CRANFIELD UNIVERSITY

L. E. Redding

A strategy formulation methodology for companies seeking to compete through IVHM enabled service delivery systems

School of Applied Sciences

PhD
Academic Year: 2008 - 2011

Supervisors:-Professor T.S. Baines & Dr P.D.Ball
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Dedication

This thesis is dedicated to the memory of:

Albert Leopold Redding

(1963 to 2005)

The memory of your strength, dignity, generosity, humour and compassion proved to be my rock as I recovered from my own chronic illness, surgery, numerous hospital visits, and my 'dark moments' during the undertaking of this work.

ABSTRACT

This thesis makes a contribution to knowledge through the development of a strategy formulation methodology for manufacturing organisations who wish to compete through advanced technology enabled service delivery systems. The research introduces the reader to the concept of Product Service Systems (PSS) and the process of '*servitization*'. It identifies Integrated Vehicle Health Management (IVHM) as one of a set of enabling technological applications, which if adopted, can facilitate the supply of "*intelligent*" or "*informated*" products. Such products enable the manufacturer to monitor the condition and usage of these products '*in the field'* thereby enabling aligned service solutions to be offered.

A five phase research programme is undertaken which seeks to understand the principles of IVHM and gain knowledge of the level of practitioner awareness of the concept and related issues. The research then explores and defines the concept of the service delivery system, and identifies and reviews operations strategy formulation methodologies. A pre-pilot methodology is adopted which is then tested via case application to generate a list of requirements and specification. A pilot methodology is designed to suit the specification and tested via industrial case studies and expert practitioner evaluation. The pilot methodology is finally refined prior to verification and validation through industrial case application and further expert practitioner evaluation.

This research delivers a sequential and iterative strategy formulation methodology which fills a gap that is identified through a state of the art literature review and practitioner survey. The documented methodology is the result of a structured development and test programme and is shown to be feasible, useable and useful by test and validation by numerous manufacturing organisations. It makes a significant contribution to knowledge. This is attained through seeking to understand the organisation's actual competitive position, its alignment to the stakeholder's service requirements, and organisational structure. It also offers alignment relative to the level of technology adoption when offering intelligent/informated products. The research provides a strategy formulation methodology to deliver an enhanced service delivery system.

ACKNOWLEDGEMENTS

I would like to thank Professor T.S. Baines of Aston Business School, (*formerly of the School of Applied Science, Cranfield University*) for his assistance and advice throughout the undertaking of this research. Further acknowledgement and gratitude is extended to Dr P. Ball of Cranfield University who acted as joint supervisor to the research in its final year and subject advisor though out the research programme.

Recognition is also extended to Professor Ian Jennions and staff of the IVHM Centre at Cranfield for making available the resources required to undertake this work and for providing access to the core industrial partners of the research group, and Vinayak Viswanath (MSc student) who aided the research in the location of strategy process literature and assisted in the undertaking of the evaluation of the pre-pilot methodology.

Acknowledgement of the contribution to this research is also made of Dr Tonci Grubic and Dr Neil Rowley (*deceased*) who together with the author jointly worked upon the practitioner survey during the first year of this study.

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GLOSSARY OF TERMS, ABBREVIATIONS, AND ACRONYMS

ACM	Automated contingency management
ACMS	Aircraft condition monitoring system
AL	Automated logistics
CBA	Cost benefit analysis
CBM_1	Condition based maintenance
CBM_2	Condition based management
CCS	Common core system™ (GE)
COTS	Commercial off the shelf
DIS	Distributed information system
DTC	Diagnostic Trouble Codes
FADEC	Full authority digital electronic and control
FDIR	Fault detection, isolation, and recovery
FMEA	Failure modes effects analysis
FMECA	Failure modes effects criticality analysis
GE	General Electric
GEAE	General Electric aircraft engines
GBR	Ground based reasoned
HCL	Higher control limit
HMS	Health management system(s)
HoQ	House of Quality
HUMS	Health and usage monitoring system
ID	Integrated diagnostics
ISHM	Integrated system health management

ISSA	Integrated self situational awareness
IVHM	Integrated vehicle health management
JDIS	Joint Distribution Information System
JSF	Joint Strike Fighter
KPI	Key performance indicator
LCC	Life cycle costs
LCL	Lower control limit
MDW	Maintenance data warehouse
MIMOSA	Machinery information management open system alliance
MMS	Mission management system
MOE	Measures of effectiveness
MTA	Maintenance task analysis
OCCAHM	Ownership Cost Calculator for Aerospace Health Management
OEM	Original equipment manufacturer
OFCDS	Online flight control diagnostic system (US Navy)
OMP	Operational maintenance system
OSA	Open system architecture
OSA-CBM	Open system architecture for condition based maintenance
PBC	Performance based contracts
PBL	Performance based logistics
PHM	Prognostics health management
	ePHM — Electronic prognostic health management
	mPHM — Mechanical prognostic health management
	cPHM — Chemical prognostic health management
PNN	Probabilistic neural networks

PSS	Product service system
RCM	Reliability centred maintenance
RD	Remote diagnostics
RTOK	Re-Test OK
RUL	Remaining Useful Life
SBU	Strategic Business Unit
SDS	Service Delivery System
SHM	System health management
SHM_1	Structural health management
SIC	Standard Industrial Classification
SPC	Statistical process control
TOC	Total cost of ownership
TTP	Time triggered protocol
UAV	Unmanned aerial vehicle(s)
UCAV	Uninhabited combat air vehicle (USAF)
UCL	Upper control limit
USAF	United States Air Force
VMS	Vehicle management system.

1 INTRODUCTION

This chapter presents the reasons and rational for the undertaking of this research (section 1.1). It then presents an overview of the research aim and objectives (section 1.2). The methodology of the research is also summarised (section 1.3) and the contribution of this work is outlined in (section 1.4). The final section of this chapter illustrates the structure and composition of the thesis (section 1.5).

1.1 Introduction to the research

The emergence of the global market, the increased price of resource, and ever stringent legislation in fiscal, employment, operational and environmental arenas has resulted in the UK manufacturing sector no longer being able to compete on a cost base alone (Vandermerwe and Rada, 1988; Mont and Lindhqvist, 2003; Davies, 2004; Goh et al., 2007; Baines et al., 2007; Neely, 2008; Baines et al., 2009b; Baines et al., 2009). This has seen more innovative approaches appear in the operations strategy of the organisation as companies seek to adopt 'whole life' revenue streams which are generated by the availability of the product in use.

Two approaches have emerged. The Product Service System (PSS) originating from Scandanavia and evolving from the desire to promote sustainability in consideration to the environment (Goedkoop et al., 1999; Mont, 2000; Meijkamp, 2000; Mont and Lindhqvist, 2003; Manzini and Vezolli, 2003; Chesborough and Spohrer, 2006), and the concept that is 'Servitization' where manufacturers seek to add services at various levels of integration in order to obtain strategic and competitive advantage. Servitization is driven by the desire to obtain competitive advantage (Vandermerwe and Rada, 1988; Wise and Baumgartner, 1999; Oliva and Kallenberg, 2003; Neely, 2008; Baines et al., 2009b; Baines et al., 2009).

Both approaches seek to establish 'whole life' added value to stakeholders by offering various levels of post sale support and ultimate incentivized disposal for the customer/user. They can provide whole life revenues for the manufacturer by way of service support and availability contracts. Typically, this has been facilitated by the evolution of maintenance strategies from 'run to failure' modes of operation, through time based strategies (scheduled inspections, preventative maintenance, and reliability centred maintenance (RCM) incentives), to 'real time' asset performance measures including condition based maintenance (CBM). Whilst all these systems mitigate the risk of component failure, thus reducing the disruption to asset availability and the generation of revenue streams thereof, they are all reactionary to an emerging system or component fault or failure. They build in levels of redundancy by way of mitigation which in turn increases the total cost of manufacture and replacement. How much better would the strategic and competitive position of the organisation be if the application of technology could supply continuous, or near continuous, predictive awareness of the current and future performance of the product whilst in use in the field thus reducing engineered redundancies.

Generic condition based maintenance offers such potential. Whilst the literature contains many contributions to the field of condition based maintenance, one emerging concept is Integrated Vehicle Health Management (IVHM). This concept is identified as a key enabler to the servitization of manufactured products. Additionally the evolution and potential adoption of the concept can facilitate a product service business model (Benedettini et al., 2009; Redding, 2010a; Grubic et al., 2009; Grubic et al., 2011). The application of sensor and communication technology, coupled with decision support algorithms can enable integrated design and modes of operation based upon real time information for 'informated' products, assemblies, sub-assemblies and components.

The research will show using gaps identified within the literature (Chapter 2) and in practice (Chapter 4), that there is a need for a greater understanding of how to achieve strategic alignment between the needs of the customer and the level of technology to be employed when wishing to deliver a servitized solution and a Product Service System business model. This thesis sets out the issues, and documents a research programme to deliver such an alignment. The research offers a methodology which if followed enables the organisation to define and inform an operations strategy which can deliver an '*Informated Product*' enabled Service Delivery System (SDS).

1.2 Overview of the research aim and objectives

This section presents an overview of the research aim and objectives that are fully developed later in the thesis. The aim of this research, as presented in (section 3.2), is:

> *To understand the landscape relative to the condition based management of products whilst in use within the field and identify potentially high value IVHM enabled applications and operations. To develop a strategy formulation methodology which seeks to target such applications to deliver an aligned service delivery system. The methodology will enable the evaluation of potential benefits of new and alternative applications in order to inform the business and/or operational strategy of manufacturing companies.*

To achieve the research aim the following research objectives have been identified.

1) To study a broad range of industrial sectors and the literature to identify the state of the art of emerging, and if they exist, failed IVHM applications.
2) To understand the concept of servitization and the service delivery system.
3) To understand the concept of strategy and strategy formulation methodologies in order to assist in the creation of such a methodology incorporating key factors and using them to formulate a strategy which will deliver a service delivery system.
4) The validation of the methodology through case exemplars.

1.3 Overview of the research programme

The research aim and objectives stated in (section 1.2) lead to a five phase research programme which is summarised in Figure 1.1.

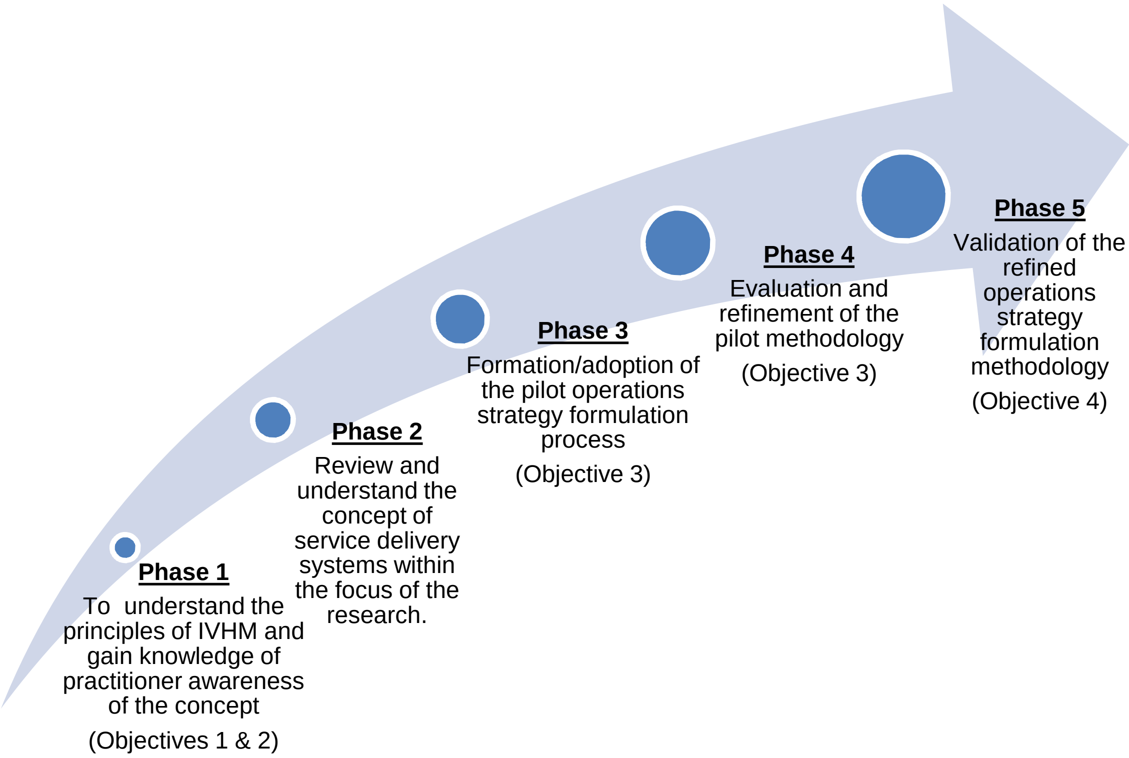

Figure 1-1 Overview of the research programme

The research is informed by a state of the art literature review of integrated vehicle health management (IVHM). This partially satisfies objectives one and two of the research and is presented in chapter two of the thesis. The thematic and descriptive review of the IVHM literature offers a definition for the applied technology concept, its evolution, and the context of its applications. The literature is mapped to identify applications, tools, and 'hot spots' within industry and IVHM research contained in academic contributions listed by author, date, and location. Finally, an analysis of the gaps identified within the literature is conducted and the results presented.

Phase one of the research seeks to partially satisfy objectives one and two of the research from the practitioner perspective and is presented in (chapter 4). The foundation for this phase is the literature review supplemented by further reading in the areas of product diagnostics and prognostics, servitization, and product service systems (PSS) which together inform the objectives of the survey. Namely:

i. What is the extent of the adoption of diagnostic and prognostic technology and informated products within UK manufacturing operations? How is this likely to change?

ii. What are the characteristics of manufacturers that use or are planning to use diagnostic and/or prognostic technology (IVHM) to supply informated products?

iii. What are the reasons for companies adopting these technologies and what benefits do they expect?

iv. What factors are likely to enable or inhibit commercial use?

Phase two of the research prepares a foundation to address the requirements of objective three. This is attained by seeking an understanding of the service delivery system within the context of the servitization of the manufacturing organisation. The mapping of strategy formulation processes is also undertaken and a benchmark study is conducted (Chapter 5). An analysis of these methodologies identify the '*Stratagem*' framework as a suitable starting point for the development of the final research deliverable.

Phase three of this research introduces and adopts the '*Stratagem*' operations strategy formulation process as the starting point and pre-pilot method for the development of the final methodology (Chapter 6). The process is applied to inform of alternative initiatives for the operations strategy of a UK based manufacturing SME. The performance of the methodology is assessed against the requirements of the research (section 6.4) and the findings from this pre-pilot study are used to identify the requirements for the final deliverable. A specification is then defined from which the pilot methodology is developed. Finally the '*ServiceStrat*' methodology is presented (Chapter 6).

Phase four addresses objective three of the research and is presented in chapter 7. This phase evaluates the pilot methodology to ascertain the framework's ability to offer a workable solution with logical incremental steps for use and the application within a manufacturing organisation. The case study method is selected for assessment with participants taken from UK based manufacturing organisations. The output from this stage of the research programme is a refined strategy formulation methodology which can then be submitted to wider testing by way of validation.

Phase five addresses objective four of the research and is presented in chapter 8. The refined methodology is evaluated for wider application using two case studies. The methodology is assessed for its usefulness, useability, and feasibility (Platts et al., 1998) when applied to different organisations throughout its testing. The validation case studies are carried out without researcher intervention to test robustness and independence of the methodology and the findings/observations used to refine the *ServiceStrat* framework. The deliverable of this phase is presented in (Chapter 9).

1.4 Overview of the research contribution

This section presents an overview of the research contribution. Full details are provided in the concluding chapter of this thesis (Chapter 10).

The research makes a contribution to knowledge through the development, test, and validation of a strategy formulation methodology. This fulfils gaps identified within the literature relating to how IVHM enabled 'informated' products may be developed and adopted to enable the servitization of a manufacturing organisation. It also identifies initiatives for future research. This is supported by a survey of UK based manufacturing organisations seeking to understand the awareness of the concept whilst verifying the gaps identified within the literature. The survey and literature combined offer a state of the art understanding of IVHM enabled informated products. They also offer an holistic understanding of the verified gaps and help position the focus of the research.

The research illustrates how technology can be used to inform the operations strategy of the manufacturing organisation seeking to compete through enhanced service delivery systems. It delivers a strategy formulation methodology by way of a validated workbook, support tools and case exemplars. The work is supported by peer reviewed academic journal and conference papers, executive reports and a contribution to an edited book.

1.5 The structure of the thesis

The thesis comprises ten chapters, a summary of which is given here and is illustrated in figure 1.2 at the end of this section.

Chapter 2 Presents a descriptive and thematic state of the art literature review relating to integrated vehicle health management systems (IVHM). It introduces IVHM, its definition and concept. The chapter illustrates how the application of this technology when applied to manufactured '*complex*' products and the wider business operations of the organisation, can mitigate risk and help enable a paradigm shift within manufacturing and operational strategy. The chapter concludes by presenting gaps identified within the literature which could offer future research initiatives.

Chapter 3 Summarises the research problem and develops the research aim, objectives and programme. Individual phases for the research programme are identified and the research methodology for each phase defined.

Chapter 4 Presents the execution of the first phase of the research programme, namely the identification of the population of UK based manufacturers offering complex products and services within the scope of the research. Considerations as to the data type and appropriate methods for analysis are presented. The survey design and execution are also discussed. The section concludes with presentation of the survey results and analysis of the data returned giving insight as to the levels of awareness within the UK based manufacturing sector of the concept and application of informated products and services.

Chapter 5 Presents the second phase of the research programme. An understanding is sought of service delivery systems within the scope and focus of servitization, and the methodologies used to formulate a strategy which seeks to align the level of service, type of organisational structure and level of technology required to deliver such a solution.

Chapter 6 Presents the third phase of the research, namely the formulation of the pilot methodology. The '*Stratagem*' methodology is discussed and adopted as a pre-pilot which is tested against the requirements of this research. The results of the test generate a requirements statement from which a specification for the pilot methodology is derived. The '*ServiceStrat*' methodology is introduced.

Chapter 7 Presents the fourth phase of the research programme. The pilot methodology is evaluated by presentation of the process by way of taught module supplemented by three presentations to manufacturing organisations with the author taking an active role, after which a critical evaluation of the process is sought. Evaluation is by survey against the parameters of feasibility, usability, and usefulness supported by 'open' and user critique

Chapter 8 Presents the fifth phase of the research programme. The refined ServiceStrat methodology is validated using two further case studies with the author acting in a passive role, that of the observer. The validation is carried out against the same parameters, namely feasibility, usability, and usefulness and 'open' critique.

