An Investigation into the Partitioning Of Major Defence Systems to Help Ensure System Integration Uses the Least Man-Hours

A dissertation submitted in partial fulfilment
of the requirements for the Open University's
Master of Science Degree
in Computing for Commerce and Industry

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23 February 2008

Word Count: **14958**

Preface

Completion of this study would not have been possible without the help of many people.

The first person to thank is Tony Kinghorn of SELEX-GALILEO UK Ltd (Edinburgh) for suggesting the subject. The next person to thank is my academic supervisor, Professor Andy Sloane of Wolverhampton and the Open University for his help and support throughout the study.

The biggest thanks should go to the many people who took the time to complete the various surveys and interviews that formed the basis of this study. The staff of SELEX-GALILEO UK (Edinburgh) and BAE Systems deserve special mention for the high response rates. Within BAE Systems the company of INSYTE deserve special mention for their high response rate.

From academia special thanks go to Carnegie Mellon University (Pittsburgh USA) who provided invaluable help by means of academic papers, survey responses and general comments. Bill Anderson and Jo Anne Lane were particularly helpful.

As individuals Bob Schaefer (Daniel Webster College, Nashua, New Hampshire, USA) and John Scott (Radian Blue Technologies, Colorado Springs, Colorado, USA) deserve mention for providing insight and information that I would not normally have access to.

Finally I would like to thank my employers SELEX-GALILEO UK (Edinburgh) for not only paying for this year's study but also for previous years' study, and for giving me time to complete tasks during the working day.

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List of Definitions and Abbreviations

Concourse – Q-methodology. 'The communication surrounding a topic'; 'the collection of all the possible statements the respondents can make about the subject at hand' (Van Exel and de Graaf, 2005).

Complex Adaptive System – 'A collection of individual, semiautonomous agents that act in ways that are not always predictable and whose actions seek to maximize some measure of goodness, or fitness, by evolving over time' (Tan et al., 2005).

Condition of Instruction – Q-methodology. 'A guide for sorting Q-sample items' (McKeown and Thomas, 1988, p. 30). The survey question.

Eigenvalue – Q-methodology. A statistical measure of the total variability of a group explained by a sub-group.

Information System – A 'discrete set of information technology, data, and related resources, such as personnel, hardware, software, and associated information technology services organized for the collection, processing, maintenance, use, sharing, dissemination or disposition of information' (OMB, 2003).

Leading Indicator – A 'measure for evaluating the effectiveness of a how a specific activity is applied on a program in a manner that provides information about impacts that are likely to affect the system performance objectives. A leading indicator may be an individual measure, or collection of measures, that are predictive of future system performance before the performance is realized' (Roedler and Rhodes, 2007).

Organisational Politics (often shortened to **Politics** or **Political** in the UK) – ‘informal, unofficial, and sometimes behind-the-scenes efforts to sell ideas, influence an organization, increase power, or achieve other targeted objectives’ (Brandon and Seldman, 2004).

P-set – Q-methodology. The survey respondents.

Partitioning/System Partitioning – the ‘functional partitioning of a system-level functional specification among hardware and software components’ (Vahid and Le, 1996).

Public Domain – Copyright-free material available to the public.

Q-grid – Q-methodology. The ‘quasi-normal’ shaped grid that survey respondents arrange the Q-sample in.

Q-methodology – A method for studying human subjectivity.

Q-sample or Q-set – Q-methodology. ‘(…) a subset of statements (…) drawn from the concourse, to be presented to the participants’ (Van Exel and de Graaf, 2005).

Q-sorting – Q-methodology. Arrangement of the Q-set within a Q-grid according to the condition of instruction.

SAP – An integrated business software application that links all the software in a business into one connected system.

Sine non qua – Latin for ‘without which not’. Indispensable, essential, a precondition.

System Integration – Integrating, testing and evaluating the complete vehicle, including software and hardware, for both stand-alone functionality and interoperability prior to building the first production prototype (based on the definition ‘a System Integration laboratory’ by Advanced Dynamics International, 2007).

System Partitioning/Partitioning – the 'functional partitioning of a system-level functional specification among hardware and software components' (Vahid and Le, 1996).

Z-scores – Q-methodology. 'The normalised weighted average statement score (…) of respondents that define that factor' (Van Exel and de Graaf, 2005). A calculation 'to facilitate comparisons between factor arrays' (McKeown and Thomas, 1988, p. 53).

See Table 1.1, below, for a list of abbreviations.

CAS	Complex Adaptive System.
COTS	Commercial off-the-shelf.
DoD	Department of Defense (United States).
I&I	Integration and Interoperability.
IS	Information System,
LI	Leading Indicator.
LTCM	Long Term Capital Management.
M&S	Modelling and Simulation.
MoD	Ministry of Defence (UK).
MR	Modification Request.
NASA	National Aeronautics and Space Administration.
OMB	Office of Management and Budget (US White House office responsible for devising and presenting the US President's annual budget proposal to the US Congress).
PCA	Principal Component Analysis.
RPG	Recommended Practices Guide.

SAP	Systeme, Anwendungen, Produkte in der Datenverarbeitung (German: Systems, Applications, Products in Data Processing).
SI	System Integration.
SME	Subject Matter Expert.
SoS	System of Systems.
US	United States.
VV&A	Verification, Validation and Accreditation.
WWW	World Wide Web (internet).

Table 1.1 – Abbreviations

Abstract

This study tried to produce a mapping between the two defence equipment development phases of system (functional) partitioning and system integration.

This study defined a defence development contract as a financial instrument called a ‘future’. It then compared defence equipment development to the ‘derivative’ financial instrument and introduced the ‘derivatives issue’. Just as two Nobel Prize winners spectacularly failed to predict accurately the derivatives market, this study failed to produce a mapping between system (functional) partitioning and system integration. This study found the two phases of defence equipment development far too complex and multidimensional.

This study has, as far as the author is aware, created the biggest ever defence development related public domain data set.

Analysis of this data set has shown that many of the influences affecting partitioning and system integration were non-technical and subjective. This study found that different levels of engineers, for instance, system architect and junior engineer, held different opinions. Even engineers performing the same job, within the same laboratory, held different opinions.

The system integration phase was investigated further. The investigation revealed different groups of opinion that did not agree and were often contradictory.

Given that mapping between partitioning and system integration was not possible, this study went on to examine further the characteristics of system integration and found strong evidence that defence system integration is a ‘complex adaptive system’.

The study then attempted to define a set of ‘leading indicators’ to point to the future success of system integration by defining system integration as an information system. This study

defined fourteen classes of leading indicator; twelve came from other information system research and two from within this study. This study identified seventy-one subclasses of the fourteen classes; thirty from within this study and forty-one from other research.

Chapter 1 Introduction

Major defence systems are ‘critical to the economic and military welfare of the United States and to much of the industrialized world’ (Humphrey, 2006). Humphrey (2006) goes on to state: ‘Unfortunately, the development of such systems has been troubled, and the systems needed in the future will be vastly more complex and challenging. If history is any guide, attempting to develop these future systems with the outmoded methods of the past will almost certainly yield unsatisfactory results’.

This study will examine two major phases of defence equipment development – system (functional) partitioning and SI (system integration) – and will improve understanding of future defence equipment development.

A secondary benefit of this study is that it will provide more understanding of defence equipment development in general. This study examines defence equipment development but will be of interest to those outside the defence industry. Technical influences may be different but it is the case that SI is still important and the non-technical factors influence projects outside the defence environment.

1.1 Aims of the Project

The primary aim of this study is to answer the research question:

Is it possible to define a mapping between partitioning a major defence system, at design time, and the man-hours spent on the system integration of the same equipment?

The secondary aim is:

If a mapping is possible, define the mapping and prepare instructions for its use.

The tertiary aim is:

If a mapping is possible subject it to verification, validation and accreditation then use it in a theoretical case study of the design of a future airborne radar.

Investigation of the research question will be by:

- Discovering the influences on system (functional) partitioning.
- Discovering the influences on the efficiency of SI.
- Analysis of the influences by themselves.
- Investigation of the connection between partitioning and SI using the results of the analysis of influences, published literature, data analysis tools, interviews and e-mail correspondence.

1.2 Defence Equipment Development Costs

Developing major defence equipment is expensive.

Listed below are the development costs for three major UK defence projects[1] (National Audit Office, 2000):

- Eurofighter – £5,649 million (30% of prime contract value of £18,832 million).
- Multi-Role Armoured Vehicle – £451 million.
- Sting Ray Lightweight Torpedo Life Extension and Capability Upgrade – £184 million.[2]

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[1] Year 2000 forecast cost.

[2] Includes pre-production phase. Pre-production is considered part of development.

No figures are available for the percentage of development costs that SI comprises. Six domain experts gave an estimate:

- 10 to 15% (systems engineer).
- 10 to 20% (senior software executive).
- 20% (SI expert and senior executive).
- 50% (senior systems engineer and senior software engineer).

Taking the lowest estimate of SI effort (10%), even a slight decrease in SI effort will produce large cost savings.

1.3 Non-Technical Problems in Defence Development

Anderson and Brown (2004) and Morris et al. (2004) confirm non-technical problems in defence equipment development. Anderson and Brown (2004) state: ‘Research findings tend to agree that many of the difficulties encountered in I&I [Integration and Interoperability] are not technical in nature’. Morris et al. (2004) also state that the problems associated with I&I are not purely technical: ‘Creating and maintaining interoperable systems of systems requires interoperation not only at the mechanistic level, but also at the levels of system construction and program management’.

More tellingly, Humphrey (2006) states: ‘With few exceptions, the reasons that large-scale development efforts have failed in the past have not been technical’.

SI is an important discipline in the non-defence industry. A Major Projects Association (2002) seminar stated: ‘Disciplined Systems Integration techniques provide the key to managing complexity across a broad range of industries and offer additional benefits when organizational systems and processes change in today's multi-owner, multi-stakeholder environment'.

Harper (2007) summarises the influence of non-technical problems outside the defence industry. Harper (2007) stated that the biggest difficulties he faced in setting up SAP across a multi-site business were 'political' (organisational politics).

1.4 Outline of the Dissertation

This study researches the partitioning and SI of defence equipment and tries to produce a mapping, with instructions for use, between the two stages of development.

The investigation has five sections:

- Chapter two – A review of current knowledge via a literature review.
- Chapter three – Research methods. A description of the exploratory investigation and the selection, justification and description of the chosen method.
- Chapter four – Implementation of the chosen research method.
- Chapter five – Description and statistical analysis of the data collected.
- Chapter six – Interpretation of the results and conclusions.

Chapter 2 Literature Review

2.1 Introduction

Figure 2.1, below, describes the structure of this chapter.

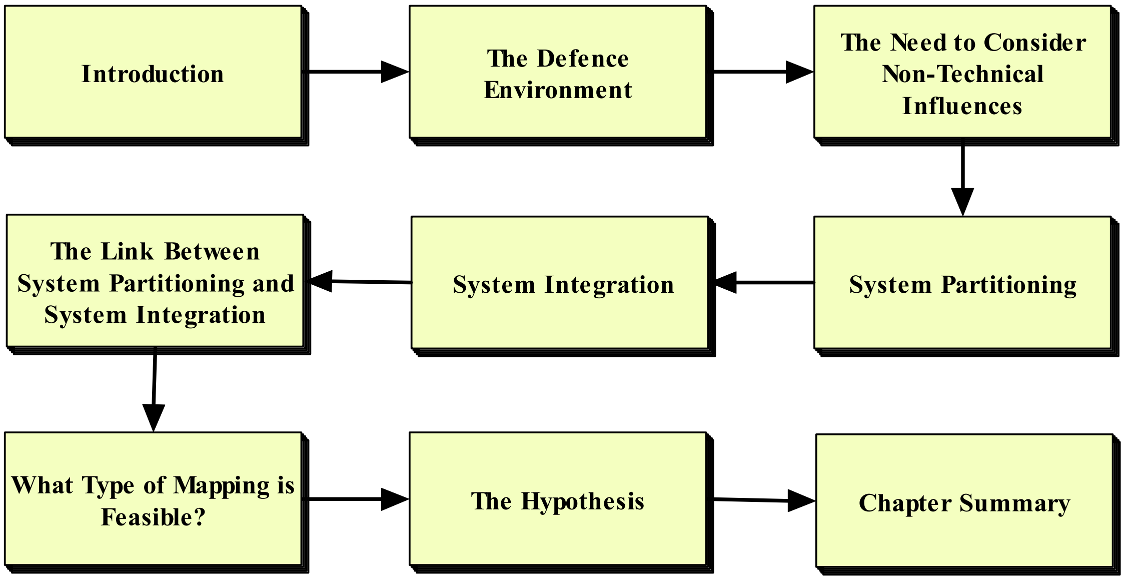

Figure 2.1 – Literature Review Chapter Structure

This chapter provides the context for the study.

This chapter first describes the defence environment and the particular, non-technical, influences on defence equipment development. It then justifies the need to consider non-technical influences. A description of system (functional) partitioning, SI and the link between the two follows.

The primary aim of this study is to define a mapping between partitioning and SI. The next section of this chapter examines the type of mapping that is possible and, finally, the hypothesis is stated.

2.2 The Defence Environment

The defence industry is a political industry. National governments strive to influence defence companies; defence companies strive to influence national governments. This two-way axis of influence changes the behaviour of defence contractors. Changing the behaviour of defence contractors changes the behaviour of defence contractor employees.

The requirements of politicians and shareholders, relayed by company executives to engineers, are non-technical by definition; they are either politically or financially oriented.

These are as well as the non-technical influences, for instance budgets, time-scales and supply chain problems, experienced by all organisations.

Gholz (2002) states that: ‘The defense industry remains a political one, and it is unrealistic to believe that efficiency will ever be the only or even paramount goal’.

Purton (2004) states: ‘The political direction of defence procurement decisions is now so embedded in the defence management system that it is no longer possible to determine whether the problems suffered by the MoD [Ministry of Defence – UK] are of their own making or the result of the political direction of MoD against its better judgement’.

The UK Defence Industrial Policy Paper (Ministry of Defence, 2002) even lists the ‘Wider factors taken into account in acquisition decisions’ in a separate table (table 2, page 12).

The defence industry/political axis of influence is not just from politicians to the defence industry: it also exists in the opposite direction.

The UK Select Committee on Defence (House of Commons, 1999) stated that the MoD must ‘be sufficiently strong to sift out any bias in the expert advice produced by vested commercial interests’. Gholz (2002) describes the effect of the influence of the defence industry on politicians: ‘Freedom to choose optimal technical solutions is constantly threatened at the margin by pressure from (…) the political power of platform producers’.

The two-way axis of influence leads to defence specific non-technical influences on equipment development, including partitioning and SI.

Defence contractors influence employees, including the engineers performing partitioning and SI, to meet the goals set by politicians and shareholders.

As Bohnet (2006) observes, ‘Institutions have several characteristics that influence behaviour’. Bohnet describes six ways that organisations influence employees’ behaviour:

- Create incentives.
- Coordinate behaviour.
- Guide self-selection.
- Provide information on procedures.
- Allow for causal attributions.
- Influence preferences.

Using the methods described by Bohnet (2006), defence executives affect the behaviour of their employees. The chain of events leads direct from the politicians to the employees by means of senior management.

2.3 The Need to Consider Non-Technical Influences

Humphrey (2006) confirms the need to consider non-technical influences on defence equipment development.

Humphrey (2006) states that ‘the systems needed in the future will be vastly more complex and challenging’ and there ‘has not yet been a concerted effort to define and understand the process management and control issues involved in the development, evolution, and operation of these systems’.

Non-technical factors influence both partitioning and SI.

Curtis et al. (1988) summarise the complex influences on partitioning during a field study into the software design for large systems. Curtis et al. (1988) found that: ‘Projects must be aligned with company goals and are affected by corporate politics, culture, and procedures. Thus, a project’s behaviour must be interpreted within the context of its corporate environment’.

Stutzke (2005) states that SI effort depends on six factors:

- The number of domains involved.
- The number of stakeholder organisations involved.
- The size and scale of the system of systems.
- Non-functional requirements.
- Project constraints.
- The development and deployment process.

Most, if not all, of the six have, at minimum, a large non-technical ingredient.

Schaefer (2006) summarises the need to consider non-technical influences and states:

> 'The current paradigm is that the software development process (and the more inclusive systems development process) must be abstracted away from the host organization, and that this abstraction must be treated as the whole of the model. This model began its life as a useful fiction to permit a cutting out of what for small projects were (at the time) second-order factors to enable a more concentrated analysis on the principal factors (…) But over the decades, as systems and systems makers have grown in size and complexity, this working fiction has outgrown its ability to model reality'.

2.4 System Partitioning

This study defines system partitioning as the 'functional partitioning of a system-level functional specification among hardware and software components' (Vahid and Le, 1996).

The partitioning model proposed by Vahid and Le (1996) relies on the number of gates available for processing and the number of functions; it does not consider the non-technical.

Vahid and Le (1996) also state: 'The model includes only the information needed by partitioning, and thus can be communicated freely and generated automatically'. Sharman (2007) sees the future of the UK defence industry as featuring 'new organisations and collaboration, particularly with academia, underpinned by new mechanisms for targeted research'. It would be difficult to produce the information needed for partitioning automatically in Sharman's (2007) future UK defence industry.

Yoon (1997) reviews four design methods: the functional approach, the process-based approach, the object-orientated approach and the net-based approach. None of Yoon's methods considers non-technical influences.

Curtis et al. (1988) do consider the non-technical. They describe a 'layered behavioural model of software development' but do not consider hardware development. Software development is a large part of defence equipment development, roughly 40% (Ferguson, 2001), but software development does not represent the total effort involved.

The paper by DeLaurentis and Crossley (2005) 'presents a three-axis taxonomy that can guide design method development and use for systems of systems'. Although DeLaurentis and Crossley (2005) consider systems of systems that include humans they do not consider the effect that humans have on design methods.

2.5 System Integration

This study defines SI as 'integrating, testing and evaluating the complete vehicle, including software and hardware, for both stand-alone functionality and interoperability prior to building the first production prototype' (based on the definition of an SI laboratory by Advanced Dynamics International, 2007).

Gholz (2002) describes three levels of SI. The objective is to 'link disparate equipment so that heterogeneous parts can operate together' (Gholz, 2002). The three levels are:

- Weapon system level (a single product), for instance a fire-control radar.
- Platform integration, where individual products are integrated into a mission-capable form.
- System of systems integration where different platforms are linked together.

