kim, K, 2002) and reliance upon the scoring to make decisions (Smith, J et al., 2002). However, matrices are and have been widely applied in a number of domains within (Smith, J, 1993) and outside (Kenley, 2004, Weiss, 2004) of defence; and provide the link to trade-off activities discussed in detail within Chapter 6, with use of the data to derive key areas for concepts and research. The benefit of collecting data once and using it for multiple applications within the process suite is efficient use of resource, with stakeholder availability a constant challenge. Secondly, there is an ability to temper one stakeholder view with another when carrying out the trade-off. For instance, the customer has strong views in a particular direction, which are not matched by the SMEs, why has this occurred? Is it a difference in world view? Or does it relate to a fundamental difference in knowledge or understanding about the problem?

The link between output from the analysis and trade-off is the ability to measure, as described in Chapter 7, section 7.4.2. This is the component of the process that relates to scrutiny and the ability to determine if requirements have been met, with acceptance from the customer. Within the current procurement practices it is usual to exclude requirements that cannot be measured as you cannot gauge whether you have been successful in achieving them (Dooley, 2000). In terms of a human related system, it may be necessary to include certain requirements that are subjective in nature and document the assumptions that have been made in their inclusion (Wright, 1997a). Although appearing unsatisfactory in terms of verification and validation (Lowe & Fitzgibbon, 1998), with no standardised approach to modelling and measurement characteristics in general (Mackley, 2005), there is a general growth required in understanding measures of effectiveness (whole system test) and measures of performance (sub-system test), as with human modelling described earlier.

The process suite deliberately separates the measurement of performance and effectiveness from the analysis in order to explore the problem, before unduly constraining the potential solutions. Chapter 5, section 5.5 defines the measurement repository that has been created for use with the process suite. This is based upon a measurement framework developed by NATO LG3 (1999), but directly linked to the FIST programme (Dooley, 2000). By separating performance from the process suite it is possible to look at generic challenges and high level requirements before applying mandatory measures in the form of legislation, and desirable measures in terms of performance and effectiveness; the latter being driven primarily by technical feasibility.

Furthermore the separation of the measurement from the process suite provides the flexibility that is desired by the customer. The MOP/MOE repository comprises a collection of measures at varying levels of detail from whole system to sub-system and component level test. It can therefore be used during the first iteration of process suite application to understand high level requirement issues, or it can be used for down selection of concepts and system level contracts with industry. Over time the contents of the repository can be updated in line with developments in other programmes and internationally promoting currency of approach, but also commonality between agencies and even allies. By creating a repository there is immediacy in finding relevant measures as it is developed using input of a number of programmes and testing bodies (British Standards, 1999, , 1990) ensuring that the analyst is not working from scratch for each problem that is presented.

Process suite development to include objective and subjective data, both within the matrices and the supporting repository and database, is intended to provide flexibility for future expansion and development. Within the context of an action research cycle it is desirable to scope the problem space, suggest methods to address the problem, test them, refine them and iterate back around the loop (Hindle et al., 1995, Flood, 2001, Coghlan & Brannick, 2004). The case study chapter (8) provides the opportunity for this to be applied to the process suite with the single domain of survivability used as a control for further development prior to a five-domain trade-off. Section 9.3 critically analyses both the process and the output from the case studies describing where alterations are made and their implications. This may lead to further work if the process continues to be applied within Government.

9.2.3 Use of case studies to validate the process suite

The focus of the thesis is derivation of a process suite. However, in creating an approach that uses existing tools and techniques in a novel way, with fusion of data, that to date has not been attempted within the domain of interest, there is a need to test if the output meets customer expectation.

Part of the challenge of introducing a new approach is validation of whether you have built the right system, or in this case, process. Does it meet the stakeholder requirements and is it supported by previous literature? Certainly decompositional matrices as a specific tool have been used within defence and more specifically for showing links from doctrine through to concept down selection (Bathe & Smith, 2002). Furthermore operational analysis is used both in research and procurement to understand operational effectiveness (Smith, J et al., 1991, Hayworth & Shepherd, 2005, Randall, 1997, Durrant, 2005) and to measure performance of concept options. Soft Systems Methodology (Checkland, 1981) is widely used, particularly for human related systems as well as organisations (Vencel & Sweetman, 2004) with overlap to the iterative and applied action research cycle (Warmington, 1980), encompassing other techniques such as subjective data collection and use, with appropriate validation (Sargent, 1996). Although specific challenges exist in terms of assumptions, the fundamental building blocks of the process suite devised within this thesis have validated foundations.

The case studies in Chapter 8 enable validation both of the tools used in the form of the decompositional matrices and their application to the domain of interest, as well as the trade-off process and the link to measurement and concept generation. Two case studies are used to test the full utility of the process suite, with the single domain of survivability acting as a control and the five domain trade-off linking to down-selection and measurement activities. The single domain of survivability has clearly defined problems, and is well understood by the SMEs. It is the contention of the author that if the single domain matrix output is found to be insensitive to changes in the scoring convention and is supported by the expectations of the SMEs it provides a level of confidence that the approach is valid before applying it to multiple domains, where the output is less predictable. Moreover, the use of a number of key questions can help to determine if the process suite, when used with representative data, achieves what it is intended to, as described in Chapter 3, section 3.1.3.

The questions are as follows:

- Do the SMEs understand their involvement in scoring the matrices?
- Are the statements within the matrices clearly understood by the SMEs, or are they considered ambiguous?
- How long does it take to complete the scoring process?
- How easy is it to process the gathered data?

- Are the matrix scores sensitive to change?
- Is there relative completeness in the information that has been captured?
- Is the study repeatable?

The feedback from the first application of the process suite (survivability) indicated that certain questions were addressed more appropriately than others. Prior to collection of data for the other capability domains, certain small adjustments were necessary to ensure continued support from the SMEs.

Use of facilitated meetings was found to be beneficial for people to discuss and challenge ideas relating to the matrices, helping to form a common understanding of statements. However, it was found that this is best applied purely as an opportunity to discuss the matrices rather than including the scoring itself. Due to the size of the matrices, scoring is sometimes unachievable in one session as consistency of SME input can be affected by 'matrix fatigue' (Haysman, 1998). It has been found that issuing supporting notes Appendix C, prior to a focused meeting to clarify misunderstandings, followed by time for SMEs to score at their leisure has received better feedback. SMEs are more inclined to engage if they can see a finite input requirement that they are in control of. This does not have a significant impact on the overall time required to fill in the matrices, with a maximum of two weeks allowed for non urgent investigation.

In terms of processing data, use of Microsoft Excel helps to minimise processing time for the matrices, as the SMEs can score sheets that have been sent electronically. These can be appropriately protected so that formulas are not affected, with drop down lists of scores for each of the boxes reducing the likelihood of rogue entries, which need subsequent verification. Although the spreadsheets contained in Annex A and represented in Appendix D are relatively time consuming to create, once completed they generate the required output with minimal effort. This makes it possible to apply tests for validity, such as sensitivity analysis with ease, with changes automatically cascading through matrix levels. This proved successful with the case studies that were applied, with results showing insensitivity to changes in scoring conventions.

In terms of completeness, the structure of the matrices captures certain critical areas at more than one level, with the intention of cross-checking for completeness. The HFI domains have many elements that can also be found at the system level of the decompositional matrix, therefore forming a check to see if an important parameter has been missed, or has relevance at a different level of resolution. This is also the intent of the 'hat' at level four of the matrix, which highlights inter-relationships between system level considerations, all of which is provided to the design entity for interpretation.

Repeatability is the last component of the process suite that is being tested and is equally important in terms of validity (Pala et al., 2003, Khisty & Mohammadi, 2001). By creating an approach with clear accompanying guidance, consistent matrices irrespective of the application and standard data processing, repeatability should be achievable. What cannot be said with any certainty is whether the same stakeholder would score a matrix identically on two different occasions as their view may be affected by other external modifiers (Bertrand & Mullainathan, 2001, Chapman, 1998).

9.3 SHORTFALLS AND PROPOSED FUTURE WORK

It is recognised that although rigour and objectivity have been adopted within the process suite wherever possible, there is still an element of subjectivity, which has limitations associated with it (Connell, 2001).

Taking a systems approach is not a holy grail, where the right answer will certainly be found if the path is followed; particularly within soft systems and organisations where no two problems are likely to be the same: or even if they are; unlikely to have the same answer. People, either as a component of a system or delivering a system will exhibit behaviour that is unpredictable (Booher, 1990). This adds richness as well as a challenge for applying systems tools and techniques, which require tailoring to a specific domain or problem in order to be effective (Martin, 1997), providing justification for different tools and techniques for different situations. There are a number of elements of the developed process that can, and have been scrutinised for their applicability with potential shortfalls identified in the following paragraphs.

Drawing of the system boundary is an area that can significantly change the processes that are developed. The boundary that is chosen reflects control and influence, but could be changed if the customer organisation or other parts of Government were restructured. This may change the fundamental premise upon which the process suite has been developed, requiring the analyst to re-visit the early modelling to check for continued applicability. However, as the boundary is clearly stated as the soldier and their personal equipment, this task is straightforward. Furthermore, it is the intention of the early modelling to explore the problem space and determine the implications of drawing the boundary, and negotiate this with the stakeholder community prior to developing ways of addressing the problem. The only difficulty arises when and if the individuals within the customer organisation move to other posts as this may require re-negotiation of the system boundary.

Another potential shortfall of the approach is the lack of validated human modelling output currently available within the Government. This is one of the reasons that the fused approach has been developed as it reduces the reliance on one data source. However, it means that certain applications of the process suite become more subjective than others if there is a lack of objective field trials or operational analysis to support it. Several sections and chapters within the thesis have discussed the link to modelling and measurement of human characteristics with shortfalls in the ability to accurately represent dynamic complexity. Although it is suggested that further work is carried out to rectify this capability gap, this is outside of the remit of this thesis. It is also recognised that it is not appropriate to wait for this information to become available before trying to address the challenges of future soldier system definition as there is potential to delay or fail in making any level of improvement over current practice. MoD discuss 80% solutions in the context of procurement[12], where trying to achieve 100% solution to a problem is neither cost effective nor proportionately beneficial in terms of effectiveness. This can equally be applied to derivation of the process suite, in that you can attempt to develop a perfect process that is fully validated before use and has every piece of relevant supporting data; however if it is not used by the customer

[12] Professor Lynn Davies, visiting lecture for SED MSc DCMT, Shrivenham. March 06. Presentation on problem project cases.

organisation and it takes several years before an answer is generated is it really fit for purpose?

The need for the process suite is driven by the customer who validates the process operationally. Therefore the approach is reliant upon customer satisfaction in order to fulfil validity (Ho & Sculi, 1994). It is possible to verify that the process achieves what it has set out to achieve if the output from the case studies conforms to expectations (which it has), but it can be argued that verification is only a test that you have built the process appropriately, not that it meets customer requirements. Part of the customer acceptance is related to risk and uncertainty, what is the consequence of doing nothing? And what is the impact if the output subsequently is found to be floored? Based on current practice, where decisions are made by a number of SMEs, potentially without recourse to previous data or research, any rigour and supporting data would indicate some form of success.

From the work presented in the chapters it can be suggested that greater value than this has been achieved through development of the process suite with multiple stakeholders interacting and engaging towards a common goal. In terms of shortfalls and future work the approach represents a step change from previous research and concept generation activities. The process suite in its current form should be considered as a tool to be applied and gain progressive assurance over time. The greater the volumes of data representing real customer enquiry that can be passed through the process the greater the assurance that it achieves what it has set out to. It is application that will, over time validate more completely the utility of the process with development and refinement taken from the iterative framework within which it has been constructed. This will form the basis of future work in addition to keeping abreast of pan-MoD developments and practices which may influence the refinement of the process suite.

9.4 DISCUSSION SUMMARY

The intent of this thesis is to ‘develop a suite of processes that can be used by Government research departments specifically concerned with dismounted soldier systems to aid the definition of future concepts and potential research direction.

The need for the process suite is a result of specific requirements from the MoD in order to deliver output in line with Smart Procurement objectives. However, the ability of the MoD to embrace such a large shift in approach may take a number of years to successfully implement.

Application of systems tools and techniques recognises the dynamic complexity of the soldier as a system and provides a basis for problem exploration, analysis and proposal of solutions. There is a realisation that modelling of the human at this time is imperfect, but that it is unacceptable to do nothing purely because of uncertainty.

Development of the process suite uses established techniques in the form of decompositional matrices and tools in the form of operational analysis wargames and field trials in a unique fusion. The use of both subjective and objective data within a clear framework, enabling fusion of data sources to provide a common output, has not been attempted previously within the dismounted soldier domain.

Endorsement of the process suite has come from acceptance of the output by the customer with continued application for real world programmes.

In the longer term, refinement of the process suite should be considered in light of continued application as well as alignment with pan-MoD initiatives.

Blank Page

CHAPTER 10: CONCLUSIONS/RECOMMENDATIONS

10.1 INTRODUCTION

10.1.1 Aim

To identify the key elements presented within the thesis and provide recommendations for future work.

10.1.2 Objectives

- To highlight the individual contribution to knowledge that the thesis represents within the field of Systems Engineering and more specifically soldier system research
- To recommend areas for future work, in line with MoD procedure and practice

10.1.3 Background

As defined in Chapter 3 the intent of the thesis is ‘to develop a suite of processes that can be used by Government research departments specifically concerned with dismounted soldier systems to aid the definition of future concepts and potential research direction.’

Each of the chapters provides a number of key outcomes that when rationalised create the basis of the conclusions and demonstrate an original contribution to knowledge, with detailed discussion and perceived shortfalls addressed in Chapter 9. Key elements are presented as bullets points in the sections below:

- Formalised systems engineering and systems thinking is a relatively new discipline that has opportunities for application across many domains.

- A shift in the UK defence procurement strategy has led to significant changes in the business approach of the MoD with a move away from equipment purchase to capability. Output from the Strategic Defence Review (HM Stationary Office,

1998) has encouraged the application of systems engineering principles with a need to develop tailored processes to meet MoD needs.

- Of particular interest within the dismounted domain are the attributes of the soldier and their impact on success or failure of combat missions. Previous studies (Booher, 1990) have identified that system designs excluding human parameters have led to a number of catastrophic platform failures suggesting that the soldier is one of the lowest common denominators when considering man-machine system success. This requires a coherent approach to understand what is needed in order to achieve combat effectiveness encapsulating a number of external influences, all characteristics of a systems approach (Waring, 1996).

10.2 ORIGINAL CONTRIBUTION TO KNOWLEDGE

- From an investigation of past and current literature (Chapter 2), there is a distinct gap in the ability to analyse and interpret the impact of humans. This extends to limitations in modelling and simulation used for financial scrutiny of defence procurement programmes, which has created a shortfall in the government capability to define future soldier system concepts and research direction underpinned with robust evidence of need. It is this gap in current knowledge that the thesis addresses using systems tools and techniques endorsed by government (HM Stationary Office, 1998).

- Definition of the soldier as a system using system tools and techniques ensures auditability and traceability of decisions to provide an enduring suite of processes. Chapter 4 contains context modelling and stakeholder analysis leading to derivation of conceptual models from which the process suite is devised. Numerous system views enable confidence to be gained in the completeness of the approach with areas of control identified and implications of drawing a system boundary discussed.

- Construction of the process suite fuses data from both qualitative and quantitative sources. This concept has not been attempted before within the soldier system domain and represents a novel process, applied to a new domain. The intent of approaching the problem in this way is to minimise difficulties associated with the use of purely subjective data which could be open to bias; it also recognises the significant contribution of subject matter experts, which to-date has been difficult due to the medium of research output (mostly reports). Furthermore, by using both objective and subjective data there is a reduction of the reliance on a specific data source in order to make decisions. This is increasingly critical with non-availability of troops for trial due to operational commitments. Using the process suite that has been devised it is still possible to analyse need, with varying degrees of confidence depending on the input that has been used.

- The key drivers for the process suite are flexibility, auditability and traceability with customer and SME involvement from an early stage to promote acceptance and aid trade-off activities.

- The requirement to trade-off reflects the defence environment within which the customer organisation resides, with fluctuating budgets and priorities. Derivation of the trade-off process enables the customer perspective to be considered whilst using data generated from the SME's to provide robustness and reduce the likelihood of data skewing. No standardised method for trade-off analysis exists (Felix, 2004), with the process presented in Chapter 6 representing a novel approach to using existing data from the process suite supplemented with stakeholder input to identify priorities and risks.

- In conjunction with trade-off is the ability to measure, determining whether requirements have been met, and which options provide greatest benefit. As with trade-off there is no universally accepted definition of measures of effectiveness and performance. This is further compounded by the difficulty of measuring intangible characteristics often attributed to the human. The process suite depicts a repository of MOE's and MOP's to provide standardisation across the dismounted soldier domain. The intent is to provide an iteratively updated resource that provides guidance on different measures at various levels of resolution, minimising replication of effort over time. Although the measurement framework (NATO LG3, 1999) has created a number of levels that are populated with performance metrics, to-date it has not dealt with the challenges of the human. The repository defined within the process suite uses the framework that has been developed and suggests ways to expand and improve upon it.

- Having devised the process suite, Chapter 8 uses case studies to determine practical utility through application. The results are not the focus of the thesis; instead it is the 'user friendly' nature and robustness of the process 'when used in anger' that is of interest. Analysis and interpretation of results shows that the approach is robust, with sensitivity analysis confirming that the outcome cannot have been achieved by chance alone. Feedback from SME's led to minor amendments to the administration of the matrices within the process suite, but in general it has been received well. Across all of the capability domains mobility was found to be the key driver for enhancement to operational effectiveness, an outcome supported by historical evidence (Bunting, A et al., 2001) and operational feedback (Shepherd et al., 2003b). Due to the ethical constraints surrounding use of troops for load carriage trials, this re-enforces the need for effective modelling and simulation of soldier system characteristics.

- Endorsement of the process has come from both the customer and the stakeholders within the dismounted soldier domain. This is a significant outcome when dealing with people who have multiple domain experience and differing 'world views'. When objective data is lacking there are techniques such as sensitivity analysis to check for robustness, but there is still a strong reliance on individuals accepting and taking on board new approaches. As stated in Chapter 2 'a systems engineer is a facilitator that brings together multiple stakeholders and unifies opinion. If all parties believe that the approach is sufficiently robust and valid then the systems engineer has been successful in their aim.'

10.3 RECOMMENDATIONS

Using the ethos prescribed by action research (Warmington, 1980), it is likely that improvement can be made over time as the process suite is used within government. The following recommendations are a combination of output from the case studies and the process suite more generally as discussed in Chapter 9. They are not presented in any particular order of merit as this decision resides with the customer.