Chapter 9 Presents the final research deliverable which is the validated ServiceStrat methodology

Chapter 10 Presents the conclusion of the thesis offering discussion of the research findings relating to the research aim and specified objectives. The contribution to knowledge is also discussed with the limitations of the work acknowledged. Finally, potential further research initiatives are highlighted.

This chapter has introduced the background to the research interest and presented an overview of research aim and objectives. The research programme to be followed to attain the aim and objectives is also illustrated. Finally a summary of the research contribution is presented and the thesis structure provided.

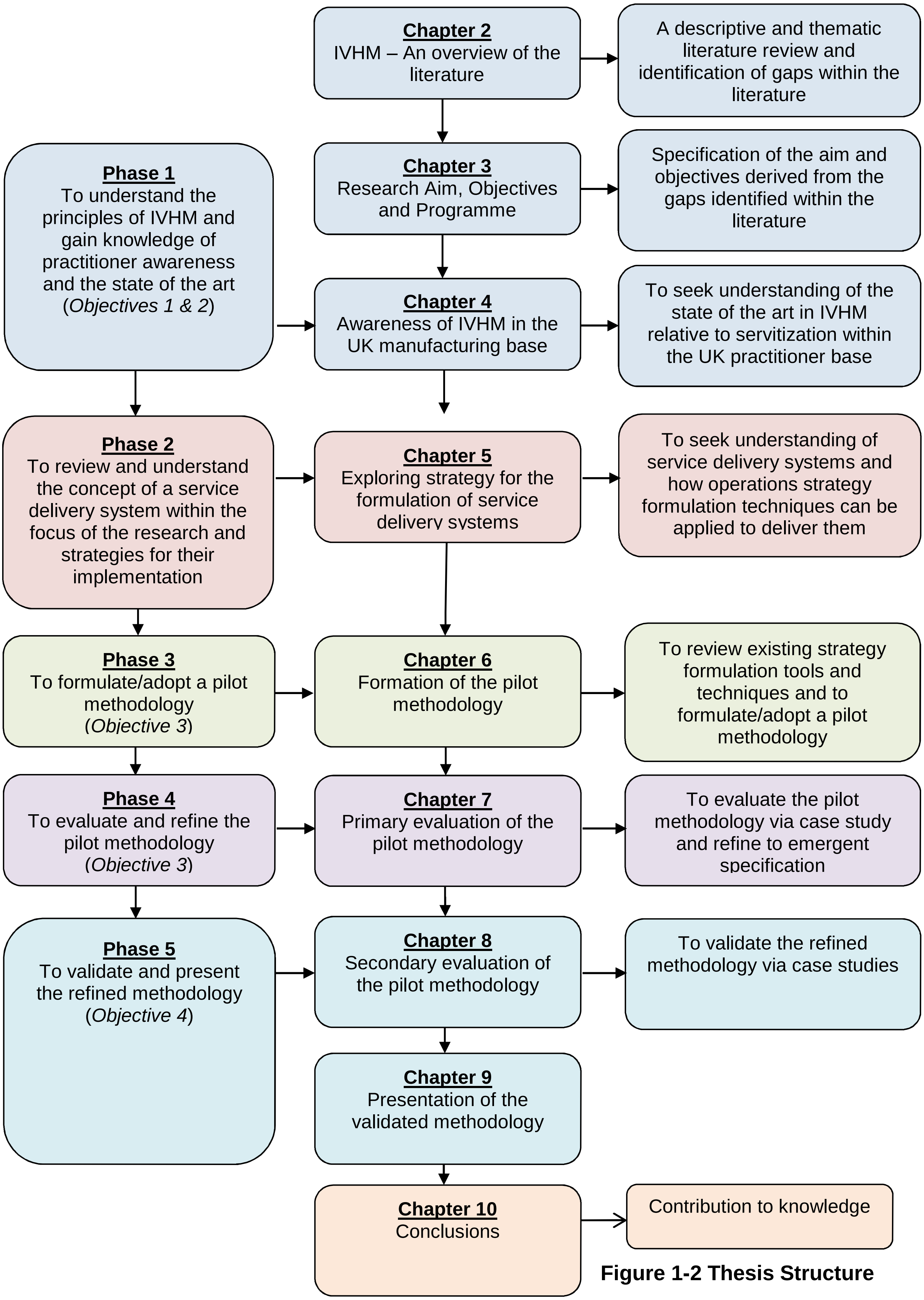

Figure 1-2 Thesis Structure

2 INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM) – A CONDITION BASED MONITORING APPLICATION FACILITATING SERVITIZATION

Integrated Vehicle Health Management (IVHM) will be shown within this chapter to be one of various techniques which are referred to as Condition Based Management (CBM_2) technologies. It's significance is that it is seen as an enabling technology for companies wishing to seek competitive advantage through the adoption of Product Service Systems (PSS) through a process of 'Servitization'. After introducing the reader to the concepts that are PSS and servitization (section 1.1) this chapter introduces the concept of IVHM (section 2.1). A definition is then offered for IVHM (section 2.1.1).

The chapter then will identify the principle elements that constitute an IVHM system (section 2.1.2) together with illustrating the operation of a typical IVHM enabled operations system (section 2.2). Design considerations, system architecture and the configuration of such systems are discussed (section 2.3) followed by a description of existing tools and techniques for the assessment of IVHM implementation (section 2.4). The drivers of, and inhibitors to, the adoption of IVHM enabled service delivery systems are also discussed (section 2.5) with cited examples of such solutions taken from the literature presented (section 2.6). The gaps which are identified whilst undertaking this overview of the literature form the justification for further research and are presented in (section 2.7).

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1. *For the purposes of this research the author wishes to make a distinction between Condition Based Maintenance (CBM_1) and Condition Based Management (CBM_2). CBM_1 is primarily concerned with Maintenance, Repair, and Overhaul (MRO) activities triggered by the current operating condition of the product. CBM_2 is far more reaching than that and is considered to be the total management of the product through the life cycle. It covers not only MRO activities but also product operating and use, thus potentially driving the business model.*

Finally the conclusions that can be drawn from this literature review are presented in (section 2.8).

In seeking to focus, identify and understand the contributions to the literature the following questions were posed. Namely:

- What is integrated vehicle health management and how does it relate to other asset monitoring applications?
- What has been achieved by the application of IVHM?
- What are the drivers of, and inhibitors to the adoption of IVHM?
- What tools are being employed to assist the adoption of IVHM?
- What are the current research issues?

This overview of the literature will illustrate that there is a requirement for a decision framework which can illustrate the benefits of IVHM enabled informated products by UK manufacturers seeking to offer products and service delivery systems. This is achieved by the following chapter structure shown in figure 2.1.

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2. *This literature review chapter cites Benedettini et al (2009) "State of the art in Integrated Vehicle Health Management" throughout. As this chapter will show, the field of IVHM is steadily emerging and gathering an increasing focus within the field of Prognostic Health Management and latterly within the servitization related literature. The literature within this emergent field is sparse. Their paper is published during the duration of this research and is used as a supporting waymark supplementing the author's own review to ensure chapter completeness.*

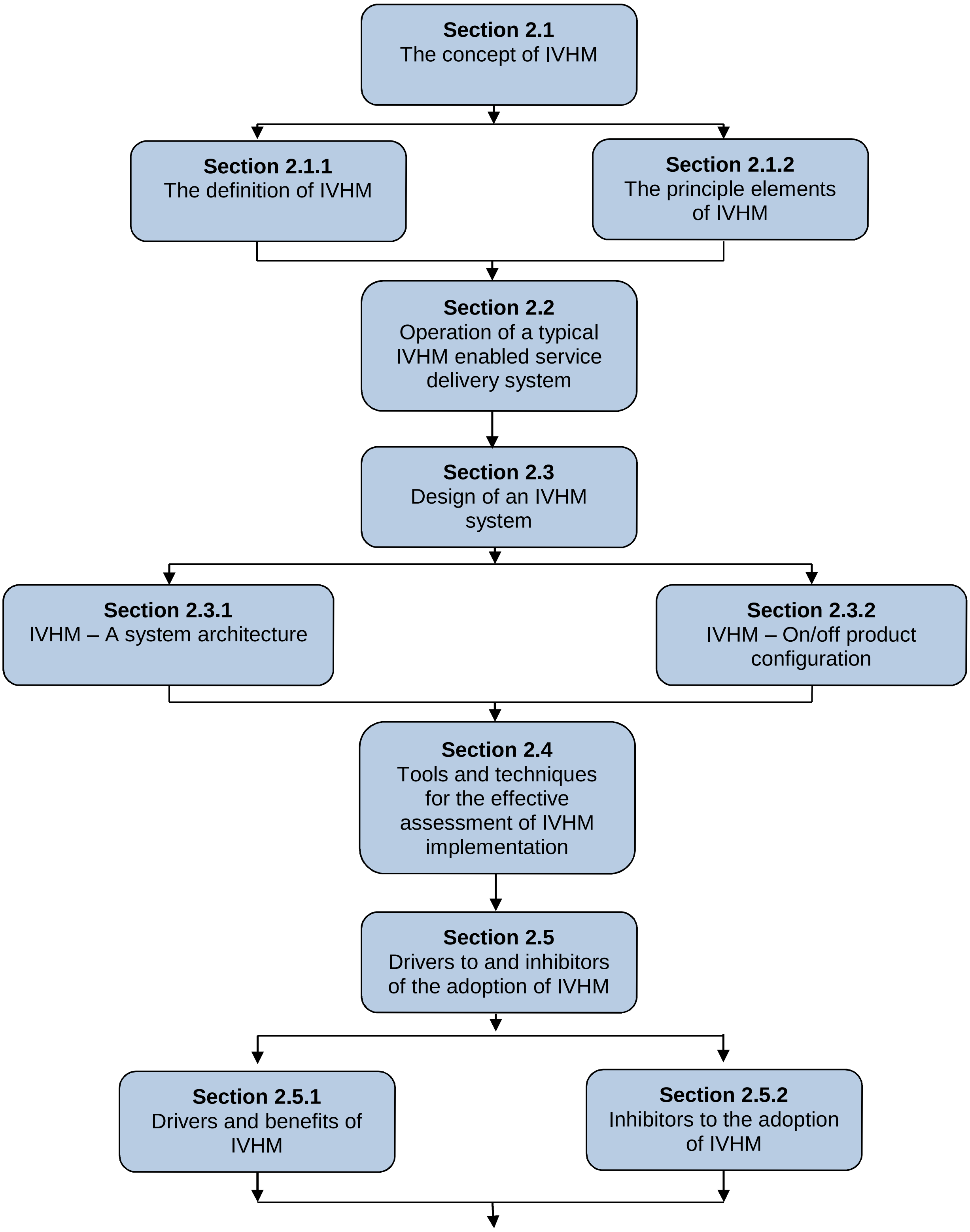

Figure 2-1 Structure of chapter two (Part 1)

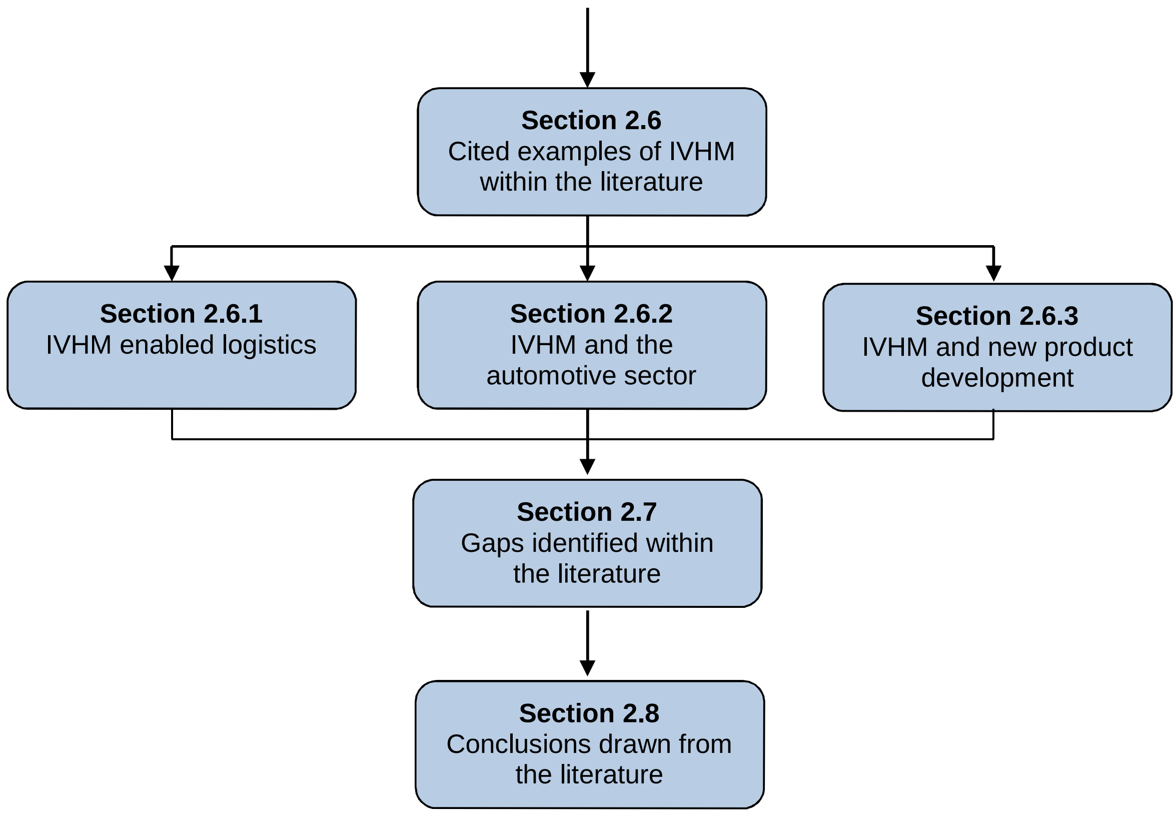

Figure 2-2 Structure of chapter two (Part 2)

2.1 The concept of IVHM

This section introduces the reader to the concept of Integrated Vehicle Health Management (IVHM) by way of offering a definition (section 2.1.1) and then discussing the principle elements that constitute an IVHM system (section 2.1.2).

2.1.1 The definition of IVHM

Benedettini et al (2009) identify the first use of the term Integrated Vehicle Health Management (IVHM) as appearing in papers published by the National Aeronautics and Space Administration (NASA). Their report outlined the future research goals of the organisation with regards to IVHM. The administration defined the concept as one which would possess

> *".....the capability to effectively perform checkout, testing, and monitoring of space transportation vehicles, subsystems, and components before, during, and after operation..... [which]..... must support fault tolerant response including system/subsystem reconfiguration to prevent catastrophic failure; and IVHM must support the planning and scheduling of post operational maintenance*" (NASA, 1992).

In reviewing this definition it is apparent that the 'vision' emerges from the space sector. The main drivers for NASA in the late 1980's and early 1990's were centred on the reliability of its vehicles and mitigation of the risk of component, sub-assembly, and sub-system failure which would impact upon the mission success. When analysed, NASA's definition comprises of five key points which serve to be the foundation of the IVHM concept. Namely,

- Check and test parameters against pre-defined norms,
- Continuous monitoring (can be open or closed loop),
- Full mission cycle application (before, during, and after execution),
- Adaptability and reconfiguration of systems to mitigate risk. (implies the potential for autonomy or partial autonomy),

- Supports ‘post operational’ maintenance.

NASA’s vision was a solution which involved continued monitoring of components and systems throughout the whole mission cycle against pre-selected parameters and metrics. The solution being either ‘open’ loop where the decision intelligence was ‘off board’, or ‘closed’ loop where the systems were able to reconfigure themselves to maximise the operability of the vehicle.

The literature offers little by way of discussion and the expansion of IVHM’s definition during the late 1990’s. As papers emerge it is observed that they remain focused upon the aerospace sector with few contributions emerging from outside this group. This review identifies nine peer reviewed papers which seek to address the identity of the IVHM concept. These concur with Benedettini et al’s (2009) findings whilst significantly more authors offer technical papers and presentations which deal with sensor, computing, communications, artificial intelligence [algorithms], and engineering issues and solutions.

A summary of definitions offered is illustrated in Table 2.1. In reviewing the elements of each definition recorded it is seen that IVHM has the ability to check, test, and monitor anomalies against design parameters throughout the operation cycle. At this juncture there would appear to be no difference between IVHM and other condition based maintenance initiatives. However, as authors seek to establish further the definition of IVHM it is seen that the concept also offers the ability to conduct diagnostic and prognostic analysis of the product whilst in use (Table 2-2). Furthermore, for some authors (Aaseng, 2001; Roemer et al., 2001; Paris et al., 2005) the ability to mitigate failed or failing systems, coupled with the enhanced ability to reconfigure the operating system (National Aeronautics and Space Administration (NASA), 1992; Aaseng; 2001) autonomously (Baroth et al., 2001) is what makes IVHM a technical application of significance.

Each contribution listed within this section seeks to offer a definition which is best suited to the application in focus with no standard ontology or transferable identity emerging. The language used within each definition is aerospace specific with each contribution seeking to introduce a new set of acronyms with little focus given in the papers reviewed to the evolution and testing of IVHM's identity. After 2001 there is seen to be a gradual 'awakening' as authors (Aaseng, 2001; Baroth et al., 2001; Karsai et al., 2006; Jakovljevic et al., 2006; Roemer et al., 2007) begin to question the identity of IVHM and its application whilst acknowledging "...that the only way to .... [achieve].... the goals of such concepts .... [will be].... to include an integrated capacity for automating the maintenance and operation of ..... [the asset]...." (Baroth et al., 2001)

In reviewing the elements of each definition offered (Table 2-2) it is seen that IVHM has the ability to check, test, and monitor systems for anomalies against designed parameters throughout the operation cycle. As authors seek to establish further the definition of the concept it is seen that IVHM also has the ability to carry out diagnostics (National Aeronautics and Space Administration (NASA), 1992; Roemer et al., 2001; Price et al., 2003; Wilmering et al., 2003; Paris et al., 2008) and use this information to make prognoses of the remaining useful life (RUL) of the system or component (Roemer et al., 2001; Price et al., 2003; Wilmering et al., 2003). As the concept emerges within the aerospace/aeronautical sectors the product/asset's location is sometimes beyond the reach of maintenance teams (i.e hostile environments) and therefore IVHM is seen to offer limited autonomy in fault mitigation and system reconfiguration (National Aeronautics and Space Administration (NASA), 1992; Aaseng, 2001; Paris et al., 2005). It is seen that IVHM is not conceived as a passive monitoring system (re: CBM_1) but is designed to be proactive to any product deterioration from the operational design parameters of the product before, during, and after use. Quite simply it initiates actions by way of detection, assessment, mitigation, and reconfiguration, and/or triggers external support to maximise operational functionality and availability. Jennions (2011) makes this distinction by stressing the importance of the word 'Integrated' in the identity of the concept.