Gholz (2002) goes on to state that 'Different combinations of system integration capabilities are found in traditional defense industry prime contractors (…)'. The details of SI depend on the equipment being integrated but at each level a large part of SI is testing the system.

Testing will typically involve a mixture of real equipment and simulations, described by Advanced Dynamics International (2007) as ‘simulation-based testing’.

Farren and Ambler (1997) develop a test strategy, and a cost model, based on a hierarchical structure of a system. Farren and Ambler (1997) define an ‘operational hierarchy’, a ‘topological hierarchy’ and a ‘physical hierarchy’. Farren and Ambler (1997) ‘derive the test process, directly or indirectly, from a behavioural description of the system under test’; they do not consider non-technical influences and, as Schaefer (2006) would say, ‘abstract the process away from the host organisation’.

Ungar and Ambler (2001) also develop a cost model of ‘Built In System Test’. The results in the paper are for numbers (5,000 and 50,000) that do not apply to major defence equipments. Ungar and Ambler (2001) do consider indirect benefits, for instance shorter time to market, but not the non-technical influences on SI.

Gholz (2002) proposes four measures of SI performance:

- Technical awareness.
- Project management skill.
- Lack of bias.
- Customer understanding.

Technical awareness is the only measure that, at first glance, is purely ‘technical’. Gholz (2002) goes on to state that ‘the ability to gain access to that knowledge (...) is the *sine qua non* of systems integration’. Even ‘technical awareness’ is not completely technical.

2.6 The Link between System Partitioning and System Integration

Partitioning defines interfaces; interfaces define SI.

> 'A basic definition of system integration emphasizes interoperability – the requirement that each military system work in concert with other systems based on sufficient communication across well-defined interfaces.' Gholz (2002)

To reduce defence equipment development and life cycle costs many future defence systems use 'Open Systems', for instance the 'F-22 fighter and the Army Comanche helicopter' (Thedens, 1997). Thedens (1997) also states, when discussing Open Systems, 'The key point in each of these definitions is their focus on interface standardization'.

Gholz (2002) and Thedens (1997) show a direct connection between partitioning of defence equipment and the effectiveness of SI.

The connection between partitioning and SI has a direct effect on the system test part of SI. Al-Hayek et al. (1997) state: 'Hardware-software partitioning of system functionality constitutes a delicate part of the design process and has a decisive impact on the final cost of system testing'.

Al-Hayek et al. (1997) do not consider the non-technical influences on the partitioning-SI connection. They connect partitioning and SI by the partitioning to system test relationship. Al-Hayek et al. (1997) state:

> 'The key task, then, is to identify basic functional computational units. We argue that it is possible to use dataflow analysis on dataflow designs to automatically recognize functions and ensure that they have been tested. Here, we define a test strategy as a set of flows that we must exercise to test a system for a criterion and a development phase.'

Bolchini et al. (2001) connect partitioning to the fault detection part of SI. They propose a partitioning method that adds to the 'traditional system partitioning metrics (…) checking and checker policies and structures, detection latency, performance degradation, fault coverage and area overhead' (Bolchini et al., 2001).

To again quote Schaefer (2006), the connection that Al-Hayek et al. (1997) and Bolchini et al. (2001) define is 'abstracted away from the host organization'.

2.7 What Type of Mapping is Feasible?

An objective of this study is to define a mapping between partitioning and SI. This section asks 'What type of mapping is feasible?'

If a defence contractor knows the cost of development it can add a profit margin to that cost. The value of the contract depends on the cost of development. If development costs are less than predicted, the value of the contract, to the contractor, rises. If development costs are more than predicted, the value of the contract, to the contractor, falls.

Lloyds TSB Corporate Markets (date unknown) define a derivative as:

> 'An instrument, such as an option, future [*Contracts stipulating the purchase or sale of commodities, currencies or securities of a specified quantity, at a specific price and on a predetermined date in the future (Lloyds TSB Corporate Markets – date unknown)*] or swap, of which the criteria and value are determined by those of an underlying asset such as a stock, currency or commodity.'

A defence equipment development contract is a derivative. It is a future 'of which the criteria and value are determined by those of an underlying asset such as a (…) commodity' (Lloyds TSB Corporate Markets – date unknown). The 'underlying', the commodity, is the equipment under development.

The 1997 Nobel Prize for Economic Sciences was jointly awarded to Robert C. Merton and Myron S. Scholes 'for a new method to determine the value of derivatives' (Nobel Prize, 1997). Merton, Scholes and financial executive John Meriwether founded the company LTCM (Long Term Capital Management).

Between January and September 1998 LTCM lost 'almost 90% of its capital (…) LTCM's trading positions and related positions of other market participants might pose a significant threat to already unsettled global financial markets' (United States General Accounting Office, 1999).

Lowenstein (2002) provides the best summary of the affair in the title of his book about LTCM: '*When Genius Failed: The Rise and Fall of Long Term Capital Management*'.

If two Nobel Laureates and a financial expert produce a model of the derivatives market that fails so spectacularly, what chance does a lesser mortal (the author of this study) have?

Any mapping must address the 'derivatives issue'.

The derivatives issue is the risk in stating a price now for the future delivery of a commodity, in this study a major defence equipment. The value of the contract is dependent on the many issues that affect the cost of development. If the cost of development increases, the value of the 'futures contract' falls.

Fixed-price contracts imply resolution of the derivatives issue and contractors know the value of the futures contract. The defence contractor agrees to deliver a previously defined system at a fixed cost. The defence contractor knows the cost of equipment development, the ‘underlying’, and adds the profit margin.

Purton (2004) makes the case for ending fixed-price contracts and for using instead ‘full cost reimbursement/no blame/no loss contracts’. Purton (2004) states: ‘the existence of a taut commercial contract binding on price, performance and timescale simply creates difficulties for both industry and government to work together in a spirit of partnership (…) Fixed price contracting for US major weapon systems production was abandoned in the 1960s’.

Fixed price contracting does not work in the defence industry where the ‘strategic environment will continue to change’ (Ministry of Defence, 2002): the risk is too high.

Hartley (2005) states: ‘Inevitably, high technology defence projects involve substantial risks and uncertainties so that some cost overruns and delays are not surprising’.

‘Projects involving complex systems integration or at the leading edge of technology can be inherently risky’ (Ministry of Defence, 2002).

The *Wall Street Journal* summarises how defence contractors feel about risk: ‘Some senators want to shift more of the financial risk of developing military technologies to contractors and away from the taxpayer. The defense industry is lobbying to thwart the initiative, saying it would “inhibit innovation and wreak havoc on profits, as a similar move did in the 1980s”’ (Karp, *Wall Street Journal,* 2006).

The lack of fixed-price defence contracts, for major equipments, and the large development risk, means the best choice, with regard to the derivatives issue, is to ignore it.

Modelling a market, to the necessary accuracy, that is subject to 'substantial risks and uncertainties' (Hartley, 2005), is not possible within the timescales of this study.

The derivatives issue will become more complex with the 'Exploitation of the potential of networked capability' (Ministry of Defence, 2002) where 'a high degree of cross-project working and co-operation among defence suppliers' (Ministry of Defence, 2002) is needed.

This study will ignore the derivatives issue.

This study will try to produce a simple mapping that considers both the technical and non-technical and will not try to model the future. The mapping will be one small consideration in defence equipment development.

'Most important, and most difficult to learn, systems thinking requires understanding that all models are wrong and humility about the limitations of our knowledge' (Sterman, 2002).

2.8 The Hypothesis

The primary research question addressed in this study is:

Is it possible to define a mapping between the partitioning of a major defence system, at the design stage, and the man-hours spent on the system integration of the same system?

The hypothesis is:

A relationship exists such that a mapping between the two activities is possible.

2.9 Chapter Summary

This chapter first described the defence equipment development environment and its political nature. It described how politicians and shareholders relay their non-technical objectives to each other by a two-way axis of influence and, via defence executives, to defence engineers.

This chapter justified the need to consider non-technical influences before describing partitioning, SI and the link between the two.

This chapter then asked ‘What type of mapping is feasible?’ and introduced the ‘derivatives issue’. This chapter has also described how two Nobel Prize winners failed spectacularly to solve the ‘derivatives issue’ and the only possible mapping, within the time-scales of this study, was a simple one that ignored the ‘derivatives issue’.

The next chapter will describe the research methods of this study; the chapter will describe the initial investigation into the influences on defence equipment development and the choice, and limits, of the chosen research method.

Chapter 3 Research Methods

3.1 Introduction

This structure of this chapter is shown in Figure 3.1 below.

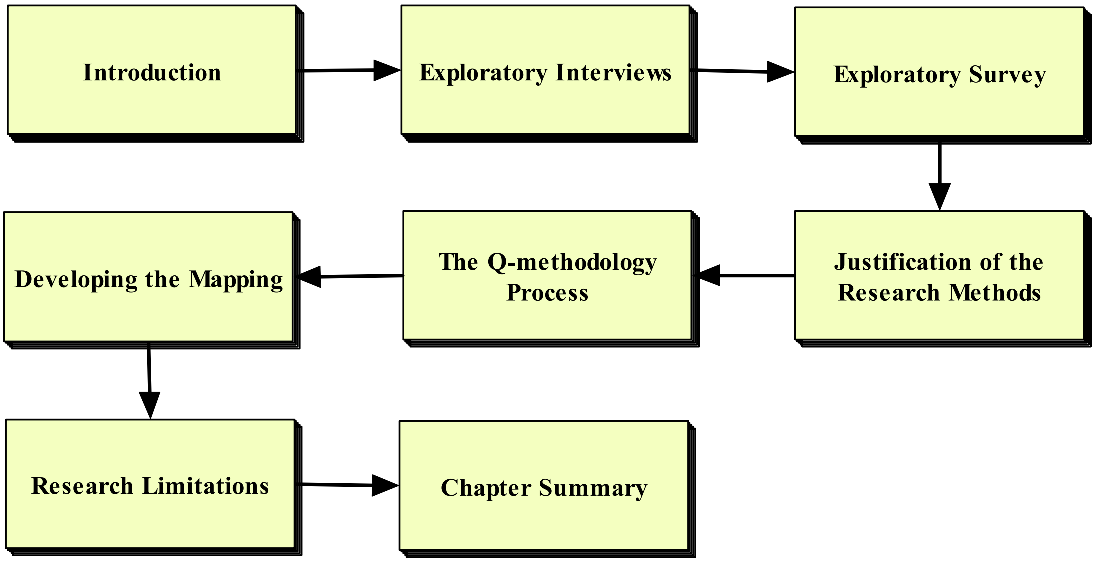

Figure 3.1 – Research Methods Chapter Structure

This chapter describes an exploratory investigation into the subject area by interview and survey. This chapter then describes the use of the exploratory investigation to justify the main research method.

This chapter also describes the main research method in detail with a description, and justification, of both the method and the tools. The chapter then describes the development of the mapping, between partitioning and SI, before explaining the limits of the research.

3.2 Exploratory Interviews

This study conducted a series of exploratory interviews to gain an understanding of the influences on partitioning and SI. The author of this study has worked in defence SI for over ten years so fewer interviews were carried out into SI. All interviews were informal.

The question asked in the partitioning interview was: ‘What factors affect system partitioning at the design stage?’ There were twelve interviewees whose responsibilities ranged from a purchasing consultant to the U.S. Coastguard to chief engineer/system architect. All interviewees were involved in the partitioning of major defence systems at design time.

The SI interviews asked: ‘What affects the efficiency of your work?’ The interviewees were four SI engineers.

Many influences, on both partitioning and SI, were non-technical and qualitative. Different engineers gave different answers. For instance, different SI engineers, working in the same laboratory, gave different answers about what affected their efficiency. It was also the case that different levels of engineer saw different influences at work. The answers from senior engineers were different from those of more junior engineers and both in turn were different from the answers from senior managers.

The answers were on multiple dimensions and many were non-technical in nature. Different engineers agreed on many of the influences but would rank them differently in importance. This difference in ranking was sometimes, but not always, dependent on the phase in the life cycle that the development had reached.

3.3 Exploratory Survey

This study, to gain more understanding of partitioning, conducted a survey into the influences on the partitioning process. The question asked was the same as in the exploratory interview: ‘What factors affect system partitioning at the design stage?’ The respondent could enter multiple replies. There were five respondents who were all involved in system design.

The survey responses were similar to the interviews, on multiple dimensions and many were non-technical in nature.

This study did not survey the SI influences because of practical time constraints and the fact that the author worked in defence SI. The author could gain information related to SI efficiency by informal interviews during normal work.

3.4 Justification for the Research Methods

The exploratory interviews and survey showed that partitioning of functionality and SI are multidimensional problems where the solution space contains multiple, sometimes subjective, influences.

Brown and Flowe (2005) confirm the multiple dimensions of the problem area when studying defence equipment development. They state: ‘The results clearly suggest that the solution space is multidimensional and, as such, may require multipath strategies’ (Brown and Flowe, 2005).

Anderson and Brown (2004) confirm the influence of subjective influences by stating: ‘We believe that many of the I&I [Integration and Interoperability] cost drivers are tacit or latent in nature; they are intangible, subjective, and contingent’.

This study needs a research method that can take account of multiple, sometimes subjective, solutions.

There is a lack of objective (numerical) public domain data about defence equipment partitioning and SI; this study could only find one data set (Brown and Flowe, 2005), despite extensive searching. A sub-objective of this study was to place objective (numerical) data into the public domain.

Placing objective data into the public domain suggests a research method that is quantitative in nature. ‘Quantitative data analysis deals with information expressed as numbers, as opposed to words, and is about statistical analysis’ (United States General Accounting Office, 1992).

Placing numerical data into the public domain has an adverse affect on the objective of analysing defence SI, which is subjective in nature (Brown and Flowe, 2005, Anderson and Brown, 2004 and the exploratory interviews and survey of this study). It is also the case that ‘Quantitative questionnaire-type surveys [are] not suitable for providing in-depth understanding of an issue’ (Marsland et al., 2001).

Marsland et al. (2001) go on to state that combining quantitative and qualitative data can lead ‘to improved quality of information’. Marsland et al. (2001) recommend collection and analysis of combined data types when the objective is ‘To obtain quantitative data with an understanding of processes or causes’ (Marsland et al., 2001). To produce a mapping from partitioning of a defence system to the SI of the same equipment requires ‘an understanding of processes or causes’ (Marsland et al., 2001).

This study will merge the two types of data collection and analysis to achieve ‘improved quality of information’ (Marsland et al., 2001) and to satisfy the two objectives of placing data into the public domain and analysing the subjective area of defence SI.

The question is: ‘What types of qualitative and quantitative and data to collect and combine?’

First, dealing with subjective data.

Personal interviews, observation and focus groups were not practicable because of the geographic spread of possible respondents and time limits. Telephone interviews and a postal survey were not practicable because of the lack of contact details. All these reasons led to considering an e-mail or WWW survey.

E-mail and WWW interview-type surveys were impractical because of time considerations; it would be time-consuming to conduct interviews, by e-mail, or, for instance, an online discussion forum, with a large number of respondents. A questionnaire type survey was the only practicable solution.

One way of classifying quantitative data is whether it ‘is nominal, ordinal, interval, or ratio’ (United States General Accounting Office, 1992). The United States General Accounting Office (1992) go on to state that:

- The attributes of a nominal variable have no inherent order.
- With an ordinal variable, the attributes are ordered.
- The attributes of an interval variable are assumed to be equally spaced.

- The attributes of a ratio variable are assumed to have equal intervals and a true zero point.

(United States General Accounting Office, 1992).

To produce a mapping from the partitioning of a major defence system to the SI of the same system requires some order of the effects. Producing a mapping would be difficult if it was not known what affects SI efficiency, for instance, the most and the least. This requirement rules out nominal data.

This study ruled out interval data as it would be time-consuming to produce a set of equally spaced influences. This study does not have the time to produce a set of equally spaced influences.

'With ratio variables, it makes sense to form ratios of observations and it is thus meaningful, for example, to say that a person of 90 years is twice as old as one of 45' (United States General Accounting Office, 1992). The exploratory interviews of this study showed that different engineers disagreed on what influences defence SI and the size of each influence. The disagreement among engineers on what, and the extent to which, influences the efficiency of defence SI rules out ratio variable data collection. This study could never, with any confidence, state that one influence has, for instance, twice the effect of another influence.

Ruling out nominal, interval and ratio variable data collection leaves ordinal data collection. This study will use ordinal data collection and analysis.

The exploratory interviews showed that many engineers saw the same influences at work but ranked them differently for various reasons. An ordinal questionnaire survey that ranked, but did not discard, and combined objective and subjective data would be suitable.

‘All modern science and engineering is based on learning from prior experience’ (Humphrey, 2006). The one survey into defence SI this study found used the Q-methodology.

Mckeown and Thomas (1988, p. 30) state: ‘(…) Q-sorting is a process whereby a subject models his or her point of view by rank, ordering Q-sample stimuli (…)’. Q-methodology ranks survey items but does not discard them and is suitable to modelling points of view (opinions).

Q-methodology is suitable to e-mail administration. Van Exel and de Graaf (2005) use e-mail to perform a Q-methodology study into ‘characteristics of travel modes and the travel decision-making process’. Van Exel and de Graaf (2005) also state that using a ‘computer-based’ method is acceptable. Van Exel and de Graaf (2005) confirm that an e-mail survey is a valid method for running a Q-methodology survey.

Anderson and Brown (2004) use the ‘Q-methodology’ survey technique within the context of defence equipment development. Anderson and Brown (2004) state: ‘The findings suggest that Q-methodology may prove helpful in isolating many of the non-technical latent cost factors associated with system integration and interoperability’.

Brown and Flowe (2005) also use the Q-methodology within a defence equipment development context. They use it to examine the ‘critical hurdles to achieving SOS [System of Systems] cost, schedule and performance requirements’.

The Q-methodology is suitable for the analysis of personal opinions and multidimensional analysis within a defence environment. This study will use ‘Q-methodology’ by e-mail. This study selected the Q-methodology because:

- It combines objective and subjective data collection and analysis which improves the ‘quality of information’ (Marsland et al., 2001).
- It produces objective data that can be placed in the public domain (obvious from the results of Q-methodology studies, for instance Van Exel and de Graaf, 2005 and Brown and Flowe, 2005).
- It can be administered by e-mail (Van Exel and de Graaf, 2005).
- It ranks but does not discard (Mckeown and Thomas, 1988, p. 30).
- It is suitable for the analysis of personal opinions (Mckeown and Thomas, 1988, p. 30).
- It is suitable for multidimensional analysis (Brown and Flowe, 2005).
- It has been used before within a defence equipment development environment by Brown and Flowe (2005) and Anderson and Brown (2004); it has academic precedence.
- Research by Anderson and Brown (2004) shows it is suitable for use within the SI phase of equipment development.