- To promote a programme of human modelling development to supplement current war games and simulation.

- To address the applicability of current combat models and simulations in characterising human attributes.

- To gain progressive assurance of the validity of the process suite through continued use.

- To ensure that pan-MoD initiatives are considered, as they are introduced over time and necessary amendments made to the process suite.

- To continue expansion of the process suite supporting data repositories (as part of the store data function) to ensure currency and configuration control.

- To ensure lines of communication are maintained between stakeholders with regular updates on who is doing what.

Blank Page

REFERENCES

Ackerman, M., Pipek, M. and Wulf, V. (eds.) (2003) *Sharing Expertise: Beyond Knowledge Management.* MIT Press, Cambridge, MA.

Ackoff, R. (1962) *Scientific Method: Optimising Applied Research Decisions.* John Wiley, New York.

Ackoff, R. (1969) Systems, Organisations and Interdisciplinary Research. IN *Systems Thinking.* Emery, F. (ed.) Penguin Books, England.

Alexander, S. (1920) *Space, Time and Deity.* 2 vols. Macmillan, London.

Anderson, T. and Marshall, S. (2000) *Synthetic Environment Based Acquisition - Supporting Smart Procurement*. DERA.

Angyal, A. (1969) Foundations for a Science of Personality. IN *Systems Thinking.* Emery, F. (ed.) Penguin Books, England.

Armstrong, D. and Goldstein, E. (1990) *The End of the Cold War.* Frank Cass, London.

Ashby, P., Iremonger, M. and Gotts, P. (2004) The Trade-Off Between Protection and Performance for Dismounted Infantry in the Assault. *Proceedings of the Personal Armour Systems Symposium 2004*. The Hague, The Netherlands. 6-10th September 2004.

Aughenbaugh, J. and Paredis, J. (2004) The Role and Limitations of Modelling and Simulation in Systems Design. *ASME International Mechanical Engineering Congress and RD&D Expo*. Anaheim, California USA. November 13-19.

Bailey, R. and Baxter, A. (1990) *A Feasibility Study into High Level Modelling (Structuring Equipment Procurement Decisions).* QinetiQ. QINETIQ/DC1095/8/1/TR.1 CORDA.

Bateson, G. (1972) *Steps to an Ecology of the Mind.* Intertext, London.

Bathe, M. and Smith, J. (2002) A Description of the Strategy to Task Technique and Example Applications. *Journal of Battlefield Technology.* 5 (1).

Beagley, N. (1998) *Human Sciences Aspects of Synthetic Environments*. DERA. DERA/CHS/MID/TR980129/1.0.

Beer, S. (1981) *Brain of the Firm.* Herder and Herder, New York.

Bertalanffy, L. (1968) *General Systems Theory: Foundations, Development, Applications.* George Braziller, New York.

Bertrand, M. and Mullainathan, S. (2001) Do People Mean What They Say? Implications for Subjective Survey Data. *American Economic Review*. 91 (2) pp. 67-72.

Blackwell, C. (1993) *The Combat Soldier System Integration (CSSI) Toolset-Development of a Systems Level Human Factors Methodology*. MSc thesis. Loughborough University, Loughborough, UK.

Boardman, J. (1997) *Systems Engineering: A Research Framework*. DERA. DERA/LSC/2026/273.

Bolger, F. and Wright, G. (1994) Assessing the Quality of Expert Judgement: Issues and Analysis. *Decision Support Systems.* 11 pp. 1-24.

Booher, H. R. (1990) *MANPRINT: An Approach to Systems Integration.* Van Norstrand Reinhold, New York.

Boulding, K. (1956) General Systems Theory: The Skeleton of Science. *Management Science.* 2 (3) pp. 197-208.

Boulding, K. (1964) General Systems as a Point of View. IN *Views of General Systems Theory.* Mesarovics, A. (ed.) John Wiley, New York.

Bourn, J. and Controller & Auditor General (2002) *Implementation of Integrated Project Teams*. HC671 Session 2001-2002.

Bowles, N. (1999) The Delphi Technique. *Nursing Standard.* 13 (45) pp. 32-36.

Bowyer, S. and Martin, B. (2003) *Personnel and Manpower Implications of FIST*. QinetiQ. QinetiQ/KI/CHS/WP030065.

Bratley, P., Fox, B. and Schrage, L. (1987) *A Guide to Simulation.* Springer. 0387964673.

British Standards (1990) *Specification for Water Vapour Permeable Apparel Fabrics*. BS 7209:1990.

British Standards (1999) *Determination of the Abrasion Resistance of Fabrics by the Martindale Method. Determination of Specimen Breakdown*. BS EN ISO 12947-2:1999 Textiles.

Broad, C. (1925) *The Mind and its Place in Nature.* Routledge & Keagan Paul, London.

Browning, D. (2003) *Development of an Amonia Borane Based Fuel Source and Extended Testing of a 25W Fuel Cell System*. QinetiQ. QINETIQ/FST/CR035178.

Bud, R. and Gummett, P. (eds.) (2002) *Cold War, Hot Science: Applied Research in Britain's Defence Laboratories 1945-1990.* NMSI Trading Ltd., Science Museum, London.

Buede, D. (2000) *The Engineering Design of Systems. Models and Methods.* John Wiley & Sons, Chichester.

Buede, D. (2004) On Trade Studies. *Managing Complexity and Change! INCOSE 2004 - 14th Annual International Symposium Proceedings*. Toulouse. 20- 24th June 2004.

Bunting, A., Bentley, M. and Myers, S. (2001) *Performance Limitations of Load Carriage for the Infantry Soldier*. QinetiQ. QINETIQ/CHS/CR010420.

Bunting, A. J. and Kelm, D. M. (2002) *IPME Assessment of the Effects of Clothing and Personal Equipment on Performance and Sustainability*. QinetiQ. QinetiQ/CHS/CAP/CR020013/1.1.

Burns, C. and Vicente, K. (1996) Judgements About the Value and Cost of Human Factors Information in Design. *Information Processing & Management.* 32 (3) pp. 259-271.

Capra, F. (1997) *The Web of Life: A New Synthesis of Mind and Matter.* Flamingo. 0006547516.

Cathcart, E., Richardson, D. and Campbell, W. (1923) Army Hygeine Advisory Committee Report No. 3 : On the Maximum Load to be Carried by the Soldier. *Journal of the Royal Army Medical Corps.* 40 pp. 435-443.

Chamberlain, G. (2004) Black Watch Commander Tells How MoD Let Down Troops in Iraq. *The Scotsman*. Thurs 22nd Jan 2004.

Chapanis, A. (1996) *Human Factors in Systems Engineering.* John Wiley & Sons Ltd. 0471137820.

Chapman, R. (1998) The Effectiveness of Working Group Risk Assessment Techniques. *International Journal of Project Management.* 16 (6) pp. 333-343.

Charnes, J. and Shenoy, P. (2004) Multistage Monte Carlo Method for Solving Influence Diagrams Using Local Computation. *Management Science.* 50 (3) pp. 405- 418.

Checkland, P. (1979) Techniques in Soft Systems Practice. 2. Building Conceptual Models. *Journal of Applied Systems Analysis.* 6.

Checkland, P. (1981) *Systems Thinking, Systems Practice.* John Wiley and Sons, Chichester, UK.

Checkland, P. (2002) *Systems Thinking, Systems Practice: Includes a 30 year Retrospective.* John Wiley and Sons, Chichester.

Checkland, P. and Scholes, J. (1990) *Soft Systems Methodology in Action.* John Wiley & Sons, Chichester, UK.

Christley, J. and Witty, S. (2001) *Stochastic Aggregation of MOE's- Phase 1 Report (UC)*. DERA. DERA/CDA/HLS/CR010024/1.0.

Clarke, M. (1995) *Experimental Investigation of Electrically Powered Hand and Footwear*. DCTA. RR/95/06.1995.

Coghlan, D. and Brannick, T. (2004) *Doing Action Research in Your Own Organisation.* Sage Publications, London. 1412902479.

Cohen, L. (1995) *Quality Function Deployment. How to Make it Work.* Addison-Wesley Publishing Company. 02016333302.

Cole, J. (1989) *Personal Defence Weapon QFD Analysis*. British Aerospace Royal Ordnance Future Systems Group. FSG/R/89. WST-T-522-R01-96027-1.

Colthurst, P., Cox, A. and Jackson, I. (1999) *The Application of Synthetic Environments to Future Integrated Soldier Technology (FIST) Research*. DERA. DERA/LSB3/SP990533.

Connell, N. (2001) Evaluating Soft OR: Some Reflections on an Apparently 'Unsuccessful' Implementation using a Soft Systems Methodology (SSM) Based Approach. *Journal of the Operational Research Society.* 52 pp. 150-160.

Controller and Auditor General (1996) *Major Projects Report 1995*. National Audit Office, HM Stationary Office. HC677.

Controller and Auditor General (1998) *Major Projects Report 1997*. National Audit Office, HM Stationary Office. HC 695.

Controller and Auditor General (1999) *Major Projects Report*. National Audit Office, HM Stationary Office. HC 613 1999-2000.

Controller and Auditor General (2002) *Building and Air Manoeuvre Capability: The Introduction of the Apache Helicopter*. National Audit Office, HM Stationary Office. HC 1246 Session 2001-2002.

Controller and Auditor General (2003) *Through Life Management*. HM Stationary Office. HC 698 Session 2002-2003.

Controller and Auditor General (2004a) *Major Projects Report 2004*. National Audit Office, HM Stationary Office. HC 1159-1 Session 2003-2004.

Controller and Auditor General (2004b) *The Management of Defence Research and Technology*. HM Stationary Office. HC 360 Session 2003-2004.

Controller and Auditor General (2005) *Driving The Successful Delivery of Major Defence Projects: Effective Project Control is a Key Factor in Successful Projects*. National Audit Office, HM Stationary Office. HC 30 Session 2005-2006.

Cordesman, A. (2005) A Lesson in Transforming Warfare. *Financial Times, London, UK*. p 17. Friday 18 February 2005

Couldrick, C. (2005a) *Assessment of Personal Armour Using CASPER*. Cranfield University, Shrivenham. DCMT/ESD/CAC/1151/05.

Couldrick, C. (2005b) *A Systems Approach to the Design of Personal Armour for Explosive Ordnance Disposal*. EngD thesis. Cranfield University, Engineering Systems Department, Shrivenham, UK.

Coyle, J., Exelby, D. and Holt, J. (1999) System Dynamics in Defence Analysis: Some Case Studies. *Journal of the Operational Research Society*. 50 (4) pp. 372-382.

Coyle, R. (1972) *Decision Analysis.* Thomas Nelson, London.

Curtis, N. (1996) *Possible Methodologies for Analysis of the Soldier Combat System: Operations Research Support to Project Wundurra*. DSTO-TR-0148.

Dalkey, N. and Helmer, O. (1963) An experimental Application of the Delphi Method to the use of Experts. *Management Science.* 9 pp. 458-467.

Daniels, J., Werner, P. and Bahill, T. (2001) Quantitative Methods for Trade Off Analysis. *Systems Engineering.* 4 (3) pp. 190-212.

Davies, L. (1989) Designing for ill Defined Problems. *International Journal of Information Management.* 9 pp. 199-208.

Davis, P. (2000) *Personal Defence Weapon Calibre Assessment*. DERA. DERA/LWS/WS4/CR000594/1.0.

De Freja, G. and Hartley, K. (1996) Defence Procurement: Theory and UK Policy. *Oxford Review of Economic Policy.* 12 pp. 70-88.

Defence Clothing IPT (2003) *UK Operational Clothing Catalogue*. DLO Caversfield. JSP529.

Defence Evaluation and Research Agency (1999) *Systems Engineering and Smart Procurement*. DERA. DERA/LS(SED)/3/1.

Defence Materiel Organisation (2001) *Corporate Governance Framework*. USDM104/2001.

Defence Procurement Agency (2005) *The Acquisition Handbook.*

Defence Science and Technology Laboratory (2004) *DSTL Annual Report and Accounts 2003/2004*. DSTL, The Stationary Office. HC728.

Delbecq, A., Van de Ven, A. and Gustafson, D. (1975) *Group Techniques for Programme Planning: A Guide to Nominal Group Technique and Delphi Processes.* Scott, Foresman, Glenview, ILL. 0673075915.

Denton, N. (2001) *Compendium of Future Integrated Systems Technology (FIST) Research*. DERA/CHS/MID/WP010049/1.0.

Director Infantry (1999) *Infantry 2010... Capability, Structures and Equipment*. 118/00/00.

Director Infantry (2000) *Future Infantry...The Route to 2020*. 118/00/00.

Dooley, P. (2000) *Future Integrated Soldier Technology (FIST) within a Systems Engineering Framework*. DRA/WX6/5/16/10/3.

Duggan, E. and Thachenkary, C. (2003) Higher Quality Requirements: Supporting Joint Application Development with the Nominal Group Technique. *Information Technology and Management.* 4 pp. 391-408.

Dunlop, A. (1997) *A Concept of Analysis for the Future Integrated Soldier Technology Demonstrator (FIST), Requirement Definition Study*.

Dunnigan, J. (2003) *How to Make War: A Comprehensive Guide to Modern Warfare in the Twenty- First Century.* Quill Books, New York.

Durrant, A. (2005) *Clothing and Textiles Operational Analysis: Sustainability Final Report*. Dstl. Dstl/CR16315 V1.0.

EC MDU AD DEV (2002) *Guide to Producing User Requirements Documents*. Defence Procurement Agency.

Edwards, P. (1967) Vitalism. IN *The Encyclopaedia of Philosophy.*

Emmeche, C., Koppe, S. and Stjernfelt, F. (2000) Levels, Emergence, and Three Versions of Downward Causation. IN *Downward Causation. Minds, Bodies and Matter.* Anderson, P., Emmeche, C., Finnemann, N. and Christiansen, V. (eds.) Aarhus University Press, Arhus.

Eum, Y., Park, K. and Kim, S. (2001) Establishing Dominance and Potential Optimality in Multi-Criteria Analysis with Imprecise Weight and Value. *Computers and Operations Research.* 28 pp. 397-409.

Eyre, C. and Syms, P. (1994) *A Comparison of Three Royal Ordnance Man Portable Anti-Armour Weapon Concepts Using CAEn*. DRA. DRA-OS-L-CR94085-2.0.

Felix, A. (2004) Standard Approach to Trade Studies. *Managing Complexity and Change! INCOSE 2004 - 14th Annual International Symposium Proceedings*. Toulouse. 20- 24th June 2004.

Ferbrache, D. (2003) *DAES Presentation to Dstl Modelling and Simulation Workshop*. DAES. 18/9/2003.

Finlan, A. (2003) *The Gulf War 1991 (Essential histories s.)*. Osprey. 1841765740.

Flood, R. (2001) The Relationship of 'Systems Thinking' to Action Research. IN *Handbook of Action Research.* Reason (ed.) Sage, London.

Flood, R. and Carson, E. (1993) *Dealing with Complexity: An Introduction to the Theory and Applications of Systems Science.* Plenum Press, London.

Flood, R. and Jackson, M. (1995) *Creative Problem Solving.* John Wiley & Sons.

Flower, J., Verall, N. and Stafford, M. (2001) *The Potential Effects of FIST on Social Interaction and Military Team Performance*. DERA/CHS/MID/WP010041/1.0.

Forsberg, K. and Mooz, H. (1992) The Relationship of Systems Engineering to the Project Cycle. *Engineering Management Journal.* 4 (3).

Franceschini, F. and Rupil, A. (1999) Rating Scales and Prioritization in QFD. *International Journal of Quality and Reliability Management.* 16 (1) pp. 85-97.

Frankfort- Nachmias, C. and Nachmias, D. (1996) *Research Methods in the Social Sciences.* Arnold, London. 0340662263.

Funaro, J. and Fletcher, J. (1980) Front-End Analysis for Emerging Systems. *Defense Management Journal.* 16 (4) pp. 33-37.

Gabbai, J. (2000) *Lead Time Reduction in BAE SYSTEMS Defence Market.* www.gabbai.com/Management/Operations/Operations.html. accessed 8/11/2005

Garlan, D., Allen, R. and Ockerbloom, J. (1995) Architectural Mismatch: Why Re-use is so hard. *IEEE Software.* 12 (6) pp. 17-26.

Gillies, G. (1984) *Task analysis and task synthesis*. APRE.

Goodwin, P. and Wright, G. (2004) *Decision Analysis for Management Judgement.* John Wiley and Sons Ltd, Chichester. 0470861088.

Grainger, P. (1997) Principles of Cost Effectiveness Analysis. *Journal of Defence Science.* 2 (4).

Green, K. (2003) *Identification of Battery Technologies and Selection*. QinetiQ. QINETIQ/FST/TR030413.

Gurr, E. and Hampson, A. (1999) *The FIST Soldier: A Study into the Future Attributes of the Soldier who will use the Future Infantry Systems Technology*. CHS. DERA/CHS/MID/WP980266/1.0.

Haisman, M. (1975) *Compatibility of Combat Clothing with Equipment*. APRE.

Hammond, D. (2005) *Dismounted Close Combat Weapons: A Summary of the Methodology and Analysis Leading to Concept Down-Selection*. QinetiQ Weapons Sector. QINETIQ/FST/WNS/CR050626/1.0.

Hammond, D. (2006) *Probability of Incapacitation (PI) Values for Future Weapon Systems*. QinetiQ. QINETIQ/D&TS/WPNS/CR0601136.

Harrington, H. (1991) *Business Process Improvement.* McGraw-Hill, New York.

Hart, P. (1994) *Government: A Study of Small Groups and Policy Failure.* The John Hokins University Press, Baltimore. 0801848903.

Haysman, P. (1998) *Judgemental Methods and Data Analysis*. British Aerospace. Systems & Technology JMDA Pre Nov 1998.

Hayworth, R. and Shepherd, N. (2005) *Clothing and Textiles Operational Analysis: Tactical Mobility Final Report*. Dstl. Dstl/CR17821 V1.0.

Hedvall, M. (2004) Change as a Cost Driver in Defence Procurement. *Defence and Peace Economics.* 15 (1) pp. 101-108.

Hein, H. (1972) The Endurance of the Mechanism - Vitalism Controversy. *Journal of the History of Biology.* 5 (1).

Higgenbottam, C. (1996) *Water Vapour Permeability of Aircrew Clothing*. DERA. PLSD/CHSS/TR96089.

Hindle, T., Checkland, P., Mumford, M. and Worthington, D. (1995) Developing a Methodology for Multidisciplinary Action Research: A Case Study. *Journal of the Operational Research Society*. 46 pp. 453-464.

Hitchins, D. (1992) *Putting Systems to Work.* John Wiley & Sons, Chichester.