Table 2-1 Definitions of IVHM taken from the IVHM literature (Benedettini, 2009)

Author	Definition
NASA (1992)	"...the capability to efficiently perform checkout, testing, and monitoring space transportation vehicles, subsystems, and components before, during, and after operation....must support fault tolerance response including system/subsystem reconfiguration to prevent catastrophic failure; and IVHM must support the planning and scheduling of post operational maintenance".
Aaseng (2001)	"...all the activities that are performed to understand the state of the vehicle and its components, to restore the vehicle to normal system status when malfunctions occur, and to minimise safety risks and mission impacts that result from system failures".
Baroth et al (2001)	"..effort to coordinate, integrate, and apply advanced software solutions, sensors, and design technologies to increase the level of intelligence, autonomy, and health state determination and response of future vehicles.
Roemer et al (2001)	"...integrates component, subsystem and system level health monitoring strategies, consisting of anomaly/diagnostic/prognostic technologies, with an integrated modelling architecture that addresses failure mode mitigation and life cycle costs"
Price et al (2003)	"....an example of an intelligence sensing system. The purpose of such a system is to detect and measure certain qualities, and to use the information and knowledge obtained from the measured data, and any prior knowledge, to make intelligent, forward looking decisions and initiate actions"

Author	Definition
Wilmering et al (2003)	"....the unified capability of an arbitrary complex system of systems to accurately assess the current state of member system health, predict some future state of health of the member systems, and assess that the state of health within the appropriate framework of available resources and operational demand".
Paris et al (2005)	"....the process of assessing, preserving, and restoring system functionality across flight and ground systems"
Jakovljevic et al (2006)	"...its goal is to provide better ways for operating and maintaining aerospace vehicles using techniques such as condition monitoring, anomaly detection, fault isolation, and managing the vehicle operations in case of faults".
Karsai et al (2006)	"....ensures the reliable capture of the health status of the overall aerospace system and helps prevent its degradation or failure by providing reliable information about problems and faults".

Table 2-2: Elements within the definitions of IVHM offered by the literature

	NASA (1992)	Aaseng (2001)	Baroth et a (2001)	Roemer et al (2001)	Price et al (2003)	Wilmering (2003)	Paris et al (2005)	Karsai et al (2006)	Jakovljevic et al (2006)
Check out	X	X	X	X	X	X	X	X	X
Test	X	X	X	X	X	X	X	X	X
Monitor	X	X	X	X	X	X	X	X	X
Diagnostics	X			X	X	X	X		
Prognostics				X	X	X			
Mitigation response	X	X		X			X		
Reconfiguration	X	X					X		
Maintenance planning									
Autonomy									
Life cycle costs									
Initiate action									

He states in the introduction to a collaboration of perspectives that:

> *"The label IVHM itself raises some fundamental challenges. In particular, the 'I' of IVHM is absent in many examples in the literature. Most of the purported applications of IVHM are point solutions, focusing on monitoring, not of a vehicle but a single component or sub system.....* [CBM_1]...... *Integration of various functional areas such as operations and maintenance as well as the wider supply network is often not part of the solution"* (Jennions, 2011)*.*

Whilst there are further contributions to the literature relating to the technical issues concerning the development and application of IVHM, no other additions to the body knowledge within the time period (1992 to 2006) deal with the definition of the concept. Of the contributions that are offered few are seen to offer a definition for IVHM which captures the identity and purpose of the concept whilst remaining sufficiently generic as to enable the application of such a definition across all sectors in relation to manufactured products. Whilst acknowledging the validity of the contributions to the literature a definition is required which is not sector specific and can be applied to any organisation's products, services, and application.

It is not until 2009 that Benedettini et al offer a definition for IVHM which seeks to serve this requirement. They define IVHM as being a system that possesses the………..

> *"....capacity to capture .... [a product's].... condition, both current and predicted, and use[s] ....this information to enhance operational decisions, support actions, and subsequent business performance*". (Benedettini et al., 2009)

This definition is significant as it captures by implication the key points of the previous contributions (Table 2-2) whilst remaining significantly generic as to be applied across industrial sectors, and applications. However it states what IVHM *does* and not what IVHM *is*. For the purpose of this research the author adopts Benedittini's definition in part but adds to this by summarizing the identities offered holistically (Redding, 2011). IVHM is defined therefore as:

> "......the application of existing and emerging technologies within the fields of computing, systems engineering, and communications technology, and the application of sensor technology which offers the capability to capture.... [a product's].... condition, both current and predicted, and use.....this information to enhance operational decisions, support actions, and subsequent business performance".

Having introduced the concept (section 2.1) and offered a definition for the IVHM which is suitably generic to facilitate its application to all sectors and applications, (section 2.1.1), the following section will inform of the principle elements of the IVHM concept (section 2.1.2).

2.1.2 The principle elements

The purpose of this subsection is to inform of the principle elements that constitute a typical IVHM system.

Bird et al (2005) cite Scandura (2005) when stating that IVHM is not ".......*a standalone subsystem added to*....[a product or asset].... *nor should a group of sensors and related instrumentation.....be considered* .... [to be an].... *IVHM* ... [system]" (Bird et al., 2005). The concept is far more than building in, or retrofitting sensors and systems to passively monitor product condition (CBM_1). Baroth et al (2001, 2006) imply acceptance of NASA's vision (National Aeronautics and Space Administration (NASA), 1992) when stating that that an effective IVHM system can only be achieved by the successful integration of "artificial intelligence with advanced sensors and communication technologies" (Baroth et al., 2001). This is endorsed by Scandura who asserts that IVHM "...is a philosophy, methodology, and process that focuses on design and development .... [of integrated technologies and systems]..... for..... [increased].... safety, operability, maintainability, reliability, and testability" (Scandura, 2005).

Effective IVHM requires embedded sensors in key components and systems coupled with "advanced reasoning" linking on-board and ground based systems (Roemer et al., 2007). The system should be "focused on establishing decision support to provide autonomous, timely, and accurate assessments of a vehicle's health and functional availability.... [for]... operations and ... [to].... maintenance personnel" (Roemer et al., 2007). The concept as defined by the definitions discussed in (section 2.1.1) and 'philosophy' as envisioned by Scandura (2005) and Roemer et al (2001) identify the functionality of the IVHM system as one which is the combination of sensor integration, intelligence (human or artificial (AI)) and communications technology (Figure 2-3).

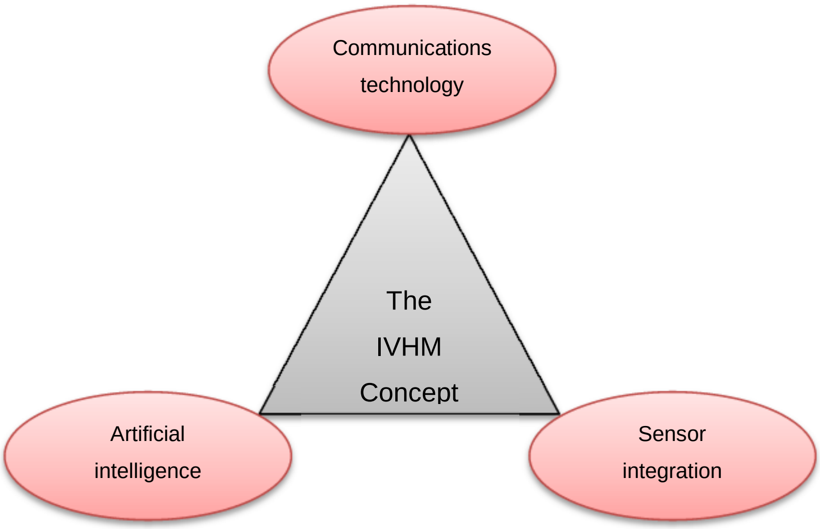

Figure 2-3: Principle elements of an IVHM system

In order to achieve the desired outcome from the implementation and fusion of these technologies a systems approach to engineering becomes apparent and the need for a systems architecture is discussed in (section 2.3.1).

Having discussed the definition and principles that identify the concept that is IVHM the next section serves to illustrate how IVHM can be applied within a macro operational environment which when looked at holistically serves to define a complex service delivery system.

2.2 Operation of a typical IVHM system

This section presents an holistic illustration of the vision that is a totally integrated IVHM system as applied at the macro level (Figure 2-4). In the example various complex products are illustrated (quarry trucks, trains, health scanners, gas turbines, machine tools and wind turbines). The products all have sensors and systems fitted at differing levels in line with the OSA-CBM (section 2.3.1). Whilst 'in use' the sensors and on-board systems monitor, record, analyse, store, and react to health and usage data whilst carrying out various levels of on-board and off-board diagnostics, prognostics and decision support. Limited risk identification (warning signals) and mitigation (fail safe routines) are also initiated by algorithm driven procedure management routines and on-board annunciation (Hess et al., 2002b; Banks et al., 2006; Benedettini et al., 2009).

Selected health and usage data is either stored on-board for download to the off-board operations support network at predetermined stages within the usage cycle, (when product is in depot, at selected operations/maintenance intervals), or via data transmission using satellite communications to the organisation's support and control room. The literature refers to the control room or hub as a ground based reasoner (GBR) (Keller et al., 2001; Callan et al., 2006; Dibsdale, 2011). Typically data warehousing (Keller et al., 2001) and open loop assessment and decision support is undertaken within the GBR by subsystems which can include portable maintenance terminals (JiaJu Wu et al., 2011), maintenance and application (useage) prognostics/diagnostics systems (Dussault and IEEE, 2007; Cook and IEEE, 2007; Bagul et al., 2008), and logistics planners (Henley et al., 2000; Faas and Miller, 2003; Bock et al., 2005).

Portable maintenance terminals can include computer laptops and or dedicated plug and play equipment that can be connected to the product/asset via cable or infra-red/bluetooth technology to download such data as usage profiles, DTC codes, etc. The data can then be processed by maintenance systems containing diagnostic/prognostic routines which contain blueprints, procedures, 'virtual workshops' (Ferrell, 1999; Hess et al., 2002a; [Anon], 2004; Banks et al., 2006; Banks et al., 2006a) prior to uploading mitigating reconfiguration data back to the product. Alternatively such data can be taken back to the GBR for further processing.

The GBR also carries out maintenance and usage diagnostics and prognostics assessments and analysis using the transmitted data via the satellite system (Redding, 2011). Maintenance data is used to assess degradation of components and systems. This determines mitigating actions and (RUL's) prior to implementing 'use or repair' decisions (Callan et al., 2006; Jakovljevic et al., 2006; Dibsdale, 2011). The results of such assessment and decision processes can then be either transmitted back to the asset/product whilst in use by way of system reconfiguration and operator instructions, or, shut down routines where appropriate. The usage data received can also be used for input into business models and charging systems which facilitate availability and usage contracts (Benedettini et al., 2009; Baines et al., 2009b; Pomfret, et al, 2011).

Finally such data can be used for 'open loop' and autonomous logistics systems (Wang et al., 2007; Banks et al., 2006a; Kalgren et al., 2006; Hess et al., 2004; Faas and Miller, 2003). The data is analogous to a KANBAN signal (Banks et al., 2006a; Redding, 2010a), which is used to trigger actions throughout the supply chain. This initiates the manufacture of replacement components and/or systems with the delivery of such items being through an integrated logistics system to locations where they can be fitted to the product (Henley et al., 2000; Faas and Miller, 2003).

This sub-section gives insight into a potential paradigm shift in operations that is realised by the application of IVHM. It is far more than just a condition based maintenance system. The concept offers a radical shift in the operations strategy and associated business models employed by organisations (Baines et al., 2009; Benedettini et al., 2009; Pomfret, C., Jennions, I. K., Dibsdale, C., 2011). Significantly it also enables manufacturing operations obtain revenue throughout the complete life cycle of the product by offering service bundles (Vandermerwe and Rada, 1988; Baines et al., 2009b; Redding, 2010a) and product service systems (PSS) (Mont, 2000; Mont and Lindhqvist, 2003; Grubic et al.; Morelli, 2006).

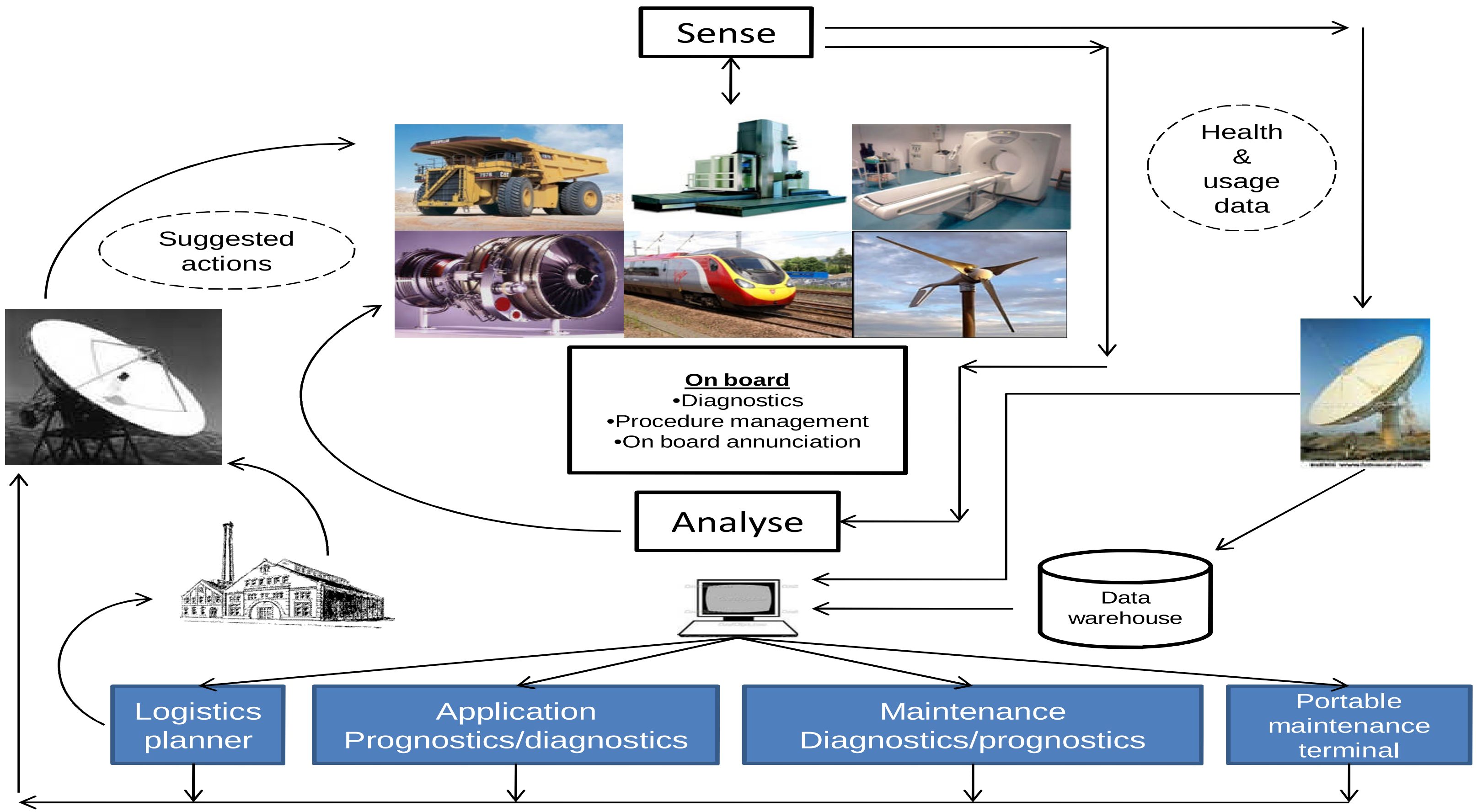

Figure 2-4: Operation and structure of an IVHM system [Adapted] (Benedettini et al., 2009)

2.3 Design of an IVHM system

This section gives insight from the literature as to the system architecture (section 2.4.1) to adopt when seeking to apply IVHM technology applications, and also the on/off product configuration considerations (section 2.4.2).

2.3.1 IVHM – A system architecture

The successful implementation of an IVHM system requires the effective design of the system architecture (Dunsdon and Harrington, 2008; Swearingen et al., 2007; Roemer et al., 2007; Bird et al., 2005; Dunsdon, 2004; Followell et al., 2004). Authors acknowledge this when stating that “the design of an IVHM system needs to be approached as a system[s] engineering process ....the IVHM system must be constructed into the host vehicle and in connection with other instrumentation systems ......[and]...... must be integrated according to an open system standard, typically ...[the]... OSA/CBM architecture” (Benedettini et al., 2009).

The majority of the literature relating to this area deals with the importance of system architecture and the adoption of IVHM as an effective methodology for whole life operations and asset management. Bird et al (2005), Scandura (2005) and Schmalzel et al (2008) propose the adoption of a layered approach to IVHM, where each “....layer is viewed as a collection of similar tasks or functions at different levels of abstraction” (Keller et al., 2007). Such a structure is illustrated in Figure 2-5.