The method of this study will be:

- E-mail Q-methodology survey on partitioning influences.
- E-mail Q-methodology survey on the influences on SI efficiency.
- Study of the survey results and production of a mapping between the partitioning and SI of a defence system.
- Verification, validation and accreditation of the mapping.
- Use of the mapping in a theoretical case study.

3.5 The Q-methodology Process

The Q-methodology analyses, and groups, personal viewpoints, the way that individuals see the world. McKeown and Thomas (1988, p. 12) state: 'Fundamentally, Q entails a method for the scientific study of human subjectivity'. Brown (2004) states: 'Q methodology is a research method with a proven history for illuminating agreement and differences among individual and group perceptions'.

Q-methodology allows quantitative analysis and clustering of personal opinions with factor analysis: 'resulting factors represent points of view, and the association of each respondent with each point of view is indicated by the magnitude of his or her loading on that factor' (McKeown and Thomas, 1988, p. 13).

It will allow, for instance, analysis that discovers whether all senior executives agree about the influences affecting SI efficiency or partitioning.

According to Van Exel and de Graaf (2005), performing a Q methodological study involves the following steps:

- Definition of the concourse.
- Development of the Q-sample.
- Selection of the P set.
- Q-sorting.
- Analysis and interpretation.

The concourse is 'The communication surrounding a topic'; 'the collection of all the possible statements the respondents can make about the subject at hand' (Van Exel and de Graaf, 2005). This study used the exploratory interviews and survey as the first phase of the concourse. Further survey and interviews of SMEs (Subject Matter Experts), described in the next chapter, was the final phase.

Q-samples, or the Q-set, are 'a subset of statements (…) drawn from the concourse, to be presented to the participants' (Van Exel and de Graaf, 2005). 'The nature of the stimuli making up the Q-sample is constrained only by the domain of subjectivity in which the researcher is interested' (McKeown and Thomas, 1988, p. 12).

In this case the Q-sample will be a series of statements that summarise the influences on partitioning and the efficiency of SI.

McKeown and Thomas (1988, p. 25) distinguish statement types by labelling them either 'naturalistic' or 'ready-made'. McKeown and Thomas (1988, p. 25) state that naturalistic statements are 'from respondents' oral or written communications' and ready-made are from ‘sources other than their own communications’, for instance journals and academic papers.

This study uses naturalistic statements. ‘Naturalistic Q-samples greatly reduce the risk of missing the respondents’ meanings or confusing them with alternative meanings deriving from an external frame of reference’ (McKeown and Thomas, 1988, p. 25).

The first step in developing the Q-sample was the analysis of the exploratory interviews and survey. The analysis of the exploratory survey and interviews produced the initial Q-sample. The next chapter describes the generation of the final Q-sample.

The next step in Q-methodology is to select the ‘P-set’, the survey respondents.

According to (McKeown and Thomas, 1988, p. 36) the purpose of Q-methodology is to ‘study intensively the self-referent perspectives of particular individuals’. Mckeown and Thomas (1988, p. 36) go on to say: ‘Subject selection, therefore, can be governed by (…) pragmatic (anyone will suffice) considerations’.

According to Brown (2004) Q-methodology is ‘less concerned with participant sampling techniques’; ‘the rigor that is often associated with identifying the target sample is redirected toward identifying the survey items’.

The objective of the Q-methodology survey in this study is to identify the different opinions in the total population. The Q-methodology survey should, to gain as wide a view of individual opinion as possible, survey as large a sample as possible. Any population analysis will be carried out in the mapping phase of the study.

McKeown and Thomas (1988, p. 37), define this type of study as an ‘extensive person sample’ and state: ‘The drawing of extensive person-samples is often affected by simple pragmatic considerations, namely, who is available?’

The Q-methodology survey, in keeping with the aims of this study, carried out no population sampling principles.

The next phase in Q-methodology is the survey – the Q-sorting.

‘Q-sorting is a process whereby a subject models his or her point of view by rank, ordering Q-sample stimuli along a continuum defined by a condition of instruction. A *condition of instruction* is a guide for sorting Q-sample items’ (McKeown and Thomas, 1988, p. 30).

This study has two ‘conditions of instructions’, one for the partitioning survey and one for the SI survey:

- What factors influence the way you partition a system at the design stage?
- What factors affect the efficiency of SI?

The P-set rank ('Q-sort' or arrange) the Q-sample statements in a 'quasi-normal distribution' grid according to their personal opinion. Figure 3.2, below, shows the 'Q-grid' used in this study.

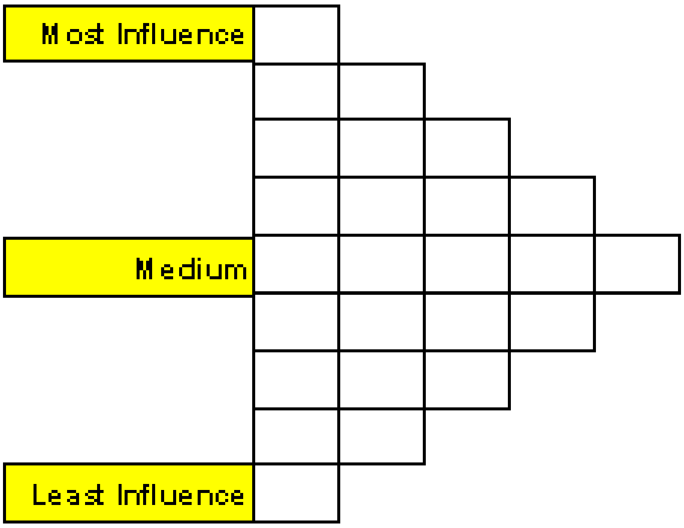

Figure 3.2 – The 'Q-grid'

The extremities are the statements respondents most agree or disagree with; the central part of the grid contains the statements respondents feel neutral about:

> 'The recommended quasi-normal distribution is merely a device for encouraging subjects to consider the items more systematically than they otherwise might. In keeping with the Law of Error, it is assumed that fewer issues are of great importance than issues of less or no significance. Thus fewer items are found at the extremes.' (McKeown and Thomas, 1988, p. 34)

Figure 3.3, below, shows an example Q-sorting of 25 statements.

						Statement Scores
Most Influence	25					4
	8	7				3
	3	1	13			2
	21	19	5	22		1
Medium	24	17	11	15	4	0
	23	2	10	9		-1
	6	20	16			-2
	14	18				-3
Least Influence	12					-4

Figure 3.3 – Example Q-sorting

In the example the respondent thought that Q-sample statement 25 had the most influence and statement 12 the least. The Q-methodology assigns each row of the grid a score from +4 (most influence) through 0 (medium) to –4 (least influence), leading to a set of statements with an assigned score. One statement will have a score of +4; two will have a score of +3 and so on down to one statement having a score of –4.

The output of the survey stage is a table containing an index of Q-sorted statements for each respondent. The first column lists the number of the Q-sample statement; the following columns identify the respondent.

In the example below, respondent 1 placed statement 1 in the –3 row, statement 2 in the +3 row and so on down to statement 25 which respondent 1 placed in the 0 (medium) row.

See Table 3.1, below, for an example Q-sort matrix.

Q-sample Statement Number	***Respondent 1***	***Respondent 2***	---------	***Respondent 'n'***
1	–3	1	---------	0
2	3	2	---------	1
3	3	2	---------	4
4	–3	2	---------	–4
5	2	0	---------	0
6	2	0	---------	0
and so on to:	---------	---------	---------	---------
25	0	0	---------	2

Table 3.1 – Example Q-sort Matrix

After Q-sorting has been done the analysis and interpretation begin.

This study uses PQMethod 2.11 for Q-methodology data analysis. PQMethod 2.11 is a freeware program. Stephen R. Brown, an expert in Q-methodology, used the program in the paper 'The Future of the Q Methodology Movement' (Hurd and Brown, 2004). Watts and Stenner (2005) and Krueger et al. (2001) also recommend PQMethod.

'Data analysis in Q Methodology typically involves the sequential application of three sets of statistical procedures: correlation, factor analysis, and the computation of factor scores' (McKeown and Thomas, 1988, p. 46). This study will follow this procedure.

The program first calculates a correlation matrix for the complete P-set. 'This represents the level of (dis)agreement between the individual sorts, that is, the degree of (dis)similarity in points of view between the individual Q sorters' (Van Exel and de Graaf, 2005).

PQMethod 2.11, after correlation, then carries out factor analysis on the correlation matrix. The program can carry out two types of factor analysis on the Q-sort matrix: centroid and PCA (Principal Component Analysis).

McKeown and Thomas (1988, p. 49) state: 'It makes little difference whether the specific factoring routine is the principal components, centroid, or any other available method'. Anderson and Brown (2004) state: 'By convention, Principal Components Analysis with a Varimax Rotation is the most common routine employed'.

This study will use PCA with varimax rotation.

After PCA and varimax rotation comes factor analysis. 'Factor analysis is fundamental to Q Methodology since it comprises the statistical means by which subjects are grouped – or, more accurately, group themselves – through the process of Q-sorting' (McKeown and Thomas, 1988, p. 49).

The output of the factor analysis stage is a set of 'factors' that group individuals who hold similar opinions. Positioning of the statements within the Q-grid sample, by individuals, defines the factors.

When talking about factor analysis Brown (1991) states:

> ‘in the case of Q methodology, [factor analysis] determines how many basically different Q sorts are in evidence: Q sorts which are highly correlated with one another may be considered to have a family resemblance, those belonging to one family being highly correlated with one another but uncorrelated with members of other families. Factor analysis tells us how many different families (factors) there are.’

‘People with similar views on the topic will share the same factor’ (Van Exel and de Graaf, 2005).

For instance, does any group of respondents group on a certain subset of Q-sample statements? Do certain classes of respondent, for instance senior executives, correlate in total or in part?

Grouping of respondents will simplify the mapping between partitioning and SI. This study will research commonalities; it will also abstract the influences affecting partitioning a defence equipment project and the efficiency of SI.

PQMethod 2.11 defines an idealised Q-sort for each factor that emerges from the factor analysis. The purpose of calculating factor scores ‘is to generate a *factor array* or model Q-sort – one for each factor’ (McKeown and Thomas, 1988, p. 53).

When describing the computing of factor scores Van Exel and de Graaf (2005) state:

> ‘statements can be attributed to the original quasi-normal distribution, resulting in a composite (or idealised) Q sort for each factor. The composite Q sort of a factor represents how a hypothetical respondent with a 100%

> loading on that factor would have ordered all the statements of the Q-set (…) Factor scores on a factor's composite Q sort and difference scores point out the salient statements that deserve special attention in describing and interpreting that factor.'

The objective is to produce a mapping between the two pattern sets, or factors, drawn from the two surveys.

3.6 Developing the Mapping

This study will develop the mapping using the guidelines contained in the US DoD (Department of Defense) RPG (Recommended Practices Guide) for M&S[3] VV&A[4], Millennium Edition, 2000 (DoD, 2006). The RPG contains guidelines for both developing a model and for VV&A.

This study will produce a set of instructions to help engineers use the mappings. These instructions, and the mapping, will then be used in a theoretical case study to partition a future airborne radar. The theoretical case study partitioning will be subject to SME review.

3.7 Research Limitations

Even though the size of the data set is large it still represents only a fraction of the total population. Readers of this study should view the results within this context.

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[3] Modelling and simulation.

[4] Verification, validation and accreditation.

The major limits of this study are because of time and resource issues and that this study is exploratory in nature. The almost total lack of public domain research into defence system integration was also a factor.

This study created the Q-sample (statements) by exploratory interview and literature search and then two rounds of statement reduction by SMEs (described in the next chapter). The literature search used many different sources. The exploratory interviewees were from two different organisations but the SME review used one organisation only. It is possible that the SME review is 'the opinion' of one organisation only.

The number of Q-samples (statements) presented in the surveys (25) is low. This study restricted the number of Q-sample statements to 25 because of time and resource limits. User testing of the two survey forms also suggested that having more than 25 Q-samples would reduce the survey response rate. This study combined, summarised and ignored many minor influences and used the 'top 25' influences.

The two Q-methodology surveys were conducted by e-mail. Anderson (2007) raised the issue of conducting Q-methodology by 'remote means', in this study's case by e-mail. Anderson (2007) commented that a follow-up interview to the Q-sort is important to understand the respondents' Q-sort fully. Van Exel and de Graaf (2005) state that 'Mail or computer-based Q sorts may be desirable in case the theoretically relevant sample has a wider geographical distribution' (Van Exel and de Graaf, 2005). A decision had to be made between conducting Q-sorts in person and remotely. The decision hinged on the requirement to have as large a response as possible. Conducting Q-sorts in person, because of practical limitations, would reduce the number of respondents and the ‘geographical distribution’ of respondents. The decision was made to conduct the Q-sort remotely (by e-mail).

Despite user pre-testing of the survey forms, an issue emerged during the survey. The issue was the name of the centre row: should it be ‘Neutral’ or ‘Medium’? See figure 3.4, below, for the original and subsequent Q-grids.

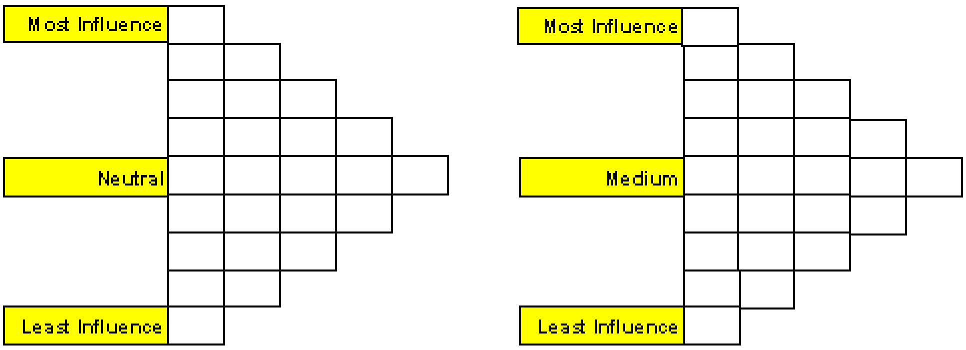


Figure 3.4 – Original (Left) and Later (Right) Q-grids

The Q-grid centre row name was initially ‘neutral’ then changed to ‘medium’ after the comment ‘Neutral seems to imply don’t care but what you don’t care about has the least influence’ (Anderson 2007). An anonymous respondent made the same comment.

Anderson (2007) also raised various issues about interpreting the statements when performing the Q-sort. For instance: ‘configuration management – what about CM? Good CM, Bad CM, I’ve had experience both ways’.

Anderson (2007) summarised the problems of designing a Q-methodology survey by stating: ‘I’ve some experience with trying to do Q surveys so I can sympathize with your challenges (…) Welcome to the world of subjective research!’

Marsland et al. (2001) state that 'there are four tests of trustworthiness' of survey data:

- Internal validity or credibility: The key question here is: how confident can we be about the 'truth' of the findings?

- External validity or transferability: Can we apply these findings to other contexts or with other groups of people?

- Reliability or dependability: Would the findings be repeated if the inquiry was replicated with the same or similar subjects in the same or similar context?

- Objectivity or confirmability: How can we be certain that the findings have been determined by the subjects and context of the inquiry, rather than the biases, motivations and perspectives of the investigators?

This study made no specific checks on the Marsland et al. (2001) tests of the trustworthiness of data from the two Q-methodology surveys.

It is possible to interpret any data set in more than one way; others may interpret the data differently from this study.

3.8 Chapter Summary

This chapter described the use of interview and survey of SMEs for an exploratory investigation into partitioning and SI.

The exploratory investigation revealed a series of influences which were multidimensional, and many were subjective: a situation suitable for the Q-methodology.

This chapter has justified using the Q-methodology as the main research method and has given a detailed description of the Q-methodology. It has also described the method for developing the mapping and has explained the limits of the research methods.

The next chapter describes the ‘Q-methodology in action’ and its use in this study to extract the multidimensional influences on defence equipment development.

Chapter 4 The Q-methodology in Action

4.1 Introduction

Figure 4.1, below, describes the structure of this chapter.

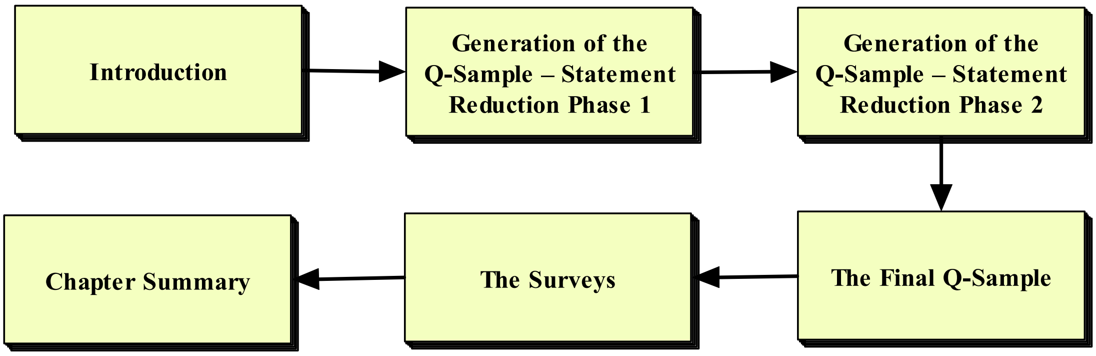


Figure 4.1 – Q-methodology in Action Chapter Structure

Analysis of the exploratory interviews and the partitioning survey, described in the previous chapter, produced a set of 48 partitioning statements, or influences, and 49 SI statements, or influences.

The requirement of the final Q-sample is that the number of statements must be 25 in each case. The final list of 25 statements will form the Q-sample for the Q-methodology survey. The reduction in statement number to 25 forms part of the concourse referred to in the previous chapter.

Brown (2004) states: ‘To ensure content validity, sample statements are usually reviewed by domain experts’. This study used four SME surveys, two for each of partitioning and SI and a series of interviews to get the final Q-sample of 25 statements. The ‘statement reduction’ was carried out in two phases in both cases.