Hitchins, D. (2003) *Advanced Systems Thinking, Engineering and Management.* Artech House, MA. 1580536190.

HM Stationary Office (1998) *Strategic Defence Review*. CM3999.

Ho, K. and Sculi, D. (1994) Organisational Theory and Soft Systems Methodologies. *Journal of Management Development.* 13 (7) pp. 47-58.

Holloway, C. M. (1999) *From Bridges and Rockets, Lessons for Software Systems*. NASA Langley Research Centre.

House of Commons Defence Committee (2003) *Defence Procurement*. 8th Session 2002-2003 HC694.

Janis, I. (1982) *Groupthink: A Psychological Study of Policy Decisions and Fiascos.* Houghton Mifflin, Boston. 0395317045.

Johanessen, J. (1996) Systemics Applied to the Study of Organisational Fields: Developing a Systemic Research Strategy. *Kybernetes.* 25 (1) pp. 33-50.

Johanessen, J., Olaisen, B. and Olsen, B. (1999) Systemic Thinking as the Philosophical Foundation for Knowledge Management and Organisational Learning. *Kybernetes*. 28 (1).

Johnson, M., McKeon, M. and Szanto, T. (1998) *Simulation Based Acquisition: A New Approach*. Defense Systems Management College.

Joint Command Headquarters (2001) *Joint Essential Task List*. UK JCHQ.

Joint Doctrine and Concepts Centre (1996) *British Defence Doctrine*. Joint Warfare Publication 0-01.

Joint Doctrine and Concepts Centre (2005) *JDCC Concepts to Capability- Defence Lines of Development*. JDCC.

JSA AG1 Small Unit Land Operations (2000) *Technology Requirements for Soldier Modernisation in the 2015 Timeframe*. The Technical Co-operation Program. JSA-AG7-2000-01.

Karnavas, W., Sanchez, P. and Bahill, T. (1993) Sensitivity Analysis of Continuous and Discrete Systems in the Time and Frequency Domains. *IEEE Transactions on Systems, Man and Cybernetics.* 23 (2) pp. 488-501.

Kauffman, S. (1996) *At Home in the Universe. The Search for the Laws of Self Organisation and Complexity.* Oxford University Press, New York. 0195111303.

Keleman, D. (1999) Function, goals and intention: Children's teleological reasoning about objects. *Trends in Cognitive Sciences.* 3 (12).

Kenley, R. (2004) Requirements Risk Assessment- Integrating QFD and Risk Assessment. *Managing Complexity and Change! INCOSE 2004 -14th Annual International Symposium Proceedings*. Toulouse. 20- 24th June 2004.

Khisty, C. and Mohammadi, J. (2001) *Fundamentals of Systems Engineering, With Economics, Probablity and Statistics.* Prentice Hall, New Jersey. 0130106496.

Kim, K. (2002) *Recent Advances in QFD.* Department of Industrial Engineering Pohand University of Science and Technology, .

Kim, Y., Yoon, C. and Yun, D. (2005) Determining Customer-Oriented Technical Importance Ratings: An Evaluative Study. *International Journal of Quality and Reliability Management.* 22 (4) pp. 393-409.

King, D. (2004) *Report on the Final Results of FRES Detailed Study*. QinetiQ. QINETIQ/04/00/44/1.0.

Kramer, R. (1998) Revisiting the Bay of Pigs and Vietnam Decisions 25 Years Later: How Well has the Groupthink Hypothesis Stood the Test of Time? *Organizational Behaviour & Human Decision Processes.* 73 (2-3) pp. 236-271.

Lacey, B. (2001) *FIST: Synthetic Environments*. DERA/LWS/WS4/CR010368/1.0.

Lakeman, J. (2000) *FIST: Power Sources Scoping Study*. DERA. DEAR/MSS/MSFC4/CR003791/1.0.

Lambert, J. (1991) The Extended Analytic Hierarchy Decision Method. *Mathematical Computational Modelling.* 15 (11) pp. 141-151.

Lane, N. and Strieb, M. (1980) *Modelling the Human Operator: Applications to System Cost Effectiveness*. NADC, NATO.

Ledington, P. and Ledington, J. (1999) Extending the Process of Comparison in Soft Systems Methodology. *Journal of the Operational Research Society.* 50 pp. 1149-1157.

Lewes, G. (1875) *Problems of Life and Mind.* Kegan-Paul, Trench, Turbner and Co, London.

Liu, F. and Hai, H. (2005) The Voting Analytic Hierarchy Process Method For Selecting Suppliers. *International Journal of Production Economics.* 97 pp. 308-317.

Lothian, N. (2004) *The Load Carried by the Soldier*. Army School of Hygiene. HB (A)/CM/.

Lowe, J. and Fitzgibbon, T. (1998) *A Study on 'HFI Cost Benefit Analysis'*. DERA. CHS7342.

MacDonald, G. (1999) Reform of UK Defense Procurement and State/ Industry Relationships During the 1980's and 1990's. *Defence Analysis.* 15 (1) pp. 3-26.

Mackley, T. (2005) Generic Measures of Effectiveness for Systems. *15th Annual International Symposium. Systems Engineering: Bridging Industry, Government and Academia*. Rochester, New York. 10-14 July 2005.

Martin, J. (1997) *Systems Engineering Guide Book: A Process for Developing Systems and Products.* CRC Press, London.

Masterman, R. (2005) *IA Malvern. ISSE Analyst Guidelines*. IA. IA/10/01/0.5 (Draft).

Mathieson, G. (2002) *Benefits Analysis- A Robust Approach*. Dstl. DSTL/JA0576.

Matthews, R. and Parker, J. (1999) Prime Contracting in Defense Contracts. *Defence Analysis.* 15 (1) pp. 27-42.

Maturana, H. (1981) Autopoiesis. IN *Autopoiesis: A Theory of Living Organization.* pp. 21-23. Zeleny, M. (ed.) Elsevier, New York.

McGraw Hill (1998) *Multimedia Encyclopedia of Science and Technology*. Mc Graw Hill Companies Inc accessed August 2005.

McKinsey & Co (1998) *Transforming the UK's Defence Procurement System.* McKinsey & Co.

McLaughlin Hymes, C. and Olson, G. (1992) Unblocking Brainstorming Through the Use of a Simple Group Editor. *Proceedings of the Conference on Computer Supported Cooperative Work*. pp. 99-106. Toronto, Canada. 31st Oct- 4th Nov.

McMillan, W. (1995) *The Soldiers Load*. Directorate of Infantry. D162-4-6.

Middleton, V., Sufton, K., McIntyre, B. and O'Keefe, J. (2000) *Soldier Integrated Protective Ensemble (SIPE) Advanced Technology Demonstration (ATD).* NATICK. Technical Report NATICK/TR-00/019.

Mill, J. (1843) *System of Logic.* Longmans, Green, Reader and Dyer, London.

Miller, S. (1989) *Experimental Design and Statistics.* Methven, New York.

Ministry of Defence (1997) *FIST Concept Paper*. D/DGD&D/1/108/11/LW1c.

Moore, G. (ed.) (1976) *Case Studies in Decision Analysis.* Penguin Education, Harmonsdworth, UK.

Nanson, P. (2000) *Future Conflict and the Infantry Soldier*. MSc thesis. Cranfield University, Shrivenham, UK.

NATO (1992) *Analysis Techniques for Man Machine System Design*. AC/243 (Panel 8) TR/7.

NATO LG3 (1999) *NATO Measurement Framework*. WG3.

O'Keefe, J. (1964) Introduction to Systems Analysis. *Journal of Industrial Engineering.* (3) pp. 163-167.

Obeng, E. (1994) *All Change! The Project Leader's Secret Handbook.* 0273607626.

Okasha, S. (2002) *Philosophy of Science: A very Short Introduction.* Oxford University Press.

Pala, O., Vennix, J. and Mullekom, T. (2003) Validity in SSM: Neglected Areas. *Journal of the Operational Research Society.* 54 pp. 706-712.

Parry, C. (2005) *Defence Lines of Development*. DG JDC.

Patching, D. (1990) *Practical Soft Systems Analysis.* Pitman Publishing, London. 0273032372.

Phillips, M., Sander, P. and Govers, C. (1994) Policy Formulation by use of QFD Techniques: A Case Study. *International Journal of Quality and Reliability Management.* 11 (5) pp. 46-58.

Pipino, L., Lee, Y. and Wang, R. (2002) Data Quality Assessment. *Communications of the ACM,.* 45 (4) pp. 211-218.

Popper, K. (2002) *Conjectures and Refutations: The Growth of Scientific Knowledge.* Routledge. 0415285933.

Pratt, R. (1994) *BICS (Battlefield Information Systems) Communications Study 12. Parts B-D- Final Report*. DRA. DRA-CIS-CSC-6-P-11-212-54-04.

Presidential Commission on the Space Shuttle Challenger Accident (1986) *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident*. Washington D.C. Government Printing Office.

Pruzan, P. (1988) Systemic OR and Operational Systems Science. *European Journal of Operational Research.* 37 pp. 34-41.

QinetiQ (2001) *FIST Assessment Phase Strategy*. QinetiQ. QinetiQ/ CDT/5/48/8.

Randall, T. (1997) *Field Trials to Support Operational Analysis of the Future Infantry Soldier Technology. Proposal and Management Plan for FY97/98.* CDA(HLS)WP1331/1 Version 2.

Rawlinson, J. (1981) *Creative Thinking and Brainstorming.* Gower, London.

Rivett, P. (1980) *Model Building for Decision Analysis.* John Wiley and Sons, Chichester.

Rogers, P. and Dando, M. (1992) *A Violent Peace: Global Security After the Cold War.* Brasseys, London.

Rook, F. (1998) *Capability Deficiency Data Capture. July 1998 FIST Trial*. DERA. DERA/WSS/WX6/TR980708.

Rowbotham, H. (2006) *What is HFI?* www.ams.mod.uk/ams/content/docs/hfi/what.doc. accessed 11.4.06

Rowe, G. and Wright, G. (1999) The Delphi Technique as a Forecasting Tool: Issues and Analysis. *International Journal of Forecasting.* 15 pp. 353-375.

Sackman, H. (1975) *Delphi Critique.* Lexington Books, Massachusetts. 0669961560.

Sage, A. (1992) *Systems Engineering.* John Wiley and Sons, New York.

Sage, A. and Olson, S. (2001) Modelling and Simulation in Systems Engineering: Whither Simulation Based Acquisition? *Modelling and Simulation.* 76 (5) pp. 283- 285.

Sargent, R. (1996) Some Subjective Validation Methods Using Graphical Displays of Data. *Winter Simulation Conference*. Coronado, CA, USA.

Satsumoto, Y. and Ishikawa, K. (1997) Evaluating Quasi-Clothing Heat Transfer: A Comparison of the Vertical Hotplate and the Thermal Manikin. *Textile Research Journal.* 67 (7) pp. 503-510.

Scheslinger, J. R. (1969) Uses and Abuses of Analysis. IN *Program Budgeting and Benefit Cost Analysis; Cases, Test and Readings.* Harley, H., Hinrichs and Taylor, G. (eds.) Goodyear Publishing Co. Inc., CA.

Schmorrow, D. and Kelsey, L. (2002) Analysis Based Modelling and Simulation in the Acquisition Process. *The Interservice/ Industry Training, Simulation and Education Conference*.

Secretary of State for Defence (2005) *Network Enabled Capability*. HM Stationary Office. JSP 777.

Senfelder, L. (1911) *The Catholic Encyclopaedia.* Robert Appleton & Co.

Shalen, P. (1994) *The Whole.* www2.math.uic.edu/~shalen/academy/words.html. accessed 9/11/05

Sharp, L., Allard, C., Barradale, D., Clutterbuck, J., Herington, J., Howes, G. and Nichols, C. (1999) *A Pilot Suite for Balance of Investment Across Capability Areas*. CDA. DERA/CDA/HLS/CR990156/1.0.

Sheard, S. (1996) Twelve Systems Engineering Roles. *INCOSE*.

Shepherd, N., Scott, J., Allen, C. and Reece, J. (2003a) *Clothing and Textiles Combat Survivability Operational Analysis - Final Report*. Dstl. DSTL/CR08119/V1.0.

Shepherd, N., Scott, J., Hellicker, M. and Kitcher, K. (2003b) *User Perceived Deficiencies in Clothing and Textiles - A Summary of Qualitative Findings*. Dstl. DSTL/TR08709/V3.0.

Simons, T. (1990) *The End of the Cold War?* MacMillan, Basingstoke.

Skinner, S., Wright, M. and Wheatley, A. (1997) *Future Infantry System Technology (FIST) Field Trials in FY 96-97. Human Factors Data Collection*. CHS. DERA/CHS/HS3/TR97004/1.0.

Skyttner, L. (2001) *General Systems Theory: An Introduction.* MacMillan Press Ltd, Basingstoke.

Slee, R. (2001) *Development of a Lightweight Tubular Fuel Cell*. DERA. DERA/FST/CMT/CP010502.

Smith, A., Cowper, D. and Emes, M. (2004) Systems Engineering Management. *Managing Complexity and Change. INCOSE 2004-14th Annual International Symposium Proceedings*. Toulouse. 20- 24th June 2004.

Smith, J. (1993) *GPMG Replacement: Quality Function Deployment Analysis*. WS-T-522-RO1-96017-1 (FSG/R/079).

Smith, J., Dyde, M. and Waldren, J. (1991) *Small Arms Operational Analysis*. Royal Ordnance New Projects Dept. NP/R/041.

Smith, J., Haysman, P. and Szalay, S. (2002) Using Strategy to Task Technique to Prioritise Technology Options. *Journal of Battlefield Technology*. 5 (2).

Smith, K. (1984) Philosophical Problems in Thinking about Organizational Change. IN *Change in Organizations.* Goodman, P. S. A. (ed.) Josey Bass, New York.

Smith, R. (2005) *Future Operational Clothing and Textiles Research Direction*. Dstl. Dstl/CR17910 V1.0.

Smuts, J. (1973) *Holism and Evolution (reprint).* Greenwood Press, Connecticut.

Sparks, E. (2004a) *Foundation Process Document*. Dstl. DSTL/TR11633/ V1.0.

Sparks, E. (2004b) *MoD Operational Clothing and Textiles Programme Capability Approach*. Dstl. DSTL/CR09814/ V1.0.

Sparks, E. (2004c) *Research Concept System Requirement Document*. Dstl.

Sparks, E. (2004d) *Systems Study - Survivability Results*. Dstl. DSTL/TR11367/ V1.0.

Sproles, N. (1999) Coming to Grips with Measures of Effectiveness. *Systems Engineering.* 3 pp. 50-58.

Sproles, N. (2002) Formulating Measures of Effectiveness. *Systems Engineering.* 5 (4) pp. 253-263.

Staker, R. (2000) Knowledge Based Soft Systems Engineering for Military Systems of Systems. *Systems Engineering Test and Evaluation (SETE)*. Brisbane. 15-17 November 2000.

Stephenson, M. and Cross, S. (1995) *Combat Soldier 2005 (Clothing and Textiles) Preliminary Study. Part 2- Research Recommendations. Issue 2*. DCTA- S&T DIV RR 94/06Pt2.

Sterman, J. (2000) *Business Dynamics: Systems Thinking and Modelling for a Complex World.* Irwin, Mc Graw -Hill. 0072311355.

Stevens, R., Brook, P., Jackson, K. and Arnold, S. (1998) *Systems Engineering: Coping with Complexity.* Prentice Hall. 130950858.

Suraska, W. (1998) *How the Soviet Union disappeared.* Duke University Press, Durham, NC. 0822321246.

Tajino, A., Jones, R. and Kijama, K. (2005) Beyond Needs Analysis: Soft Systems Methodology for Meaningful Collaboration in EAP Course Design. *Journal of English for Academic Purposes.* 4 pp. 27- 42.

Taylor, B. (2005) *Guide to Capability Based Planning*. Dstl. Dstl/CP000688 RTO-MP-SAS-055.

Townshend, C. (ed.) (1997) *The Oxford Illustrated History of Modern War*. Oxford University Press, Oxford.

Vang, L. (1991) *Handbook on Clothing. Biomedical Effects of Military Clothing and Equipment Systems*. Panel 8 on the Defence Applications of Human and Bio-medical Sciences.

Vaughan, D. (1996) *The Challenger Launch Decision: Risky Technology, Culture and Deviance at NASA.* University of Chicago Press, Chicago.

Vencel, L. and Sweetman, E. (2004) Application of SSM Architecture Framework as a Method of Enquiry for Organisational Behaviour. *Managing Complexity and Change! INCOSE 2004-14th Annual International Symposium Proceedings*. Toulouse. 2004.

Vicary, H. (2005) *Review of MoD Research Concerned with Military Load Carriage Equipment*. Dstl. Dstl/TR14504/1.0.

Voorhees, D. and Bahill, T. (1995) Parametric Sensitivity Analysis: A Tool for Robust Design. *IEEE Software.* pp. 971-982.

Waddington, M. (1999) *Assessment of Decision Analysis Methods for Trade-Off Studies in Procurement Projects*. DERA/AT&E/MC/WP0033.

Walmsley, N. and Hearn, P. (2004) Balance of Investment in Armoured Combat Support Vehicles: An Application of Mixed Integer Programming. *Journal of Operational Research Society*. 55 pp. 403-412.

Wang, C. (2001) *Measuring the Quality of Mission Oriented Research*. Airframes and Engines Division and Aeronautical and Maritime Research Laboratory. DSTO-GD-0276.

Waring, A. (1996) *Practical Systems Thinking.* International Thomson Business Press, London.

Warmington, A. (1980) Action Research: Its Methods and Its Applications. *Journal of Applied Systems Analysis.* 7 pp. 23-39.

Weinberg, G. (1975) *An Introduction to General Systems Thinking.* John Wiley & Sons, New York.

Weiner, N. (1947) *Cybernetics: or Control and Communication in the Animal and the Machine.* MIT Press, Cambridge, MA.

Weiss, S. (2004) From Stakeholder Values to Product Requirements: An Application of Quality Function Deployment Methods. *Managing Complexity and Change! INCOSE 2004 - 14th Annual International Symposium Proceedings*. Toulouse. 2004.

Westwood, E. (2001a) *R201 Final Report. Leather Seam Sealing by Molecular Design*. R&PS. RR/2001/02.

Westwood, E. (2001b) *R297 Final Report. Analysis of Hand Anthropometry Data*. R&PS. RR2001/03.

Westwood, E. (2003) *A Systems Approach to the Infantry Soldier*. MSc thesis. Cranfield University, Engineering Systems Department, Shrivenham, UK.