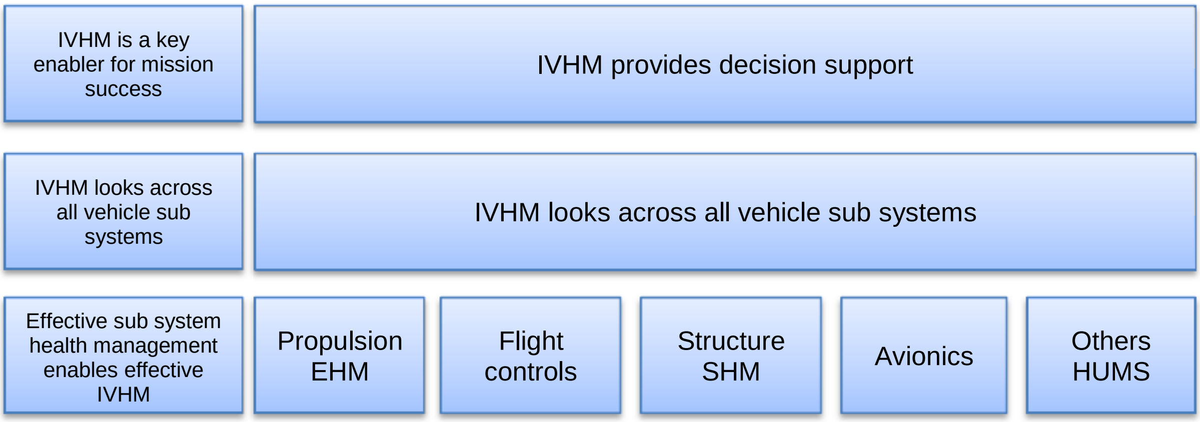

Figure 2-5: Layered approach to IVHM (Scandura, 2005)

Each subsystem has its own data collection sensors at the lowest level which monitor key parameters of each component within the system. At this level physical parameters such as temperature, pressure, and vibration are monitored and warnings issued should any of the parameters exceed predetermined limits. Faults can be either catastrophic, in which case warnings are issued and corrective action are required immediately, or more importantly for the consideration of effective IVHM systems, data signals warn of degradation of future function in which case a decision process is initiated.

The next level within the architecture is a product wide monitoring level which would monitor and report the interactions of performance and degradation across the vehicle. This requires an understanding of cause and effect as faults may propagate through systems resulting in whole system failures. The ability to monitor these complex interactions is required at this layer. The top layer is the decision support layer where such decisions as to ‘use’, ‘mitigate’, or ‘terminate, operation is made.

The OSA-CBM is used as the building blocks for the IVHM system and is borne from the need to interface differing supplier and manufacturing standards (Aaseng, 2001; Followell et al., 2004; Scandura, 2005; Hess et al., 2006; Pell et al., 2008; Vachtsevanos, G., Goebel, K., 2011).

Level 7 **Presentation**
Level 6 **Decision support**
Level 5 **Prognostics, remaining useful life (RUL), or future time status**
Level 4 **Health Assessment – identify degradation and performs discrete or grey scale diagnostics**
Level 3 **– State detection – comparison against datums/limits – display condition**
Level 2 **Data manipulation layer**
Level 1 **Data acquisition layer – sensors collecting physical measurements**

Figure 2-6: The OSA-CBM architecture [Adapted] (Followell et al., 2004)

The structure (figure 2-6) illustrates that the first five levels deal with data acquisition and processing against predetermined parameters and algorithms, whilst levels 6 and 7 provide the connection to the wider IVHM system. The decision support and presentation frameworks are greatly dependent upon the external systems and architectures to which the system is to be linked. The introduction of this reference framework reduces development costs of such systems and allows for greater performance of the system through the increased integration between layers and external systems (Followell et al., 2004; Swearingen et al., 2007). It also allows for the purchasers of such systems to enjoy greater competition from the supply chain. This is demonstrated by Followell (2004), Swearingen (2007) and Dunston et al (2008) when identifying Boeing, GE and (presumably their competitors) as system integrators. For Boeing the "…..open architecture implemtation….. enable[s] multiple vendors to competitively contribute to integrated …. [vehicle health management] VHM systems by virtue of of obtaining access to the necessary data and interfaces" (Followell et al., 2004); whereas a closed loop system requires the suppliers co-operation in ensuring that the systems remain compatible at the interface level thus increasing the cost of design, ownership, and operation.

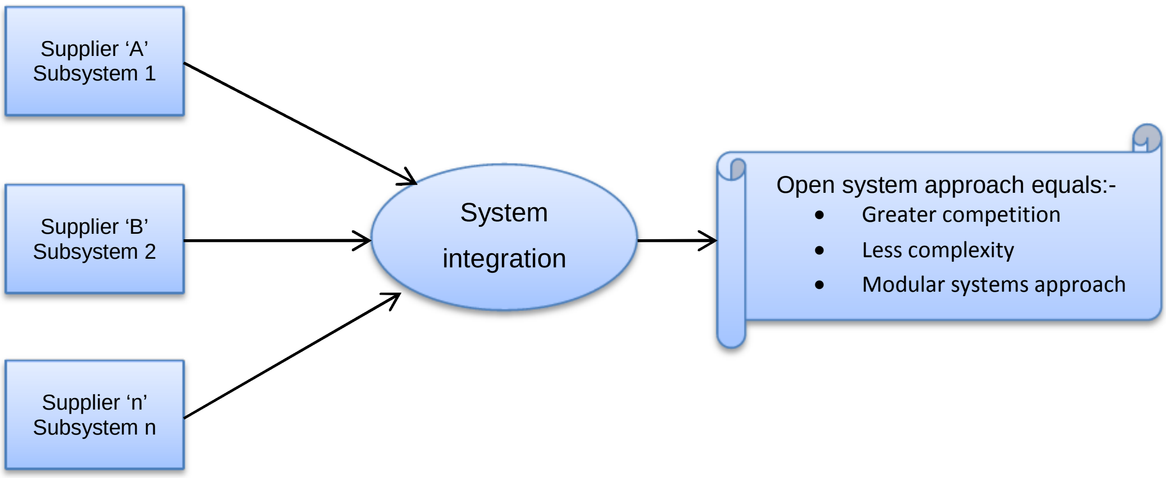

Figure 2-7: IVHM systems integration

Such an architecture "...allow[s]....[for product].... and system design updates with mature PHM information, knowledge based algorithms, the ability to quickly and easily update the algorthims and knowledge bases.... [which].... provide significant advantages over legacy platforms. Software updates do not affect the critical operational.......programmes" (Hess et al., 2004).

Having recognised the importance of the OSA-CBM framework, and reviewed the generic offerings within the literature, (Li Yi-bo et al., 2007; Swearingen et al., 2007; Hamilton et al., 2007; Pell et al., 2008; Dunston, J., Harrington, M., 2008) offer the following as a typical example of the IVHM architecture as applied to products which is summarised by Benedettini et al (2009).

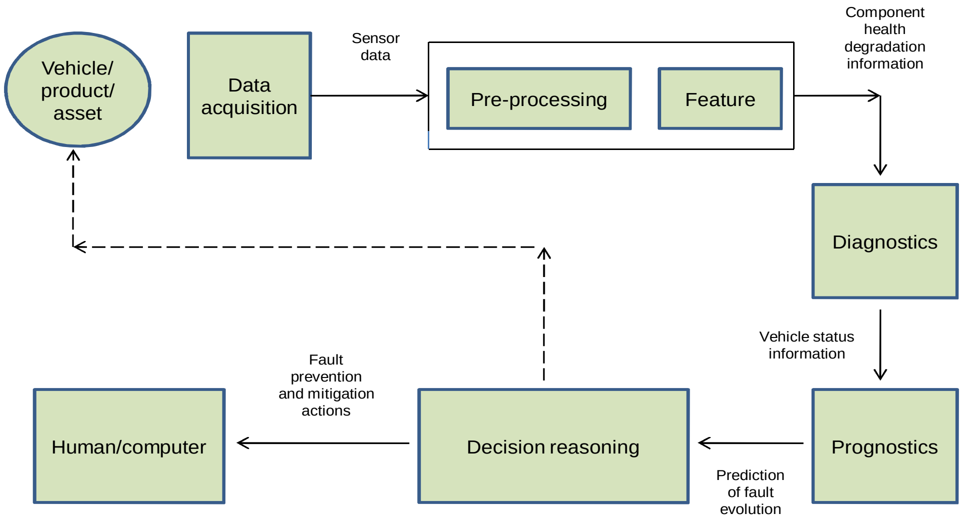

Figure 2-8: Generic architecture of a typical IVHM system (Benedettini et al., 2009)

When figure 2-8 is compared to the OSA-CBM architecture (figure 2-6) a match is observed in that at the component level, peripheral or embedded sensors are employed to measure parameters whose degradation are indicative of current or future faults (National Aeronautics and Space Administration (NASA), 1992; Aaseng, 2001; Prosser et al., 2003; Baroth and Pallix., 2006). Paris et al (2008) demonstrate this when focusing on sensor intelligence as an architecture serving to "integrate advanced computational techniques with technologies........that can generate responses through detection, diagnosis, reasoning, and adapt to system faults in support of integrated intelligent health management (IIVM)" (Paris et al., 2008). Their main focus is upon IVHM yielding autonomy when introducing 'layers' of architecture, thereby leading to a new descriptor and acronym.

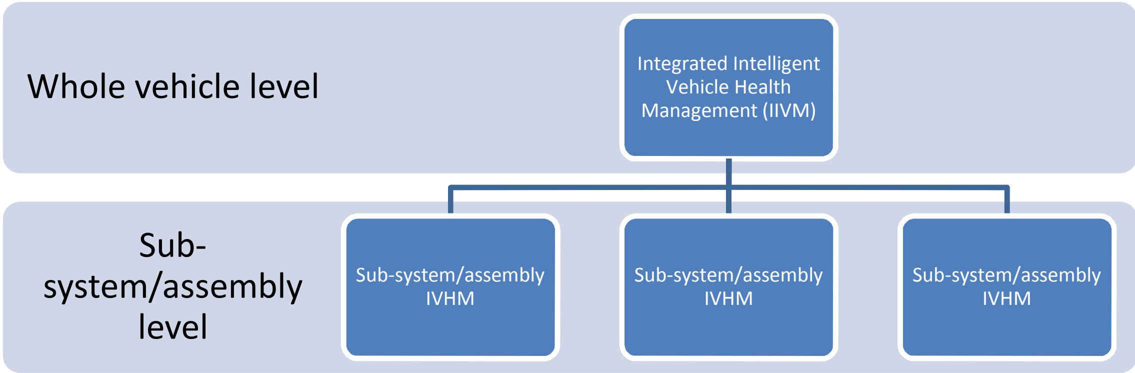

Figure 2-9: IVHM and IIVM relationship within the system architecture (Paris et al., 2008)

They propose that IVHM exists at the subsystem level and introduce the concept of IIVM as being the layer which exists at the whole vehicle level. Paris et al clarify their architecture by offering the system structure presented in figure 2-9. This distinction is a deviation from the consensus of opinion within the literature and is the first attempt to relegate the concept of IVHM to the subsystem level. The body of the literature makes no such distinction although Zuniga et al (2002) introduce Integrated Systems Health Management (ISHM) to the literature stating that it is "....implemented at the subsystem level and integrated at the system level for the maximum benefit and optimum performance .....[achieving this by thinking]...... at the system level whilst working at the subsystem level" (Zuniga et al., 2002).

This emerging focii within the literature demonstrates that the content and structure of IVHM is being investigated at two levels, namely the micro level where diagnostics and prognostics are looking at 'real time' data relative to individual components, and the macro level where a focus upon the correlation 'symptoms' is under investigation (Aaseng, 2001).

This section has introduced to the reader the OSA-CBM architecture. It illustrates that "...the ideal IVHM system is built into the vehicle....from the ground up... [with].... optimal sensor placement, distribution of diagnostics and health reporting, and integration of health monitoring and control systems ....[being].... the goal for the IVHM system development" (Aaseng, 2001). The architecture also enables IVHM solutions to be retrofitted to the product's installed base if a modular rather than federated system is employed the critical factor being the "...early integration ....[of the concept]..... into the ..[product]...design" (Swearingen et al., 2007).

This sub-section has illustrated the importance of using the CBM-OSA when seeking to employ IVHM technical applications to informated products. The question which naturally follows is how much of the holistic system should be built into the product and what elements of the solution should be remote from the product in use. The following section will discuss the on-product off-product considerations.

2.3.2 IVHM – On product/off product configuration

The literature gives insight into the future aims and visions for research and industrial applications when seeking the realisation of the extended impact of IVHM. This is predominantly centred upon the aerospace and military sectors and becomes particularly significant when applied to fleet management (Swearingen and Keller, 2007; Keller et al., 1998). When considering aerospace applications and operations it is evident that system integrators (the OEM's) cannot fit the whole vehicle with IVHM technology and associated decision hardware /software as weight and system complexity become major considerations. Decisions are therefore required as to the level of on-board off-board configuration and application to adopt as such considerations as weight and resultant operating fuel costs become significant (Dunston, & Harrington, 2008).

Swearingen et al (2007) state that due to these considerations only those technology applications that contribute to critical operational functions and 'revenue protection' are fitted on board with all other functions being located off-board. It should be remembered however that the IVHM is seen as an holistic systems solution and as such the location of the technology (off/on board) does not diminish or degrade the identity of the concept.

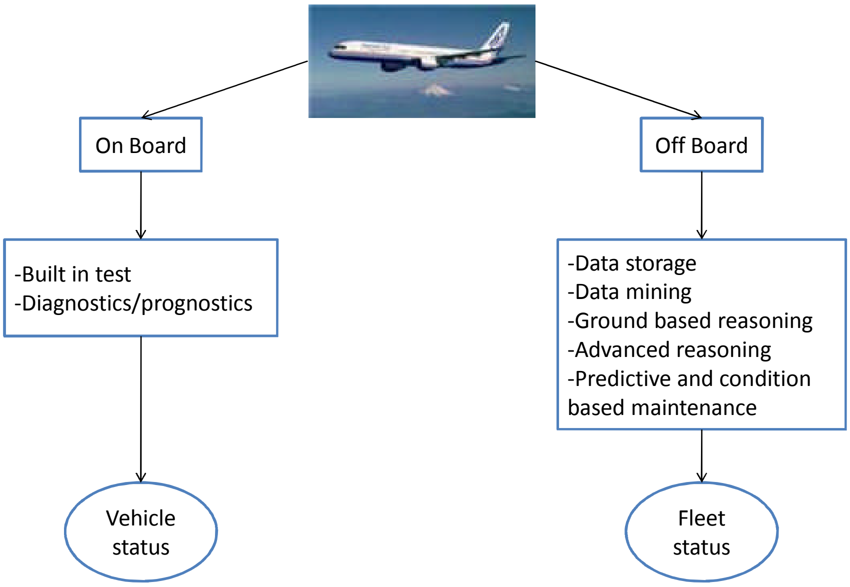

Figure 2-10: On/off board configuration of IVHM systems (Swearingen and Keller, 2007)

With advancements in the development of sensor technology, the introduction of passive on board RFID technology, and passive wireless SAW sensors (Wilson et al., 2008) coupled with the move from federated to modular systems have facilitated "..the implementation of support critical IVHM functionality" (Swearingen and Keller, 2007) to on-board systems. Fox et al (2000) suggest that the system consists of sensors, limited data processing and data storage on-board, with control and automated systems being ground based and controlled by a 'ground based reasoner'.

The question raised in the literature (Fox et al., 2000) is the level of autonomy that is offered to the vehicle/product by the application of IVHM. This revolves around the distinction of monitoring and management. At one end of the spectrum, the technology allows for monitoring, (i.e. the system recognises that action is required – (CBM_1)), whilst at the other end of the spectrum the system is capable of active management of issues and takes actions upon the data it detects with the "....autonomic support concept.... [being].... analogous to the autonomic nervous system that directs the ..... [human].... body to 'breath in, breath out' without being told to do so" (CBM_2) (Smith et al., 1997).

It is evident that the configuration decision (on or off board) is dependent upon many issues not least the product. Weight becomes an issue with aerospace products (Swearingen and Keller, 2007), whilst detection of the signal signature during transmission is of importance to ground based military vehicles (Banks et al., 2006). All the IVHM elements of the holistic system are inherent within each solution discussed. However it is seen from reading the contributions that the positioning of each element within the system is dependent upon the mode of operations for the product.

2.4 Tools and techniques identified for effective assessment of IVHM implementation.

The literature illustrates that the effective application of IVHM solutions requires the interaction of many technologies (section 2.1). This multidiscipline solution requires a systems approach (Wilmering et al., 2003; Baroth and Pallix, 2006) and an agreed methodology for implementation and assessment (Wilmering and Ramesh, 2005) if such initiatives are to be successful. Although IVHM can be applied to legacy products (products within the installed base) to maximise the benefits that may be obtained for the stakeholders, the technology is better designed into the product from conception to attain maximum advantage (Keller et al., 2007; Wilmering, & Davies, 2011). In seeking to implement these technological solutions it is beneficial to have guidance from assessment 'tools' so as to predict, measure the impact, and to monitor the performance of these systems prior to, and during their performance in the field. The research has identified (Chapter 4 - Survey) typical questions and considerations for which answers are sought when considering IVHM type applications, namely:

- Can the product facilitate IVHM technology?
- Is there sufficient means to collect the data from the system?

- Do we have the infrastructure to operate such a system?
- What type of data do we wish to collect (Performance data, logistics data, or both)?
- What do we wish to do with the data?
- What is the financial case for IVHM (Investment, benefits, payback)?
- Should the system be open or closed loop (Levels of autonomy ..etc)?

Authors observe that "...various tools have been developed to support IVHM design. Overall these implement a wide range of approaches for the solution of technology related trade off's and assist in the definition of the most appropriate architecture" (Benedettini et al., 2009).

To facilitate the effective integration of product monitoring sensors and decision support systems the literature offers the adoption of standardisation through the OSA architecture (section 2.3.1) as a universal methodology and an aid when moving from federated to modular systems. Benedettini et al cite (Dunsdon and Harrington, 2008; Followell et al., 2004; Swearingen et al., 2007; Gonzalez et al., 2007; Karsai et al., 2006; Callan et al., 2006), when stating that the application of such an architecture ".....reduce[s] cost, improve[s] portability, and increase[s] competition in the market or IVHM solutions". (Benedettini et al., 2009).

The literature relating to the tools and methods employed is generally split into two fields, namely tools to assess the technical design and performance of IVHM enabled applications (Datta et al., 2004b; Datta et al., 2004a; Wilmering and Ramesh, 2005), and tools for assessing the impact and wider benefits of the application for organisational performance at the operational and strategic level (Byer et al., 2001; Ashby and Byer, 2002; Banks et al., 2006b; Kurien et al., 2008; Hoyle et al., 2008; Datta and Roy, 2011; Krichene, & Roemer, 2011). Whilst technical assessment methodologies are well documented, systems and procedures which assess the design and implementation of suitable 'soft' functions within the management sphere appear to be fragmented and near to non-existent.