This chapter first describes the two stages for deciding the final Q-sample of 25 statements before listing them.

This chapter then describes user testing of the survey forms and shows the final forms. Finally, the details of the number of surveys forms sent out, and returned, are given, with a brief description of the wide range of respondents.

4.2 Generation of the Q-sample – Statement Reduction Phase 1

The initial partitioning and SI statement lists were sent to a set of domain experts (SMEs). The SMEs were asked to rank the statements and to produce a final list of 29 statements that, in their opinion, had the most influence on partitioning or the efficiency of SI. Comments on the two statement lists were invited.

Clarification of responses and comments was by interview. Analysis of the returns and the interviews created a list of 29 statements.

The study author incorporated the comments into the statement sets to produce two statement sets of 29 statements.

The subject matter experts for the first partitioning statement iteration consisted of:

- Two senior software executives.
- Two software managers.
- Two system architects.
- Two chief engineers.
- One systems engineering manager.

- Three systems engineers.

The subject matter experts for the first SI statement iteration consisted of:

- One chief engineer.
- Four SI engineers.
- Two software engineers.

4.3 Generation of the Q-sample – Statement Reduction Phase 2

The second, and final, phase of statement reduction, to 25, was again by survey and interview using a different group of subject matter experts from the first phase.

The subject matter experts for the second partitioning statement iteration were:

- One senior systems engineering executive.
- One systems engineering manager.
- One programme manager.
- Two systems engineers.
- Three hardware engineers.
- Two software engineers.

The subject matter experts for the second SI statement iteration were:

- Two software engineers.
- One systems engineer manager.

- One software manager.
- Three SI engineers.
- One systems engineer.

4.4 The Final Q-sample

The two phases of statement produced two lists of final statements; these two lists form the Q-sample for the survey.

'Finally, the statements are (…) randomly assigned a number' (Van Exel and de Graaf, 2005).

The Microsoft Excel 'RANDBETWEEN' function was used to 'randomise' the order of the final Q-sample.

The final partitioning Q-sample:

1. Simple or well understood interfaces.
2. Future system growth.
3. Re-use (designs, equipment, etc.).
4. Co-operation and communication.
5. Budget constraints.
6. Form, fit, thermal or weight.
7. Key technology owner.

8. Standards.

9. Industry trends.

10. Match a unit or function to a department or company.

11. Proprietary information considerations.

12. Timescales.

13. Available technologies.

14. Requirements.

15. Commercial off-the-shelf (COTS) considerations.

16. Bounding of responsibilities.

17. Security.

18. The customer.

19. Company experience.

20. Company technological base.

21. Obsolescence.

22. Work share process and outcome.

23. Testability/maintainability/producability.

24. Operational use knowledge.

25. External contractors' competencies.

The final SI Q-sample:

1. Co-operation and communication – external.
2. Clear, well understood requirements.
3. Configuration management (CM).
4. Short-termism.
5. Informed and timely decisions.
6. Operational environment – level of knowledge.
7. Accessibility and availability of platform hardware.
8. Availability of commercial off-the-shelf (COTS) test equipment.
9. Co-operation and communication – internal.
10. Simple or well understood interfaces.
11. Knowledge flow, written and oral.
12. Accessibility and availability of specialist engineers.
13. Accessibility and availability of test equipment.
14. Useable equipment status information.
15. Level of testing at sub-system level.
16. Conflicting priorities.
17. Level of system design for system integration.

18. The size of the system.

19. Accessibility and availability of decision-makers.

20. Re-use (test equipment, procedures, analysis tools, etc.).

21. Level of system level knowledge at sub-system level.

22. Stable working environment.

23. Problem-reporting mechanisms.

24. Usability of testing plans and procedures.

25. Level of change between software builds.

4.5 The Surveys

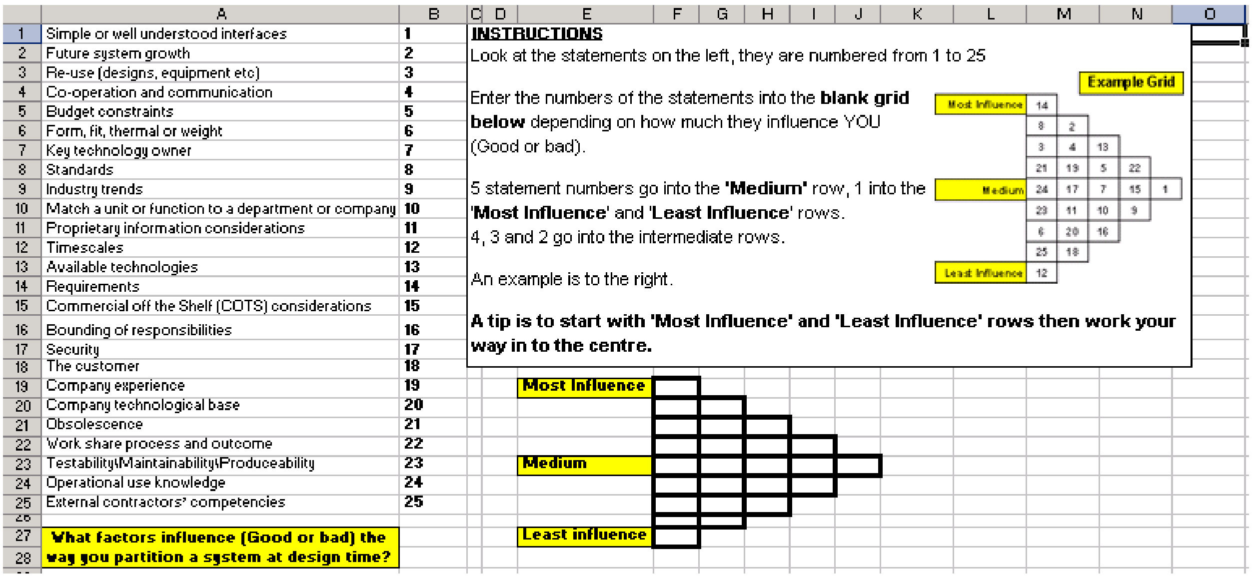
Potential respondents came from many sources, for instance academic papers, journal articles and personal contacts. This study produced 239 names for the SI survey and 135 for the partitioning survey.

The surveys were carried out between July and October 2007.

A survey form (Microsoft Excel spreadsheet) and a set of instructions were e-mailed to each potential respondent. The survey forms, and instructions, were subject to ‘user testing’ before use. This user testing used a survey on people’s views of their car as a ‘test survey’. Respondents were asked to arrange various statements, for instance ‘its main use is to get me to work’, in a Q-grid. The survey was conducted in ‘slow time’, users were observed and comments invited and noted. These comments were then incorporated into the next version of the survey form.

First use of the final survey form was in the partitioning survey. The first two respondents were asked to comment on the survey form usability as well as to complete the survey. The comments of these two individuals were then incorporated into both final survey forms and instructions.

Figure 4.2, below, shows the partitioning survey form.



	A	B
1	Simple or well understood interfaces	1
2	Future system growth	2
3	Re-use (designs, equipment etc)	3
4	Co-operation and communication	4
5	Budget constraints	5
6	Form, fit, thermal or weight	6
7	Key technology owner	7
8	Standards	8
9	Industry trends	9
10	Match a unit or function to a department or company	10
11	Proprietary information considerations	11
12	Timescales	12
13	Available technologies	13
14	Requirements	14
15	Commercial off the Shelf (COTS) considerations	15
16	Bounding of responsibilities	16
17	Security	17
18	The customer	18
19	Company experience	19
20	Company technological base	20
21	Obsolescence	21
22	Work share process and outcome	22
23	Testability\Maintainability\Produceability	23
24	Operational use knowledge	24
25	External contractors' competencies	25
27	**What factors influence (Good or bad) the**	
28	**way you partition a system at design time?**	

INSTRUCTIONS

Look at the statements on the left, they are numbered from 1 to 25

Enter the numbers of the statements into the **blank grid below** depending on how much they influence YOU (Good or bad).

5 statement numbers go into the **'Medium'** row, 1 into the **'Most Influence'** and **'Least Influence'** rows.
4, 3 and 2 go into the intermediate rows.

An example is to the right.

A tip is to start with 'Most Influence' and 'Least Influence' rows then work your way in to the centre.

Figure 4.2 – Partitioning Survey Form

Figure 4.3, below, shows the SI survey form.

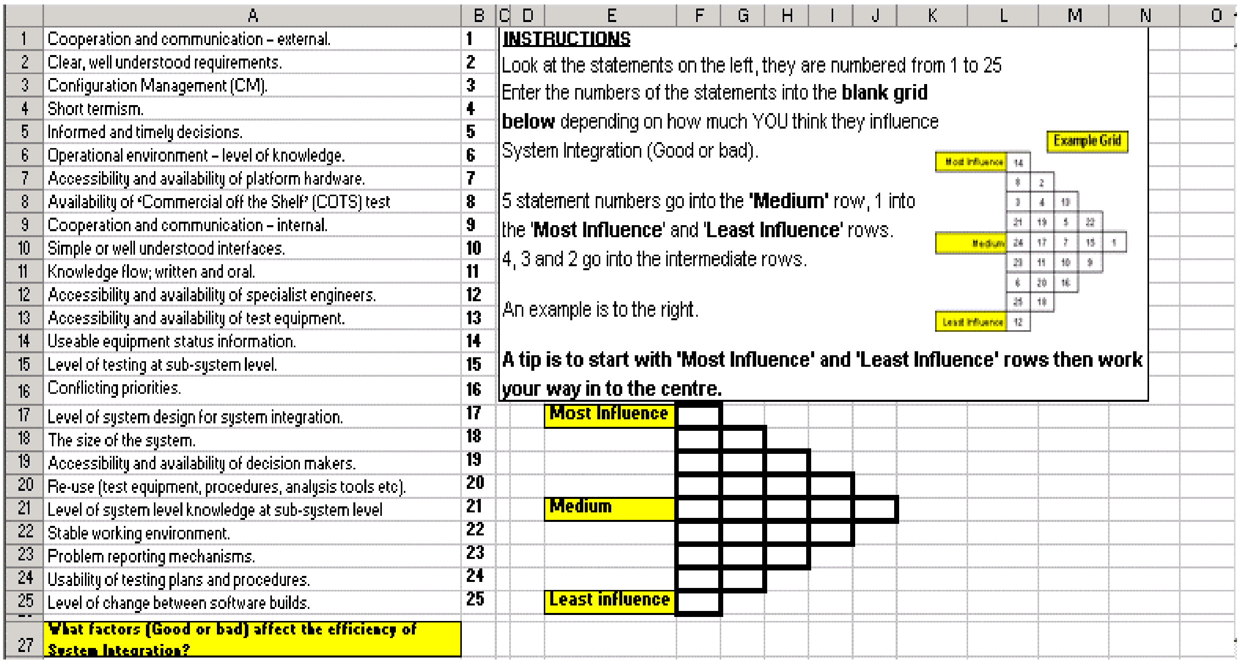


Figure 4.3 – System Integration Survey Form

Return rates were 63% (85 returns) for the partitioning survey and 31% (73 returns) for the SI survey. No survey forms were spoiled.

Respondents were asked to group themselves into one of 13 job descriptions:

- Chief engineer or technical lead.
- System architect.
- Systems engineer.
- Hardware engineer.
- Software engineer.
- System integration engineer.

- Software engineer manager or supervisor.
- Hardware engineer manager or supervisor.
- Program manager.
- Senior executive.
- Academic.
- Engineering manager (general or multidiscipline).
- None of the above.

The survey respondents were from many different countries and institutions and worked at different levels, from junior engineer to senior executive, from junior to senior researcher. The job description of respondents also varied, for instance software engineer, system architect, chief engineer.

4.6 Chapter Summary

This chapter first justified the use of SMEs (Brown, 2004) to define the final Q-sample. This chapter then described the two-phase statement number reduction, to 25, by 37 SMEs.

The survey process was then described, from user testing of the survey form to the response rates for the two surveys.

The two surveys produced 158 responses. The next chapter describes the survey respondents and the statistical analysis of the data.

Chapter 5 Survey Returns and Statistical Analysis

5.1 Introduction

Figure 5.1, below, describes the structure of this chapter.

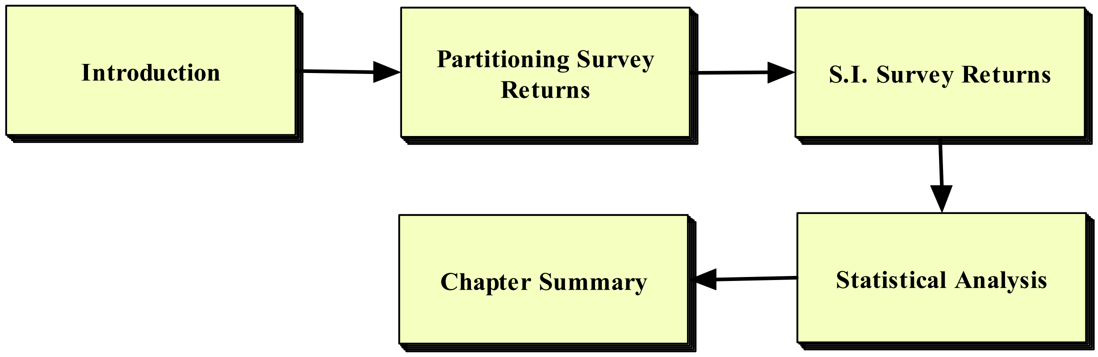


Figure 5.1 – Survey Results Chapter Structure

This chapter first presents the details of the survey returns before carrying out a statistical analysis of the returns.

5.2 Partitioning Survey Returns

The condition of instruction (survey question) was:

What factors influence the way you partition a system at design time?

Table 5.1, below, shows respondent's job description, and the number of respondents for that job.

Job Title	***Number of Respondents***
System Architect	4
Chief Engineer or Technical Lead	16
Systems Engineer	13
Hardware Engineer	6
Software Engineer	6
Software Engineer Manager or Supervisor	5
Hardware Engineer Manager or Supervisor	7
Senior Executive	10
Engineering Manager (General or Multidiscipline)	17
None of the above/not applicable	1
Total	**85**

Table 5.1 – Partitioning Survey Job Descriptions and Totals

Appendix A shows the full set of survey results.

5.3 SI Survey Returns

The condition of instruction (survey question) was:

What factors affect the efficiency of System Integration?

Table 5.2, below, shows respondent's job description, and the number of respondents for that job.

Job Title	***Number of Respondents***
Chief Engineer or Technical Lead	3
Systems Engineer	8
Hardware Engineer	4
Software Engineer	4
SI Engineer	8
Software Engineer Manager or Supervisor	2
Hardware Engineer Manager or Supervisor	3
Programme Manager	4
Senior Executive	18
Academic	10
Engineering Manager (General or Multidiscipline)	8
None of the above/not applicable	1
Total	**73**

Table 5.2 – SI Survey Job Descriptions and Totals

Appendix B shows the full set of survey results.

5.4 Statistical Analysis

PQMethod 2.11 produces four main outputs:

- **Groups of similar Q-sorts (factors or groups) with an assigned eigenvalue.**

'The Eigenvalues reflect the amount of variation accounted for by the corresponding factor. In essence, the relative magnitude of the Eigenvalues can be used to order the importance of the factors' (Brown, 2004). 'By convention, factors with eigenvalues greater than 1.00 are considered significant' (McKeown and Thomas, 1988, p. 51).

- **An idealised Q-sort for each factor (group).**

- **A list of distinguishing statements for each group**. Statements that are 'placed in significantly different locations in the opinion continuum' (McKeown and Thomas, 1988, p. 53).

- **A list of 'consensus statements'** – 'a statement that is not distinguishing between any of the identified factors' (Van Exel and de Graaf, 2005).

The maximum number of groups PQMethod 2.11 produces is eight; both surveys produced at least eight significant groups.

Tables 5.3 and 5.4, below, show the factors, and the percentage of the total variance explained by each factor.

Group (Factor)	*Eigenvalue*	*% of Total Variance*
1	24.8	29
2	9.2	11
3	6.9	8
4	4.8	6
5	4.0	5
6	3.5	4
7	3.5	4
8	3.4	4
Total Explained Variance		71

Table 5.3 – Partitioning Survey Eigenvalues and Percentage Variance

Group (Factor)	*Eigenvalue*	*% of Total Variance*
1	19.5	27
2	7.4	10
3	5.8	8
4	4.9	7
5	4.0	5
6	3.7	5
7	3.4	5
8	3.0	4
Total Explained Variance		71

Table 5.4 – SI Survey Eigenvalues and Percentage Variance

To keep the analysis to a manageable level only the first five factors, from each survey, were output for full analysis.

This study used the idealised Q-sort to get the most and least important influences from each of the five factors. Table 5.5 below summarises the data for the partitioning survey. The number in brackets, after each influence, is where in the Q-grid the idealised Q-sort placed the influence.

Group	***Most Important***	***Least Important***
1	• Requirements (+4). • The customer (+3). • Simple or well understood interfaces (+3).	• Match a unit or function to a department or company (–4). • Security (–3). • Bounding of responsibilities (–3).
2	• Simple or well understood interfaces (+4). • Re-use (designs, equipment, etc.) (+3). • Future system growth (+3).	• Match a unit or function to a department or company (–4). • External contractors' competencies (–3). • Industry trends (–3).
3	• Simple or well understood interfaces (+4). • Requirements (+3). • Match a unit or function to a department or company (+3).	• Obsolescence (–4). • Industry trends (–3). • Budget constraints (–3).
4	• Requirements (+4). • Testability/maintainability/produceability (+3). • Available technologies (+3).	• Industry trends (–4). • Match a unit or function to a department or company (–3). • Proprietary information considerations (–3).
5	• Form, fit, thermal or weight (+4). • Requirements (+3). • Budget constraints (+3).	• Work share process and outcome (–4). • Security (–3). • Co-operation and communication (–3).

Table 5.5 – Most and Least Important Influences – System Partitioning

The influences that each group places in a different position to other groups are output by PQMethod. These ‘significant factors’ characterise each group. The influences that each group placed higher or lower than all other groups is shown in Table 5.6 below.