Wheatley, E. (1991) *MANPRINT: Human Factors in Land Systems Procurement*. Army Staff Duties.

Wheatley, E. (2001) *FIST: Human Factors: Opportunities for Pull Through From Defence Research Programmes*. Centre for Human Sciences, DERA. DERA/CHS/MID/CR010178/1.0.

White, A. and Parker, R. (1999) *Cost- Benefit Analysis Concepts for Insensitive Munitions Policy Implementation*. DSTO. DSTO-GD-0230.

Willis, R. (1982) *Models, Measures of Effectiveness and Scenario Assumptions- A Sensitivity Analysis*. Working Paper OR/WP/19.

Wilson, A., Bunting, A. and Wheatley, A. (2000) *FIST Technology Options and Infantry Performance*. DERA/CHS/PPD/TR000151.

Wilson, B. (1993) *Systems: Concepts, Methodologies and Applications.* John Wiley & Sons, Chichester. 0471927163.

Woolford, A. and Randall, T. (1997) *Future Infantry System Technology Support. May 1997 FIST Baseline Trial Interim Report*. CDA/HLS/9765/1.

Working Party of the Council for Science and Society (1986) *UK Military R&D.* Oxford University Press, Oxford.

Wright, M. (1997a) *Directions in FIST Human Performance Modelling (UKR). The Use of IPME*. DERA/CHS/HS3/CR97222/1.0.

Wright, M. (1997b) *Human Factors Input to CAEn Model Development*. DERA. DERA/CHS/H83/CR97253/1.0.

Yates, A., Vernik, R., Maheswaran, N. and Allwright, A. (1999) *Systems Characteristics and Modelling Approaches for C3I.* Information Technology Division Electronics and Surveillance Research Laboratory, Defence Science and Technology Organisation. DSTO-TR-0782.

Zairi, M. (1995) Quality Function Deployment: A Main Pillar for Successful Total Quality Management and Product Development. *International Journal of Quality and Reliability Management.* 12 (6) pp. 9-23.

APPENDIX A HFI Pick Lists

Human Factor Domain/sub group	
<u>HEALTH HAZARDS</u>	
The process of identifying and addressing conditions inherent in the operation or use of a system (e.g. vibration, toxic fumes, radiation, shock, recoil) which can cause death, injury, illness or disability).	
Noise/ vibration	
Continuous/impulse sound or vibration that causes damage to hearing or vibration injuries in the short term or long term.	
	Will the system protect the user from the effects of continuous/ impulse sound?
	Will the system need to identify the associated platform characteristics to define the protection level?
	Will the system protection levels be different depending on the role of the user?
	Will the system protect the user from defined levels of vibration?
	Will the system increase the amount of vibration entering into the user, or the way in which the vibration travels through and leaves the user?
	Will the system interact with other noise and vibration protective systems?
Toxicity	
Poisonous materials of fumes generated by equipment, capable of causing injury or	

death in the short or long-term.	
	Will the systems material properties be hazardous when exposed to heat/ flame?
	Will the systems materials properties be hazardous when exposed to defined chemicals?
	Will the systems materials properties be hazardous when exposed to specified environmental conditions?
	Will the systems materials properties be hazardous if torn or damaged through combat situations?
Electrical	
Equipment which may provide easy exposure to electrical shock.	
	Will the system be required to integrate with other electrical equipment?
	Will the system require power from an electrical source?
	Must the system protect the user from electric shock?
	Will the system house equipment that has electrical components?
Mechanical	
Exposed equipment with moving parts that are capable of causing injury.	
	Will the system contain any moving parts?
	Will the sub-systems contain any moving parts?
	Does the system design have to mitigate the likelihood of being caught within

	moving parts of associated equipment?
	Will the system need to protect the wearer from risk of injury from moving parts?
NBC	
Nuclear, biological or chemical hazards resulting from exposure to weapons.	
	Does the system need to protect the user from defined chemical threats?
	Does the system need to protect the user from defined biological threats?
	Will the system need to be disposed of after exposure to defined NBC threats?
	Will the sub-systems need to integrate to provide the required level of protection?
	Does the system need to protect the user from defined chemical hazards?
Musculoskeletal	
Tasks that adversely affect either the muscles or skeleton separately or in combination, e.g. lifting of heavy equipment, repetitive movement, G forces etc.	
	Will the system provide support to the musculoskeletal system?
	Will the system weight impact the likelihood of injury?
	Will the system protect the wearer from the effects of impact loading?
	What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?

	Will the system restrict movement, which may affect the way in which tasks are carried out e.g. manual handling?
	Will the system add a substantial amount of weight or bulk to a certain area of the user?
Heat/ cold	
Sources that provide potential hazards, either from equipment generation or scenario e.g. heat/cold.	
	Will the system protect the user from the impact of extreme physical environments?
	Will the system protect the user when operating other equipment in extreme environmental conditions?
	Will the system protect the user from fluctuations between extremes of temperature occurring within a defined operating environment?
	Does the system affect the user’s ability to thermoregulate?
	Could the system contribute to the onset of heat stress?
	How does the system affect manual dexterity?
Optical	
Equipment that is most likely to provide ocular injury, or burns caused by coherent light sources through optics.	
	Will the system protect the user from defined optical threats?

	Will the system need to interface with other equipment, which may cause an ocular threat?
	Will the system cause restriction in visual acuity?
	Does the system accommodate all optical threats or does it need to be used in conjunction with other protection?
EM radiation	
Other electromagnetic sources e.g. magnetic fields, microwaves.	
	Will the system protect the user from defined EM radiation?

Human Factor Domain/sub group	
<u>HUMAN FACTORS ENGINEERING</u>	
The comprehensive integration of human characteristics into system definition, including all aspects of workstation and workplace design and, for warships, accommodation and habitability issues.	
User system interface	
The point at which the user carries out the required tasks. The user may include the operator, maintainer or supplier. Performance factors of the interface will be physical and cognitive i.e. physical matching of the interface to the user, comprehensibility of the interface, etc.	
	Will the system affect the interface between equipment and user?
	Will the system impact the user's visual acuity?
	Can the system be easily and safely removed and stored if needed to complete a task?
Task allocation	
Matching of tasks with individuals and groups with associated performance effects on stress, fatigue, workload and motivation.	
	Will the system impair the ability of the user to carry out required tasks?

	Will the user’s ability to don and doff the system be impaired by fatigue?
	Can mission essential equipment be accessed easily within the system?
	Will the system impact the wider task allocation?
	Will the system impact the users speed of movement when fatigued?
	Will the system contribute to increased stress, fatigue, workload and decreased motivation?
Environment	
All external effects based primarily on neighbour workstations and users, also linked with scenario type and effects on clothing. Where appropriate this should include accommodation and habitability separately.	
	Will the physical environment require changes in the system configuration?
	What is the impact of the system on use of other associated equipment?
	What is the impact of the system on the storage capability of associated platforms?
	What is the impact of the system on integration with modes of deployment?
	Is the system suited to all environments or is it designed for one particular environment?

Human Factor Domain/sub group	
MANPOWER	
The number of men and women, military and civilian, required and available to operate, maintain, sustain and provide training for systems.	
	How often will the system require maintenance?
	How many people are needed to operate the system?
	Will the system need to be serviced/ reviewed or updated and if so how regularly?
	Is the system gender specific?
Phasing	
Planning and availability of people at introduction and throughout the life of the system. With emphasis not only on operation, but maintenance and support personnel.	
	Will the system be stored by the individual or by another source?
	When should the system be issued if scenario/ mission dependent?
	Will system life negatively impact cost?
	Will system life have a negative impact on re-supply?
	Will the system change the way in which the Armed services operate?
	Will system life negatively impact

	planning cycles?
	Will storage impact operational availability and mobility?
	Is the system environmentally sensitive thus affecting the operational context where it will be effective?
	How reliable is the system?
	What is the cost of system failure?
	How important is the system in the overall operational effectiveness?
Force Structure	
Allocation of tasks between branches, arms and trade groups. It also includes organisational policy (rank and responsibility), military/ civilian balance, role of reservists and the peace/war establishment.	
	Will the system be role specific?
	Can the system be consolidated for multiple roles?
	Will use of the system potentially change the Armed Forces structure?
	Will the system or part of the system require storage centrally?
	Will the system be multiple role?
	Is there a need for the system to be used for peace as well as war operations?
	Will the system be supported by civilians or by military personnel?
	Does the system have a tri-service context?
	Will the role involve interfaces with other

	platforms?
	Is the system affected by other systems, for example chemical and biological protective equipment?
Availability	
The proportion of labour resources and their demography required for all of the specified tasks involved, including operation, maintenance and support. This can be based on military, reservist and civilian personnel.	
	Will the system require high levels of maintenance?
	Will the system reduce the numbers of users required?
	Will the system require specialist maintenance?
	Will repair potentially be costly? (Financing, time constraints and man-hours required?)
Workload	
The amount of work expected to operate, maintain and support the system. Factors affecting this are the balance between manning versus shift size and task sustainability.	
	Will the system reduce the physical workload of the wearer? (Potential reduction on task difficulty).
	Will the system negatively impact the ability to carry out the task?
	Will the system increase the maintenance

	load?
	Will the system reduce the cognitive load of the wearer? (Potential reduction on task difficulty).
	Is there any reliance on other systems?
	Does the system need to work within or in conjunction with another system?
	Is the system an upgrade/modification or is it a new system that is being introduced?

Human Factor Domain/sub group	
PERSONNEL	
The aptitudes, experience and other human characteristics, including body size and strength, necessary to achieve optimum system performance.	
	Will the systems size and weight impact the end user?
Physical	
Current and future profiles including fitness levels, physical size, gender and non-typical specific requirements e.g. colour blindness.	
	Will the system require gender variances?
	Will the size of the user impact concealment characteristics of the system?
	Will the system impact the level of fitness required by new entrants?
	Will the system need to integrate with existing personal medical equipment?
	Will the physical size of the individual impact the system design?
	Will the system potentially impact young recruits when entering training?
	Is the system designed for all personnel, or for specialist trades?
Cognitive	
Current and future profiles including	

trainability and mental aptitude.	
	Will the system require and existing level of skill to operate?
	Will the system require cognitive screening of new personnel?
Recruitment and retention	
Engaging newly tasked personnel from non-similar tasked military reservist or civilian sources; or maintaining the currently tasked personnel.	
	Will the system be conceived as being at the cutting edge of technology?
	Will the system be designed in an intuitive way for easy skill transfer?
Cultural/ social factors	
Influential factors based on military and/or national culture. Expectations with regard to career prospects, ambience and aesthetics.	
	Will the system instil confidence in the wearer?
	Will the system aesthetically enhance wearer perception?
	Will the system require further instruction to ensure 'best practice' for use?
	How will acceptance be ensured within the user community?
	Will the system require labelling to ensure appropriate use?
	Will the system be issued to all personnel or just a proportion?

	Will the wearer see the system as an improvement to overall effectiveness?
	Can the system be shared between those using it or is it specific to the user?
Previous experience/ training	
Attributes that are inherent with resource pool, which will provide closer match or disparity with requirement, such as educational requirements and achievement, current trade, career pattern, knowledge of parallel systems.	
	Will the system be used in the same way as previous pieces of equipment?
	Will existing skill levels enhance system attributes?
	Will the system cause resistance due to changes in use?
	Will the system potentially enhance use of other equipment?
	Does the system represent a step change that will require new skills to be learned by experienced personnel?
Human- human interaction	
Structure of envisaged tasking roles between people, whether based on team or individual work, likely role of the personality in interaction.	
	Will the system be generic?
	Will the system have built in flexibility?
	Will the system have to accommodate other equipment in different configurations depending on the user

	role?
	Will the system be different for the higher command?
	Will the system affect communication channels?
	Will the system continue to work if elements require maintenance?
	Will the system affect the ability to recognise individuals or affect their ability to camouflage?

Human Factor Domain/sub group	
SYSTEM SAFETY	
The process of applying human factors expertise to minimise safety risks occurring as a result of the system being operated or functioning in a normal or abnormal manner.	
Error sources	
The use of a system and/or subsystems which is likely to lead to error.	
	Will the system be designed to cope with human error?
	What is the cost/impact of human error within the system?
	Will the system give the user any feedback to warn of errors?
	Will errors be easy to recognise and correct?
User behaviour	
Misuse and abuse of sub-systems which have safety implications for the user.	
	Will the system harm the user if damaged due to misuse?
	Will degradation of the system over time cause harm to the user?
	Will misuse of the system cause use of other equipment to become dangerous to the safety of the user?
	Will sub-systems cause harm to the user if damaged due to misuse?

Surroundings	
External and environmental conditions which have safety implications for the user or third party.	
	Will the system when placed in the physical environment cause potential harm to the user?
	Will the system protect the user from potential harm in all environmental conditions?
	Will the systems material construction be affected by the physical environment?
	Will the system performance be affected by the physical environment?
	Will the system protect the user when interfacing with other platforms?
	Will the system protect the wearer from all specified threats?

Human Factor Domain/sub group	
<u>TRAINING</u>	
Specification and evaluation of the optimum combination of: instructional systems, education and on the job training required to develop the knowledge, skills and abilities needed by the available personnel to operate and maintain systems to the specified level of effectiveness.	
	Is training needed in the maintenance equipment?
	How many people will be required to maintain the system?
	Will training time impact system delivery?
Legacy Transfer	
Main or sub systems that require switch between different styles of operation. This could be due to multiple style sub-systems or retrofit or differently styled sub-systems. ‘de-skilling’ can occur when basic functions are automated.	
	Will the system be used in the same way as previous pieces of equipment?
	Will the system change the way that other pieces of equipment are used?
	Will the introduction of new sub-systems at a later date affect the overall system training/performance?
	Can a transfer of skill occur?

	Is there scope for mistakes to be made due to similarities in system design, but differences in functionality?
Type	
Mix of training technologies and effect on performance, such as synthetic environment, computer based war gaming, battlefield war gaming etc. Use of individual versus group sessions. Use of instructors with actual experience versus simulated experience. Definition of standards and fidelity of performance.	
	Will previous experience of the user impact the delivery of training?
	Does the system require introduction at recruit training stage?
	What impact will changes in the system have on delivery of training material?
	What training literature will need to accompany the system?
	How will the training interfaces with other platforms be managed?
	Who will manage and update the training literature?
	Should system training become embedded in basic training?
	Will there be consistency within the training technologies, for example set procedures, icons, symbols and overriding methodologies?
	How is each training technology presented? Is it possible to combine or

	inter-link any training?
	When does the training for the system need to take place? Does any other training need to be completed first?
Availability	
Timing and proportion of initial training and continuation for new and existing personnel. Therefore requiring facilities of correct type and size. Minimisation of training 'bottleneck'.	
	At what point should the training providers be taught delivery of the new system?
	Is there a need to check on the implementation of the training programme?
	Will there be a requirement for different tiers of training depending on specialism?
	Will there be a requirement for specialist personnel for certain subsystems?
	Who is carrying out the training?
	Once trained can personnel train other personnel?
	Does training need to be reviewed and checked after a certain period of time?

APPENDIX B Analysis data pack guidance

ANALYSIS DATAPACK OPERATIONAL CLOTHING AND TEXTILES PROGRAMME SUGGESTED CONTENTS[13].

The following elements will need to be drawn together in a coherent package with a logical thread for the design team to follow.

BACKGROUND

This is really a scene setting exercise so that the design team are not coming into the process cold. They need to have confidence in the validity of the data that they are working with as well as the rationale for the approach. Background should include:

- The intent of the programme of work
- The link to the five NATO capability domains
- The quantitative input to the analysis process (highlight the OA to ensure they appreciate the validity of the process)
- The types of SMEs involved in the qualitative input

SUPPORTING DOCUMENTS

There are two key supporting documents that the design team will require to provide context to the analysis work:

1. Working paper on Operational Clothing and Textiles Equipment Baselines.
    - This will need to be checked for current completeness and should also be cross-referenced with the DC IPT database contained within the capability database as that has information on current projects and elements of kit that have been updated or been brought in as a UOR.

---

[13] This guidance forms part of a package of consultancy work provided to Dstl under contract number Z30578V

2. Research Concept Systems Requirement Document
    - This provides all of the background to the systems analysis and presents the key statements in a more standard requirement form (i.e. "the system shall….."). It should be checked to see if it is still up-to-date. Also it must be remembered that it does not include level 6 of the matrix as this varies depending on the system perspective.

OTHER SUPPORTING INFORMATION

- From the capability database you will need to supply information on platforms and interfaces with other equipment. One of the relevant documents will be the Soldier Systems Integration authority database that has all of the key interfaces and dependencies for FIST.
- From the capability database, information on the personnel that will be using the system is another important underpinning piece of information.

ANALYSIS OUTPUT

There will be a need to provide the output from the systems analysis as per the final report. This will need relevant supporting explanation and embellishment to make sure it is user friendly. In the first instance, I would be inclined not to put the rankings against the statements as there is a fear that it will overly constrain the design team's creativity.

It will be necessary to provide the inter-linkages at level 4 of the matrix (the matrix hat) as key statements that have been identified will have far wider implications.

The initial concepts are likely to be quite similar in level of detail to those from the survivability study. At this stage the process should still be a paper exercise with the potential concepts being run back through the matrix analysis to look at their wider impact. This would occur from level 5 down with the concepts replacing the 'capability enhancement requirements' used in layer one of the analysis.

In parallel with the design entity work, the systems team will need to be working on the performance bounds for the system. These will be used for subsequent iterations of the concept generation and form the basis for trade-off decisions. There will be a need for customer interaction from the beginning of this task as 'buy in' will be essential. The over-arching performance bounds can be found at level 3 of the matrix, in addition to further detail as part of the Research Concept System Requirement Document. Some of these bounds will be driven by legislation, but a number will be based on future threat, scenarios, tasks and activities as per the operational analysis input.

The capability database can be used to underpin the decisions made with upper and lower bounds identified within which trade-off can occur. This will help to constrain subsequent iterations of the concept design.

SUBSEQUENT CONCEPT ITERATIONS

As greater detail is achieved it will be necessary to provide further information to the design team. This is likely to take the form of a concept specification. A lot of the background detail will be found in the capability database e.g. relevant standards for testing of fabrics. The specification will start to form the basis of any contract for further development to much higher technology readiness levels.

The more detailed concepts could be considered for an operational analysis study to help in further down selection and to provide more quantitative evidence for later scrutiny. This part of the process is very iterative in nature.

CONCLUSIONS

In essence there are varying levels of detail that will need to be provided to the design team at different stages within the concept generation process. It is important to note that the requirements for industry to produce concepts will necessitate more detail to be provided by Dstl and a far closer working relationship to be maintained. It is suggested that a dedicated point of contact is established to ensure effective management of this task.