For the technical assessment of the IVHM system such quality tools as failure modes and effects criticality analysis (FMECA), event tree analysis (ETA), root tree analysis (RTA), and ISHIKAWA diagrams are commonly deployed in order to assist designers develop effective systems (Dale, et al., 2007). Benedettini et al cite (Vachtsevanos et al., 2006; Callan et al., 2006; Banks et al., 2005; Kacprzynski et al., 2002) when stating that "........advanced FMECA approaches ....[and other such tools] ... analyse failure symptoms and ...suggest sensor suites and diagnostic and prognostic technologies that are most appropriate for the IVHM system" (Benedettini et al., 2009). This approach coupled with the various test bench initiatives and case study approaches (Keller et al., 2007; Keller et al., 2006; Vachtsevanos et al., 2006; Keller et al., 2007; Janasak et al., 2006; Banks et al., 2006b) documented in the literature are facilitating a greater level of integrated solution.

The second set of tools focus upon assessing the perceived/potential benefits that can be achieved relating to the operational performance of the organisation (Pomfret, et al., 2011; Williams, 2006) and propose the application of an iterative approach using discrete event simulation coupled with the application of a cost benefit analysis to assess the optimum application for an IVHM solution. It is important to note that the identification of the key performance indicators (KPI's) will vary depending upon the processes being used and the interests of the stakeholders. Williams suggests that it is essential to fully map the process prior to any simulation model construct to ensure that the correct measures of effectiveness (MOE's) are identified. The question arises of who is best suited to define the KPI's and/or MOE's. Is the OEM or the product owner/operator the best suited to define these parameters and should an assessment be made as to the ability of each to make these decisions. There are no contributions to the literature which attempt to deal with this alignment of the needs of the customer and the measured offering of the supplier/user relative to the service delivery system (level of servitization, the organisation, the technology, and product suitability). This is a key insight into the larger issues surrounding the decision making process when considering the adoption of IVHM solutions as it enables a paradigm shift in the future design of operations strategy and the resultant business case preparation and subsequent business model.

Williams (2006) asserts that the effective application of IVHM is dependent upon seeking to influence the balance between cost of development, installation, and operation of the IVHM system to yield the maximum operational benefit. (Figure 2-11).

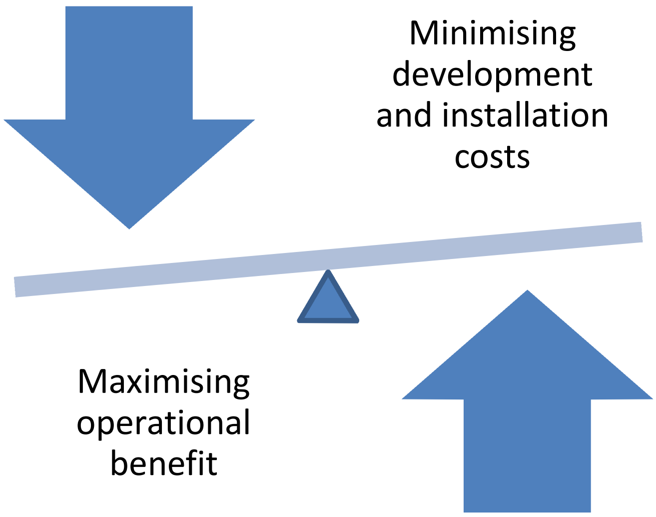

Figure 2-11: Tilting the balance for maximum operational benefit

The main issues arise when seeking to ask “in whose eyes?” and “against which indicators and parameters?”. Clearly a relationship between the operators/owners of the product and the support/logistics infrastructure will be subject to change with the adoption of an operations strategy facilitated and driven by IVHM.

At Boeing’s IVHM solution centre for example, ongoing research is being undertaken into evermore complex discrete simulation models with the stated aim of assessing the impact of IVHM upon the overall product performance using such MOE’s as:

- The number of maintenance man hours
- Operational availability
- Maintenance man hour requirements and inventory
- Mean time to repair
- Fault isolation times
- Logistics lead times
- Mean sortie hours before failure (Williams, 2006)

Whilst Janasak et al (2006) cite Datta et al (2004b; 2004a) in stating that "....simulation based scenarios .... [are]..... used to conduct testability trade studies resulting in a more optimat testability solution of robust diagnostics and prognostics..... [and has].... proved to be successful in determining .... [the].... areas to target for the introduction of IVHM" (Janasak et al., 2006). Additionally Janasak continues to inform that the ongoing research interest within this area "....has also lead Raython to develop a closed loop HMS....[Health monitoring system]..... based on methodology to achieve a robust design and that results in superior product availability" (Janasak et al., 2006) using their five point analytical framework (Beshears and Butler, 2006).

Such frameworks appear to be developing in silos based upon the needs and operations of the commercial organisation rather than contributions from within the academic and research communities. In contrast to the initiatives of Raytheon, Boeing also offer a framework for the assessment of suitable candidates for the application of IVHM principles and technologies.

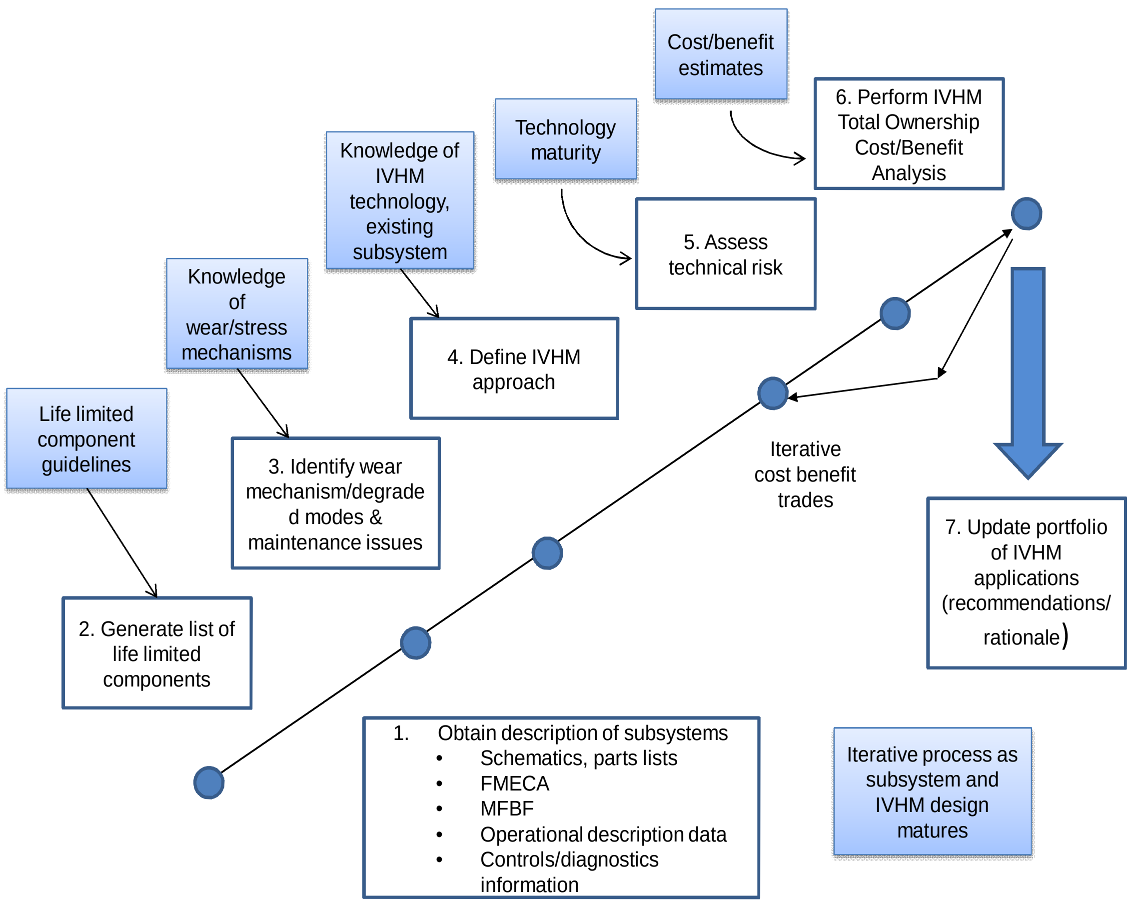

Figure 2-12: IVHM Candidate Analysis Process (CAP) (Wilmering and Ramesh, 2005)

For Wilmering and Ramesh such frameworks and "...model based techniques can concisely represent knowledge more completely and at a greater level of detail than techniques that encode experience (e.g. rule based systems) because they employ models that are compact axiomatic systems from which large amounts of information and behaviour can be deduced" (Wilmering and Ramesh, 2005).

Boeing have also produced the 'Ownership Cost Calculator for Aerospace Health Management' (OCCAHM) which models maintenance and logistics solutions induced by failures for the military, commercial, and space sectors offering solutions based upon ROI and break even analysis. Whilst such an initiative yields significant decision knowledge, it is significant that the outputs are only fiscal against established criteria.

2.5 Drivers of, and inhibitors to, the adoption of IVHM

This section is divided into two sub-sections. Section 2.5.1 identifies and discusses both the drivers and benefits that can be obtained when adopting IVHM generic systems whilst section 2.5.2 will identify and discuss the inhibitors to the adoption of the application.

2.5.1 Drivers and Benefits when adopting IVHM

Contributions to the literature are grouped into four broad categories, namely reliability and maintainability, logistics, need for autonomy, and strategic business vision. The majority of authors (Roemer et al., 2007; Williams, 2006; Hess et al., 2006; Baroth and Pallix, 2006; Bird et al., 2005; Paris et al., 2005; Scandura, 2005; Aaseng, 2001) discuss IVHM, its architecture, design and application as a facilitator to CBM_1, CBM_2, EHM, SHM, PHM, and health and usage monitoring (HUMS) initiatives. By focusing upon these areas there is also the underlying assumption of continued enhancements to safety although the literature is seldom explicit in this area. In discussing with published authors, the commercial sensitivities are acknowledged whenever safety and the world of commercial flight are linked. To acknowledge openly that such technology improves the safety of aircraft is to imply that air travel involves safety risk. Whilst such risk is kept to a minimum through rigorous technical, engineering, and operational standards and procedures, the risk of product failure is still a tangible parameter and although minimal is very real. The open acknowledgement of such risk does not align with the business models of civil airlines. When reviewing institutions and organisations from which contributors to the literature originate it is observed that many work within the civil aerospace sector. It is therefore assumed that this could be the reason why there are few contributions which explicitly address IVHM applications and enhanced safety directly.

In military aerospace operations, when referring to the re-use of legacy components it is stated that “..........increased mission duration and complexity increase the probability of operational mission failures that must be mitigated without jeopardising safety of the objectives of the current mission.......[and that IVHM]..... technologies have been developed to address safety, replace time based maintenance with condition based maintenance, and to reduce life cycle costs" (Reichard et al., 2006).

The application of such technology allows for the effective management of the whole aircraft, its systems and components. Benedettini et al cite Scandura et al (2005) and Bird et al (2005) when stating that ".....commercial aerospace experience has shown that nearly 95% of aircraft lifecycle costs are attributable to maintenance activities.....and that the cost of operating a vehicle is ten times it's initial purchase price" (Benedettini et al., 2009). Other contributors focus upon the benefits to be obtained within the field of logistics (section 2.6.1) citing initiatives undertaken by the US military programmes relating to the Joint Strike Fighter (JSF), US Navy and US Marine Corps (USMC) logistic support group (Ferrell, 1999; Henley et al., 2000; Hess et al., 2004).

Autonomy is also a driver for both the military and aerospace/aeronautics sectors. The remote positioning of assets and products and the "...time delays in the communication, the inability to perform unscheduled re-supply.... [and maintenance and repair]...... and the mass penalty of carrying large spare part inventories...." (Paris et al., 2008) are also driving factors. Spacecraft and submarines for example, must by the nature of their operations, [remote distance and stealth], be able to operate autonomously.

Emerging contributions recognise that there is a need to manage the whole life performance of the vehicle, asset, or product, and the application of such generic technology is starting to facilitate this vision (Williams, 2006; Vachtsevanos et al., 2006; Hess et al., 2006). These authors state that IVHM has the potential to offer an "...increased viability for performance based arrangements, where comprehensive aftercare services are offered to end users who actually pay a flat rate for a set level of product performance". (Benedettini et al., 2009; Cohen, 2007; Davies et al., 2006). This research concurs with Benedettini et al in their assertion that:

> "*IVHM development has been substantially driven by end user pressures to reduce maintenance costs, improve safety of ....[product performance]..., and facilitate logistics management..... [and is].... increasingly developed as a strategy for performance based service providers to meet their obligations at reduced cost*. (Benedettini et al., 2009)

A list of the drivers identified from the literature for the adoption of IVHM generic technology application is presented in table 2.3.

Having discussed the drivers for the adoption of IVHM, the research then asks what are the benefits when adopting the technology? All contributions to the literature advocate both real and potential benefits that can be achieved when adopting IVHM and generic technology. Whilst a fully mapped presentation of the benefits discussed in the papers reviewed by way of a table, the contributing authors offer significant duplicity. A 'bubble map' presentation of the benefits identified is offered therefore in figure 2-13.

For (Williams, 2006) the key advantage is identified as being significantly fewer maintenance events when employing IVHM facilitated CBM in preference to time based initiatives. Maintenance activity times are also reduced as on board diagnostics and data capture systems guide technicians to root causes which in turn minimise unnecessary replacement of components. These efficiency gains are also achieved through reduced manning in both operational and front line arenas. Within the aerospace sector, reduced mission training is required of the flight crew and operations teams due to advancement of the open and closed loop systems (Aaseng, 2001). This increasing level of data capture, and the incremental move to closed loop systems is increasing the level of autonomy whilst increasing the level of 'in operation' management of the product also is enabling real time logistics solutions and reductions in inventory (Hess et al., 2006; Paris et al., 2005).

Table 2-3 Drivers of IVHM Adoption

Reduced inspections	Reduced lead times	Increased availability	Small logistics foot print
No RTOK	Condition based maintenance	Ability to anticipate problems	Ability to anticipate actions
Ability to predict future health state	Low levels of inventory	Reduced false alarms	Accurate inventory tracking
No surprises	Short supply chains	Minimum inspections	System performance feedback
Concurrent engineering initiatives	Product development	Technical risk mitigation	Commercial risk mitigation
Financial risk mitigation	Need for enhanced safety	Need for greater autonomy	

(Hess et al., 2004; Benedettini et al., 2009; Grubic. T. et al., 2009; Baines T.S., 2010)

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Figure 2-13: Potential benefits derived by the adoption of IVHM and generic technology as documented in the literature (National Aeronautics and Space Administration (NASA), 1992; Aaseng, 2001; Hess et al., 2004; Williams, 2006; Banks et al., 2006a; Benedettini et al., 2009)

2.5.2 Inhibitors to the adoption of IVHM

Whilst not discussed explicitly within the literature the adoption of IVHM requires incremental and often radical change to the organisational, technological, financial, economic, commercial, operational, cultural, political, systems of the organisation. It can also have an affect on, and be affected by, legislative systems. Whilst recognising the potential for a paradigm shift in operations driven by the benefits that can be achieved, the majority of contributions focus upon the technological and economic issues associated with the adoption of IVHM.

Technical literature discusses engineering issues relating to the design and application of sensors (Datta et al., 2004b; Davis et al., 2005; Gonzalez et al., 2007; Dunsdon and Harrington, 2008) whilst others address the matching of systems between new and legacy systems and components as such items are installed form differing suppliers and using differing architectures and protocols (Wilmering and Ramesh, 2005; Wilmering et al., 2003). When questioning the motives for such application Williams (2006) states "....technologies ..... should be applied to.....systems to maximise the operational benefit .....and what value.... the customer will apply to this benefit" (Williams, 2006). He states that it is a balance between the greater upfront installation costs weighed against the whole life revenue streams across..... [in his example].....a fleet of aircraft and clarifies the point by saying that "....a proportionate amount fo design and development resources are not applied to reliability, maintainability, and testability functions of an.... [asset/product]..... because the returns on investment (ROI) for supportability have not been the focus for winning contracts" (Williams, 2006).

For Reichard et al (2006) there is a "....fundamental lack of the ability for the engineering community to trade the implementation and adoption of .... [IVHM].... technology against adding additional reliability and redundancy" and points to an emerging sentiment that "...if systems can be designed with the highest level of reliability.... [then]... there will be no need for health monitoring".

(Reichard et al., 2006). Baroth et al (2006) state that ".... one of the major goals of IVHM is to convince the subsystem people that sensors and the information they provide are part of the solution and not the problem" (Baroth and Pallix, 2006). In order to do this the literature states that IVHM should be designed 'in' from product conception, thus removing many of the 'matching' issues identified (Wilmering and Ramesh, 2005; Williams, 2006). By building IVHM into the product the number of sensors (and consequently false alarms), are reduced as sophisticated algorithms and models are incorporated. (Figure 2-14).

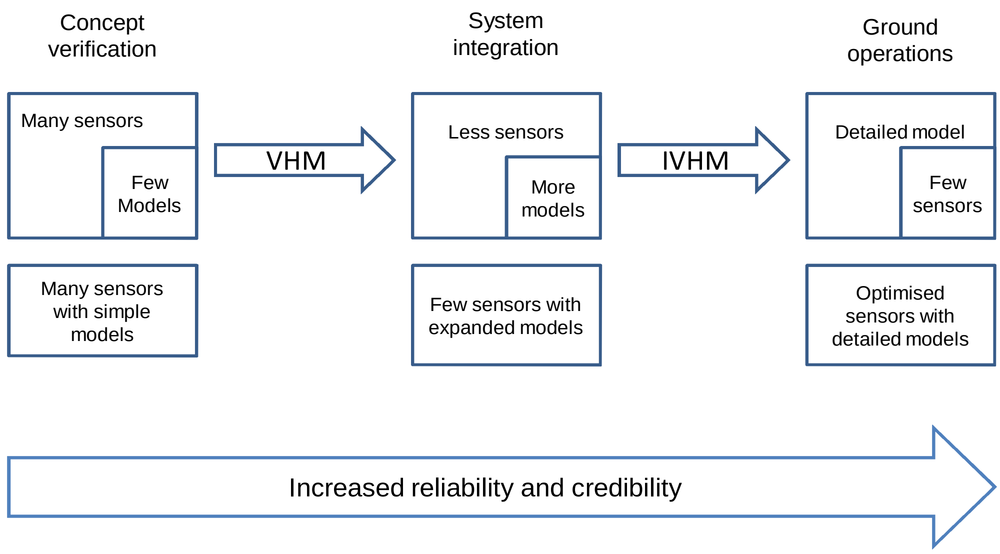

Figure 2-14: Improvements if IVHM is introduced early

(Baroth and Pallix, 2006)

Benedettini et al identify that this is a significant barrier because of the challenge proposed by the need to accurately assess the trade off's between the associated costs and risks. For (Williams, 2006) it is a question of balancing the technical and operational considerations where the technical 'push' initiative appears greater than the operational and customer 'pull'. In seeking this understanding there becomes a need for a greater understanding of the cost model (Benedettini et al., 2009; Hoyle et al., 2008; Hoyle et al., 2007; Banks et al., 2005).