Group	***Distinguishing Influences***	***Group Name/Short Description***
1	• The customer (high). • Company technological base (high). • Bounding of responsibilities (low).	The customer and us.
2	• Re-use (designs, equipment, etc.) (high). • Future system growth (high). • Security (high). • Requirements (low). • External contractors' competencies (low).	Re-use for the future.
3	• Match a unit or function to a department or company (high). • Bounding of responsibilities (high). • Work share process and outcome (high). • Available technologies (low). • Budget constraints (low). • Obsolescence (low).	Match the task you are given.
4	• Standards (high). • Obsolescence (high). • Company experience (low). • Industry trends (low).	Use standards to avoid obsolescence.

Group	*Distinguishing Influences*	*Group Name/Short Description*
5	• Form, fit, thermal or weight (high). • Co-operation and communication (low). • Work share process and outcome (low).	Size matters.

Table 5.6 – Distinguishing Influences – System Partitioning

Table 5.7 below summarises the data for the SI survey. The number in brackets, after each influence, is where in the Q-grid the idealised Q-sort placed the influence.

Group	***Most Important***	***Least Important***
1	• Clear, well understood requirements (+4). • Simple or well understood interfaces (+3). • Co-operation and communication – external (+3).	• The size of the system (–3). • Knowledge flow, written and oral (–3). • Short-termism (–4).
2	• The size of the system (+4). • Clear, well understood requirements (+3). • Informed and timely decisions (+3).	• Usability of testing plans and procedures (–3). • Re-use (test equipment, procedures, analysis tools, etc.) (–3). • Level of change between software builds (–4).
3	• Operational environment – level of knowledge (+4). • Short-termism (+3). • Accessibility and availability of platform hardware (+3).	• Re-use (test equipment, procedures, analysis tools, etc.) (–3). • Availability of commercial off-the-shelf (COTS) test equipment (–3). • The size of the system (–4).
4	• Co-operation and communication – external (+4). • Co-operation and communication – internal (+3). • Knowledge flow, written and oral (+3).	• Stable working environment (–3). • Accessibility and availability of decision makers (–3). • Level of system design for system integration (–4).
5	• Clear, well understood requirements (+4). • Simple or well understood interfaces (+3). • Accessibility and availability of test equipment (+3).	• Operational environment – level of knowledge (–3). • Accessibility and availability of decision makers (–3). • Availability of commercial off-the-shelf (COTS) test equipment (–4).

Table 5.7 – Most and Least Important Influences – System Integration

A summary of the system integration survey significant factors is shown in table 5.8 below.

Group	***Distinguishing Influences***	***Group Name/Short Description***
1	• Knowledge flow, written and oral (low). • Short-termism (low).	The standard view.
2	• The size of the system (high). • Accessibility and availability of decision-makers (high). • Usability of testing plans and procedures (low). • Level of change between software builds (low).	Size matters.
3	• The size of the system (low).	Size doesn't matter.
4	• Availability of commercial off-the-shelf (COTS) test equipment (high). • Re-use (test equipment, procedures, analysis tools, etc.) (high). • Clear, well understood requirements (low). • Accessibility and availability of specialist engineers (low). • Level of system design for system integration (low).	COTS and re-use.

Group	*Distinguishing Influences*	*Group Name/Short Description*
5	• Accessibility and availability of test equipment (high). • Configuration management (CM) (high). • Level of system design for system integration (high). • Stable working environment (high) • Co-operation and communication – internal (low). • Informed and timely decisions (low). • Co-operation and communication – external (low). • Operational environment – level of knowledge (low).	Test equipment and CM in a stable working environment.

Table 5.8 – Distinguishing Influences – System Integration

Neither survey had any consensus statements.

5.5 Chapter Summary

This chapter has detailed both the characteristics of the survey respondents from the two surveys and a statistical analysis of the returns.

This chapter details the broad range of respondents, both by job and by organisation.

It has shown that there is a broad range of opinions and that these opinions often conflict. It has also shown there are no Q-methodology consensus statements where everyone agrees on the influence of a particular statement.

The next chapter carries out a more subjective interpretation of the results based on the statistical analysis carried out in this chapter.

Chapter 6 Results Interpretation

6.1 Introduction

Figure 6.1, below, describes the structure of this chapter.

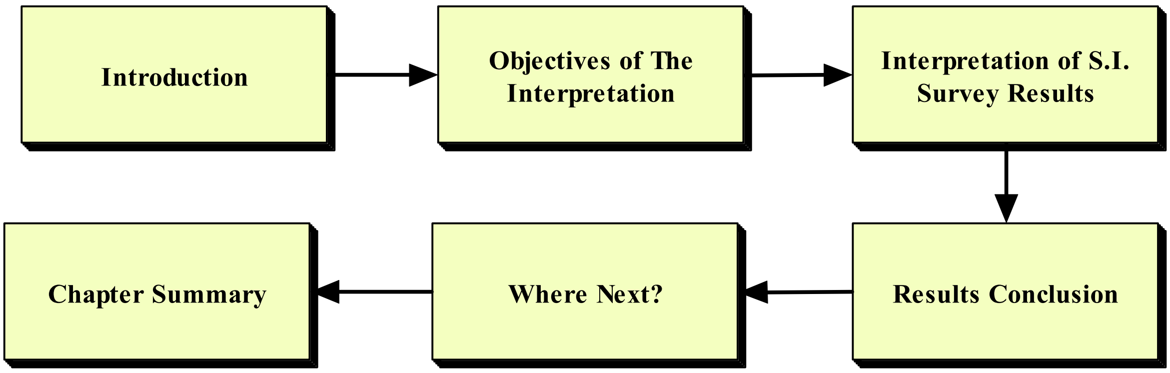


Figure 6.1 – Results Interpretation Chapter Structure

This chapter first defines the objectives of the interpretation before analysing the SI survey results.

This chapter presents the results of the analysis of the SI survey before asking, and answering, 'Where next?'

6.2 Objectives of the Interpretation

This study needs to answer at least four questions before defining a mapping, from partitioning to SI:

- Are enough influences on SI efficiency due to system partitioning so as to ensure any mapping is valid?
- Can the mapping take account of enough of any variance of opinion to ensure any mapping is valid?

- Is there agreement on the influences on the efficiency of SI?
- Is it possible, within the timescales of this study, to assign definitive measures of the factors that affect the efficiency of SI and perform verification and validation on the scaling?

6.3 Interpretation of SI Survey Results

Out of the 25 influences this study found to influence SI only the following seven are technical in nature:

1. Clear, well understood requirements.
2. Availability of commercial off-the-shelf (COTS) test equipment.
3. Simple or well understood interfaces.
4. Useable equipment status information.
5. Level of system design for system integration.
6. Re-use (test equipment, procedures, analysis tools, etc.).
7. The size of the system.

This study will assume that all the technical influences, on SI efficiency, are due to partitioning.

Table 6.1 below shows the percentage of variance explained by all eight groups from the SI survey.

Group	***% of Total Variance***
1	27
2	10
3	8
4	7
5	5
6	5
7	5
8	4
Total	**71**

Table 6.1 – SI Survey Percentage Variance

PQMethod 2.11 can only output the details for eight groups. These eight groups only explain 71% of the total variance.

PQMethod 2.11 produced no consensus statements.

SI Respondents, from the five groups that were subject to analysis, ranked 11 different influences at +4 or +3, and 12 at –4 or –3.

Different groups of respondents ranked the following influences as both most important (+4 or +3) and least important (–4 or –3):

- The size of the system.
- Operational environment – level of knowledge.
- Short-termism.

- Knowledge flow, written and oral.

Analysis of the results (Appendix B) reveals other areas of disagreement among the groups:

- Clear well understood requirements – Ranked as most important by group 1 (+4) and 5 (+4) but medium by group 4 (0).

- Simple or well understood interfaces – Ranked as most important by groups 1 (+3) and 5 (+3), groups 2 (–1) and 3 (–1) rank it below medium.

- Level of system design for system integration – Ranked above medium by group 3 (+2) but medium by group 1 (0) and most unimportant by group 4 (–4).

- Availability of commercial off-the-shelf (COTS) test equipment – Ranked above medium by group 4 (+1) but most unimportant by group 5 (–4).

- Re-use (test equipment, procedures, analysis tools, etc.) – Ranked above medium by group 4 (+1) but below medium (–1 or –2) by the rest of the groups.

- Co-operation and communication – external – Ranked most important by groups 1 (+3) and 4 (+4) and below medium by group 5 (–2).

- Informed and timely decisions – Ranked most important by group 2 (+3) and below medium by group 5 (–1).

Respondent IDs 8 and 32 in the SI survey are SI engineers performing the same job in the same SI laboratory; they disagree on what affects the efficiency of SI.

PQMethod 2.11 creates a 'factor loading matrix' which shows how each respondent loaded on each factor. The factor loading is 'the extent to which each Q-sort is associated with each factor’ (Van Exel and de Graaf, 2005). A factor matrix value of +1 shows perfect agreement with the idealised Q-sort for that factor; –1 shows perfect disagreement. PQMethod 2.11 defines a factor loading value of magnitude greater than 0.5 as being a ‘defining sort’ having significant agreement, or disagreement, with the relevant factor.

Table 6.2, below, shows the factor loadings for respondents 8 and 32 from the SI survey.

Factor	*Respondent 8 Factor Loading Matrix Value*	*Respondent 32 Factor Loading Matrix Value*	*Factor Name*	*Comments*
1	–0.2257	0.2621	The standard view.	Some disagreement between respondents 8 and 32 over the influence of factor 1.
2	0.1475	–0.1926	Size matters.	
3	0.5903	0.255	Size doesn’t matter.	Respondent 8 is a defining sort for factor 3 and has significant association with factor 3. Respondent 32 is not a defining sort for factor 3.
4	0.1747	0.0792	COTS and re-use.	
5	0.0203	0.1823	Test equipment and CM in a stable working environment.	

Table 6.2 – Factor Matrix for Respondents 8 and 32

Of the 25 influences on the efficiency of SI it would not be possible, within the timescales of this study, to assign, verify and validate a scaling of ‘goodness’ and ‘badness’ to the following influences:

- Co-operation and communication – external.
- Short-termism.
- Informed and timely decisions.
- Co-operation and communication – internal.
- Knowledge flow, written and oral.
- Conflicting priorities.
- Accessibility and availability of decision-makers.
- Stable working environment.

6.4 Results Conclusion

Interpretation of the results shows that only seven of the 25 influences on the efficiency of SI were technical in nature and could therefore be directly affected by the partitioning process.

The analysis program, PQMethod, can only define eight groups. These eight groups only captured 71% of the variance in opinion of what affects the efficiency of SI. A mapping should capture more than 71% of opinion to have any authority.

Analysis of the SI survey results produced different, sometimes conflicting, opinions on what affects the efficiency of SI and PQMethod 2.11 produced no consensus statements. Different groups ranked the same four statements as most or least important. Further analysis showed more disagreement among the groups of opinions on the influences on SI efficiency and even disagreement between different engineers within the same SI laboratory.

For eight of the statements it would not have been possible to produce a measure of 'goodness' and perform verification and validation of the measures within the timescale of this study.

This study has shown that defence SI is complex and far more 'multidimensional' than thought at the start of this study.

This study concludes that, within the timescales and resources, it is not possible to define a mapping between the partitioning of a major defence system, at the design stage, and the man-hours spent on the system integration of the same system.

The hypothesis of:

A relationship exists such that a mapping between the two activities is possible

is concluded to be false within the timescales and resources of this study.

6.5 Where Next?

The two Q-methodology surveys reveal the complexity and contradictions of functional partitioning and defence SI.

Some respondents added comments to the survey returns. McKay (2007) said he based his responses on 'experience of all the projects that I have worked on, whether internal to my department or working with other parts of the company [BAE Systems] or different companies'.

McKay (2007) is saying that the boundaries of what influences development can change: sometimes the boundary is internal to his department, sometimes external.

McKay's (2007) comments also suggest that the context, and stakeholders, of defence development are changing, as new interconnections form or end, and there are connections and dependencies outside the project. Prince (2007) confirms the influence of the factors outside the development environment and the complexity of the connection. Prince (2007) states 'I have interpreted the factor "the customer" not as his requirements (…) but as our perception of him in terms of his potential interaction with us during the systems development life cycle'.

Carlyon (2007) commented 'I have completed the Survey 4/5 times hoping to arrive at a consolidated submission however each time I get different results depending on the view point I adopt'. Carlyon's (2007) comments show that some senior engineers within defence development do not fully understand the influences on their work. Prince (2007) confirms the complexity of defence equipment development by stating 'the reality of partitioning isn't black and white'. Prince (2007) goes on to state how the influences can change: 'So a system might initially be partitioned on the basis of the rankings I have entered but reviewing the emergent design re risk, cost, perceived development timescale, etc, etc, and even contracting framework, could then prompt a change' (Prince 2007).

The comments that came with the survey response also suggest that opinion on what affects defence SI may be a personal opinion. Schaefer (2007) commented 'basically we all look at the same problem from our [own] unique skills and perspectives'.

Software engineering represents about 40% of defence equipment development effort (Ferguson, 2001) and contracts typically last over six years (drawn from data presented by United States General Accounting Office, 2006). Defence systems often contain millions of lines of software code, for instance the Joint Strike Fighter contains nineteen million lines of code (United States General Accounting Office, 2006).

Herbsleb and Mockus (2003) carried out a field study of a project that lasted for two years and contained 1.3 million lines of code. Figure 1 in their study shows a workflow graph of a 'slightly simplified version of an MR [modification request] process'.

An MR represents one part of software development which, in turn, represents 'about 40% of defence equipment development effort' (Ferguson, 2001). The figure has many flow lines (this author counted at least 30). Herbsleb and Mockus (2003) admit 'the appearance of the graph is cluttered'.

An expansion of the workflow graph of the study by Herbsleb and Mockus (2003) to represent the full defence equipment development process would produce a workflow graph with many flow lines.

Putting together the comments by McKay (2007), Prince (2007), Carlyon (2007) and Schaefer (2007) with the theoretically scaled-up workflow diagram of Herbsleb and Mockus (2003) would present a complex model. The model would exist in a changing context that has changing boundaries and stakeholders; defining the connections and dependencies would depend on the opinion, and perceptions, of individuals within the model, not all of whom fully understand the model.

This study then looked into describing such a model.

When talking about I&I Anderson and Brown (2004) state that 'stakeholders derive from multiple disciplines across multiple organizations'. Anderson and Brown (2004) go on to state that I&I 'programmatic efforts' are 'often termed multi-agent systems, or complex adaptive systems, their performance levels are often a function of their ability to develop joint solutions that meet both individual and collective needs'. Anderson and Brown's (2004) description of I&I effort could describe the findings of this study; could defence SI be a CAS (Complex Adaptive System)?

'A CAS is a collection of individual, semiautonomous agents that act in ways that are not always predictable and whose actions seek to maximize some measure of goodness, or fitness, by evolving over time' (Tan et al., 2005). This study will use the Tan et al. (2005) definition of a CAS.

Tan et al. (2005) also state that a CAS shows the following characteristics:

- 'Exchanges resources with the environment'.
- 'Consists of interconnected components that work together'.
- 'Self-organisation'.
- 'Has structure and behavior that are difficult to understand and predict'.
- Is 'based on insights and competence of the actors'.

Nine of the influences on SI efficiency involve an exchange of resources with the external, to SI, environment:

- Level of testing at sub-system level.
- Level of system design for system integration.
- Level of change between software builds.
- The size of the system.

- Level of system level knowledge at sub-system level.
- Accessibility and availability of specialist engineers.
- Co-operation and communication – external.
- Operational environment – level of knowledge.
- Clear, well understood requirements.

Four of the influences are internal to the SI environment and involve 'self-organisation' and engineers working together:

- Co-operation and communication – internal.
- Knowledge flow, written and oral.
- Usability of testing plans and procedures.
- Problem-reporting mechanisms.

The different opinions on what affects the efficiency of SI show that SI 'Has structure and behavior that are difficult to understand and predict' (Tan et al., 2005). If SI was easy to understand and predict there would be more agreement on what affects the efficiency of SI and not (at least) eight different, and sometimes conflicting, opinions.

Five of the SI factors are ‘based on insights and competence of the actors’ (Tan et al., 2005). The factors below suggest the actors, in this case, are SI managers:

- Short-termism.
- Informed and timely decisions.
- Conflicting priorities.
- Stable working environment.
- Accessibility and availability of decision-makers.

Given the hints that defence SI is a CAS the new objective of this study is to research the question:

Is defence SI a complex adaptive system?

The secondary hypothesis of this study is:

Defence System Integration is a Complex Adaptive System.

Given that this study does not have the time to develop a mapping between partitioning and the SI of the same system, the rest of this study will research whether defence SI is a CAS. It will also research defining a set of ‘Leading Indicators’ to signal the success of SI.

6.6 Chapter Summary

This chapter has shown that defence SI is a complex process that is more ‘multidimensional’ than was thought at the beginning of the study.

It has shown that, within the timescales and resources of this study, it is not possible to define a mapping between the partitioning of a major defence system, at the design stage, and the man-hours spent on the system integration of the same system.

The hypothesis of:

A relationship exists such that a mapping between the two activities is possible.

has been shown to be false.

This chapter then studied SI as a CAS and provided enough evidence to justify further work to confirm that SI is a CAS. This chapter also stated that a new objective of this study is to research the question:

Is defence SI a complex adaptive system?

The accompanying hypothesis is:

Defence System Integration is a Complex Adaptive System

The next chapter explores whether defence SI is a CAS.

Chapter 7 Is Defence System Integration a CAS?

7.1 Introduction

Figure 7.1, below, describes the structure of this chapter.

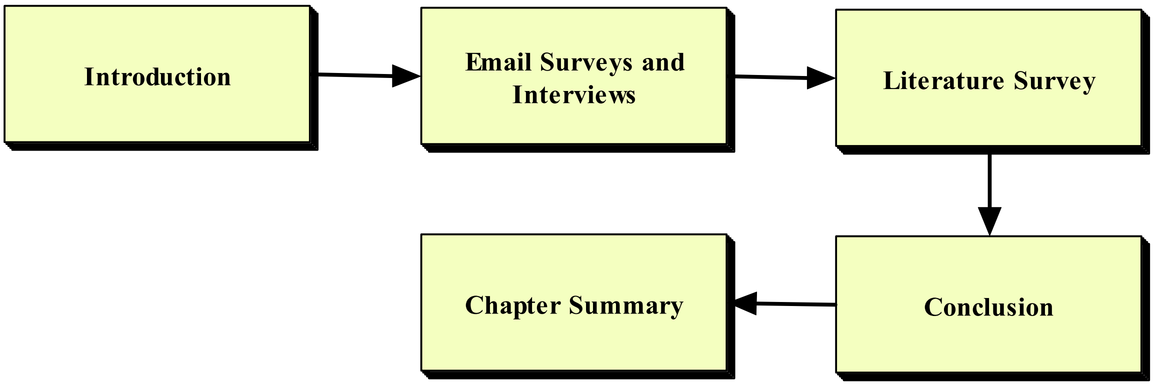


Figure 7.1 – Is Defence System Integration a CAS? Chapter Structure

To answer the question 'Is defence SI a CAS?' this chapter details an e-mail survey, a series of interviews and a literature review. This chapter then presents the results of the survey before summarising the interviews and literature review with tables of quotes before presenting the conclusion.