Blank Page

APPENDIX C Matrix scoring guidance document

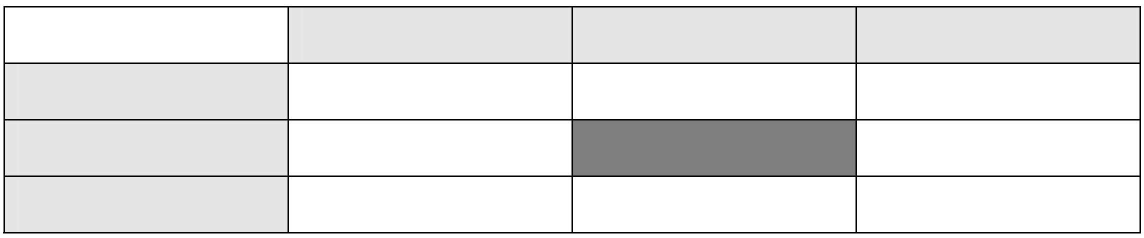
Matrix Scoring Accompanying Notes

The scoring session that you have been invited to is the next step in the systems analysis which intends to understand the design challenges for future soldier systems (2020 timeframe). This will allow trade-off decisions to be made across the domains to ensure that overall soldier effectiveness is enhanced.

These notes explain the purpose of the scoring and help those that have been invited to be aware of what is expected prior to embarking on scoring. The process of scoring should be short, which is one of the strengths of using this type of matrix approach. To ensure robustness a number of statistical tests are applied after the matrices are returned, but the only thing that those involved need worry about is answering the questions based upon individual knowledge and experience. All of the answers will be pooled together and the most common response taken forward.

The matrices themselves have several levels, which allows the information to cascade down from high level doctrine to lower level more technical detail. The top levels involving military doctrine are scored independently, with the technical levels being the focus for this exercise.

The matrix presents the individual with two sets of information within a grid.



The light grey shading depicts where the statements are placed; for instance environmental protection may be one of the boxes on the left-hand side. Along the top is another set of statements for instance anthropometric measures (fit). The point where the two intersect (depicted by the dark grey box) is where the score should be placed. The score is broken into five levels:

9- Very strong relationship

3- Significant relationship

1- Some relationship

0- Definitely no relationship

Space (appears as ' in the list) - Cannot comment on relationship (either through lack of understanding of the question or lack of familiarity with the area of interest)

The scorer has to decide the level of relationship that the two statements have to one another for the purposes of defining a soldier system in the context of the domain being scored (e.g. lethality). Using the previously mentioned example, what level of relationship exists between environmental protection and fit in the context of lethality? Well, it could be suggested that there is a strong relationship between fit and environmental protection, not only because there may be multiple layers to consider, but also, that in hot climates, design and fit can aid the individual (e.g. the bellows affect). However, is there still a strong relationship if related to lethality? The suggestion is that fit is important, but not necessarily in the context of environmental protection, as lethality does not have a direct relationship. This is just one example, and may be argued.

This type of scoring is carried out at a number of levels with different statements that cascade to show links between layers of statements. The intent of each of the layers is described below to aid the scoring process.

- <u>Level 1</u>

  This is the very highest level of the matrix cascade and is scored by military personnel from the three services. It takes the seven defence missions as part of British military doctrine and looks at their relationship against the operational and strategic tasks of the Armed Forces. These are taken from the Joint Essential Task

List to ensure a Tri-service context (although work to-date is focused on the land domain).

- <u>Level 2</u>

This level takes the operational and strategic tasks from the first level and identifies where relationships exist between these statements and 'Land Domain User Requirements'. It is important not to assign too much relevance to the titles of the various levels, as they do not have classical systems engineering meaning attached to them. The land domain user requirements identify the high level issues for land, taken from the FIST user requirements document (but amended to make them more generic in nature). The intent is to ensure commonality across programmes with the fundamental requirements for FIST still having applicability in the timeframe of interest (2020). FIST will also represent a significant legacy component of any future systems designed. The statements are separated into capability domains with the intent of scoring the relationship between the land domain statements and the operational and strategic tasks in the context of the domain being scored e.g. lethality. An example may be the relationship between provision of defence against weapons systems and operational availability in a lethality context. It could be suggested that the availability of lethality in defence against weapons systems is a very strong relationship, and as such should have a score of 9.

- <u>Level 3</u>

This level takes the land domain user requirements and identifies where relationships exist between these statements and 'Generic Requirements'. The generic requirements reflect the areas that will impact the design of the soldier system. When the more detailed designs are considered in the later stages of the programme these statements will have performance bounds attached to them. Many are driven by legislation and will require conformance, for instance hearing protection. These may well become key system level requirements that cannot be traded. This is however a separate element of work which is running in parallel to the matrix scoring. The intent at this level is to score the relationship between the land domain user requirements and the generic requirements. An example may be the relationship between the ability to access loads whilst moving, according to tactical demands and overloading of the man in the context of lethality. It could be suggested that there is a relationship as some form of ammunition will most likely be required for any lethality option. This will need to be accessed when involved in combat and will have a weight associated with it. The level of relationship will depend upon the individual SME.

- Level 4

This level takes the generic requirements and identifies where relationships exist between these statements and 'System Requirements'. The system requirements are very high level issues reflecting design challenges broken out into the five NATO capability domains. They are not concerned with solution specific issues instead focusing on the overarching design considerations. The intent at this level is to score the relationship between the generic requirements and the system requirements. An example may be the relationship between integration with existing medical equipment e.g. glasses, and protection against detection, within the thresholds for thermal imaging, in the context of lethality. It may be suggested that there is a relationship if lethality requires some form of sighting system. The person may be easier to detect if they have to use a sighting system for longer because they are struggling to use the sight because of glasses? It is one viewpoint that could be applied. Not all statements will be applicable for all of the capability domains. It is important to always consider the domain context, as issues will be captured across various capability domains, which then form part of the trade-off. There is not a necessity to fill every box if it is not applicable.

- Level 5

This level represents the fusion between SME input and more quantitative input from either trials data or operational analysis. It takes the system requirements from the level above and identifies where relationships exist between these statements and the 'high level requirements'. These high level requirements are defined specifically for the domain that is being scored e.g. lethality or sustainability. The statements are as a result of investigating representative scenarios, threats and tasks and activities in conjunction with user perceived deficiencies. Therefore they also cover areas such as training and fit, if this has been highlighted as a problem by the user community. An example may be the relationship between instilling confidence in the wearer and providing enhanced range lethality. It may be suggested that this has a strong relationship as the person will feel more confident based on the distance to engage the enemy.

- <u>Level 6</u>

This level deals with the wider issues such as logistics and manpower. It starts to identify where risks exist in delivery of the high level requirements. It takes the high level requirements from the level above and identifies where relationships exist between these statements and the HFI domain statements. The HFI statements have been generated within the categories developed by the Defence Procurement Agency. As before, the intent is to ensure commonality with other agencies and programmes wherever possible. The list is tailored for each domain using a larger selection of statements. An example may be the relationship between enhanced range lethality and the need to integrate with other pieces of equipment. This may be suggested to have a relatively strong relationship as no piece of equipment is generally used in isolation.

This concludes the levels required to be scored. It is then the responsibility of the systems team to co-ordinate the output and ensure that relevant sensitivity analysis has been conducted.

Blank Page

APPENDIX D Blank matrices

Level 1 High level military tasks/ High level military functions

Level 1

High level missions of the Armed Forces	Initial Weight	The Strategic and Operational tasks which represent the high level military functions: Deploy and Recover								Shape				Conduct						
		Move forces to/from theatre of operations	Establish lines of communication	Construct a movement plan	Conduct intra theatre movement	Conduct tactical movement	Monitor battlespace management	Conduct tactical manoeuvre	Conduct support operations	Plan and direct own force disposition	Implement information operations	Co-ordinate with other national/international organisations	Provide counter mobility	Control/dominate operationally significant areas	Support civil authorities	Peace support operations	Plan joint targeting force	Non-combatant evacuation procedures	Attack targets	Conduct information operations
Peacetime Security	0.125																			
Security of the overseas territories	0.125																			
Defence Diplomacy	0.125																			
Support to wider British interests	0.125																			
Peace support & humanitarian operations	0.125																			
Regional conflict and crisis	0.125																			
Regional aggression against NATO	0.125																			
Strategic attack on NATO	0.125																			
Raw Technical Importance	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
Normalised Technical Importance		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

High level missions of the Armed Forces	Protect						Sustain							
	Provide defence against weapons systems	Co-ordinate survival and control measures	Force protection	Provide physical protection	Provide personal security measures	Co-ordinate force security	Conduct logistics support	Conduct equipment support	Provide personnel support	Conduct medical support	Establish forward bases	Maintain field records	Raw technical importance	Normalised technical importance
Peacetime Security													0	#DIV/0!
Security of the overseas territories													0	#DIV/0!
Defence Diplomacy													0	#DIV/0!
Support to wider British interests													0	#DIV/0!
Peace support & humanitarian operations													0	#DIV/0!
Regional conflict and crisis													0	#DIV/0!
Regional aggression against NATO													0	#DIV/0!
Strategic attack on NATO													0	#DIV/0!
Raw Technical Importance	0	0	0	0	0	0	0	0	0	0	0	0	0	
Normalised Technical Importance	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

Level 2 High level military functions/ C&T user requirements

Level 2		Initial Weight	Soldier Modernisation User Requirements (C&T Context)																					
			Over Arching			Sustainability			Mobility				Survivability		C4I						Lethality			
The Strategic and Operational tasks which represent the high level military functions			mission effectiveness of the individual	Individuals level of performance in all environments	Equipment availability for training	Ability to conduct operations within defined notice periods	Operational availability of the system	Ability to store personal supplies for the duration of the mission	Ability to access loads whilst moving, according to tactical demands	Ability to conduct operations at a faster rate than baseline	Ability to carry loads appropriate to mission completion	Ability to move over ground at a rate commensurate with the tactical situation	Survivability of the individual	Ability to detect the individual at a specified range	Ability to acquire, manage and exploit information at a rate comensurate with baseline	Provision of situational awareness (SA) commensurate with the role, area of interest and tactical situation	Ability to find targets at ranges commensurate to the role, area of interest and tactical situation	Ability to determine location at a rate commensurate with ther tactical situation	Provision of spatial awareness commensurate with the role and area of interest	Ability to manoeuvre accurately, commensurate with the tactical situation	Ability to supress targets within areas of influence	Ability to incapacitate targets within areas of interest	Raw technical importance	Normalised technical importance
Move forces to/from theatre of operations	Deploy and recover	#DIV/0!																					#DIV/0!	#DIV/0!
Establish lines of communication		#DIV/0!																					#DIV/0!	#DIV/0!
Construct a movement plan		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct intra theatre movement		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct tactical movement		#DIV/0!																					#DIV/0!	#DIV/0!
Monitor battlespace management		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct tactical manoeuvre		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct support operations		#DIV/0!																					#DIV/0!	#DIV/0!
Plan and direct own force disposition	Shape	#DIV/0!																					#DIV/0!	#DIV/0!
Implement information operations		#DIV/0!																					#DIV/0!	#DIV/0!
Co-ordinate with other national/international organisations		#DIV/0!																					#DIV/0!	#DIV/0!
Provide counter mobility		#DIV/0!																					#DIV/0!	#DIV/0!
Control/dominate operationally significant areas	Conduct	#DIV/0!																					#DIV/0!	#DIV/0!
Support civil authorities		#DIV/0!																					#DIV/0!	#DIV/0!
Peace support operations		#DIV/0!																					#DIV/0!	#DIV/0!
Plan joint targeting force		#DIV/0!																					#DIV/0!	#DIV/0!
Non-combatant evacuation procedures		#DIV/0!																					#DIV/0!	#DIV/0!
Attack targets		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct information operations		#DIV/0!																					#DIV/0!	#DIV/0!
Provide defence against weapons systems	Protect	#DIV/0!																					#DIV/0!	#DIV/0!
Co-ordinate survival and control measures		#DIV/0!																					#DIV/0!	#DIV/0!
Force protection		#DIV/0!																					#DIV/0!	#DIV/0!
Provide physical protection		#DIV/0!																					#DIV/0!	#DIV/0!
Provide personal security measures		#DIV/0!																					#DIV/0!	#DIV/0!
Co-ordinate force security		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct logistics support	Sustain	#DIV/0!																					#DIV/0!	#DIV/0!
Conduct equipment support		#DIV/0!																					#DIV/0!	#DIV/0!
Provide personnel support		#DIV/0!																					#DIV/0!	#DIV/0!
Conduct medical support		#DIV/0!																					#DIV/0!	#DIV/0!
Establish forward bases		#DIV/0!																					#DIV/0!	#DIV/0!
Maintain field records		#DIV/0!																					#DIV/0!	#DIV/0!
Raw Technical Importance			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
Normalised Technical Importance			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

Level 3 C&T user requirements/ Generic requirements

Level 3														
		Initial Weight	Generic Requirements											
Clothing and Textiles User Requirements			Protection from environmental categories as defined in DEF-STAN 00-35 Part 4	Protection from defined biological and chemical agents	Protection from a defined level of fragmentation and bullet type	Conformance to legislation and standards (Hearing)	Conformance to legislation and standards (Vision)	Conformance to legislation and standards (Flame)	Protection against defined levels of directed energy threat in relation to the eyes	Protection against detection within the thresholds for Thermal Imaging	Protection against detection within the thresholds for Infra red	Protection against overloading (man)	Raw technical importance	Normalised technical importance
mission effectiveness of the individual	Over arching	#DIV/0!											#DIV/0!	#DIV/0!
Individuals level of performance in all environments		#DIV/0!											#DIV/0!	#DIV/0!
Equipment availability for training		#DIV/0!											#DIV/0!	#DIV/0!
Ability to conduct operations within defined notice periods	Sustainability	#DIV/0!											#DIV/0!	#DIV/0!
Operational availability of the system		#DIV/0!											#DIV/0!	#DIV/0!
Ability to store personal supplies for the duration of the mission		#DIV/0!											#DIV/0!	#DIV/0!
Ability to access loads whilst moving, according to tactical demands	Mobility	#DIV/0!											#DIV/0!	#DIV/0!
Ability to conduct operations at a faster rate than baseline		#DIV/0!											#DIV/0!	#DIV/0!
Ability to carry loads appropriate to mission completion		#DIV/0!											#DIV/0!	#DIV/0!
Ability to move over ground at a rate commensurate with the tactical situation		#DIV/0!											#DIV/0!	#DIV/0!
Survivability of the individual	Survivability	#DIV/0!											#DIV/0!	#DIV/0!
Ability to detect the individual at a specified range		#DIV/0!											#DIV/0!	#DIV/0!
Ability to acquire, manage and exploit information at a rate comensurate with baseline	C4I	#DIV/0!											#DIV/0!	#DIV/0!
Provision of situational awareness (SA) commensurate with the role, area of interest and tactical situation		#DIV/0!											#DIV/0!	#DIV/0!
Ability to find targets at ranges commensurate to the role, area of interest and tactical situation		#DIV/0!											#DIV/0!	#DIV/0!
Ability to determine location at a rate commensurate with ther tactical situation		#DIV/0!											#DIV/0!	#DIV/0!
Provision of spatial awareness commensurate with the role and area of interest		#DIV/0!											#DIV/0!	#DIV/0!
Ability to manoeuvre accurately, commensurate with the tactical situation		#DIV/0!											#DIV/0!	#DIV/0!
Ability to supress targets within areas of influence	Lethality	#DIV/0!											#DIV/0!	#DIV/0!
Ability to incapacitate targets within areas of interest		#DIV/0!											#DIV/0!	#DIV/0!
Raw Technical Importance			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
Normalised Technical Importance			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

Level 4 Generic requirements/ C&T system requirements

Level 4																													
	Initial Weight	Over Arching					Survivability					Sustainability											Mobility						
Generic Requirements		Accommodate 5-95 percentile anthropometric range	Be capable of being laundered in accordance with available facilities	Be capable of repair	Impact of individual variance on the design of the equipment	Conform to British Standards for wear testing	Impact of radiant heat on detection of the individual from surveillance equipment	Be capable of being donned and doffed within a prescribed time	Allow access to equipment whilst carrying out mission essential tasks	Impact on the situational awareness of the individual	Instil confidence in the wearer	Creation of sweat whilst being used	Impact on the tactility and dexterity of the wearer	Allow storage of commodities required for sustainment of the individual	Take into account the impact of being worn for prolonged periods of time	Potential heat burden to the wearer	Likelihood of bacterial growth	Impact of layers on the positioning of fasteners and closures	Allow adjustment to create a 'best fit' for the wearer	Allow for integration with existing medical equipment e.g. glasses	Energy cost to the wearer	Allow sustainment to be taken whilst wearing	Load on the biological structures of the body	Ensure physical stability of the individual whilst carrying load	Range of movement	Speed of movement	Physical limits beyond which injury will be caused to the wearer	Raw technical importance	Normalised technical importance
Protection from environmental categories as defined in DEF-STAN 00-35 Part 4	#DIV/0!																											#DIV/0!	#DIV/0!
Protection from defined biological and chemical agents	#DIV/0!																											#DIV/0!	#DIV/0!
Protection from a defined level of fragmentation and bullet type	#DIV/0!																											#DIV/0!	#DIV/0!
Conformance to legislation and standards (Hearing)	#DIV/0!																											#DIV/0!	#DIV/0!
Conformance to legislation and standards (Vision)	#DIV/0!																											#DIV/0!	#DIV/0!
Conformance to legislation and standards (Flame)	#DIV/0!																											#DIV/0!	#DIV/0!
Protection against defined levels of directed energy threat in relation to the eyes	#DIV/0!																											#DIV/0!	#DIV/0!
Protection against detection within the thresholds for Thermal Imaging	#DIV/0!																											#DIV/0!	#DIV/0!
Protection against detection within the thresholds for Infra red	#DIV/0!																											#DIV/0!	#DIV/0!
Protection against overloading (man)	#DIV/0!																											#DIV/0!	#DIV/0!
Raw Technical Importance		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
Normalised Technical Importance		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