These authors conclude that for the successful application of IVHM the benefits must be greater than the sum of the development costs, operational fuel increases due to increased weight, increased power consumption and generation costs, verification and validation costs, and the costs associated with computer and communications resources. Understanding this trade off between design, development, installation, maintenance, and operational costs against whole life revenue streams is a major inhibitor to cross sector adoption of IVHM related solutions today.

2.6 Cited applications of IVHM within the literature

Cited applications within the literature relating to IVHM are rare. Of those given duplication exists across several papers as each contribution seeks to discuss the *potential* benefits and limitations of the concept with few detailing *actual* performance of such systems within the installed product base. The majority of cited applications relate primarily to the aerospace sector (Aaseng, 2001; Prosser et al., 2003; Price et al., 2003) whilst other authors seek to discuss contrasting applications between the aerospace and automotive sectors, (Baroth and Pallix, 2006; You et al., 2005) with some focussing upon military ground and air platforms (Banks et al., 2008; Janasak et al., 2006; Hess et al., 2006; Banks et al., 2004; Faas and Miller, 2003).

In their state of the art review of IVHM, Benedettini et al (2009) tabulate a list of the main applications identified and this is presented in table 2-4. Further examples of IVHM applications identified since the publication of Benedettini et al's contribution are presented in table 2-5.

Table 2-4 Examples of IVHM Applications (Benedettini et al., 2009)

Body	Description	Link
US DoD	The US DOD is developing the JSF. Health management capabilities are 'designed in' to the aircraft and implemented within an integrated maintenance and logistics system.	http://www.jsf.mil
Boeing	Boeing commercialises an AHM solution that uses remote analysis of real time airplane data to provide airlines and operators with customised maintenance decision support	http://www.boeing.com
GM	General Motors offers the 'ONSTAR' telematics system that monitors automobile performance in real time and makes available to the driver a customised set of safety, security, and convenience services.	http://www.onstar.com
NASA	NASA is developing various IVHM systems for the next generation of Reusable Launch Vehicles, crew and cargo transfer. IVHM technologies will be used to provide both real time and lifecycle vehicle information which will enable informed decision making and maintenance.	http://www.nasa.gov
Smiths Aerospace & UK MOD	Smiths Aerospace and the UK MOD are collaborating to evolve a 'Fleet and Usage Management System', a ground based management framework that, on the basis of processing health usage data, will be able to perform advanced diagnostics, prognostics, and life management on military helicopters, airplanes and engines.	http:/www.smiths-aerospace.com/
US Navy	The US Navy is installing an ICAS on its ships that integrates with remote support to provide system level monitoring and performance trending for CBM .	http://www.idax.com
Lockheed Martin	...has been commissioned to supply an 'Enhanced Platform Logistics Platform' by the US Marine Corps. This will provide ground vehicles with an embedded capability to monitor their own performance ad provide predictive information allowing CBM, improved logistics support and more efficient fleet management.	http://www.lockheed.com

Table 2-5: Further examples of IVHM post Benedettini et al (2009) Part 1 of 2

Body	Description	Link
GE	IVHM Technology for Business Aviation – Video of Aeroplane operations	http://www.youtube.com/watch?v=bSbReXT_bBs
Goodrich	"Goodrich Sensors and Integrated Systems' integrated vehicle health management system (IVHMS) consists of a combination of on-aircraft hardware and software and ground-based software applications".	http://www.goodrich.com/Goodrich/Businesses/Sensors-and-Integrated-Systems/Products/Vehicle-Health-Management-Systems/Integrated-Vehicle-Health-Management-Systems-(IVHMS)
Ridgetop Group Inc.	"....model-based laboratory test fixture to identify and characterize the fault-to-failure progression (FFP) signatures of dominant failure modes associated with the EMA servo drive, and to analyze the propagation of damage through the drive".	http://www.ridgetopgroup.com/about/newsletter/issue-3/article4-nasa.html
Honeywell	"...vehicle health management technology is on board the 777 and on multiple business jets.......utilizing Honeywell's Primus Epic Platform...... [supported by]..... Honeywell's Aircraft Maintenance and Operations Support System (AMOSS)".	http://www.google.co.uk/#sclient=psy-ab&hl=en&source=hp&q=ivhm+applications&pbx=1&oq=ivhm+applications&aq=f&aqi=&aql=&gs_sm=s&gs_upl=0l0l0l5842l0l0l0l0l0l0l0l0ll0l0&bav=on.2,or.r_gc.r_pw.,cf.osb&fp=acc135da6d1347b&biw=1280&bih=821
BAe	"...key elements of IVHM are already being tested in defence vehicles - fault diagnostic tools are being trailed in the Tornado fighter jet, while the Hawk is using acoustic sensors to detect fatigue cracks. Basic health and usage monitoring systems are also already fitted to both Bulldog and Panther vehicles to provide vital information to support their 'contracting for availability' support arrangements, which make industry more accountable for keeping the vehicles running".	http://www.baesystems.com/Capabilities/Technologyinnovation/NewTechnologies/advanceddiagnostics/index.htm

Table 2-6: Further examples of IVHM post Benedettini et al (2009) Part 2 of 2

Body	Description	Link
Rolls Royce	“It provides a single source solution ensuring "peace of mind" for the lifetime of the engine, from the time the engine is delivered to the customer until the engine goes out of service. This is achieved through our sharing of knowledge, expertise and experience”.	http://www.rolls-royce.com/civil/services/totalcare/
Bombardier	“The ORBITA solution is rooted in the principles of condition-based maintenance (CBM), an approach used extensively in the aerospace industry. CBM involves closely measuring the condition of rail equipment and analyzing performance trends to predict when future failures are likely to occur. Knowledge is then used to identify and address issues before they can impact transit service. The ORBITA system is designed to help rail transit operators increase on-time performance, improve reliability, reduce in-service failures, maximize equipment utilization and cost-effectively maintain rail asset”.	http://www.marketwire.com/press-release/Bombardier-Launches-ORBITA-Rail-Maintenance-Solution-in-North-America-TSX-BBD.A-739049.htm
Alstom	“......is an important strategy for advanced, cost-effective, rolling stock maintenance. It uses an indicator of equipment and component health as a trigger for maintenance action. This means that maintenance staff are engaged in inspection and monitoring tasks rather than repair and replacement of worn-out or defective components”.	http://www.redorbit.com/news/technology/225494/alstom_proves_value_of_conditionbased_maintenance/

Janasak et al (2006) focus upon remote diagnostics and the evolution towards prognostics as being an “....enabler to support a product growing service and maintenance business” (Janasak et al., 2006), whilst recognising the ability to carry out remote access via the revolution in telecommunication technology. They cite GM’s ‘Onstar™’ Vehicle Diagnostics Programme as such an application. The application of Onstar facilitates the transmission of usage and diagnostic data and the organisation then supplies a report monthly on the condition of key systems within the automobile. Whilst this is far from being a closed loop autonomous system as envisioned by research contributions, it clearly facilitates condition based management and informs operational decisions through the use of IVHM principles and technology.

Further to their cited Onstar example, Janasak et al (2006) present General Electric Aerospace Engineering (GEAE) as an organisation using the technology to monitor and implement maintenance and operational decisions regarding it's jet engines whilst in fleet use. Details of this can be found upon the organisations promotional film (Anonymous: Accessed 06-01-2012). The transmitted data is prioritised into 'critical' (requiring direct notification to the pilot), and 'routine' which results in download to the operator or ground based support infrastructure.

In reviewing the literature particular attention was focused upon the 'tense' used by each author in their contributions. It becomes apparent that the majority of the literature relates to the ongoing development and future expectation for the concept with few, outside military citations, being written in the past or present tense. This implies that the application if IVHM is very much in the emergence stage of the technology cycle with successful widespread adoption yet to be achieved. This observation is also made by Benedettini et al when they state that".......few initiatives have been currently undertaken in diverse industrial sectors to deliver IVHM type systems..... [and].... most of these systems are still under development" (Benedettini et al., 2009).

2.6.1 IVHM enabled logistics

Historically logistics solutions have been reactive to identified needs. The literature offers a wealth of knowledge related to logistics (planning and supply), materials resource planning (MRP), KANBAN systems, and the evolution of lean and agile initiatives within operations (manufacturing) systems. IVHM offers the potential for autonomous logistics as a "proactive enabler" (Faas and Miller, 2003) thus offering support on a real time basis (Henley et al., 2000). This potential is identified within the literature and promises to radically change the character of business models within the fields of logistics and supply chain management. (Faas and Miller, 2003; Faas et al., 2002; Hess and IEEE, 2005;

Hess et al., 2006; Reichard et al., 2006; Banks et al., 2006a; MacConnell 2007; Banks et al., 2008).

Henley et al state that autonomous logistics (AL) are "…….essentially …. [an]…. automatic set of processes to ensure maximum …. [operability] …. with… [a]… minimum logistics footprint and cost, while still maintaining high ….[levels of product availability]…." (Henley et al., 2000) whilst Byer et al suggest that it is "….the application of automation to locating and ordering ….[spare]… parts so that they are available when needed" (Byer et al., 2001).

The idea "…for the AL system was ….[envisioned from]….. the workings of the autonomous nervous system of the human body, who's functions occur autonomically: they… [being]… spontaneous based on…. internal stimuli" (Hess et al., 2004).

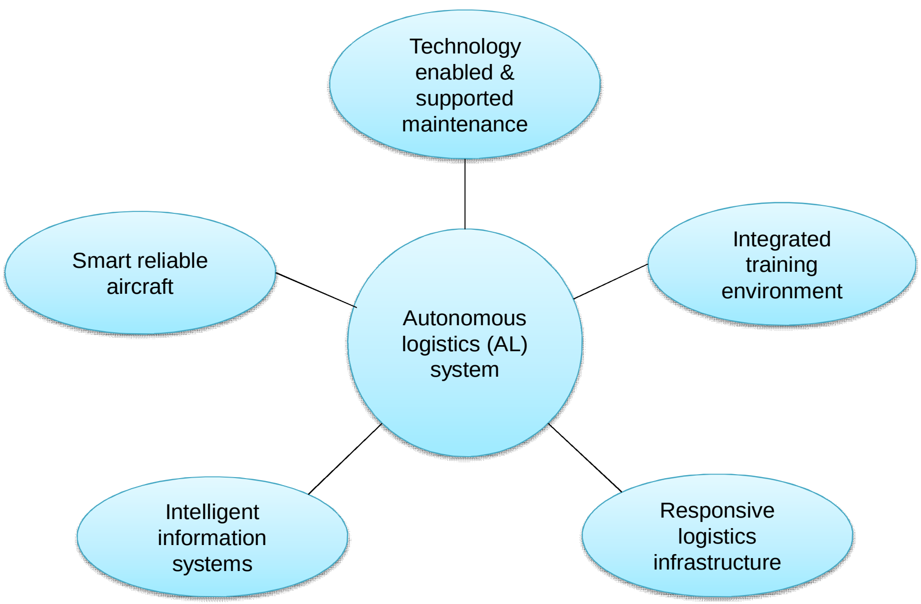

Figure 2-15: The five key elements for an autonomous logistics system (Hess et al., 2004)

The literature informs that autonomous logistics systems have four key components, they being:

i. An intelligent, maintainable, and reliable [asset/product] enabled by prognostics and health management
ii. A joint distribution information system (JDIS) to provide a communication network
iii. A technology enabled maintainer
iv. A responsive logistics infrastructure.

In the military arena, mission success is founded upon the level of integration across effective sector supply and logistics chains (Smith et al., 2006). This cross service integration within military supply chains is essential if strategic military goals are to be achieved (Smith et al., 2006). Typical military examples of IVHM enabled systems which support autonomous logistics include:

- Joint strike fighter (JSF) automated logistics programme (Ferrell, 1999; Hess et al., 2004; Tuttle, 2005).
- The US Marine Corps CACE system (Banks et al., 2006a)
- The US Marine Corps autonomous logistics programme (Banks et al., 2006a)
- The US Navy's sense and respond logistics programme (Reichard et al., 2006).

When considering the JSF programme (Smith et al., 2006) state that it provides an affordable platform based upon survivability, lethalness, and supportability. Underlying these 'pillars' rests the supply chain and logistics that major contractors within the supply chain can offer.

With such networks the need for real time response triggered by the actual asset condition becomes evident. The logistics systems are called upon to supply cross service support in an ever changing theatre of operation. The need for real time response and alignment of the asset and logistics systems are obvious.

2.6.2 IVHM and the automotive sector

The automotive sector is evolving towards the application of early stage IVHM. However in contrast to other sectors it is ".....[attempting]..... to minimize the number of sensors needed to cover an automobile and implement remote diagnostics and maintenance systems" (Benedettini et al (2009).

Baroth et al (2006) suggest that the automotive industry is leading way with ground based and on-board vehicle systems citing Nissan's 'Electronic Concentrated Controls System' (ECCS) as a system providing Diagnostic Trouble Codes (DCT's) via CD roms. Other automotive organisations such as "....GM Onstar, NEXIQ Technologies, ATX Technologies, Toyota, Vetronix Inc, Jentro AG, BMW, Volkswagen, IBW, and .... [the] Dearborne Group either already have or are actively developing RD&M applications" (You et al., 2005). Ford also supply their 'Ultimate Toolbox', supplying on-board service codes and supporting test procedures, guides, and schematics of the vehicle systems to their dealer networks.

The required prognostics element is however only just evolving with most solutions being limited to vehicle monitoring and remote diagnostics for cars, trucks and buses. The solutions that do exist are developing in silos based upon such organisations as Ford, GM, Toyota, Honda, and Crysler (You et al., 2005). Limitations with the current solutions include the following:

- No standardisation of diagnostics between OEM's due to differing data protocols
- The majority of solutions do not include telematics and result in the need to physically be at a service provider to download the data,
- Once data has been analysed there is no certainty that correct parts or personnel are at the site,
- DTC codes are not accurate enough to diagnose the condition at the component level (You et al., 2005).

There are a plethora of contributions to the literature advocating telematics, remote diagnostics, and condition based maintenance solutions but in the majority of offerings the prognostic element is missing for the offered solution. Whilst all these contributions are significant advancements, they cannot truly be termed IVHM when compared to our definition offered earlier (section 2.1.1).

2.6.3 IVHM and new product development

Of those contributions made to the literature the majority focus upon applications relating to maintenance, reliability, availability and logistics. However IVHM also has the potential to offer a significant contribution to the field of product development through concurrent engineering initiatives driven by data that can be achieved from the product whilst in use in the field. Whilst this is applicable to all complex products nowhere is this more visible than in the automotive industry and in particular, Formula 1 (F1).

IVHM technologies also have the ability to support the design development of products as performance data acquired during use can be made available to manufacturers. This facilitates design modifications based on function data which can greatly improve turn-around times between issue levels and costs. It can also facilitate state of the art concurrent engineering initiatives..

When considering F1 racing team operations "....each car is outfitted with hundreds of sensors, wirelessly streaming data back to an operational and analytical hub located in the ..... [pits or]..... team van parked on the in-field. This data is analyzed by computers and vehicle experts who in turn forward instructions directly to the pit crew, the race strategists and the driver allowing real time adjustments to improve performance and capability. Bulk data is also collected and forwarded immediately to automotive engineers back at the home office for analysis, where the planning begins for the vehicle design modifications and upgrades before the next race" (Bird et al., 2005).

2.7 Gaps identified in the literature

This review has identified and discussed current contributions to the literature which have identified existing challenges and future initiatives driven by gaps that have emerged within the body of knowledge. The scope of the review has focused upon the ability of IVHM and its associated technologies to deliver a 'vision' which is predominantly centred upon the aerospace, aeronautical, and military sectors. Little attempt has been made within the IVHM literature to review or contribute to the body of knowledge relating to other industrial sectors. This lack of evidence and intuition (investigated by industrial survey, chapter 4) suggests that potential applications may exist in many more arenas than those discussed which leads to the identification of three gaps within the IVHM literature reporting knowledge of such applications in other sectors. Namely:

Gap1: There is little evidence as to the level of IVHM adoption within different market sectors (other than aerospace) supplied by the manufacturing sector.

Gap 2 The literature offers very little by way of examples or case studies of successful applications of IVHM across differing industrial sectors, and of those that do exist, they are limited to ongoing developments within the military, and civilian aerospace, aeronautics, and ground based military platforms.

Gap 3 There are no documented examples or case studies of failed IVHM applications.

The literature identifies the need for methodologies and frameworks that can be applied to specific applications at the component, product, and system design stage that can assist in the identification and assessment of the benefits of introducing IVHM to the product offering and to what level of integration (Hoyle et al., 2008; MacConnell, 2008; MacConnell and IEEE, 2007; Hoyle et al., 2007; Aaseng, 2001). Significant investigation into product [and asset] usage patterns applied to IVHM location and risk is being undertaken in the field of 'reasoner' research but the development of models, frameworks, and guidance for practitioners to assist them in leveraging the technology to achieve strategic intent needs to be undertaken (Benedettini et al., 2009; Janasak et al., 2006). This highlights two further knowledge gaps within the literature.

Gap 4: The literature offers no generic decision framework, tool, or methodology that enables the manufacturing organisation to assess the technical, commercial, financial, and business case of introducing IVHM to its products and adopting IVHM enabled servitzed solutions.

Gap 5 There are no prescriptive methodologies that seek to identify the level of IVHM that should be applied to both the product and the organisation's operations in order to achieve its strategic intent.

In seeking to identify the returned benefits obtained by the introduction and application of IVHM it becomes apparent that an accepted set of KPI's are required that allow industry and sector comparisons. The majority of contributions focus solely upon cost benefit methodologies and return on investments (ROI). If IVHM is to be applied to facilitate whole life business models driven by the need to servitize then additional research is required that identifies additional metrics which consider extended but reduced revenue streams and margins. This is identified by Hess (2006) when stating that ".....the development of well defined performance, cost, and scheduled metrics, financial and other incentives, and award fee and award term plans are prerequisites to establishing successful long term based arrangements" (Hess et al., 2006). This will further be endorsed by the findings of the survey of UK based practitioners (Chapter 4).