7.2 E-mail Surveys and Interviews

This study carried out a further e-mail survey of respondents to the main SI survey and conducted a series of short interviews.

The e-mail respondents were from a similar range of organisations and countries as the main survey. The e-mail respondents also performed a similar range of jobs, for instance senior executive, systems engineer.

The interviewees came from three defence companies:

- SELEX-GALILEO (UK).
- BAE Systems (UK).
- EADS Defence and Security (Germany).

They also performed different roles, for instance SI engineer, hardware engineer.

The e-mail survey and interviews asked questions relating to the characteristics of a CAS as defined by Tan et al. (2005). The e-mail survey asked one question; interviewees were asked all questions.

Table 7.1, below, details the questions and related CAS characteristics.

CAS Characteristic	***E-mail Survey Question***	***Interview Question(s)***
Exchanges resources with the environment.	No relevant question asked.	Do you think the factors that affect the efficiency of system integration change at different stages of a project? AND Do you think the actions of system integration engineers are influenced by their experiences of working with people external to the system integration laboratory?
Consists of interconnected components that work together.	Do you think the policy of your department, project, institution or company influenced your views (responses)?	No relevant question asked.
Self-organisation.	Do you find that small groups of people in your department, group or organisation come together (or interact) without prompting, to address specific problems?	Do you find that small groups of engineers come together, without prompting, to solve a system integration problem? AND Do you think that system integration engineers organise themselves to some extent?
Has structure and behaviour that are difficult to understand and predict.	Do you think you can predict, accurately and in total, the resources your department, group or organisation need in the long term?	Do you think you can predict, accurately and in total, the resources that you need to perform the system integration of a system? AND Do you find that system integration engineers sometimes do not act as you would predict, or expect, but are still acting for the good of the department?
Is based on insights and competence of the actors.	Do you think engineers approach problems they have never encountered before based on some type of general experience?	Do you think system integration engineers approach problems they have never encountered before based on some type of general experience?

Table 7.1 – CAS Survey and Interview Questions

Besides the question about being able to predict accurately and in total the resources needed in the future (has structure and behaviour that are difficult to understand and predict), a 'yes' answer pointed to SI being a CAS.

Table 7.2 below summarises the answers to both the e-mail survey and the interviews.

CAS Characteristic	***Total Number of Answers Pointing to Defence SI Being a CAS***	***Total Number of Answers Pointing to Defence SI NOT Being a CAS***	***Comments***
Exchanges resources with the Environment.	11	0	
Consists of interconnected components that work together.	8	4	Two of the Yes answers were qualified with comments.
Self-organisation.	14	0	
Has structure and behaviour that are difficult to understand and predict.	10	2	
Is based on insights and competence of the actors.	7	0	
Totals	**50**	**6**	
Percentage of Total	**89%**	**11%**	

Table 7.2 – CAS Survey and Interview Results Summary

A series of more in-depth interviews and e-mail correspondences were then carried out, the subject being defence system integration. Table 7.3, below, shows a selection of comments:

CAS Characteristic	***Comments***
Exchanges resources with the environment.	‘The organisation should change with the stage of the life cycle that the product sits within’ (McKay, 2007). ‘It helps to have very clear requirements which not only capture the technical side but include budget, timescale and operational use for the system’ (Carlyon, 2007).
Consists of interconnected components that work together.	‘At the start of a project the communication channels are not set up – you need to get people talking’ (Bogner, 2007).
Self-organisation.	‘A fully controlled group of people is not a team’ (Bogner, 2007).
Has structure and behaviour that are difficult to understand and predict.	‘System Integration is “touchy-feely” – it’s a women’s thing’ (O’Neil, 2007). ‘The biggest problem we have is people blocking information; the purchasing department act as information blockers in the supply chain’ (Anonymous 1, 2007).
Is based on insights and competence of the actors.	‘Engineers use a set of general problem solving skills – it’s the results that matters. I have to stand back and let my men get on with it.’ (Anonymous 2, 2007).

Table 7.3 – CAS In-Depth E-mail and Interviews – Selected Quotes

7.3 Literature Survey

This study carried out a literature survey to find out whether the characteristics of a CAS were in evidence within defence system development.

Table 7.4, below, shows a selection of quotes.

CAS Characteristic	***Quote***
Exchanges resources with the environment.	‘The Government’s new policy responds positively to a rapidly changing global defence market’ (Ministry of Defence, 2002). ‘Senior MoD managers have given evidence at Defence Committee hearings of the need for flexibility in a constantly changing world’ (Purton, 2004). ‘Almost nothing is exogenous’ (Sterman, 2002).
Consists of interconnected components that work together.	‘Integration and interoperability efforts, by definition, involve collaborative efforts among independent organizations’ (Anderson and Brown, 2004). ‘Product quality and program progress are affected by a complex set of interacting external constraints and internal program issues’ (Ferguson, 2001). ‘Man has almost constant occasion for the help of his brethren’ (Smith [1], 1776).
Self-organisation.	‘We will not constrain UK companies from expanding into new markets’ (Ministry of Defence, 2002). ‘For these processes to be properly and consistently used, everyone at every level in the organization must use them’ (Humphrey, 2006 when talking about what is needed for the successful development of future systems).
Has structure and behaviour that are difficult to understand and predict.	‘Protectionism is not a viable way forward, but we recognise that not all governments approach acquisition with similar openness’ (Ministry of Defence, 2002). ‘We should never underestimate the human capacity to mess things up’ (Hall, 2004). ‘All models are wrong’ (Sterman, 2002). ‘Every individual is led by an invisible hand to promote an end which was no part of his intention’ (Smith [2], 1776).
Is based on insights and competence of the actors.	‘Investment in research and technology is crucial to the future prosperity of the defence industrial base and the capability of the Armed Forces’ (Ministry of Defence, 2002). ‘All modern science and engineering is based on learning from prior experience’ (Humphrey, 2006). ‘If you are out of trouble, watch for danger’ (Sophocles, c.450BC).

Table 7.4 – Evidence of CAS Characteristics in Defence System Development

7.4 Conclusion

The secondary hypothesis of this study is:

Defence System Integration is a Complex Adaptive System

The opinion of the author is that there is strong evidence that defence SI is a complex adaptive system. The evidence that has led to the conclusion that defence SI is a complex adaptive system is:

- The main SI e-mail survey produced at least eight groups of opinion on what affects the efficiency of SI.
- The eight groups of opinion had no Q-methodology consensus statements and were often contradictory.
- Eighteen of the statements from the main SI survey fitted into the definition of a CAS as given by Tan et al. (2005).
- 89% of answers from the short e-mail survey and interviews suggested that SI is a CAS.
- In-depth interviews and e-mail correspondence backed up the results of the short surveys and interviews.
- A literature search produced further evidence that defence SI is a CAS.

7.5 Chapter Summary

This chapter has analysed the results of an e-mail survey, a series of short interviews and a literature review.

The conclusion is that there are strong suggestions that defence SI is a CAS. This study concludes that the secondary hypothesis of:

Defence System Integration is a Complex Adaptive System

is true.

All that remains of the investigation part of this study is to research whether it is possible to define a set of LIs for defence SI. The next chapter details the investigation.

Chapter 8 Defence SI Leading Indicators

8.1 Introduction

Figure 8.1, below, describes the structure of this chapter.

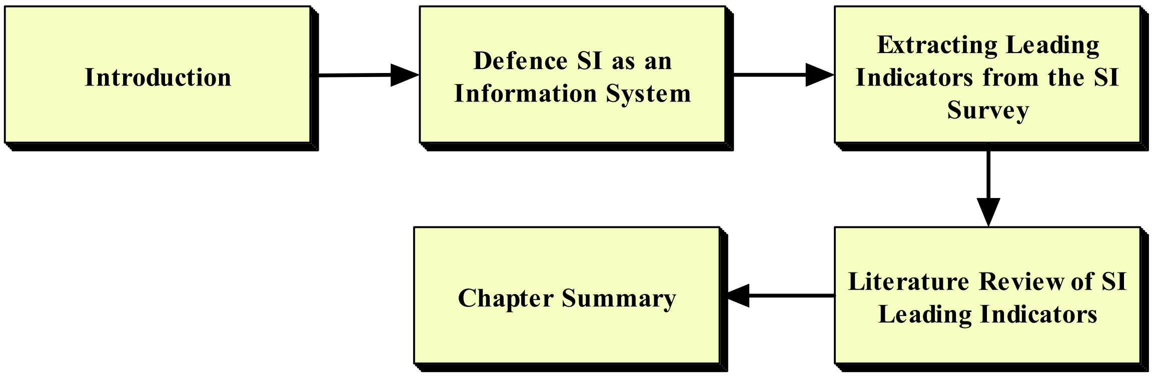


Figure 8.1 – Defence SI Leading Indicators Chapter Summary

This chapter fist defines defence SI as an IS (Information System), then extracts LIs (Leading Indicators) from the SI survey of this study and a literature review of defence SI related papers.

This study has the resources (time) to define, but not review, a set of LIs.

Roedler and Rhodes (2007) define an LI as 'a measure for evaluating the effectiveness of how a specific activity is applied on a program in a manner that provides information about impacts that are likely to affect the system performance objectives. A leading indicator may be an individual measure, or collection of measures, that are predictive of future system performance before the performance is realized'. This study will use the Roedler and Rhodes (2007) definition.

8.2 Defence SI as an Information System

The OMB (Office of Management and Budget) define an IS as a 'discrete set of information technology, data, and related resources, such as personnel, hardware, software, and associated information technology services organized for the collection, processing, maintenance, use, sharing, dissemination or disposition of information' (OMB, 2003). This study will use the OMB (2003) definition.

Defence SI can be defined as an IS given that it does not produce a new artefact and the 'collection, processing, maintenance, use, sharing, dissemination or disposition of information' (OMB, 2003) is an important SI function.

Gholz (2002) states: 'the systems integrator need not have the capability to actually design and build (…) Developing new sources and kinds of technical awareness may be the core competency of a systems integrator'.

Gholz (2002) further states that all levels of defence SI 'involve decisions among technical alternatives and linking disparate equipment so that heterogeneous parts can operate together'. The 'disparate equipment' that Gholz (2002) mentions will 'typically involve many smaller largely independent development projects' (Humphrey, 2006), meaning that 'I&I efforts require unusually high levels of coordination and cooperation' (Anderson and Brown, 2004).

Gholz (2002), Humphrey (2006) and Anderson and Brown (2004) confirm the IS definition of defence SI. SI involves much decision-making and high levels of co-ordination and co-operation between different projects. Defence SI, to achieve the high levels of co-ordination and co-operation, must collect, process, maintain, use, share and disseminate various sources of information.

SI will become more of an IS in the future.

Humphrey (2006) studies the needs of future defence equipment development; much of the changes, from current practices, that Humphrey (2006) recommends involve 'the collection, processing, maintenance, use, sharing, dissemination or disposition of information' (OMB, 2003). For instance, Humphrey (2006) states that developers must 'stay current with process research developments and (…) not waste time experimenting with processes that have already produced unsatisfactory results'.

Humphrey (2006) states that future defence equipment development will need to address issues about 'organizing, planning, measuring, tracking, reporting on, and controlling the work'. Humphrey (2006) recommends a 'development process (…) that can dynamically respond to changing requirements'.

Humphrey's (2006) vision of future defence equipment development involves more 'collection, processing, maintenance, use, sharing, dissemination or disposition of information' (OMB, 2003) than is the case at present.

8.3 Extracting Leading Indicators from the SI Survey

Sumner (1995) summarises 12 reasons IS fail:

- Resource failures.
- Requirements failures.
- Goal failures.
- Technique failures.
- User contact failures.

- Organisational failures.
- Technology failures.
- Size failures.
- People management failures.
- Methodology failures.
- Planning and control failures.
- Personality failures.

Of the 25 influences this study found to affect the efficiency of SI two, ‘Level of system design for system integration’ and ‘Level of testing at sub-system level’, are defined (or ‘pre-ordained’) before SI begins. Three influences, ‘Knowledge flow, written and oral’, ‘Level of system level knowledge at sub-system level’ and ‘Useable equipment status information’ do not fit neatly into any of the IS failure reasons. One, ‘Simple or well understood interfaces’, is seen as very important to the success, or otherwise, of SI (Gholz, 2002 and the main survey of this study).

This study left out the two ‘pre-ordained’ influences, since SI engineers cannot affect these factors and created two new classes of LI – ‘Knowledge Flow’ and ‘Interfaces’.

This study will use the Sumner (1995) classes of IS failures and the two new classes of ‘Interfaces’ and ‘Knowledge Flow’ as a set of 14 LI classes. This study will also put each influence, from the SI survey, into one of the 14 main LI classes as a subclass.

Wording of the influences was changed to keep the LI measures consistent. The wording of the influences was changed so that an answer of ‘yes’ suggested a positive influence on the efficiency of SI.

One influence, ‘The size of the system’, is a relative measure. A system may be large to one manufacturer and small to another. Stutzke (2005) stresses ‘Unprecedentedness’ and states that ‘Unprecedented systems are risky to build and integrate’ (Stutzke, 2005). This study, to incorporate ‘Unprecedentedness’, changed the wording of the influence ‘The size of the system’ to ‘Similar size to past experience’.

Where influences could be split into two, for instance ‘Accessibility and availability of decision makers’ they were. In this case the influence was split into ‘Decision-makers accessible’ and ‘Decision-makers available’.

Table 8.1, below, summarises the LI classes and the suggested subclasses drawn from the SI survey of this study.

LI Class	***Suggested Subclasses***	***Original Influence(s) From Survey***
Resource failures.	Platform hardware available? Platform hardware accessible?	Accessibility and availability of platform hardware.
	Is commercial off-the-shelf (COTS) test equipment available?	Availability of commercial off-the-shelf (COTS) test equipment.
	Test equipment accessible? Test equipment available?	Accessibility and availability of test equipment.
	Is there re-use (test equipment, procedures, analysis tools, etc.)?	Re-use (test equipment, procedures, analysis tools, etc.).
Requirements failures.	Are the requirements clear? Are the requirements understood?	Clear, well understood requirements.
Goal failures.	Is the working environment stable?	Stable working environment.
	Are the priorities clear and non-conflicting?	Conflicting priorities.
Technique failures.	None.	
User contact failures.	High level of operational environment knowledge?	Operational environment – level of knowledge.
Organisational failures.	Decision-makers accessible? Decision-makers available?	Accessibility and availability of decision-makers.
Technology failures.	None.	
Size failures.	Similar size to past experience?	The size of the system.
People management failures.	Specialist engineers accessible? Specialist engineers available?	Accessibility and availability of specialist engineers.

LI Class	***Suggested Subclasses***	***Original Influence(s) From Survey***
Methodology failures.	Good configuration management?	Configuration management (CM).
	Testing plans and procedures useable?	Useability of testing plans and procedures.
	Correct level of change between software builds?	Level of change between software builds.
	Good problem-reporting mechanisms?	Problem-reporting mechanisms.
Planning and control failures.	Informed decision-making? Timely decision-making?	Informed and timely decisions.
	Lack of short-termism?	Short-termism.
Personality failures.	Good internal co-operation and communication?	Co-operation and communication – internal.
	Good external co-operation and communication?	Co-operation and communication – external.
Knowledge flow.	Good written knowledge flow? Good oral knowledge flow?	Knowledge flow, written and oral.
	High level of system level knowledge at sub-system level?	Level of system level knowledge at sub-system level.
	High level of useable equipment status information?	Useable equipment status information.
Interfaces.	Are the interfaces simple? Are the interfaces well understood?	Simple or well understood interfaces.

Table 8.1 – Leading Indicator Classes and Subclasses from This Study

8.4 Literature Review of SI Leading Indicators

This study carried out a brief literature review to gather further subclasses of LIs.

The literature review includes subclasses with a possible overlap to the subclasses gathered from the SI survey of this study. To keep the new LI measures consistent the wording was changed so that an answer of ‘yes’ was suggesting a positive influence on the efficiency of SI.

Table 8.2, below, details the subclasses gathered from the literature review.

LI Class	***Suggested Subclasses from Literature Search***	***Reference***
Resource failures.	Are resources available to encourage interoperability?	Morris et al. (2004).
	Are contractors incentivised to achieve interoperability?	Morris et al. (2004).
	Have the full costs of the SI process been properly defined?	Humphrey (2006).
	Is the SI lab adequately staffed?	Humphrey (2006).
Requirements failures.	Are the requirements stable?	Humphrey (2006).
	Can the SI lab respond to changing requirements?	Humphrey (2006).
	Are all changes planned and managed?	Humphrey (2006).
Goal failures.	Are the goals non-conflicting?	Anderson and Brown (2004).
	Are goals and objectives aligned?	Humphrey (2006).
Technique failures.	Is the SI process defined and proven?	Humphrey (2006).
	Is the SI process accurately planned?	Humphrey (2006).
	Is the SI process measured?	Humphrey (2006).
	Is the SI process quality controlled?	Humphrey (2006).
	Does the SI process learn from the past?	Humphrey (2006).
	Is risk anticipated and managed?	Humphrey (2006).
	Are system-wide effects of sub-system changes defined and managed?	Humphrey (2006).
	Do individuals plan and manage their own work?	Humphrey (2006).
User contact failures.	High level of customer understanding?	Gholz (2002).
Organisational failures.	Is there a lack of bias in decisions by the prime contractor?	Gholz (2002).
Technology failures.	Is the technology mature ('unprecedentedness')?	Stutzke (2005).
Size failures.	Has the SI lab integrated this size of system before ('unprecedentedness')?	Stutzke (2005).