Level 5 System requirements/ High level requirements

Level 5											
		Initial Weight	High Level Requirements								
System Requirements			The scale of issue should be appropriate to operational tasks and activities	To reduce replacement time of kit in theatre (mean time to repair)	To provide correctly sized clothing and equipment	To improve guidance to commanders on scale of provisions required for all operating environments	Supply adequate resources to meet mission need and levels of expenditure (prior and during combat)	Minimise degradation in human performance from carriage of load (prior and during combat)	Prevent and/or minimise incapacitating injuries from carriage of load (prior and during combat)	Raw technical importance	Normalised technical importance
Accommodate 5-95 percentile anthropometric range	Over arching	#DIV/0!								#DIV/0!	#DIV/0!
Be capable of being laundered in accordance with available facilities		#DIV/0!								#DIV/0!	#DIV/0!
Be capable of repair		#DIV/0!								#DIV/0!	#DIV/0!
Impact of individual variance on the design of the equipment		#DIV/0!								#DIV/0!	#DIV/0!
Conform to British Standards for wear testing		#DIV/0!								#DIV/0!	#DIV/0!
Impact of radiant heat on detection of the individual from surveillance equipment	Survivability	#DIV/0!								#DIV/0!	#DIV/0!
Be capable of being donned and doffed within a prescribed time		#DIV/0!								#DIV/0!	#DIV/0!
Allow access to equipment whilst carrying out mission essential tasks		#DIV/0!								#DIV/0!	#DIV/0!
Impact on the situational awareness of the individual		#DIV/0!								#DIV/0!	#DIV/0!
Instil confidence in the wearer		#DIV/0!								#DIV/0!	#DIV/0!
Creation of sweat whilst being used	Sustainability	#DIV/0!								#DIV/0!	#DIV/0!
Impact on the tactility and dexterity of the wearer		#DIV/0!								#DIV/0!	#DIV/0!
Allow storage of commodities required for sustainment of the individual		#DIV/0!								#DIV/0!	#DIV/0!
Take into account the impact of being worn for prolonged periods of time		#DIV/0!								#DIV/0!	#DIV/0!
Potential heat burden to the wearer		#DIV/0!								#DIV/0!	#DIV/0!
Likelihood of bacterial growth		#DIV/0!								#DIV/0!	#DIV/0!
Impact of layers on the positioning of fasteners and closures		#DIV/0!								#DIV/0!	#DIV/0!
Allow adjustment to create a 'best fit' for the wearer		#DIV/0!								#DIV/0!	#DIV/0!
Allow for integration with existing medical equipment e.g. glasses		#DIV/0!								#DIV/0!	#DIV/0!
Energy cost to the wearer		#DIV/0!								#DIV/0!	#DIV/0!
Allow sustainment to be taken whilst wearing		#DIV/0!								#DIV/0!	#DIV/0!
Load on the biological structures of the body	Mobility	#DIV/0!								#DIV/0!	#DIV/0!
Ensure physical stability of the individual whilst carrying load		#DIV/0!								#DIV/0!	#DIV/0!
Range of movement		#DIV/0!								#DIV/0!	#DIV/0!
Speed of movement		#DIV/0!								#DIV/0!	#DIV/0!
Identify the physical limits beyond which injury will be caused to the wearer		#DIV/0!								#DIV/0!	#DIV/0!
Raw Technical Importance			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
Normalised Technical Importance			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

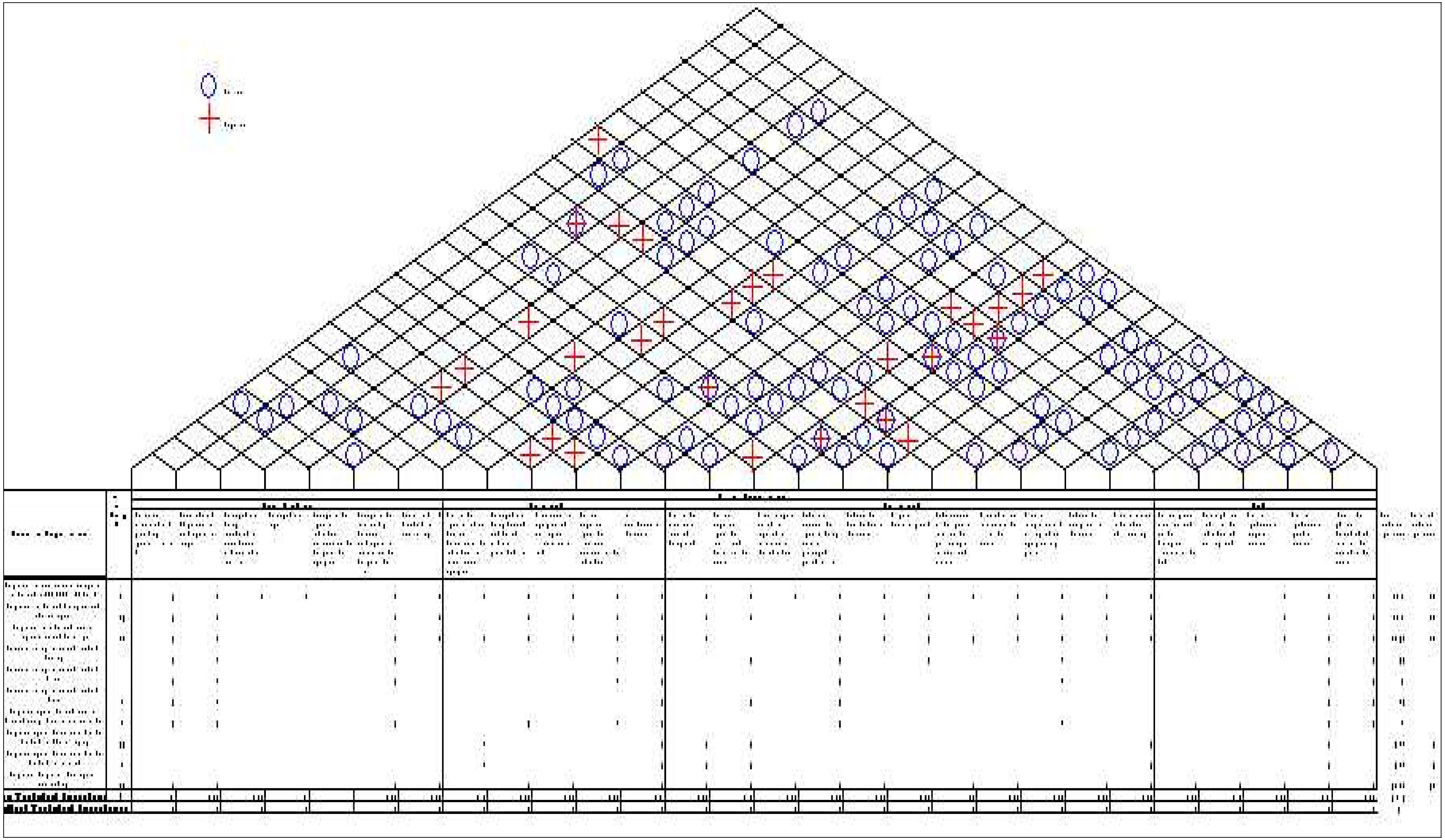
Level 6 Weighted requirements/ HFI shortlist

Level 6

		Human Factors Domains Short List																
	Initial Weight	Manpower									Personnel				Safety	Training		
High Level Requirements		Will the system be mission dependant?	Will system life have a negative impact on re-supply?	Will storage impact operational availability and mobility?	Is the system environmentally sensitive thus affecting the operational context where it will be effective?	Will the system be supported by civilians or by military personnel?	Will the system negatively impact the ability to carry out the task?	Does the system need to work within or in conjunction with another system?	Is there a need for the system to be used for peace as well as war operations?	Is the system affected by other systems, for example chemical and biological protective equipment?	Will the systems size and weight impact the end user?	Will the system potentially impact young recruits when entering training?	Will the system instil confidence in the wearer?	Will the system have to accommodate other equipment in different configurations depending on the user role?	Will the system protect the use from potential harm in all environmental conditions?	Will the system change the way that other pieces of equipment are used?	Does the system require introduction at recruit training stage?	Will systems training be embedded in basic training?
The scale of issue should be appropriate to operational tasks and activities	#DIV/0!																	
To reduce replacement time of kit in theatre (mean time to repair)	#DIV/0!																	
To provide correctly sized clothing and equipment	#DIV/0!																	
To improve guidance to commanders on scale of provisions required for all operating environments	#DIV/0!																	
Supply adequate resources to meet mission need and levels of expenditure (prior and during combat)	#DIV/0!																	
Minimise degradation in human performance from carriage of load (prior and during combat)	#DIV/0!																	
Prevent and/or minimise incapacitating injuries from carriage of load (prior and during combat)	#DIV/0!																	
Raw Technical Importance		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Normalised Technical Importance		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

	Human Factors Engineering						Health Hazard									
High Level Requirements	Will the system impair the ability of the user to carry out required tasks?	Will the system impact the users speed of movement when fatigued?	Will the physical environment require changes in the system configuration?	Will the system impact use of associated equipment?	Will the system impact integration with modes of transport?	Will the system impact storage capacity of associated platforms?	Will the system require power from an electrical source?	Will the system need to be disposed of after exposure to defined NBC threats?	Will the system weight impact the likelihood of injury?	Will the combination of sub systems have an impact on musculoskeletal loading rate?	Will the system restrict movement, which may affect the way in which tasks are carried out e.g. manual handling?	Will the system add a substantial amount of weight or bulk to a certain area of the user?	Will the system protect the user from the impact of extreme physical environments?	Will the system protect the user when operating other equipment in extreme environmental conditions?	Raw technical importance	Normalised technical importance
The scale of issue should be appropriate to operational tasks and activities															#DIV/0!	#DIV/0!
To reduce replacement time of kit in theatre (mean time to repair)															#DIV/0!	#DIV/0!
To provide correctly sized clothing and equipment															#DIV/0!	#DIV/0!
To improve guidance to commanders on scale of provisions required for all operating environments															#DIV/0!	#DIV/0!
Supply adequate resources to meet mission need and levels of expenditure (prior and during combat)															#DIV/0!	#DIV/0!
Minimise degradation in human performance from carriage of load (prior and during combat)															#DIV/0!	#DIV/0!
Prevent and/or minimise incapacitating injuries from carriage of load (prior and during combat)															#DIV/0!	#DIV/0!
Raw Technical Importance	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Normalised Technical Importance	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	

APPENDIX E Level 4 matrix 'hat'



Blank Page

APPENDIX F Survivability sensitivity analysis (Sparks, 2004d)

Impact of changes to the scoring convention

	0,3,9		1,3,5		1,3,7		1,3,9	
	Key	Important	Key	Important	Key	Important	Key	Important
Level 1	Plan and direct own force disposition		Plan and direct own force disposition		Plan and direct own force disposition		Plan and direct own force disposition	
Level 1	Implement information operations		Implement information operations		Implement information operations		Implement information operations	
Level 1	Co-ordinate with other national/international organisations		Co-ordinate with other national/international organisations		Co-ordinate with other national/international organisations		Co-ordinate with other national/international organisations	
Level 1	Provide personnel support		Provide personnel support		Provide personnel support		Provide personnel support	
Level 1	Conduct medical support		Conduct medical support		Conduct medical support		Conduct medical support	
Level 2	The user shall be able to conduct operations within defined notice periods	The user shall be able to conduct operations efficiently at a faster rate than baseline	The user shall be able to conduct operations within defined notice periods	The mission effectiveness of individuals shall be enhanced in all environments	The user shall be able to conduct operations within defined notice periods	The mission effectiveness of individuals shall be enhanced in all environments	The user shall be able to conduct operations within defined notice periods	The user shall be able to carry loads appropriate to completing the mission
Level 2	The system shall have a high level of operational availability	The user shall be able to carry loads appropriate to completing the mission	The system shall have a high level of operational availability	The individuals performance shall be enhanced in all environments	The system shall have a high level of operational availability	The individuals performance shall be enhanced in all environments	The system shall have a high level of operational availability	
Level 2		The user shall be able to move over ground at a rate commensurate with the tactical situation	The user shall have significantly improved survivability		The user shall have significantly improved survivability	The user shall be able to conduct operations efficiently at a faster rate than baseline	The user shall have significantly improved survivability	
Level 2		The user shall have significantly improved survivability				The user shall be able to carry loads appropriate to completing the mission		
Level 2						The user shall be able to move over ground at a rate commensurate with the tactical situation		
Level 3	To protect from environmental categories as defined in DEF-STAN 00-35 Part 4		To protect from environmental categories as defined in DEF-STAN 00-35 Part 4		To protect from environmental categories as defined in DEF-STAN 00-35 Part 4		To protect from environmental categories as defined in DEF-STAN 00-35 Part 4	
Level 3	To protect from defined biological and chemical agents		To protect from defined biological and chemical agents		To protect from defined biological and chemical agents		To protect from defined biological and chemical agents	
Level 3	To protect from a defined level of fragmentation and bullet type		To protect from a defined level of fragmentation and bullet type		To protect from a defined level of fragmentation and bullet type		To protect from a defined level of fragmentation and bullet type	
Level 4	Accommodate 5-95 percentile anthropometric range		Accommodate 5-95 percentile anthropometric range		Accommodate 5-95 percentile anthropometric range	Minimise the creation of sweat whilst being used	Accommodate 5-95 percentile anthropometric range	
Level 4	Allow access to equipment whilst carrying out mission essential tasks		Allow access to equipment whilst carrying out mission essential tasks		Allow access to equipment whilst carrying out mission essential tasks	Reduce the heat burden to the wearer	Allow access to equipment whilst carrying out mission essential tasks	
Level 4	Reduce the energy cost to the wearer		Reduce the energy cost to the wearer		Reduce the energy cost to the wearer		Reduce the energy cost to the wearer	
Level 4	Minimise impedance of range of movement		Minimise impedance of range of movement		Minimise impedance of range of movement		Minimise impedance of range of movement	
Level 4	Minimise impedance of speed of movement		Minimise impedance of speed of movement		Minimise impedance of speed of movement		Minimise impedance of speed of movement	

Level 5	Enhanced High Velocity Bullet protection		Enhanced High Velocity Bullet protection		Enhanced High Velocity Bullet protection		Enhanced High Velocity Bullet protection	
	Enhanced fragmentation protection		Enhanced fragmentation protection		Enhanced fragmentation protection		Enhanced fragmentation protection	
	Improved body coverage		Improved body coverage		Improved body coverage		Improved body coverage	
Level 6	How important is the system in the overall operational effectiveness?	Will the system weight impact the likelihood of injury?	How important is the system in the overall operational effectiveness?	Will the system be multiple role?	How important is the system in the overall operational effectiveness?	Will the system weight impact the likelihood of injury?	How important is the system in the overall operational effectiveness?	Will the system weight impact the likelihood of injury?
	Does the system affect the users ability to thermoregulate?	Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling	Will the system impair the ability of the user to carry out required tasks?	Will the system impair the ability of the user to carry out required tasks?	Does the system affect the users ability to thermoregulate?	Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling	Does the system affect the users ability to thermoregulate?	Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling
	Could the system contribute to the onset of heat stress?	Will the system add a substantial amount of weight or bulk to a certain area of the user?	Could the system contribute to the onset of heat stress?	Will the system weight impact the likelihood of injury?	Could the system contribute to the onset of heat stress?	Will the system add a substantial amount of weight or bulk to a certain area of the user?	Could the system contribute to the onset of heat stress?	Will the system add a substantial amount of weight or bulk to a certain area of the user?
				Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling				
				Will the system add a substantial amount of weight or bulk to a certain area of the user?				
Concepts Level 5	Frog suit integrated option		Frog suit integrated option	Passive camouflage with current CBA	Frog suit integrated option	Passive camouflage with current CBA	Frog suit integrated option	Passive camouflage with current CBA
	Enhanced fragmentation protection		Enhanced fragmentation protection		Enhanced fragmentation protection		Enhanced fragmentation protection	
	Active camouflage with current CBA		Active camouflage with current CBA		Active camouflage with current CBA		Active camouflage with current CBA	
	Light weight EOD style option		Light weight EOD style option		Light weight EOD style option		Light weight EOD style option	
Concepts Level 6	What is the cost of system failure?	Will the system reduce physical workload of the wearer?	What is the cost of system failure?	Will the system impact the users speed of movement when fatigued?	What is the cost of system failure?	Will the system impact the users speed of movement when fatigued?	What is the cost of system failure?	Will the system reduce physical workload of the wearer?
	Is the system an upgrade/ modification or is it a new system that is being introduced?	Will the system impact the users speed of movement when fatigued?	Will the system reduce physical workload of the wearer?	Will the system contribute to increased stress, fatigue, workload and decreased motivation?	Will the system reduce physical workload of the wearer?	Will the system contribute to increased stress, fatigue, workload and decreased motivation?	Is the system an upgrade/ modification or is it a new system that is being introduced?	Will the system impact the users speed of movement when fatigued?
	Will the system require labelling to ensure appropriate use?	Will the system contribute to increased stress, fatigue, workload and decreased motivation?	Is the system an upgrade/ modification or is it a new system that is being introduced?	What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?	Is the system an upgrade/ modification or is it a new system that is being introduced?	What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?	Will the system require labelling to ensure appropriate use?	Will the system contribute to increased stress, fatigue, workload and decreased motivation?
		What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?	Will the system require labelling to ensure appropriate use?		Will the system require labelling to ensure appropriate use?			What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?