Issues exist when discussing suitable metrics and KPI's serving the whole business strategy of the organisation as such metrics must take into account economies of scale. Benedettini et al (2009) cite NASA (Anonymous, 2007) when stating that "....IVHM systems are specifically intended to improve the overall .....[product]..... characteristics, yet it has been proven that achievable benefits exceed the cost of developing, implementing, and using technologies"

(Cohen, 2007; Pomfret et al, 2011). Aaseng (2001) acknowledges the problem when stating that cost models fundamentally rely on economies of scale too but there are clear differences between single project costs incurred in satellite production and low volume aircraft manufacture, to those in other high volume mass produced industries such as the automotive industry. The same considerations occur throughout differing sectors such as marine, energy, and health sectors plus the supporting industries within each sector.

Metrics and KPI's should be identified by approaching all the relevant stakeholders by sector in order to formulate the assessment of requirements to suit the OEM's and associated operators. This enables the correct metrics to be identified to suit the application which may be other than conventional financial KPI's.

Two further gaps are identified:

Gap 6 There is little understanding of the identity of the stakeholders to IVHM applications and their expectations by sector, or of perceived/expected benefits for the supplier and customer of the product and related services.

Gap 7 Identification of additional KPI's are required which are better suited to emerging business models of servitized manufactured products and product service systems facilitated by IVHM.

Osterwalder et al (2005) offer a framework illustrating the position of the business model within the organisation. To identify the KPI's required, consideration of the decision making processes and the forces acting upon the organisation should be undertaken. In order to achieve this a greater understanding of the forces acting upon the operating strategy employed by the organisation and the mode of strategy formulation is required.

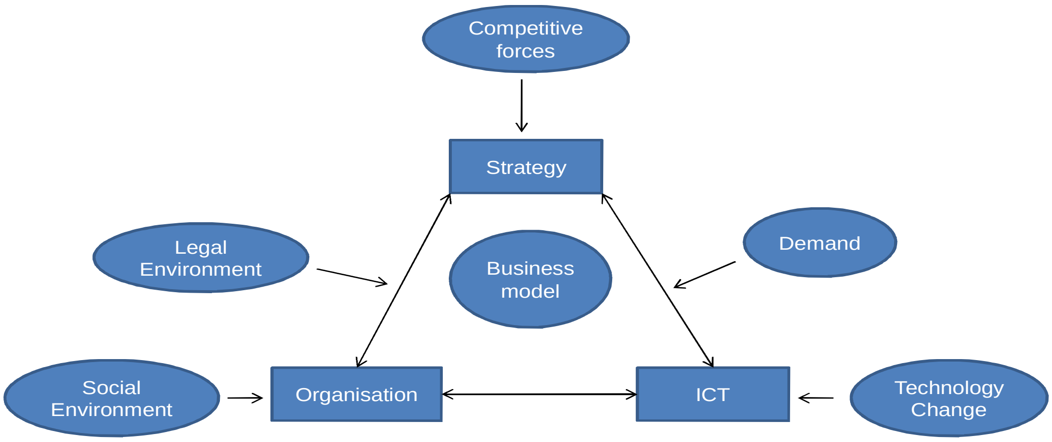

Figure 2-16: The business model's place within the firm (Osterwalder et al., 2005)

This reveals two further gaps in the literature:

Gap 8: The literature documents the driving forces for IVHM adoption that are technology pushed but offers no enlightenment or methodology to identify the extent to which the concept is market pulled.

Gap 9: There is no contribution by way of analysis as to the requirements of stakeholders (the beneficiaries) when they are seeking to adopt IVHM intelligent products and service offerings.

Benedettini et al (2009) cite Wilmering and Ramesh (2005), Hess et al (2004), and Cohen (2007) when asserting that "......understanding the support that IVHM can give in the context of innovative business models, such as performance based logistics or product service systems is a growing subject within the literature" (Benedettini et al., 2009). When looking at the potential of this application of technology to leverage change within the logistics and supply chain of the organisation Hess et al suggest that "a key target of this new logistics strategy is the move to long term performance based upon contracting, an approach for buying set levels of performance, such as the payment per flight hour approach ....” (Hess et al., 2006).

The gaps identified within the IVHM literature show that there is a requirement to contribute to the body of knowledge by introducing improved methodologies that will enable the wider understanding and adoption of IVHM generic technologies. This will enable both a more holistic but aligned solution within the evolving servitization process and service offerings of the organisation.

2.8 Conclusions drawn from the overview of the literature

This chapter has presented an overview of the literature relating to Integrated Vehicle Health Management (IVHM). The chapter began by introducing the concept of this application of existing and emergent technologies, and then adopting a definition for the phenomenon which is sufficiently generic as to be applied across all sectors of industry. Design considerations relating to the system architecture, on/off product decisions, and the drivers/inhibitors to the adoption of IVHM systems have also been highlighted, identifying applications within the fields of maintenance, operations, logistics, and new product development with a sector analysis being offered. This has been supplemented by a descriptive analysis of the body of the literature identified and adopted for the review. Finally gaps are identified which offer the potential for further research.

The principle observation from the literature review and the gaps identified is that current research is being undertaken within the technical and scientific areas of the concept, mainly in the areas of sensor technology, system design, signal technology, and control systems. However, there is little or no research which seeks to inform the business case of strategic direction which should or could be adopted when considering the application of the concept to drive the servitization agenda and PSS solutions. In this case the key questions to ask are:

1. *Is IVHM the right initiative for the organisation?*

2. *What strategy should be followed when seeking to adopt the concept?*

The literature does not address these questions. There is no holistic research seeking to offer methodologies, guidance or frameworks seeking to align the technology, the organisation, or product suitability to formulate strategy for the manufacturing organisation producing complex products and wishing to offer advanced services. The formulation of an operations strategy for manufacturing organisations seeking to adopt IVHM enabled intelligent products and the need for a generic guidance methodology is seen as a valuable contribution to the literature. Such a methodology will assist in achieving a greater alignment of the current position of the organisation with stakeholder demands and offer a 'best fit' strategy to meet expectation. The following chapter (Chapter 3) will establish the research aim, objectives, and the programme to be followed in undertaking this research.

3 THE RESEARCH AIM, OBJECTIVES AND PROGRAMME

The review of the literature relating to IVHM (chapter 2) and the gaps identified have established the area of interest for this research. The following sections of this chapter give an overview of the research problems (section 3.1) and the research aim and objectives (section 3.2). The research programme and a description of each phase of the research is described (section 3.3) with a summary being offered at the end of the chapter (section 3.4).

3.1 The research problem

The current crises within the global financial sector (e.g. collapse of confidence in the banking sector, restricted lending, the euro crisis, the near default of Greece, Ireland, Spain, Italy, and indeed the USA), and the ongoing and increasing austerity measures within the UK (ref: press and media 2011/12), have in part resulted in manufacturing organisations seeking ever more innovative ways to improve and retain their competitive position. As if these macro-economic issues were not enough, manufacturers have endured the continued assault to their competitive position from changing customer expectations, low price pressures, global competition and diminishing market share, advancements in technology, and environmental issues driven by diminishing resources and the sustainability agenda (Chapter 1).

For the manufacturing organisation to survive and prosper it is imperative that its offerings align with the actual needs and expectations of its stakeholders and the forces which act upon it. Traditional responses to the problem have been to follow restructuring and reductionist initiatives such as cutting costs, regressing to core competences, relocating to low cost economies, greater outsourcing, vertical integration, and/or adopting lean manufacturing. Such responses, whilst having validity, are not the only means by which the organisation may wish to react to the forces acting upon it. Driven by such pressures one is seeing the emergence of a non-reductionist response as organisations start to move up the value added supply chain through the adoption of services (Vandermerwe and Rada, 1988; Chase and Garvin, 1989; Alonso-Rasgado et al., 2004; Brax, 2005; Allmendinger, & Lombreglia, 2005; Neely, 2008; Baines et al., 2009; Baines et al., 2009b). Here we see the evolution of the '*Manu-service*' organisation where such companies receive ever increasing levels of revenue from the sale of fully integrated service packages underpinned by the manufacture of their products (Chapter 1) (Chase and Garvin, 1989; Baines et al., 2009b; Holguin and IEEE, 2005).

The literature informs us that the risks to the revenue stream are mitigated by the implementation of condition based maintenance strategies (Holguin and IEEE, 2005; Dussault and IEEE, 2007; Gulledge et al., 2010) and IVHM generic applications (Chapter 2). Some organisations are adopting this mode of operation with success (Rolls Royce, MAN Trucks, Xerox, and Caterpillar) but it is emerging only where organisations exist as world class market leaders and is yet to be seen mainstream. A review of the IVHM literature gives insight into some of the issues identified by gaps within the literature (Chapter 2) which are confirmed by a survey of UK manufacturers (Chapter 4).

The review of the literature and subsequent survey (Chapter 4) illustrate that there is little evidence as to wide spread adoption of IVHM enabled informated products across all manufacturing market sectors other than defence and aerospace (Gap 1). Documented case studies are also very rare (Gap 2) and are only just emerging (Parker, 2011) and there are few documented examples of either successful or failed IVHM applications (Gap 3).

There are numerous contributions to the literature relating to Product Service Systems, servitization, $CBM_{1,}$ CBM_2, the technical aspects of IVHM generic systems, and service delivery systems (Chapter 5). However the literature offers no generic decision framework, tool, or methodology that enables the manufacturing organisation to assess the technical, commercial, financial, and business case for introducing IVHM to its products in order to facilitate IVHM enabled servitzed solutions (Gap 4).

The gaps further inform that there are no methodologies seeking to identify the level of IVHM technology that should be applied to both the product and the organisation in order to achieve the strategic intent. This is also revealed when seeking the opinions of practitioners via the implementation of an 'awareness' survey (Chapter 4). Furthermore the literature review has informed the research that there are few insights into the identity of the stakeholders to IVHM applications and their expectations (if aware of the concept) of the application (Gap 6). This lack of awareness of expectation is also confirmed when reviewing the practitioner opinions expressed within the survey (Chapter 4). The drivers for the adoption of IVHM applications also appear to be 'technology pushed' with few stakeholders (manufacturers who wish to servitize their product offerings) fully understanding the potential and alignment to their operating objectives (Gap 8). The literature offers little by way of analysis as to requirements of stakeholders who seek, or maybe wish to adopt IVHM informated products and service offerings (Gap 9).

Having identified the research problem it is important to define the issue that the research addresses and more importantly, what the research is not. This research offers a strategy formulation methodology (addressing gap 4) seeking to assist senior management formulate the organisation's operations strategy. The framework will also seek to understand the organisations competitive position by identifying the stakeholders and their needs (Gap 6) thus clarifying the driving forces in each particular case (Gap 8). It does not attempt to formulate the business case and subsequent business model which are seen as the logical steps that follow the formation of a operations/service delivery strategy. It may be that subsequent detailed business assessment such a strategy may result in a re-iteration of the process but that is the nature of strategic management. Such assessment is not the focus of this thesis. The developed aim for this research addresses Gap 4 (section 2.7) identified within the literature. In so doing the resultant methodology will also identify stakeholder requirements when organisations seek to adopt intelligent (informated) products to facilitate service offerings (Gap 9).

3.2 Research aim and objectives

The research problem as identified (section 3.1) illustrates that there is a need for an holistic strategy formulation framework that can be used by manufacturing companies (SME's) when seeking to adopt IVHM 'type' applied technologies to produce 'informated' products. The aim of the research is:

> "*To understand the landscape relative to the condition based management of products whilst in use within the field and identify potentially high value IVHM enabled applications and operations. To develop a strategy formulation methodology which seeks to target such applications to deliver an aligned service delivery system. The methodology will deliver an understanding of the organisations competitive position and its performance gaps. It will guide the user in assessment of stakeholder requirements, levels of technology, and organisational structure required to deliver an aligned operations strategy delivering an effective service delivery system".*

In seeking to achieve the research aim, several research objectives are identified which serve as 'way marks' to the aim's deliverance. The objectives to be achieved by this research are:

i. To study a broad range of industrial sectors and the literature to identify the state of the art of emerging, and if they exist, failed IVHM applications.

ii. To identify and understand the factors which have enabled or inhibited the technical and commercial effectiveness of the adoption of the concept.

iii. The creation of a decision support tool that incorporates key factors and transforms them into business performance measures.

iv. The validation and verification of the decision framework through case exemplars.

Having informed of the research aim and objectives to be addressed, the next section (section 3.3) documents the research programme.

3.3 Development of the research programme

This section of the thesis presents an overview of the research programme and illustrates the structure of investigation. In order to achieve the research aim and meet the set objectives this research programme has been constructed to guide the study through the undertaking of six phases. Detail relating to content and deliverables of each phase of the research programme is found in the associated chapters. What follows is a description of each of the research phases, the research method undertaken and the rationale for each phase.

3.3.1 Structure of the overall research programme

This sub-section presents an overview of the structure of the research programme followed. In seeking to define research there are many contributions but this study adopts the definition offered by Saunders et al as a process undertaken ".......in order to find out things in a systematic way, thereby increasing.........knowledge" (Saunders et al., 2007). These authors stress that in offering this definition what is important is the need to '*find things out*' and that it should be done in a '*systematic way*'. The need to find things out has been discussed and justification emerges in the gaps identified within the literature review (Chapter 2) and the findings of the practitioner survey (Chapter This sub-section informs of the research programme and demonstrates that it is conducted in a rigorous and systematic way. The research has four objectives which act as 'way marks' to achieving the research aim and is split into six distinct phases. Phases 1 – 3 collectively seek to develop the pilot methodology aligned to the research problem.

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3. For the purpose of this research an 'informated' or 'intelligent' product will be defined as one which is fitted with IVHM generic technology and possess the ability to sense, detect a fault and then monitor, analyse, and mitigate (on or off board). The terms will be used interchangeably.

Phase 1 identifies Integrated Vehicle Health Management (IVHM) (Chapter 2) as a means of creating 'intelligent' products that can facilitate organisations adopting servitized approaches within their operations strategies. The identification of the gaps within the literature provide justification (in part) of the research aim. This is supplemented by a survey of manufacturing organisations within the UK to test awareness of the IVHM concept and where such awareness exists, the need for a decision framework when considering the adoption of IVHM for the organisation's offerings and operations. The literature review (Chapter 2) and the survey (Chapter 4) will illustrate that there is a need for a decision framework as specified by the research aim.

Phase 2 of the research offers a brief overview of the literature relating to strategy formulation relative to a manufacturing organisation seeking to implement a service delivery system. The review of the literature will introduce the service delivery system and observe that the literature relating to strategy categorises the contributions into content, context, and process. The research focuses upon the process of strategy formulation.

Phase 3 describes the formulation of the pilot methodology. An existing methodology is adopted as a pre-pilot process and applied to a manufacturing SME by way of case study. An evaluation of the performance of the pre-pilot methodology generates a set of requirements which in turn enables a specification for the pilot methodology to be evolved. An operations strategy is in itself a product, the product of strategic thinking. The research will adopt a product development approach in the formulation of the final research deliverable. The generation of a specification from the performance of the pre-pilot methodology when compared against a defined set of requirements will aid in the development of a pilot methodology to generate a strategy fulfilling the requirements identified in Phases 1 & 2.

Phases 4 & 5 seek to evaluate the operations strategy formulation methodology. Phase 4 evaluates the pilot methodology by way of multiple of case study with the researcher adopting a 'observer as participant' role and/or professional review. Phase 5 evaluates by way of validation the final methodology by multiple case studies with the researcher acting as ‘participant as observer’ and/or professional review.

Finally the validated operations strategy formulation methodology ‘ServiceStrat’, which is a product development approach to the development of aligned operations strategy, is presented.

When considering the choice of research method to adopt for each phase of the research programme this study is guided by the literature (Saunders et al., 2007; Sekaran, 2000; Jankowicz, 2005; Davies, 2007; Yin, 2009). Whilst Saunders et al give guidance to detail regarding sampling, questionnaire and survey design, interview techniques etc, Yin’s guidance was adopted for the choice of method relative to case design. Baines (1994) and Lim et al (2007) advise that there are three approaches to the development of a research. Namely:-

i. Develop the methodology based upon existing knowledge from within the literature
ii. Critically evaluate all methodologies found within the literature
iii. A hybrid approach which combines elements of both (i) and (ii) above (Chandraprakaikul, 2008).

In conducting this research option (iii) is adopted when formulating the pilot methodology. The choice of method to adopted for the evaluation of the pre-pilot and pilot methodology (Chapters 6 & 7) and the verification and validation of the final methodology (chapter 8) is guided by Yin (2009). The evaluation phases seek to understand the real time performance of the strategy formulation process and to also understand the ‘how’ with regards to the strategy formulation process. The ‘why’ the process succeeds or fails. For this reason the case study method is adopted. Further explanation of the rationale behind the choice of the case study approach is given within (chapter 7).

This section as discussed the rationale behind the development of the research programme. An illustration of the methodology is shown in figure 3-1. The following sections within this chapter will discuss the objectives and tools carried out in each of the five phases of the research programme.