LI Class	***Suggested Subclasses from Literature Search***	***Reference***
People management failures.	Does the SI process have top level management support?	Major Projects Association (2002).
	Are individual and group activities co-ordinated?	Humphrey (2006).
Methodology failures.	Is the ‘system(s)’ the equipment interfaces with available for use as either a finished equipment or simulation?	Advanced Dynamics International (2007), Farren and Ambler (1997), Humphrey (2006).
	Does the organisation consider SI a discipline in its own right?	Farren and Ambler (1997).
	Is there a system test strategy?	Farren and Ambler (1997).
	Has adequate time been allocated for system testing?	Major Projects Association (2002).
	Can solutions be mandated across organisations?	Anderson and Brown (2004).
Planning and control failures.	Good project management?	Gholz (2002).
	Is the SI lab considered part of a ‘system making system’?	Schaefer (2006).
	Has ‘unwanted emergent behaviour’ been planned for?	Schaefer (2006).
	Is there a central leadership function?	Anderson and Brown (2004).
	Are there processes in place to achieve interoperability?	Morris et al. (2004).
Personality failures.	No organisations with ‘agendas’?	Morris et al. (2004).
	Good level of communication between management and technical authorities?	Morris et al. (2004).
Knowledge flow.	Is there technical awareness in a wide range of relevant disciplines?	Gholz (2002).

LI Class	***Suggested Subclasses from Literature Search***	***Reference***
Interfaces.	Have the interfaces to legacy equipment been considered?	Morris et al. (2004).
	Are the exact needs of the system defined, for instance the semantic value of data being exchanged?	Morris et al. (2004).
	Is there ‘tight coupling’ within a system?	Morris et al. (2004).
	Is there ‘loose coupling’ between systems?	Morris et al. (2004).

Table 8.2 – LIs Derived from Literature Review

8.5 Chapter Summary

This chapter has been a brief study of defining a set of LIs from both the SI survey of this study and a literature review.

This chapter ends the investigative part of this study.

The next chapter summarises the conclusions of this study, evaluates the research methods and provides a project review before suggesting further research.

Chapter 9 Project Conclusions

9.1 Project Conclusions

This study is the start of the journey to understand defence equipment development; a full understanding will only come from more research.

This study has, as far as the author is aware, collected and analysed the largest ever public domain data set on defence equipment development. Even though the size of the data set is large it still represents only a fraction of the total population. Readers of this study should view the results within this context.

The primary aim of this study was to answer the question:

Is it possible to define a mapping between partitioning a major defence system, at design time, and the man-hours spent on the system integration of the same equipment?

The hypothesis to the primary objective was:

A relationship exists such that a mapping between the two activities is possible.

If the hypothesis was true a secondary objective was:

If a mapping is possible, define the mapping and prepare instructions for its use.

The tertiary objective was:

If a mapping is possible subject it to verification, validation and accreditation then use it in a theoretical case study of the design of a future airborne radar.

This study concludes that:

Within the timescales and resources of this study, it is not possible to define a mapping between the partitioning of a major defence system, at the design stage, and the man-hours spent on the system integration of the same system.

The hypothesis of 'A relationship exists such that a mapping between the two activities is possible' has been shown to be false within the timescales and resources of this study.

Proving the main hypothesis to be false means that the secondary and tertiary objectives of this study cannot be met.

Chapter six details the reasons for rejecting the hypothesis. The main reason is that this study found that defence SI is a more 'multidimensional' and complex than was at first thought.

A summary of the reasons for rejecting the main hypothesis follows:

- Only seven of the 25 influences on SI (System Integration) this study discovered were technical in nature and could therefore (possibly) be assigned to partitioning.
- The Q-methodology analysis program, PQMethod 2.11, was overloaded with 'Q-methodology factors' (groups of opinion).
- PQMethod 2.11 only captured 71% of the total variance in opinion: 29% was unaccounted for.
- PQMethod 2.11 produced no Q-methodology consensus statements on the efficiency of SI.
- Analysis of the SI survey results produced conflicting opinions on what affects the efficiency of SI.

Chapter two defined a defence equipment development contract as a financial instrument called a ‘future’. Chapter two then introduced the ‘derivatives issue’ – the risk in stating a price now for the future delivery of a commodity, in this case a defence equipment. Chapter two also detailed the spectacular failure of two Nobel Prize winners to solve the issue. The author of this study believes that understanding the ‘derivatives issue’ is important to understanding the ‘multidimensionality’ and complexity of defence SI.

Rejection of the primary hypothesis meant that this study defined a new secondary objective, to answer the question:

Is defence SI a complex adaptive system?

The accompanying hypothesis of the new secondary objective was:

Defence SI is a complex adaptive system.

This study found strong evidence that defence SI is a CAS (Complex Adaptive System).

This study concludes that defence SI is a CAS.

Chapter seven gives the detailed reasons for this conclusion, as summarised below:

- The complexity and contradictions of the SI Q-methodology survey results.
- Eighteen of the 25 SI influences from the original SI Q-methodology survey fitted into the definition of a CAS as given by Tan et al. (2005).
- 89% of the answers from an e-mail survey and interviews suggested that defence SI is a CAS.

- A second series of interviews and e-mail correspondence provided further evidence that defence SI is a CAS.

- A literature search provided more evidence that defence SI is a CAS.

The final investigative phase of this study was to define a set of LIs (Leading Indicators) to signal the success of the SI process: see chapter eight for full details. Resources (time) means the investigation is not much more than a cursory one.

The first part of the investigation defines SI as an IS (Information System) given that SI does not produce a new artefact and the 'collection, processing, maintenance, use, sharing, dissemination or disposition of information' (OMB, 2003) is an important SI function.

The investigation defined 14 classes of LI; 12 from the work of Sumner (1995) and two from the work of this study. A review of the influences this study found to affect SI produced 31 subclasses and a literature review produced a further 40.

The author's opinion is that the best definition of defence SI is as an IS. Future research can learn from the process of setting up the business software application SAP. The multisite implementation of SAP bears a likeness to multisite defence SI.

9.2 Evaluation of the Research Methods

The objective of placing a large volume of data into the public domain affected the richness of the data collected and the depth of analysis. With hindsight it probably would have been better to study fewer individuals more intensively – in Q-methodology terms an intensive rather than an extensive study. The Q-methodology surveys showed the diversity of opinion without finding out why the survey respondents held that opinion.

Q-methodology is a ‘self-referent’ survey method: the Q-methodology concourse extracts people’s opinion based on their own experiences. The self-referent model may not extract all influences on defence development and, therefore, may not be suitable for an exploratory investigation into defence equipment development. Having a stable electricity supply was not part of the Q-methodology concourse; without a stable electricity supply equipment development would be difficult. The author believes the concourse of this study worked in and around a ‘generally accepted’ development environment that everyone assumes is present. Having an unstable electricity supply is an extreme example but how many other, more subtle, influences were not part of the concourse?

9.3 Project Review

This study could be considered a failure in that it has failed to meet any of its original objectives. Alternatively, this study could be considered a success in that it has shown the complexity of defence SI in particular and defence equipment development in general.

Another success of this study has been the placing into the public domain of the largest ever data set, as far as the author is aware, on the subject of defence equipment development. The data set includes the biggest two surveys, in numbers (again as far as the author is aware), into defence system partitioning and defence SI.

The data set includes interviews, e-mail correspondences and survey data. The survey data in particular is open to more analysis.

This study has been successful in gathering and disseminating data, but there are doubts over the validity of the data:

- Only a basic preparation for the conduct of interviews and surveys.
- Doubts over the validity of Q-methodology e-mail surveys.
- Doubts over wording of the survey statements.
- Doubts over wording of the survey form.
- No checking of the trustworthiness of survey data.

These criticisms of the data collection are perhaps unavoidable given a finite set of resources and fixed timescales; mostly the choice was between quantity and quality. This study always leant towards quantity – the author is a firm believer in the aphorism, often credited to Stalin, that 'quantity has a quality all of its own'.

It is the author's belief that whatever criticisms there are of 'quantity', it is hard to ignore and we write to be read.

9.4 Future Research

The author's opinion is that we know little about the influences that affect defence equipment development; follow-up research should concentrate on gaining a deeper understanding. Future research should aim to increase the richness of the data collection, for instance through observation, interview or single person Q-methodology studies. Future studies should consider observation, in particular, to extract influences that were not part of the concourse of this study.

Follow-up research could carry out more analysis of the data collected by this study. This study did not carry out an in-depth analysis; future researchers could learn a lot more about defence development from the data collected by this study.

Future research into system partitioning and SI could expand the two surveys of this study by:

- Performing Q-methodology surveys with more statements. Most, if not all, of the statements this study used could be split up into two or more statements.

- Carrying out more exploratory surveys and interviews to discover more influences. It was obvious to the author that more influences were present.

- Carrying out research based on the stage of the life cycle development. There was more than one suggestion that the influences changed with the life cycle.

Future SI research should consider defining SI as an IS with consideration of the similarity between SI and SAP implementation.

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Appendix A – Partitioning Survey Results

The partitioning survey results are presented in Table 9.1 below.

The left-most column is the respondent ID. The next column is the respondent job code. The job codes are:

- **CE** – Chief engineer or technical lead.
- **AR** – System architect.
- **SE –** Systems engineer.
- **HW** – Hardware engineer.
- **SW** – Software engineer.
- **SS** – Software engineer, manager or supervisor.
- **HS** – Hardware engineer, manager or supervisor.
- **SX** – Senior executive.
- **EM** – Engineering manager (general or multi-discipline).
- **NA** – None of the above/not applicable.

The numbers in the top rows, columns 3 to 27, are the statement numbers.

Taking the top row:

- The respondent ID is 1.
- The respondent's job is Engineering Manager (general or multi-discipline).
- The respondent placed statement 1 (simple or well understood interfaces) in the Q-grid row 4, statement 2 (future system growth) in Q-grid row 1, etc. Respondent 1 Q-grid is shown in Figure 9.1 below.

						Row Number
Most Influence	1					4
	3	16				3
	11	15	23			2
	2	6	21	24		1
Medium	5	13	17	19	20	0
	8	10	14	22		-1
	4	7	9			-2
	12	18				-3
Least Influence	25					-4

Figure 9.1 – Partitioning Results Example Q-grid

ID	Job	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	EM	4	1	3	-2	0	1	-2	-1	-2	-1	2	-3	0	-1	2	3	0	-3	0	0	1	-1	2	1	-4
2	AR	1	2	4	0	0	0	0	-2	-1	3	-2	-1	1	0	2	-1	-2	-4	3	2	1	-1	1	-3	-3
3	CE	1	1	0	0	1	-4	-1	0	2	-2	-3	2	3	4	-2	-1	0	3	-1	2	-2	-1	1	0	-3
4	SX	3	-1	-1	-1	2	3	-2	-3	-4	-3	-1	2	1	4	-2	0	-2	1	1	0	0	0	2	1	0
5	HS	2	-2	3	3	-1	1	-3	-2	2	-4	0	0	1	4	-1	-3	-2	1	0	0	2	-1	1	0	-1
6	SS	4	-1	0	3	0	1	1	-1	-1	2	1	-4	-1	1	0	0	-3	-3	3	2	0	2	-2	-2	-2
7	HW	1	1	1	1	-1	0	-3	0	-4	-3	-2	2	3	4	0	0	-1	2	-1	-2	2	0	3	-2	-1
8	HW	3	3	2	-1	-4	1	0	-3	-3	1	2	-2	0	2	1	-1	0	-2	-1	-1	1	0	4	-2	0
9	HS	3	0	3	-1	-1	0	0	1	-4	-3	0	2	1	4	-1	2	2	1	-1	-3	-2	0	1	-2	-2
10	SX	3	2	4	0	0	1	1	-2	-2	-4	-1	-1	2	3	2	0	-1	-2	0	0	-1	-3	1	1	-3
11	CE	2	-1	3	-1	-1	1	0	0	-2	2	0	-1	3	4	-2	0	-4	1	0	2	-3	-3	1	-2	1
12	SE	2	0	3	2	-4	-2	-1	-2	-3	4	-1	0	-1	1	0	3	1	1	2	-1	-3	1	-2	0	0
13	SS	2	1	4	1	-4	-2	-2	0	1	-1	0	-3	3	-3	2	2	0	0	-1	3	-1	0	1	-2	-1
14	NA	-3	-1	-1	-2	3	-3	0	1	0	2	-2	4	0	3	-1	2	-4	-2	1	1	1	0	2	0	-1
15	SW	3	-1	2	-1	2	-2	4	-2	-4	1	0	0	-2	0	-1	1	-3	0	2	3	-3	-1	1	1	0
16	SE	-3	0	-3	0	1	1	-1	0	-4	2	-2	3	3	4	-2	1	-1	1	-1	2	-2	-1	0	2	0
17	SW	1	2	4	0	2	0	-2	1	-4	-1	-1	1	0	3	-2	-1	-2	3	1	0	-3	-1	2	0	-3
18	SE	3	1	1	2	-1	-1	-2	0	-3	3	-2	-1	0	0	2	4	1	-3	-1	-2	0	-4	1	0	2
19	SW	2	0	1	-2	2	-1	-3	0	1	0	-4	2	1	3	4	-1	-1	-1	0	3	-2	0	1	-2	-3
20	22	1	3	2	-2	2	1	0	2	3	-1	-3	1	0	4	-1	-3	-1	0	-1	-2	0	-2	1	0	-4
21	HS	1	1	2	-1	2	2	0	-1	-1	0	0	4	-1	3	1	-2	-3	-4	0	0	1	-3	3	-2	-2
22	SS	1	-1	1	3	1	0	-1	0	-2	-1	-2	3	-1	4	-2	1	0	2	2	-3	0	2	0	-4	-3
23	CE	3	0	-1	-2	0	0	1	0	-1	0	1	-2	2	4	-2	-4	-3	2	2	3	-3	1	1	-1	-1
24	SE	2	3	4	-1	0	1	-2	2	-1	-3	0	0	2	3	0	-1	1	1	-2	-2	0	-3	1	-1	-4
25	SW	0	0	0	-1	3	1	-2	1	-2	-4	-3	2	2	4	0	-2	0	3	-1	1	-1	-3	2	1	-1
26	HS	2	1	2	-1	0	2	0	-3	-3	1	0	-4	-2	0	-1	1	0	-1	-2	3	-1	4	3	-2	1
27	SS	2	2	4	3	3	-1	-1	-1	0	-3	0	0	0	2	1	-1	-3	1	1	1	0	-2	-2	-2	-4
28	CE	1	2	3	-1	0	1	-2	0	-2	0	-4	-2	2	2	1	0	-1	1	0	-3	-1	3	4	-1	-3
29	CE	4	0	1	-2	1	3	-1	-4	-1	-3	1	-2	2	3	1	0	-3	2	0	0	0	-1	2	-2	-1
30	SE	3	-2	-1	4	0	-4	0	-2	-3	-3	-2	2	0	2	-1	1	1	1	-1	0	1	-1	0	3	2
31	CE	4	3	2	-2	0	0	-2	2	-1	-3	-1	0	0	2	0	-1	-1	1	1	1	-4	-2	3	1	-3
32	SE	1	0	3	-1	2	0	0	-2	-1	0	-1	3	-1	2	1	-3	-4	4	1	0	1	2	-2	-3	-2

ID	Job	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
33	SE	0	0	1	0	-1	-2	-1	-2	-4	2	-2	2	-1	1	0	0	-3	3	-1	-3	2	3	4	1	1
34	AR	0	-2	-2	1	3	-1	-2	2	-3	-3	1	3	1	2	-1	0	1	4	0	0	-4	0	-1	2	-1
35	HW	0	0	3	-3	3	4	0	-1	-1	1	-2	1	2	2	2	-1	-3	0	0	-1	-2	-4	1	-2	1
36	CE	0	0	2	-2	1	0	-1	1	-1	-2	-3	-1	2	4	-1	-4	-3	3	2	3	1	-2	1	0	0
37	SE	2	1	2	0	0	-3	-2	-4	-2	-2	-1	1	0	4	0	-3	-1	3	3	1	1	-1	2	0	-1
38	SX	2	-2	0	-1	2	1	-1	2	-2	-4	-2	1	1	4	0	-1	-3	3	1	0	-1	0	0	3	-3
39	AR	3	0	3	-2	1	2	-2	-3	-2	-1	-3	1	2	1	2	-1	-4	1	0	0	0	-1	4	0	-1
40	AR	0	1	0	0	2	3	0	3	0	-2	-1	2	4	2	-1	-1	-2	1	-2	-3	1	-3	-4	1	-1
41	CE	3	0	1	-3	2	1	-1	-1	-2	-4	-3	2	0	4	0	-2	-2	1	3	0	-1	1	-1	2	0
42	SX	4	0	2	0	3	2	0	-1	-1	-2	-1	-1	-2	3	1	0	1	1	0	-2	-3	1	2	-4	-3
43	CE	2	1	2	0	3	3	-3	0	-3	-2	-2	1	2	4	1	-4	-2	1	0	0	-1	-1	-1	0	-1
44	HS	0	-1	-1	-1	0	1	-2	0	-2	-3	-4	1	3	4	3	2	-1	-2	1	1	-3	2	0	2	0
45	HS	4	-4	2	2	1	0	0	-1	-2	-1	0	1	0	3	1	0	-1	3	-3	-3	-2	-2	2	1	-1
46	SS	4	3	3	0	2	-1	-3	-4	-2	0	-1	1	2	2	1	1	-1	-1	0	1	-3	0	0	-2	-2
47	SX	4	0	2	1	-4	-2	-1	-1	-3	3	0	-1	-3	2	1	1	-2	1	0	0	-2	3	0	-1	2
48	SE	3	3	4	2	2	1	-3	1	-1	-4	-3	0	-2	2	-2	-1	0	-2	1	0	1	-1	0	-1	0
49	SX	2	-3	1	-4	0	0	1	0	-1	3	-1	-2	-1	4	-2	3	-1	0	1	1	-3	2	0	-2	2
50	SE	4	3	2	2	-1	-1	0	-3	-3	-4	-2	-2	1	3	1	1	0	-1	1	-1	0	0	2	0	-2
51	CE	3	-1	-1	-2	3	1	-1	0	-1	-3	0	1	1	4	-2	0	-4	2	2	2	-2	-3	1	0	0
52	SE	2	-2	-4	3	3	0	0	0	0	-3	-1	2	1	1	-1	-3	-1	4	-2	2	1	1	-2	0	-1
53	CE	3	-3	-2	-2	-2	0	-4	0	-1	3	0	-1	0	4	-1	2	1	2	2	0	-3	1	1	-1	1
54	CE	0	3	0	-3	0	1	-2	2	-1	-2	0	-1	1	4	2	-1	1	-1	-3	0	2	-2	3	1	-4
55	SW	-1	-1	-1	-1	3	-3	1	-2	-2	1	1	3	0	2	1	-3	0	2	4	0	0	2	0	-4	-2
56	EM	2	1	1	-4	0	4	-1	-3	1	3	1	0	0	0	-1	-2	2	3	2	-3	-1	-2	-1	0	-2
57	EM	1	-2	-1	0	1	1	0	3	-4	-3	-3	0	3	4	-2	-2	0	2	0	-1	2	-1	2	1	-1
58	EM	1	0	1	0	3	-1	-1	0	-3	-4	0	3	1	4	1	0	-3	2	-2	-2	-1	-1	2	2	-2
59	EM	0	2	2	-1	3	0	-1	1	-4	-3	-3	3	2	4	1	0	-1	0	-2	-2	1	0	-1	1	-2
60	HW	1	4	0	-4	3	-3	0	2	-2	-3	-2	0	1	1	0	-2	-1	2	2	3	-1	-1	1	-1	0
61	EM	0	1	1	-1	4	-2	-4	2	-3	-3	-1	2	0	2	3	0	-2	1	0	0	1	-2	-1	3	-1
62	EM	3	1	2	-2	-1	-2	0	1	1	0	-4	-3	0	4	-1	0	-2	2	3	1	-3	0	-1	2	-1
63	EM	2	0	-2	0	1	-2	1	-2	-1	0	2	0	1	-1	-3	3	-1	0	3	2	-1	4	-4	-3	1
64	SX	3	0	0	0	0	1	-2	2	-2	1	-4	-1	1	4	-1	2	-3	0	3	-1	-3	2	-1	1	-2
65	SW	-1	0	3	-2	2	-4	-3	3	-3	-2	-2	2	0	4	1	-1	1	0	-1	-1	1	1	2	0	0
66	EM	-1	3	2	-2	-1	-1	-3	1	-4	-1	0	0	1	4	3	1	0	0	-2	-2	2	1	2	0	-3
67	SX	2	3	2	1	-4	-1	-2	-3	-2	0	0	-3	1	4	1	1	-2	0	0	0	-1	3	2	-1	-1