Required changes on score to change key and important requirements

	From	To	Current Unweighted Score for the Column	Unweighted score the column needs to become to change category	% Difference	Change in Score	
Level 1	The highest column currently not a key relationship (includes important)	Higher than a current key relationship	48	72	50.0	24	
	The lowest column currently a key relationship	Lower than a current none a key relationship	72	48	33.3	24	
Level 2	The highest column currently not a key relationship	Higher than a current key relationship	126	138	9.5	12	
	The lowest column currently a key relationship	Lower than a current none a key relationship	139	127	8.6	12	
Level 3	The highest column currently not a key relationship	Higher than a current key relationship	54	N/A	N/A	N/A	With current relationships, it is not possible for anything else to become a key relationship
	The lowest column currently a key relationship	Lower than a current none a key relationship	96	58	39.6	38	
Level 4	The highest column currently not a key relationship	Higher than a current key relationship	30	36	20.0	6	Only need to change 1 value
	The lowest column currently a key relationship	Lower than a current none a key relationship	36	30	16.7	6	Only need to change 1 value
Level 5	The highest column currently not a key relationship	Higher than a current key relationship	88	114	29.5	26	
	The lowest column currently a key relationship	Lower than a current none a key relationship	115	89	22.6	26	
Level 6	The highest column currently not a key relationship	Higher than a current key relationship	31	45	45.2	14	
	The lowest column currently a key relationship	Lower than a current none a key relationship	39	33	15.4	6	Only need to change 1 value
Concepts Level 5	The highest column currently not a key relationship	Higher than a current key relationship	37	53	43.2	16	
	The lowest column currently a key relationship	Lower than a current none a key relationship	59	41	30.5	18	
Concepts Level 6	The highest column currently not a key relationship	Higher than a current key relationship	42	54	28.6	12	
	The lowest column currently a key relationship	Lower than a current none a key relationship	54	42	22.2	12	

Impact on key and important statements depending on war or peace weighting

Both	Peace	War
Level 1:		
		Move forces to/from theatre of operations
		Establish lines of communication
		Construct a movement plan
		Conduct intra theatre movement
		Conduct tactical movement
		Monitor battlespace management
		Conduct tactical manoeuvre
		Conduct support operations
Plan and direct own force disposition	Plan and direct own force disposition	Plan and direct own force disposition
Implement information operations	Implement information operations	Implement information operations
Co-ordinate with other national/international organisations	Co-ordinate with other national/international organisations	Co-ordinate with other national/international organisations
		Provide counter mobility
		Control/dominate operationally significant areas
		Plan joint targeting force
		Non-combatant evacuation procedures
		Attack targets
		Conduct information operations
		Provide defence against weapons systems
		Co-ordinate survival and control measures
		Force protection
		Provide physical protection
		Provide personal security measures
		Co-ordinate force security
		Conduct logistics support
		Conduct equipment support
Provide personnel support	Provide personnel support	Provide personnel support
Conduct medical support	Conduct medical support	Conduct medical support
		Establish forward bases
Level 2:		
The user shall be able to conduct operations within defined notice periods	The user shall be able to conduct operations within defined notice periods	The user shall be able to conduct operations within defined notice periods
The system shall have a high level of operational availability	The system shall have a high level of operational availability	The system shall have a high level of operational availability
The user shall have significantly improved survivability	The user shall have significantly improved survivability	The user shall have significantly improved survivability
Level 3:		
To protect from environmental categories as defined in DEF-STAN 00-35 Part 4	To protect from environmental categories as defined in DEF-STAN 00-35 Part 4	To protect from environmental categories as defined in DEF-STAN 00-35 Part 4
To protect from defined biological and chemical agents	To protect from defined biological and chemical agents	To protect from defined biological and chemical agents
To protect from a defined level of fragmentation and bullet type	To protect from a defined level of fragmentation and bullet type	To protect from a defined level of fragmentation and bullet type
To protect against detection within the thresholds for Thermal Imaging		
To protect the platform (Man) against overloading		

Level 4:		
Accommodate 5-95 percentile anthropometric range	Accommodate 5-95 percentile anthropometric range	Accommodate 5-95 percentile anthropometric range
Allow access to equipment whilst carrying out mission essential tasks	Allow access to equipment whilst carrying out mission essential tasks	Allow access to equipment whilst carrying out mission essential tasks
Reduce the energy cost to the wearer	Reduce the energy cost to the wearer	Reduce the energy cost to the wearer
Minimise impedance of range of movement	Minimise impedance of range of movement	Minimise impedance of range of movement
Minimise impedance of speed of movement	Minimise impedance of speed of movement	Minimise impedance of speed of movement
Level 5:		
Enhanced High Velocity Bullet protection	Enhanced High Velocity Bullet protection	Enhanced High Velocity Bullet protection
Enhanced fragmentation protection	Enhanced fragmentation protection	Enhanced fragmentation protection
Improved body coverage	Improved body coverage	Improved body coverage
Level 6:		
How important is the system in the overall operational effectiveness?	How important is the system in the overall operational effectiveness?	How important is the system in the overall operational effectiveness?
Will the system weight impact the likelihood of injury?		
Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling		
Will the system add a substantial amount of weight or bulk to a certain area of the user?		
Does the system affect the users ability to thermoregulate?	Does the system affect the users ability to thermoregulate?	Does the system affect the users ability to thermoregulate?
Could the system contribute to the onset of heat stress?	Could the system contribute to the onset of heat stress?	Could the system contribute to the onset of heat stress?
Level 5b:		
Frog suit integrated option	Frog suit integrated option	Frog suit integrated option
Enhanced fragmentation protection	Enhanced fragmentation protection	Enhanced fragmentation protection
Active camouflage with current CBA	Active camouflage with current CBA	Active camouflage with current CBA
Light weight EOD style option	Light weight EOD style option	Light weight EOD style option
Level 6b:		
What is the cost of system failure?	What is the cost of system failure?	What is the cost of system failure?
Will the system reduce physical workload of the wearer?	Will the system reduce physical workload of the wearer?	Will the system reduce physical workload of the wearer?
Is the system an upgrade/ modification or is it a new system that is being introduced?	Is the system an upgrade/ modification or is it a new system that is being introduced?	Is the system an upgrade/ modification or is it a new system that is being introduced?
Will the system require labelling to ensure appropriate use?	Will the system require labelling to ensure appropriate use?	Will the system require labelling to ensure appropriate use?
Will the system impact the users speed of movement when fatigued?	Will the system impact the users speed of movement when fatigued?	Will the system impact the users speed of movement when fatigued?
Will the system contribute to increased stress, fatigue, workload and decreased motivation?	Will the system contribute to increased stress, fatigue, workload and decreased motivation?	Will the system contribute to increased stress, fatigue, workload and decreased motivation?
What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?	What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?	What is the impact of the sub-systems when worn in combination on the musculoskeletal loading rate?

Blank Page

APPENDIX G Five domain trade-off: Ranked summary tables (Smith, R, 2005)

Level 1 High level military tasks/ High level military functions

Strategic/Operational activities	**Rank**
Conduct medical support	1
Co-ordinate with other national/international organisations	1
Implement information operations	1
Plan and direct own force disposition	1
Provide personnel support	1
Conduct equipment support	6
Conduct information operations	6
Conduct logistics support	6
Conduct support operations	6
Construct a movement plan	6
Co-ordinate force security	6
Co-ordinate survival and control measures	6
Establish forward bases	6
Establish lines of communication	6
Provide defence against weapons systems	6
Provide personal security measures	6
Conduct intra theatre movement	17
Move forces to/from theatre of operations	17
Provide physical protection	19
Control/dominate operationally significant areas	20
Force protection	20
Non-combatant evacuation procedures	20
Provide counter mobility	20
Monitor battlespace management	24
Plan joint targeting force	24
Peace support operations	26
Attack targets	27
Conduct tactical manoeuvre	28
Conduct tactical movement	28
Support civil authorities	30
Maintain field records	31

Level 2 High level military functions/ C&T user requirements

Domain	**Land system user requirements**	**C4I**	**Lethality**	**Mobility**	**Survivability**	**Sustainability**	**Domain Average**	**Customer**	**Customer Weighted**
Sustainability	Operational availability of the system	7	8	1	1	1	1	1	1
Sustainability	Ability to conduct operations within defined notice periods	11	13	1	1	5	2	2	2
Overarching	Individuals' level of performance in all environments	6	5	7	7	9	5	5	3
Survivability	Survivability of the individual	15	11	3	3	3	4	12	4
Mobility	Ability to move over ground at a rate commensurate with the tactical situation	13	15	5	5	14	8	6	5
Mobility	Ability to conduct operations at a faster rate than baseline	14	9	5	5	15	6	4	6
Mobility	Ability to carry loads appropriate to mission completion	18	17	4	4	7	7	7	7
Overarching	mission effectiveness of the individual	5	5	7	7	6	3	13	8
Survivability	Ability to detect the individual at a specified range	17	16	10	10	17	9	16	9
C4I	Ability to acquire, manage and exploit information at a rate commensurate with baseline	1	1	15	14	4	12	3	10
Sustainability	Ability to store personal supplies for the duration of the mission	20	18	13	12	18	13	10	11
Mobility	Ability to access loads whilst moving, according to tactical demands	19	20	9	9	16	11	9	12
Overarching	Equipment availability for training	16	19	11	11	11	10	18	13
C4I	Provision of situational awareness (SA) commensurate with the role, area of interest and tactical situation	4	2	16	17	2	14	8	14
C4I	Ability to manoeuvre accurately, commensurate with the tactical situation	3	12	12	18	20	14	11	15
C4I	Ability to determine location at a rate commensurate with their tactical situation	2	7	14	13	12	14	14	16
C4I	Provision of spatial awareness commensurate with the role and area of interest	9	14	20	19	13	14	14	16
C4I	Ability to find targets at ranges commensurate to the role, area of interest and tactical situation	8	10	19	20	19	14	17	18
Lethality	Ability to suppress targets within areas of influence	12	3	17	15	8	14	19	19
Lethality	Ability to incapacitate targets within areas of interest	10	4	17	16	10	14	20	20

Level 3 C&T user requirements/ Generic requirements

Generic system requirements	**C4I**	**Lethality**	**Mobility**	**Surviv-ability**	**Sustain-ability**	**Domain average**	**Customer**	**Customer Weighted**
Protection from defined biological and chemical agents	1	4	2	2	2	1	(-)	1
Protection from a defined level of fragmentation and bullet type	3	1	3	1	4	2	(-)	2
Protection against overloading (man)	2	3	1	4	1	3	(-)	3
Protection from environmental categories as defined in DEF-STAN 00-35 Part 4	4	2	4	3	3	4	(-)	4
Protection against detection within the thresholds for Thermal Imaging	5	6	7	5	7	5	(-)	5
Protection against detection within the thresholds for Infra-red	7	8	8	6	6	6	(-)	6
Protection against defined levels of directed energy threat in relation to the eyes	9	5	6	8	5	7	(-)	7
Conformance to legislation and standards (Vision)	6	7	5	9	8	8	(-)	8
Conformance to legislation and standards (Hearing)	8	9	9	10	9	9	(-)	9
Conformance to legislation and standards (Flame)	10	10	10	7	10	10	(-)	10

Level 4 Generic requirements/ C&T system requirements

Specific system requirements	**C4I**	**Lethality**	**Mobility**	**Survivability**	**Sustainability**	**Average**	**Customer**	**Customer Weighted**
Potential heat burden to the wearer	1	13	6	6	2	1	(-)	1
Take into account the impact of being worn for prolonged periods of time	3	4	5	12	1	2	(-)	2
Allow adjustment to create a 'best fit' for the wearer	15	23	1	9	3	2	(-)	2
Range of movement	8	8	2	3	7	4	(-)	4
Speed of movement	5	8	2	1	9	4	(-)	4
Physical limits beyond which injury will be caused to the wearer	9	24	7	16	5	6	(-)	6
Creation of sweat whilst being used	14	8	12	7	10	7	(-)	7
Energy cost to the wearer	2	19	14	3	6	7	(-)	7
Accommodate 5-95th percentile anthropometric range	13	3	16	2	3	9	(-)	9
Allow access to equipment whilst carrying out mission essential tasks	19	1	18	3	21	10	(-)	10
Allow sustainment to be taken whilst wearing	7	12	19	14	8	11	(-)	11
Instil confidence in the wearer	10	2	4	11	12	12	(-)	12
Impact on the tactility and dexterity of the wearer	12	13	7	13	18	13	(-)	13
Impact of layers on the positioning of fasteners and closures	16	13	7	25	13	14	(-)	14
Load on the biological structures of the body	4	5	12	20	14	15	(-)	15
Ensure physical stability of the individual whilst carrying load	6	13	7	24	11	16	(-)	16
Impact of individual variance on the design of the equipment	21	6	7	8	15	17	(-)	17
Be capable of being donned and doffed within a prescribed time	20	22	16	15	16	18	(-)	18
Allow for integration with existing medical equipment e.g. glasses	17	20	15	18	19	19	(-)	19
Impact of radiant heat on detection of the individual from surveillance equipment	24	17	23	17	24	20	(-)	20
Conform to British Standards for wear testing	26	6	24	9	22	21	(-)	21
Allow storage of commodities required for sustainment of the individual	18	18	20	22	20	22	(-)	22
Impact on the situational awareness of the individual	11	11	22	18	26	23	(-)	23
Likelihood of bacterial growth	25	26	25	23	17	24	(-)	24
Be capable of repair	22	21	21	26	22	25	(-)	25
Be capable of being laundered in accordance with available facilities	23	25	26	21	25	26	(-)	26

Level 5 System requirements/ High level requirements

Domain	High level (capability enhancement) requirement – domain specific	Rank when in single domain	Trade off Rank across 5 domains	Customer Weighted Trade Off	Customer Priorities, independent of SMEs, single domain only	Customer Priorities, independent of technical SMEs across all domains
Survivability	Enhanced high velocity bullet protection	2	14	14	7	36
	Enhanced fragmentation protection	3	14	14	6	35
	Enhanced camouflage	7	22	22	9	40
	Improved body coverage	1	13	13	5	33
	Full integration of components	6	21	21	1	1
	Fully integrated with personal kit	8	35	35	1	1
	Accommodate 5-95th percentile	4	38	38	4	23
	Training	9	36	36	1	1
	Issuing policy	5	39	39	8	38
Mobility	Training	3	12	12	1	1
	Issuing policy	10	16	16	10	38
	Accommodate 5-95th percentile	4	9	9	9	37
	Accommodate mission essential equipment	8	10	10	5	23
	Fully integrated with personal kit	1	1	1	1	1
	Minimise injuries sustained in a mobility context	5	6	7	7	30
	Minimise degradation in human performance	2	2	2	1	1
	Reduce/Minimise marching order weight	6	4	4	1	1
	Reduce/Minimise combat order weight	6	4	4	6	26
	Reduce/ Minimise assault order weight	9	8	8	7	30
Sustainability	The scale of issue should be appropriate to operational tasks and activities	5	24	24	1	1
	To reduce replacement time of kit in theatre (mean time to repair)	6	29	29	1	1
	To provide correctly sized clothing and equipment	2	7	6	1	1
	To improve guidance to commanders on scale of provisions required for all operating environments	7	33	33	1	1
	Supply adequate resources to meet mission need and levels of expenditure (prior and during combat)	4	19	19	1	1

	High level (capability enhancement) requirement – domain specific	Rank when in single domain	Trade off Rank across 5 domains	Customer Weighted Trade-Off	Customer Priorities, independent of SMEs, single domain only	Customer Priorities, independent of technical SMEs across all domains
	Minimise degradation in human performance from carriage of load (prior to and during combat)	1	3	3	1	1
	Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)	3	11	11	7	32
Lethality	Integrate with other pieces of personal equipment	2	25	25	1	1
	Enhanced effectiveness against structures	8	32	32	9	29
	Increased area effectiveness	7	30	30	8	25
	Reduced system weight	1	17	17	6	21
	Improved system ergonomics	5	28	28	1	1
	Increased probability of hit (reduced firer error)	3	26	26	7	20
	Increased suppression effectiveness	3	26	26	5	18
	Increased probability of incapacitation given a hit	6	37	37	14	34
	Ability to identify friend or foe	9	40	40	11	27
C4I	Minimise cognitive workload on the individual	4	31	31	3	19
	Minimise bulk and weight penalty	3	23	23	4	22
	Minimise loss of spatial awareness	5	34	34	5	28
	Minimise impact of system on 24hr operations	1	18	18	1	1
	Optimise man machine interface	2	20	20	1	1

Level 6 Weighted requirements/ HFI shortlist

HF statement	Rank over one or more domains	Number of domains spanned
How important is the system in the overall operational effectiveness?	1	4
Will the system instil confidence in the wearer?	2	4
Will the systems size and weight impact the end user?	3	4
Will the system add a substantial amount of weight or bulk to a certain area of the user?	4	5
Will the system weight impact the likelihood of injury?	5	5
Will the wearer see the system as an improvement to overall effectiveness?	6	3
Will the system restrict movement, which may affect the way in which tasks are carried out? E.g. manual handling	7	5
Will the combination of sub systems have an impact on musculoskeletal loading rate?	8	2
Does the system need to work within or in conjunction with other systems?	9	5
Will the system negatively impact the ability to carry out the task?	10	2
What is the cost of system failure?	11	3
Is there a need for the system to be used for peace as well as war operations?	12	5
Will the system require gender variances?	13	4
Will the system protect the user from potential harm in all environmental conditions?	14	3
Does the system affect the user's ability to thermo-regulate?	15	2
Will the system change the way in which the Armed Forces operate?	16	3
Will the system impact the user's speed of movement when fatigued?	17	2
Will the system potentially impact young recruits when entering training?	18	4
Could the system contribute to the onset of heat stress?	19	2
Will the physical environment require changes in the system configuration?	20	5
Will the system have built in flexibility?	21	4
Will the system have to accommodate other equipment in different configurations depending on the user role?	22	5
Will the system reduce the physical workload of the wearer? (potential reduction on task difficulty)	23	3
Will the system be mission dependent?	24	2
Can the system be shared between those using it, or is it specific to the user?	25	3
Will the system change the way that other pieces of equipment are used?	26	5

Blank Page

APPENDIX H Five domain trade-off sensitivity analysis (Smith, R, 2005)

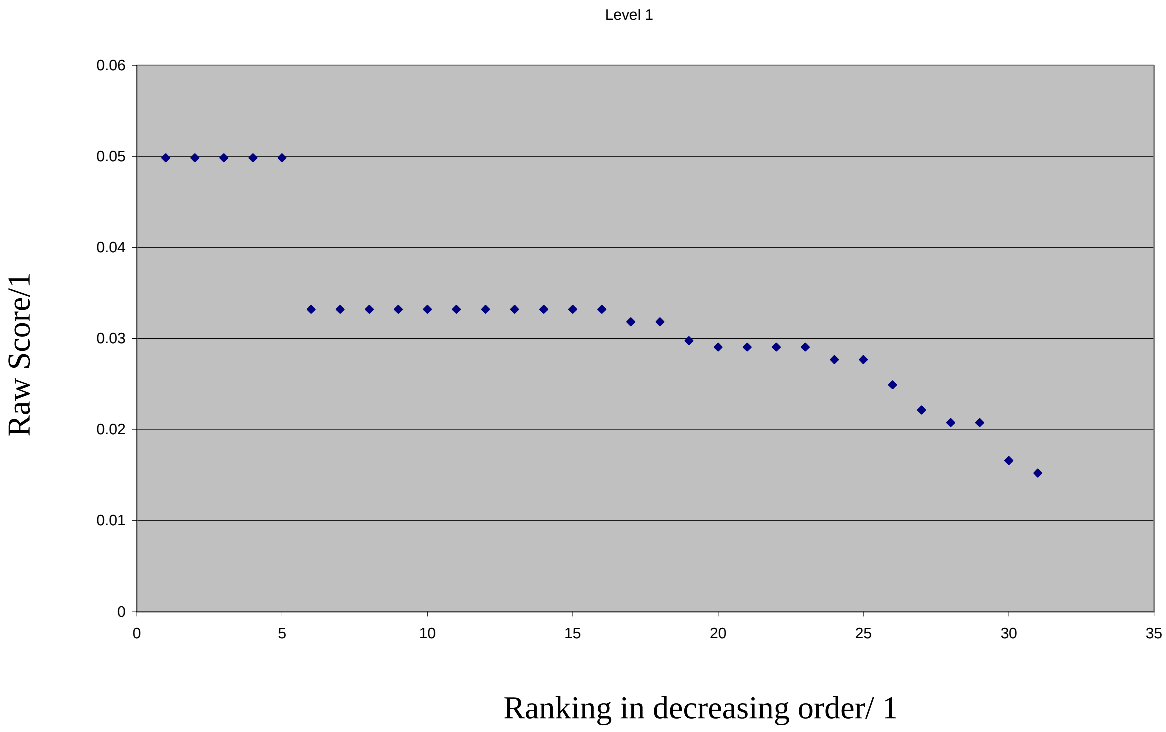
Impact of changes to the scoring convention