ID	Job	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
68	EM	3	2	1	-1	1	2	-1	0	-3	-4	-3	1	1	4	0	-2	0	2	-1	-2	-1	3	0	0	-2
69	SE	4	0	2	-1	0	-2	-1	1	-3	0	2	-2	-3	3	1	2	1	0	-2	-1	0	-1	1	3	-4
70	HW	4	-1	0	-1	3	2	-4	1	-3	-1	-1	3	1	2	1	-3	-2	2	0	0	-2	-2	1	0	0
71	CE	1	2	2	3	2	-1	-2	0	-1	-2	0	-1	0	3	-1	-2	0	1	1	-3	-3	1	0	4	-4
72	SX	3	0	3	-3	1	2	-2	1	-2	-4	-1	0	0	4	1	-1	1	0	-1	0	2	-3	2	-2	-1
73	CE	-2	0	0	0	2	4	1	1	-3	-1	-1	0	2	3	2	1	0	3	1	-2	-1	-2	-1	-4	-3
74	CE	1	2	-3	-1	0	-2	1	0	-1	-3	0	0	2	4	2	-1	-1	3	1	-2	0	-2	1	-4	3
75	HS	1	1	0	-2	1	3	-1	-2	-3	-3	0	2	2	4	2	0	-4	-1	0	-1	1	-2	3	-1	0
76	EM	3	1	2	-2	0	1	-3	-2	-1	-1	2	-1	1	4	0	2	1	-1	0	0	-4	3	0	-2	-3
77	EM	4	2	3	-2	0	2	0	1	-1	-3	0	-2	-1	0	3	0	1	-2	-1	-4	1	-1	2	1	-3
78	EM	0	0	-3	-2	3	1	-1	1	-4	-3	-2	2	3	4	0	-2	0	0	-1	1	-1	1	2	2	-1
79	EM	3	1	-1	-1	3	0	-3	-2	-4	2	0	2	1	4	-1	1	-2	0	-1	1	-2	2	0	0	-3
80	EM	1	1	-1	0	0	3	1	0	-2	2	-1	-3	0	4	0	-2	-1	1	-3	-2	3	-1	2	2	-4
81	CE	4	0	3	2	-2	-1	0	0	-4	-2	0	-3	1	2	2	-1	3	-2	1	1	0	-3	1	-1	-1
82	SX	-1	0	-1	-3	2	-3	2	4	0	-2	-1	0	0	3	-1	-2	3	2	-4	1	0	-2	1	1	1
83	EM	1	-1	-1	0	0	-1	4	0	-2	-3	3	-4	3	-2	2	-1	-2	-3	2	2	0	1	0	1	1
84	SE	3	1	4	-2	1	-4	-2	0	-1	-3	-3	2	0	3	1	1	2	2	0	-1	0	-2	0	-1	-1
85	EM	3	0	0	0	2	-1	-1	-2	-2	-2	-3	1	-3	2	1	-1	-4	3	2	1	0	1	-1	4	0

Table 9.1 – Partitioning Survey Detailed Results

Appendix B – SI Survey Results

The SI survey results are presented in Table 9.2 below.

The left-most column is the respondent ID. The next column is the respondent job code. The job codes are:

- **CE** – Chief engineer or technical lead.
- **SE –** Systems engineer.
- **HW** – Hardware engineer.
- **SW** – Software engineer.
- **SS** – Software engineer manager or supervisor.
- **HS** – Hardware engineer manager or supervisor.
- **AC** – Academic.
- **SX** – Senior executive.
- **EM** – Engineering manager (general or multi-discipline).
- **SI** – System Integration engineer.
- **PM** – Programme manager.
- **NA** – None of the above/not applicable.

The numbers in the top rows, columns 3 to 27, are the statement numbers.

Taking the top row:

- The respondent ID is 1.
- The respondent's job is Systems Engineer.
- The respondent placed statement 1 (cooperation and communication – external) in the Q-grid row 0, statement 2 (clear, well understood requirements) in Q-grid row 4, etc. Respondent 1 Q-grid is shown in Figure 9.2 below.

						Row Number
Most Influence	2					4
	10	11				3
	12	13	16			2
	4	5	7	20		1
Medium	1	9	15	17	18	0
	3	6	8	19		-1
	14	21	22			-2
	23	25				-3
Least Influence	24					-4

Figure 9.2 – SI Results Example Q-grid

ID	Job	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	SE	0	4	-1	1	1	-1	1	-1	0	3	3	2	2	-2	0	2	0	0	-1	1	-2	-2	-3	-4	-3
2	SI	2	3	0	-1	0	1	3	-4	2	-2	-3	4	0	2	-3	0	1	-2	-1	1	-1	0	-2	1	-1
3	HW	2	1	-1	-4	2	1	0	-2	0	3	0	2	-2	0	1	-1	3	-2	0	-1	4	1	-1	-3	-3
4	SS	0	2	0	0	0	1	3	-1	0	4	-1	1	2	-3	1	1	-2	-3	-1	-4	3	2	-2	-1	-2
5	SI	3	2	-1	0	-1	1	2	-4	4	0	3	-1	-1	-3	-2	2	-2	-2	1	-3	1	0	0	1	0
6	HW	-1	4	2	1	-3	0	3	-2	2	0	1	-2	3	0	0	2	0	-1	-4	-2	1	1	-1	-1	-3
7	SX	-1	2	-1	-4	-2	-1	2	-3	4	0	0	3	1	-1	2	0	3	0	1	-2	1	-2	-3	1	0
8	SI	-3	1	-4	3	-2	4	0	1	1	0	3	2	2	0	-1	2	0	-2	-1	-2	-1	1	-3	0	-1
9	SE	-2	4	-1	-1	1	-2	-3	-4	3	3	-2	0	2	0	0	1	0	-3	1	1	0	2	-1	2	-1
10	SS	4	1	3	1	0	0	-1	-2	0	2	-1	2	-2	-3	1	3	0	0	-1	-4	-1	-3	1	-2	2
11	SI	-3	1	-3	-4	0	4	3	-2	1	-1	2	2	2	-2	0	-1	0	0	-2	-1	0	3	-1	1	1
12	SI	0	4	0	-3	0	-4	3	1	1	-1	0	-1	3	1	-2	-1	2	2	-1	-2	-3	-2	0	2	1
13	SE	1	3	-2	-2	0	2	-1	-4	2	0	1	4	3	-3	0	2	0	-1	1	-3	-1	-1	1	0	-2
14	SW	2	2	-2	3	1	4	1	0	2	1	3	-1	1	-2	-1	-2	-3	-1	-3	0	0	-4	-1	0	0
15	AC	3	0	0	-4	2	1	2	0	3	4	-2	1	2	-3	-1	-2	0	0	-1	1	1	-3	-2	-1	-1
16	CE	-3	3	1	-4	2	0	1	-1	3	4	0	2	0	-1	2	-1	1	0	0	-2	-1	-3	1	-2	-2
17	PM	1	2	-1	1	0	4	3	-3	0	1	-1	2	2	-2	0	3	0	-4	0	-3	1	-2	-2	-1	-1
18	HS	-3	0	-4	-3	4	-2	3	-2	3	0	0	1	1	-1	-1	1	0	1	2	-1	0	2	-1	-2	2
19	SE	-2	1	0	-1	0	0	1	-3	3	2	4	-1	1	-4	2	-1	1	3	0	-2	2	0	-1	-3	-2
20	HS	-1	3	1	-1	1	0	3	-2	1	-1	0	2	4	0	0	-1	2	-3	1	-2	-2	0	-4	-3	2
21	SW	0	4	-2	0	1	3	2	0	0	2	2	1	1	-2	-2	-4	-1	-1	-3	-3	3	1	-1	0	-1
22	SE	0	3	0	-2	-1	-4	2	-1	1	2	3	2	4	0	1	-3	-1	-2	-3	0	0	1	-2	-1	1
23	AC	0	4	2	-1	3	-1	-1	0	1	1	-1	2	-3	-3	0	2	0	3	1	-2	-2	0	1	-2	-4
24	HW	-1	4	3	3	0	2	1	-2	2	0	0	0	2	-3	-2	-1	-2	-4	1	-1	1	1	-3	0	-1
25	SE	1	4	-1	-4	-1	-2	3	-3	1	2	-2	2	-1	3	0	0	-2	0	-1	-3	0	1	0	2	1
26	SI	1	0	0	-3	1	4	3	-4	0	2	-1	2	2	1	-2	-2	-1	-3	-1	-1	3	0	1	0	-2
27	HS	3	4	0	-1	2	-2	1	2	2	3	-2	1	0	0	1	0	-3	-3	1	-2	0	-1	-1	-1	-4
28	SW	-1	0	-2	-4	-2	0	2	-1	2	4	3	2	0	-1	1	-3	0	-2	1	0	1	3	1	-3	-1
29	NA	3	4	3	-4	1	2	0	0	1	1	-3	2	2	-1	-1	-2	1	0	0	-2	0	-3	-2	-1	-1
30	HW	0	4	1	-3	3	0	1	0	0	3	-2	1	0	-3	-2	-1	2	-4	-1	-1	2	-2	1	2	-1
31	SW	-2	2	0	0	1	-1	1	-2	3	4	3	0	2	-3	0	2	1	-1	-2	-4	-1	1	0	-3	-1
32	SI	-1	1	0	-4	-1	3	2	-1	0	-2	2	1	2	-3	0	0	3	-3	-2	-1	4	1	0	1	-2

ID	Job	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
33	AC	3	4	-2	-4	2	2	1	-3	3	2	0	1	0	-3	0	0	-1	1	-1	1	0	-2	-2	-1	-1
34	SI	-4	4	3	-3	2	-2	1	-2	0	-1	-1	2	-2	-1	0	1	0	1	3	-3	1	-1	0	0	2
35	SX	2	4	-1	1	1	2	-1	0	2	-1	3	0	-1	0	-2	1	-2	3	1	-4	0	0	-3	-2	-3
36	SX	-3	4	0	-2	0	1	2	-2	2	1	0	1	2	-1	1	-3	3	0	-1	-2	-1	0	-4	-1	3
37	AC	1	3	1	0	3	1	0	-3	0	-1	1	0	2	-1	2	0	-2	4	2	-4	-1	-1	-2	-2	-3
38	SE	-1	2	-4	0	1	-2	3	-2	1	0	-1	3	2	-3	4	2	-1	0	-2	-1	1	0	-3	1	0
39	AC	1	0	0	4	3	2	2	-2	1	0	1	-1	-1	-2	-2	3	2	-3	1	-3	0	-1	-4	0	-1
40	SX	0	4	-1	-3	2	0	-1	-2	1	3	2	1	-2	-4	0	2	-1	0	3	-3	1	0	1	-2	-1
41	SX	4	-1	0	-2	2	0	1	-2	2	1	0	-1	-1	-2	-1	0	0	3	3	-4	1	-3	-3	2	1
42	SX	-1	0	2	4	1	1	0	-2	0	-3	3	2	1	0	-1	-2	-1	3	2	-2	-3	-4	1	0	-1
43	EM	0	1	0	0	2	-1	-2	-4	4	3	3	-1	-3	-3	1	0	2	-1	1	-2	2	1	0	-2	-1
44	EM	1	4	3	-1	2	1	0	0	1	3	2	0	0	0	-1	-2	-1	-2	2	-4	-1	-2	1	-3	-3
45	AC	-2	2	2	-3	-2	0	1	-4	-1	4	-1	0	1	-1	1	-1	3	3	-3	0	2	0	-2	0	1
46	CE	0	3	2	-4	0	0	2	-2	0	4	-1	1	1	-1	-1	-3	3	-1	-2	-3	1	2	1	-2	0
47	EM	2	3	2	0	-1	1	0	-4	3	4	0	-2	2	-3	-1	-2	-3	1	-1	1	1	0	0	-1	-2
48	SX	1	3	2	-3	-1	0	0	-4	1	4	1	0	0	-2	2	-3	3	2	-1	-2	-1	0	-2	1	-1
49	AC	3	2	1	2	1	0	-3	-3	4	1	3	0	-2	-2	-1	1	-1	2	0	-4	-1	0	0	-2	-1
50	SX	2	0	0	1	2	-1	-1	-3	4	-1	1	1	1	-2	-3	3	0	3	2	-2	0	0	-1	-2	-4
51	SX	-1	3	1	-2	-1	2	-1	-4	2	-2	4	0	0	1	0	2	3	-3	1	-3	-1	0	0	-2	1
52	SX	4	-2	1	0	1	1	0	2	3	3	2	-3	-1	-2	0	-1	-4	-3	-2	2	1	-1	0	0	-1
53	EM	-2	3	2	-2	0	-1	4	-3	-1	0	1	1	2	0	0	1	-1	1	0	-4	-1	2	-2	3	-3
54	SX	-3	3	0	-2	-1	-1	4	-4	0	-1	0	2	3	-1	2	-3	1	2	-2	1	1	-2	1	0	0
55	SX	3	4	0	-4	3	2	0	-1	0	2	-2	2	0	-1	1	-3	1	-2	1	-3	1	-1	-2	-1	0
56	EM	2	3	-4	-1	0	1	2	-2	2	-3	1	3	0	-1	1	4	-1	1	0	-3	0	-1	-2	0	-2
57	SX	0	0	-4	-1	-1	-2	-1	-3	0	0	1	1	0	1	2	2	3	4	-3	-2	3	1	-1	2	-2
58	PM	2	1	0	3	1	-3	-1	-2	3	1	-1	0	1	-2	-1	-1	4	0	-3	0	2	-4	-2	2	0
59	AC	-1	0	0	-2	0	2	2	-3	3	1	0	1	2	0	4	-1	3	-4	-2	1	1	-3	-1	-1	-2
60	SX	-2	2	3	0	-1	-4	1	-3	-2	4	2	0	3	-2	0	-1	2	0	-1	-3	-1	1	0	1	1
61	SX	0	4	0	-1	3	3	1	-2	0	2	0	2	-4	-3	1	-1	2	-1	1	-1	-2	-2	-3	1	0
62	AC	4	3	-1	-2	1	-2	0	-4	1	2	-1	2	-3	-3	-2	2	1	3	0	-1	0	1	0	-1	0
63	SX	1	3	2	1	0	-2	0	-1	-1	3	1	-3	2	-2	-4	-1	2	4	-1	1	0	0	-3	-2	0
64	SE	2	2	0	-1	-1	0	-1	-3	2	3	3	1	-2	-4	1	-2	4	0	0	-3	0	1	-2	-1	1

ID	Job	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
65	PM	2	3	-1	2	1	1	-2	-4	1	3	0	-1	-1	-2	-2	1	2	4	-1	-3	0	-3	0	0	0
66	EM	4	1	0	3	-1	2	3	-3	2	-2	2	0	0	1	0	1	1	-4	-1	-2	-3	-1	-2	-1	0
67	CE	3	3	-1	-1	2	0	-2	-4	2	1	-2	0	0	-2	-1	1	2	4	1	-3	1	-3	0	-1	0
68	SX	2	3	2	0	1	-2	1	-2	2	0	-1	3	1	-3	0	0	1	4	-2	-4	-1	-3	-1	-1	0
69	SX	0	4	0	1	0	-2	-2	-4	0	1	1	-1	-1	-2	1	3	2	-3	0	-1	-1	3	-3	2	2
70	AC	-2	1	-1	-3	0	2	2	-3	3	3	-1	-1	1	1	2	-2	4	0	-4	-2	-1	0	0	1	0
71	EM	0	0	-1	-2	2	-3	-3	-1	1	4	0	3	1	-4	-1	-1	3	0	1	2	2	-2	1	-2	0
72	PM	1	4	1	-2	0	-1	-3	-2	1	3	-1	-3	0	0	2	0	3	0	-1	-4	2	-1	2	1	-2
73	EM	-2	2	1	-3	1	0	0	-4	1	3	-2	2	3	1	-1	-1	0	-3	0	-2	2	4	-1	-1	0

Table 9.2 – SI Survey Detailed Results

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