Level	0,3,9		1,3,5		1,3,7		1,3,9	
	Key	**Important**	**Key**	**Important**	**Key**	**Important**	**Key**	**Important**
2	Operational availability of the system	Individuals' level of performance in all environments	Operational availability of the system	Individuals' level of performance in all environments	Operational availability of the system	Individuals' level of performance in all environment	Operational availability of the system	Individuals' level of performance in all environments
	Ability to conduct operations within defined notice periods		Ability to conduct operations within defined notice periods		Ability to conduct operations within defined notice periods		Ability to conduct operations within defined notice periods	Survivability of the individual
								Ability to move over ground at a rate commensurate with the tactical situation
								Ability to conduct operations at a faster rate than baseline
								Ability to carry loads appropriate to mission completion
3	Protection from defined biological and chemical agents	Protection against overloading (man)	Protection from defined biological and chemical agents	Protection against overloading (man)	Protection from defined biological and chemical agents	Protection against overloading (man)	Protection from defined biological and chemical agents	Protection against overloading (man)
	Protection from a defined level of fragmentation and bullet type		Protection from a defined level of fragment-ation and bullet type		Protection from a defined level of fragment-ation and bullet type		Protection from a defined level of fragment-ation and bullet type	
4	Potential heat burden to the wearer	Accommodate 5-95th percentile anthropometric range	Allow adjustment to create a 'best fit' for the wearer	Creation of sweat whilst being used	Potential heat burden to the wearer	Allow access to equipment whilst carrying out mission essential tasks	Potential heat burden to the wearer	Allow adjustment to create a 'best fit' for the wearer

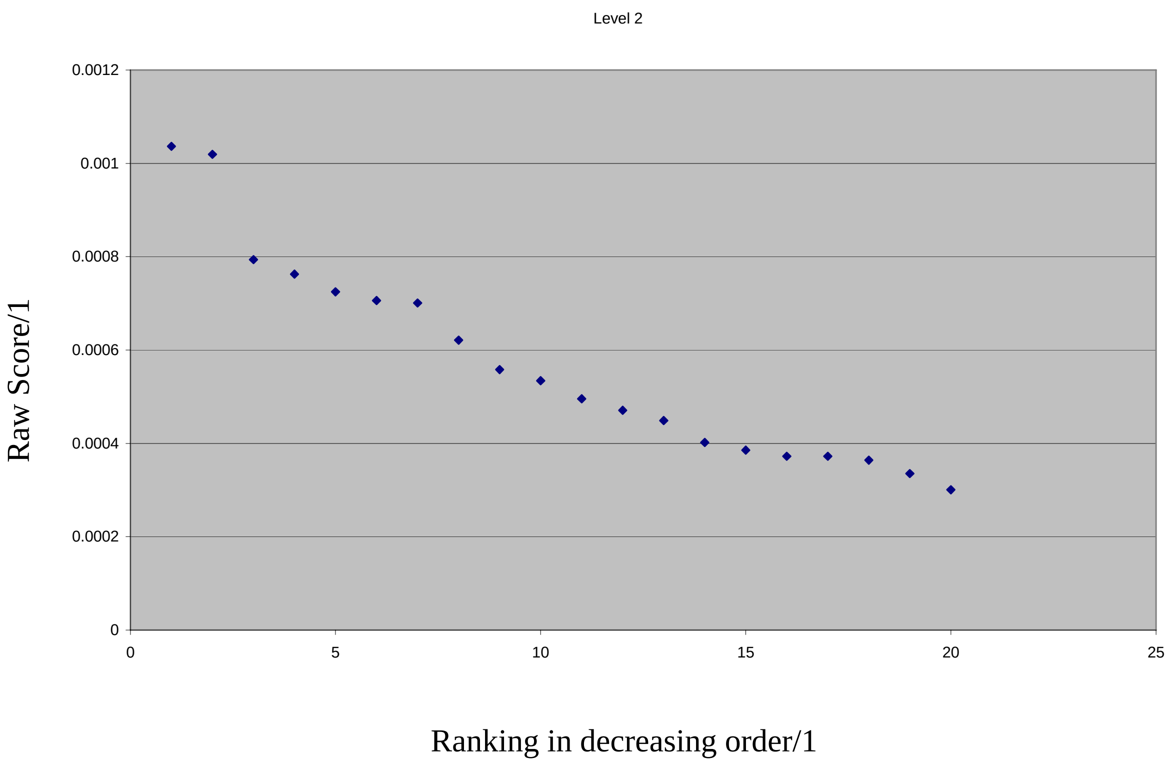
	Take into account the impact of being worn for prolonged periods of time	Allow access to equipment whilst carrying out mission essential tasks	Take into account the impact of being worn for prolonged periods of time	Energy cost to the wearer	Take into account the impact of being worn for prolonged periods of time			Take into account the impact of being worn for prolonged periods of time
	Allow adjustment to create a 'best fit' for the wearer	Allow sustainment to be taken whilst wearing	Potential heat burden to the wearer	Instil confidence in the wearer	Allow adjustment to create a 'best fit' for the wearer			Range of movement
	Range of movement	Instil confidence in the wearer	Range of movement	Impact on the tactility and dexterity of the wearer	Range of movement			Speed of movement
	Speed of movement	Impact on the tactility and dexterity of the wearer	Speed of movement	Allow access to equipment whilst carrying out mission essential tasks	Speed of movement			Physical limits beyond which injury will be caused to the wearer
	Physical limits beyond which injury will be caused to the wearer	Impact of layers on the positioning of fasteners and closures	Physical limits beyond which injury will be caused to the wearer		Physical limits beyond which injury will be caused to the wearer			Creation of sweat whilst being used
	Creation of sweat whilst being used		Accommo-date 5-955th percentile anthropometric range		Creation of sweat whilst being used			Energy cost to the wearer
	Energy cost to the wearer				Energy cost to the wearer			
					Accommo-date 5-95 th percentile anthropometric range			
5	Minimise injuries sustained in a mobility context	Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)	Minimise injuries sustained in a mobility context	Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)	Minimise injuries sustained in a mobility context	Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)	Minimise injuries sustained in a mobility context	Prevent and/or minimise incapacitating injuries from carriage of load (prior to and during combat)
	Reduce/ Minimise marching order weight		Reduce/ Minimise marching order weight		Reduce/ Minimise marching order weight		Reduce/ Minimise marching order weight	

Visual representation of data groupings

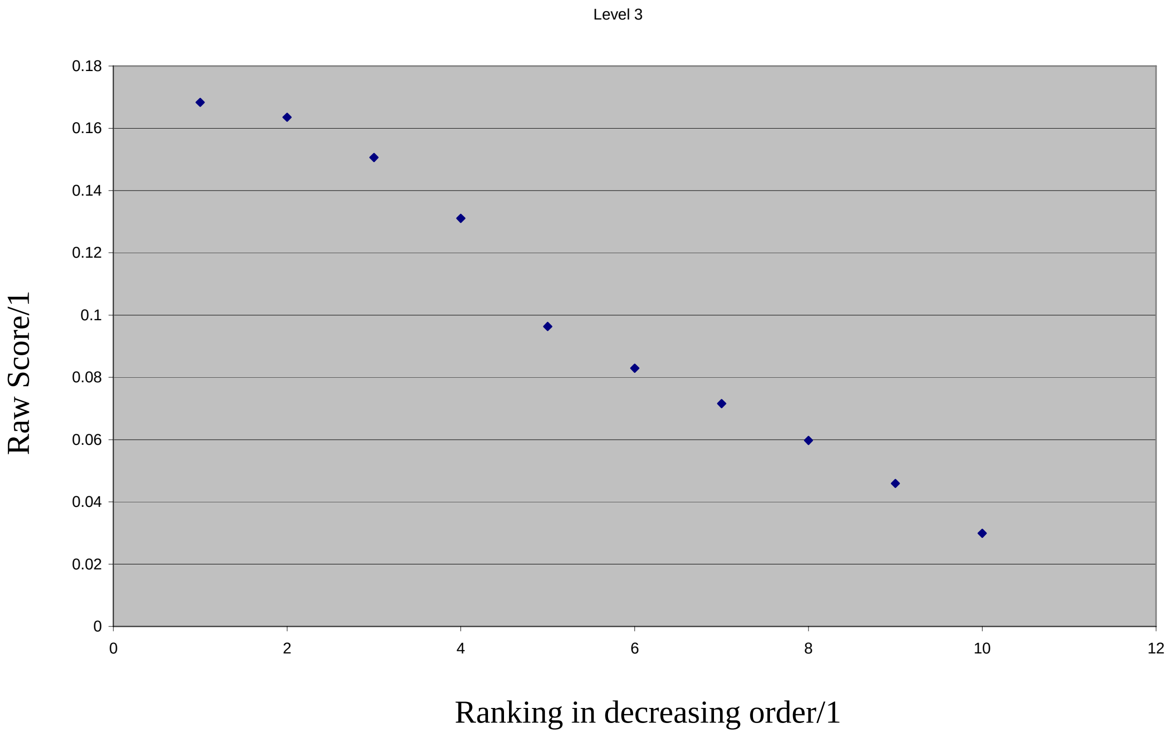
Level 1



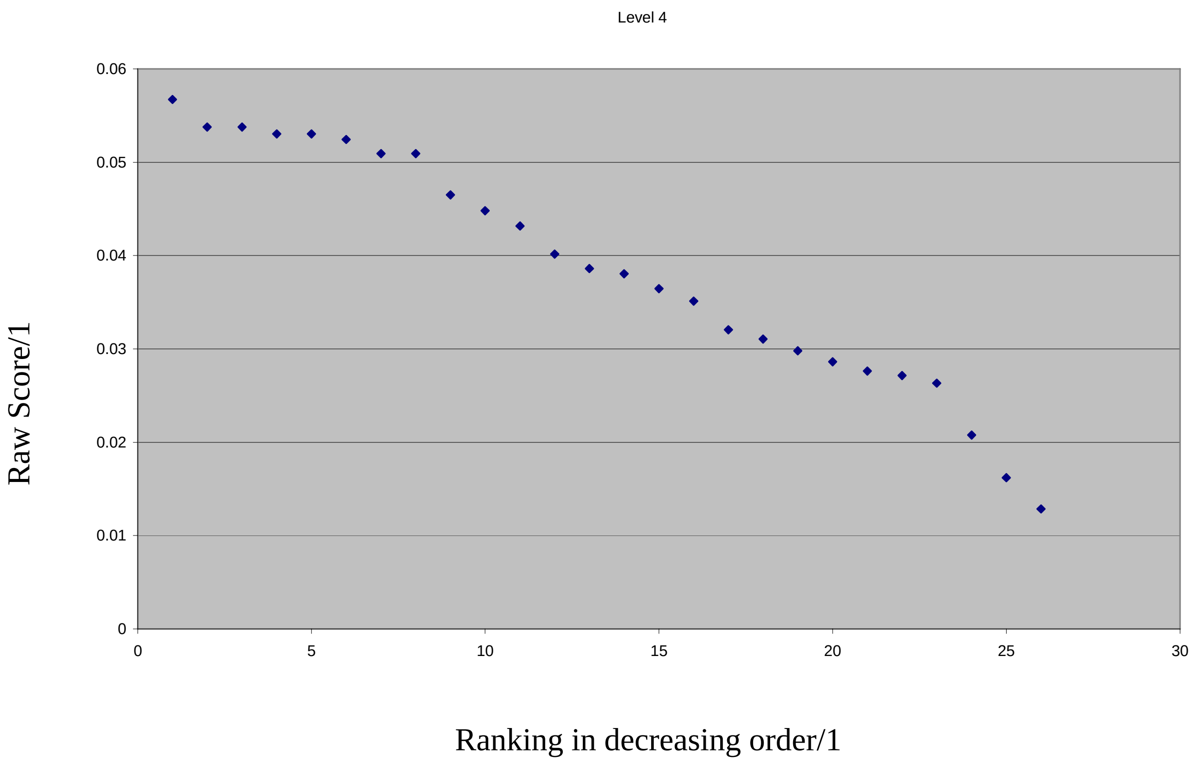
Level 2



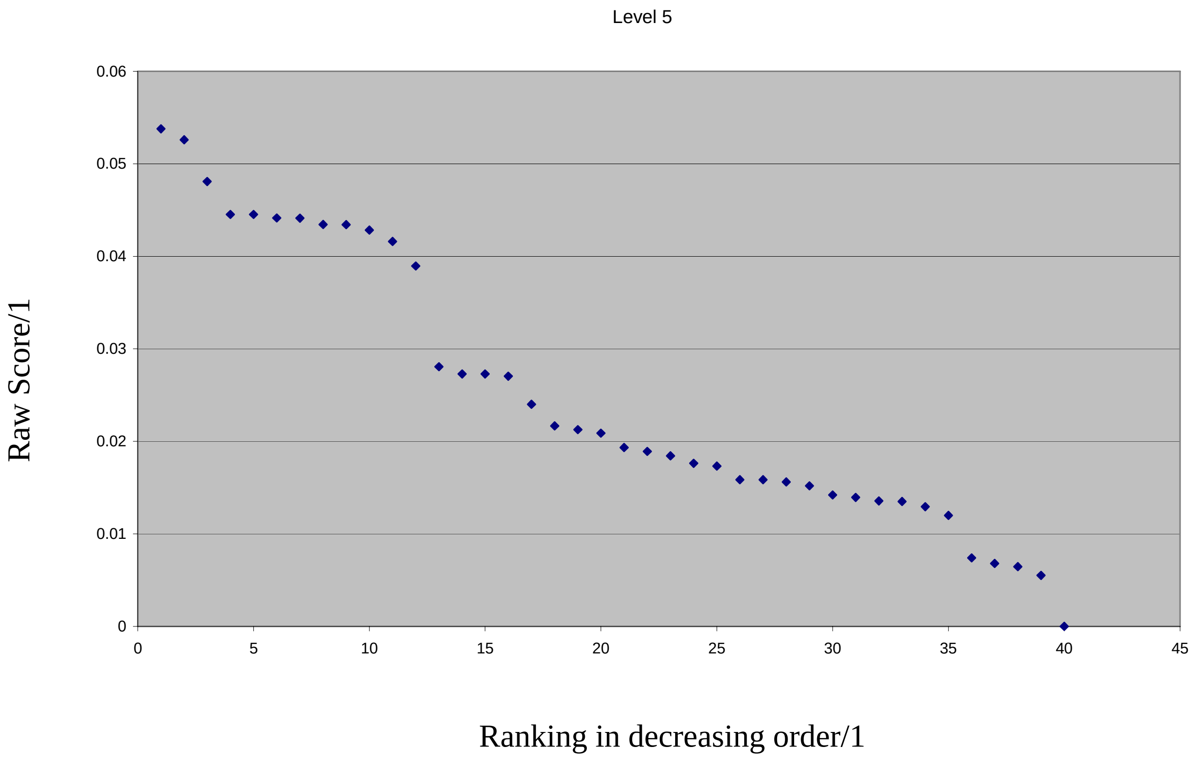
Level 3



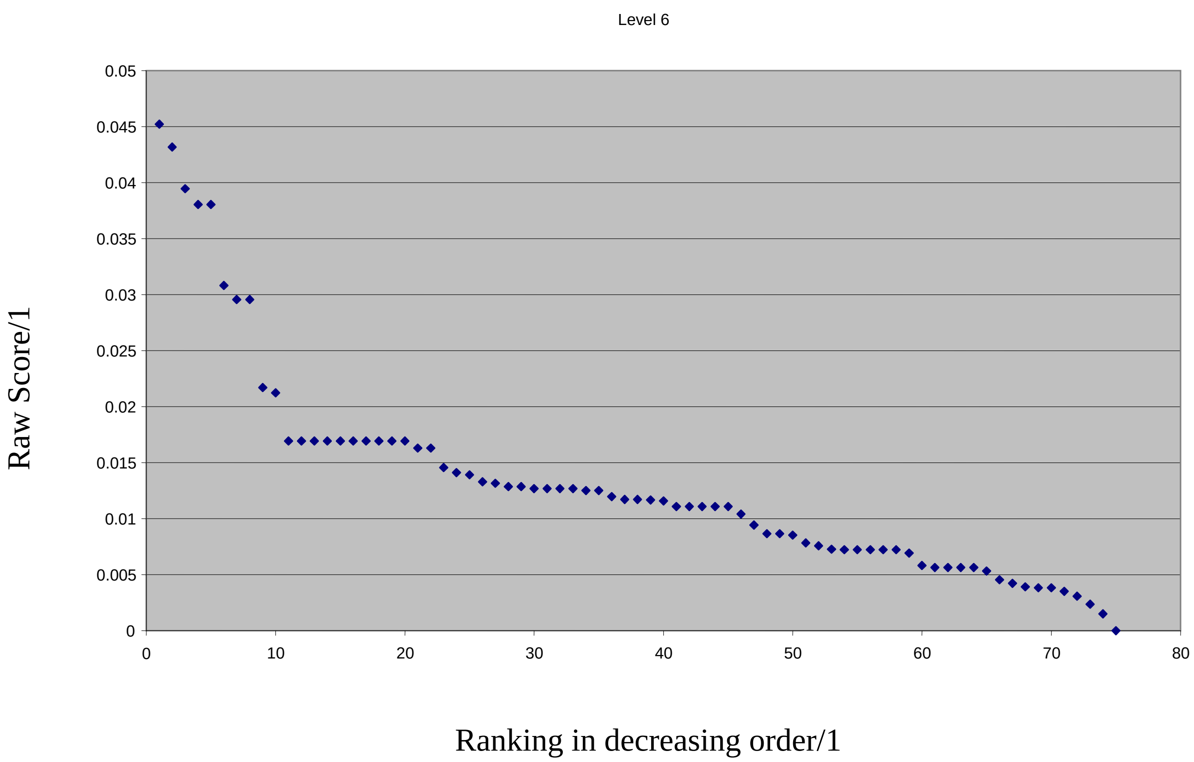
Level 4



Level 5



Level 6



Blank Page