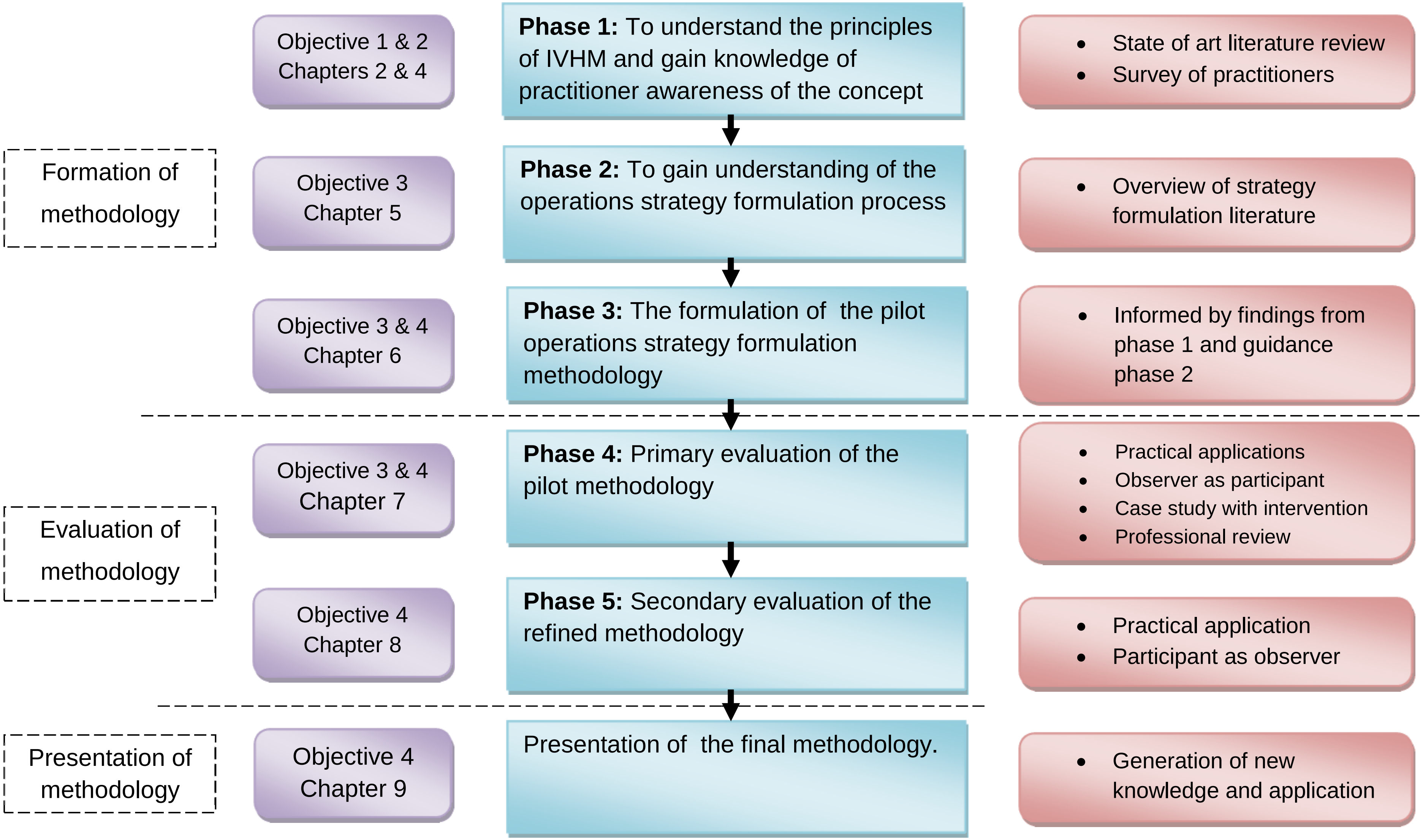

Figure 3-1 Structure of the research programme

3.3.2 Phase 1: Obtain an understanding of IVHM from both the literature and practitioner perspectives.

Having identified the research problem phase one of the research programme seeks to gain a thorough understanding of the IVHM concept by way of a state of the art literature review (Chapter 2) supplemented by a practitioner awareness survey (Chapter 4). A review of the IVHM literature is presented and gaps that exist within the contributions are identified (section 2.8). An exploratory survey, informed by the literature, is then undertaken of the UK manufacturing organisations producing complex products. The population surveyed is a stratified sample of all manufacturing organisations operating within the UK and seeks to understand practitioner's awareness of the IVHM concept. A greater knowledge of perceived enablers and inhibitors to the commercial and technical success of IVHM, and the benefits of the adoption to the company's stakeholders is achieved. An understanding of where each company is positioned within the value chain, the characteristics of the product, the level of IVHM integration, and the future intentions of the organisation with regards to the IVHM concept is also revealed.

Finally a synthesis of the survey data is undertaken with the findings presented (section 4.6). This is compared with the gaps identified within the literature thus defining the research aim and objectives (section 3.2).

3.3.3 Phase 2: Evaluation of potential methodologies

This phase of the research programme lays down a foundation for the satisfaction of objective three later in the research programme. It introduces and discusses the concept of the service delivery system (section 5.1). The concept of operations strategy and its formulation is then discussed (section 5.2). Strategy is seen as comprising of three components, namely content, context and process (Pettigrew, 1992; Pettigrew and Whipp, 1993). Whilst acknowledging the importance of the first two components of strategy this phase will focus upon the process of operations strategy formulation. An evaluation of potential strategy formulation methodologies is undertaken (section 5.3) and an existing methodology is chosen as a pre-pilot study for this research.

3.3.4 Phase 3: Formation of pilot methodology

The third phase of the research programme develops the pre-pilot and pilot methodologies (chapter 6). A review of the requirements for the process leads to the 'Stratagem' process being adopted as the pre-pilot methodology (section 6.2). The process is evaluated using the case study method with the researcher adopting the role of 'observer as participant'. Two cases are used to measure the performance of the method. The techniques employed for the evaluation are quantitative (survey) and qualitative (observation, discussion, and invited personal reflection). During the evaluation stage of the pre-pilot methodology interviews were also conducted within two OEM's who are successfully competing through enhanced services facilitated by 'intelligent' products in order to gain further insight into the requirements of such a strategy. The analysis of the pre-pilot evaluation (section 6.5), and the series of interviews within the two OEM's, facilitates the construction of the 'requirements' set (section 6.5.3) and a specification for the pilot methodology (section 6.5.4). Finally an overview of the pilot methodology is presented (section 6.6).

3.3.5 Phase 4: Primary evaluation of pilot methodology

This phase of the research assists in the development of the strategy formulation methodology required to satisfy objective three of the research programme (section 3.2). The primary evaluation tests if a workable process exists and establishes if the methodology offers practical procedural steps towards the formulation of an effective operations strategy when the organisation is considering servitization facilitated by '*intelligent*' products.

Platts et al (1993) offer guidelines for the undertaking of such an evaluation and this forms the basis of the evaluation.

3.3.6 Phase 5: Secondary evaluation of refined methodology

This final phase of the research seeks to validate the final methodology by application to organisations or seeking evaluation from experts in the field. Two case study organisations are introduced (Section 8.3) and the results of the evaluation are presented (Section 8.5). An analysis of the findings is discussed using three widely accepted parameters for the evaluation of such methodologies (Section 8.6). A record of final refinements is offered (Section 8.7) prior to the presentation of the validated methodology.

3.3.7 Presentation of final methodology

The ServiceStrat methodology is presented which meets objectives 3 and 4 of the research. This is the main research contribution. The validated methodology illustrating the content, structure and supporting tools for the methodology is presented. (Chapter 9).

3.4 Chapter summary

The chapter has introduced and discussed the research problem and offered a process to its solution. The research aim and objectives have been defined and a five phase research programme has been developed to fulfil the requirements of the aim and objectives of the study. Phases 1-3 inform the research of the gaps within the literature and practitioner identified requirements which define and corroborate the research problem. A pre-pilot methodology is adopted and is used to formulate a pilot methodology for the formulation of an aligned operations strategy to deliver an effective service delivery system. Phases 4-5 adopt a case study approach to evaluate and validate the methodology with the researcher adopting an ‘observer as participant’ and ‘participant as observer’ position respectively. A contingent methodology of professional review is also proposed. The research concludes with the delivery of the operations strategy methodology.

4 AWARENESS OF IVHM IN THE UK MANUFACTURING BASE

The research thus far has introduced the concepts of the Product Service System (PSS) and '*servitization'* as ways in which the manufacturing organisation may seek to respond to increased competition thereby maintaining and potentially improving its competitive position (Chapter 1). The research has identified Integrated Health Management (IVHM) as a set of enabling technologies which facilitate the monitoring and potential control of the product as used in the field (Chapter 2). The gaps identified within the literature (section 2.8) have informed the research aim (section 3.2) and a research programme has been presented (section 3.3).

This chapter seeks to gain a greater understanding of the practitioner awareness of IVHM within the UK manufacturing base. Such an understanding will validate further the research aim and objectives offering a more holistic understanding of the issues surrounding the research problem (section 3.1). The objective and method of this phase of the research is presented (section 4.1) and the identification of the population to be surveyed is discussed (section 4.2). In seeking to obtain the required data the methodology adopted for survey design is presented (section 4.3) and the questionnaire design, content, and execution are discussed (section 4.4). The methodology to be used for the analysis of the survey results are reviewed (section 4.5) and the survey results presented (section 4.6) together with an analysis (section 4.6.1) and synthesis (section 4.6.2) discussed.

Finally a chapter summary is presented (section 4.7). An overview of the chapter structure is illustrated in Figure 4-1.

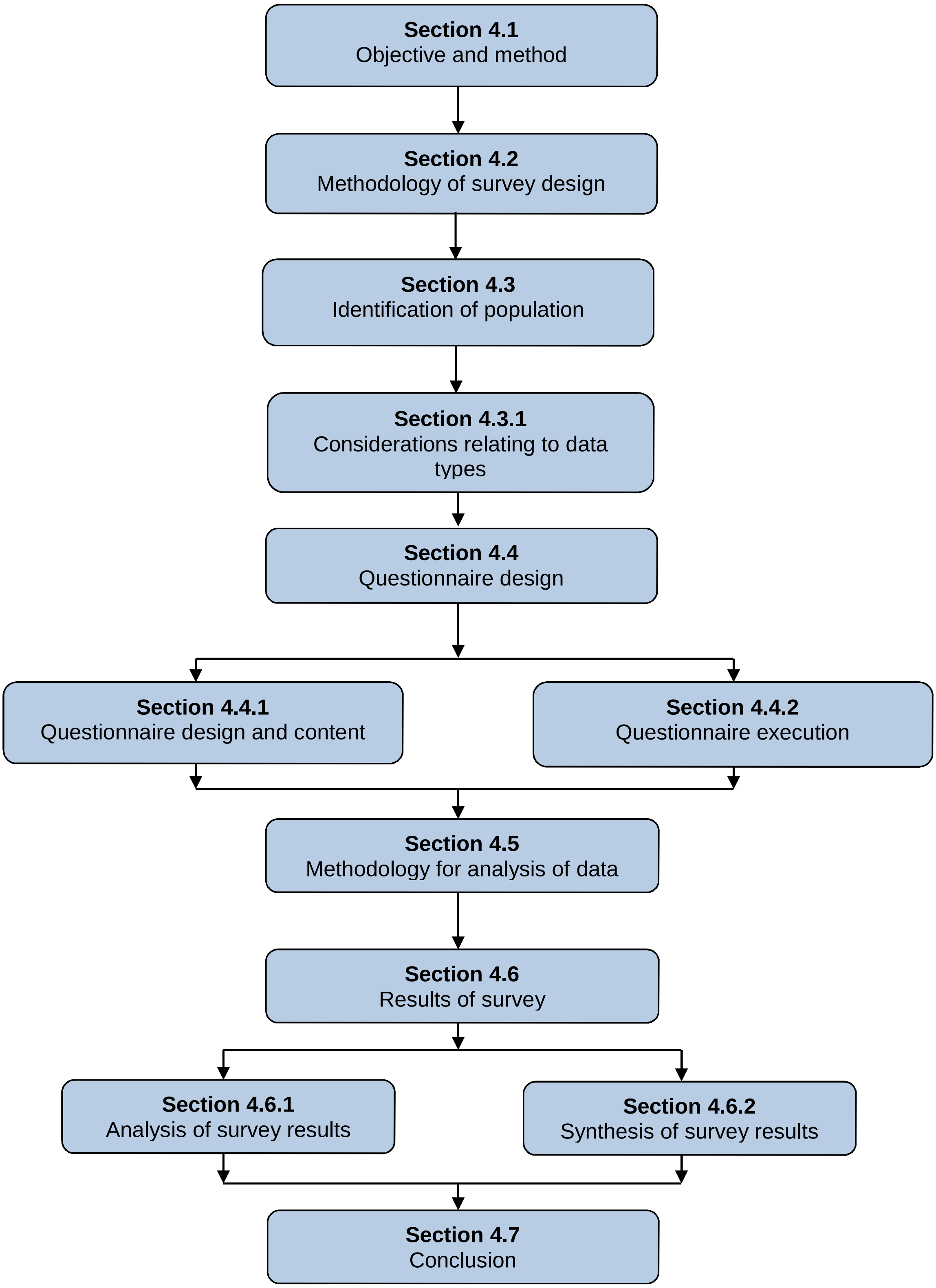

Figure 4-1: Structure of chapter four

4.1 Phase 1 Objective and method

The objective of this stage of the research programme is to ascertain and understand the level of organisational awareness relating to informated products within UK based manufacturing organisations and the level of adoption of the concept. This is achieved through the identification of the population to be surveyed (section 4.2).

4.2 Methodology for the survey design

The review of the IVHM literature (chapter 2) and supplementary overviews of the contributions to the literature in the areas of product diagnostics and prognostics, CBM, servitization and product service systems (Baines et al., 2007; Baines et al., 2009b) served to identify the focus for the survey and formulate the principle research questions to be asked of practitioners (Grubic. et al., 2009; Grubic et al., 2011). Namely:

1) What is the extent of the adoption of diagnostic and prognostic technology within the UK manufacturing base, and how is this likely to change?

2) What are the characteristics of manufacturers that use or are planning to use diagnostic and prognostic technology within their products?

3) What are the reasons for these companies adopting diagnostics and prognostics and what are the benefits that they expect to gain from this adoption?

4) What are the characteristics of the products manufactured which have such functions and what are the characteristics of the diagnostic and prognostic functions?

5) What factors are likely to enable or inhibit the commercial success of the adoption of the concept?

The questions above serve as a focus for the development of the questionnaire which was used for the survey. To ensure completeness and alignment to the focus above the survey was presented to, and validated by, three large manufacturing organisations taken from the aerospace sector. The organisations chosen were already using the diagnostic and prognostic concepts to offer informated products which in turn facilitated greater levels of integrated service to their customers. By adopting this approach to the design of the survey it helped to “inform both the technical content and the clarity and precision of the questions” (Grubic et al., 2011).

4.3 Identification of population to be surveyed

In seeking to identify the target population for the survey, a review of available databases sought to identify sources of information relating to company location, activities, offerings, size and turnover. Although resources such as Companies House, and the EEF: The Manufacturers Organisation could have been used to identify the target population, this research identifies the Forecasting Analysis & Modelling Environment (FAME®) (Anonymous) as the preferred database for identification of the population to be surveyed. This source was chosen as it serves the requirements of this phase of the research programme and contains details of the parameters defined by the scope of the study, namely; ownership, location, activities, and turnover. In addition, the FAME® database possesses the ability to subdivide the search outputs into industrial sectors and activities to suit the input parameters defined by the scope of the study. This methodology was supported by the use of additional databases, typically Applegate® (Anonymous) and NEXIS UK® (Anonymous) to verify the outputs in line with the parameters defined by the scope of the study. An illustration of the parameters input into the FAME® database is shown in figure 4-2.

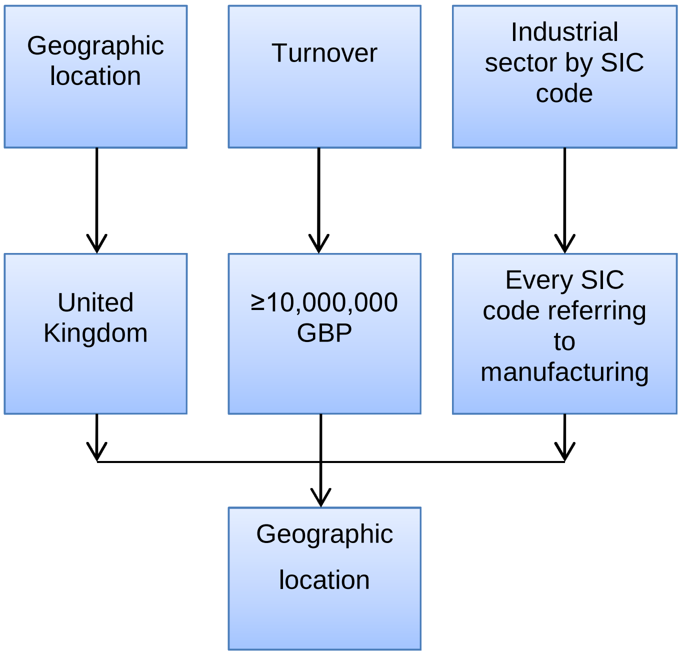

Figure 4-2: Population parameters entered into FAME®

When entering the search parameters into the FAME® database organisations were selected which had addresses for their operations within the UK. Care was taken to ensure that the companies selected conducted actual manufacturing operations within the UK and that their presence was not purely one of an head office or administration centre. It was assumed that it was unlikely that companies with a turnover of less than £10 million would be likely to produce products, or offer services associated with their products, in line with the defined scope of this study. This decision is however subjective. It is based upon the judgement and experience of the author and two other academics who collectively possessed extensive industrial experience.

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4. The selection of the parameters above is based upon the collective judgement of the author (possessing 30 years in industry with 20 years at senior management and executive level), Dr T. Grubic (Post Doc Researcher on IVHM Mapping Project), and Dr N. Rowley (Research Fellow IVHM Mapping and previous Senior Executive of GE Health).

Finally the Standard Industrial Classification (SIC) codes where reviewed and all those codes referring to 'manufacturing' were selected. The resultant list of organisations was then reviewed with only those companies who manufactured '*complex*' products selected.

At this point clarification is given to the term 'complex' product as applied to this research. Clearly some manufactured products are not suited to the application of sensors and intelligent systems as defined by IVHM/CBM concepts. Companies producing furniture, jewellery, domestic goods (excluding white goods) etc, and single items such as metallic pressings, castings, mouldings, and fabrications were all excluded from the study.

This research defines a complex product to be:

> "....*a product which can be electrical, mechanical, electro-mechanical, or a combination of all three, which is an assembly or a sub assembly capable of accommodating applied sensor or system technology to generate either on or off product intelligence which measures the dynamic operating conditions and/or performance*".

Products which include aircraft, automotive products, (cars, buses, trucks), rail products (locomotives and rolling stock), marine (ships, submarines, exploration equipment (rigs etc)), boilers, power generating equipment, medical equipment, machine tools etc, and sub-assemblies thereof, have all been included as condition based monitoring (CBM_1) and management (CBM_2) approaches could potentially be applied to these items.

Figure 4-3 illustrates the number of companies returned by the FAME® database at each stage of input of the parameters as recorded in figure 4-2. In seeking to verify the repeatability of the returned population several iterations of the framing process were carried out for the first three stages of the definition using this database [*during June 2009*] and a variation for the number of companies returned was found to be no more than ±0.1%. [*1837 ±2 companies returned*]

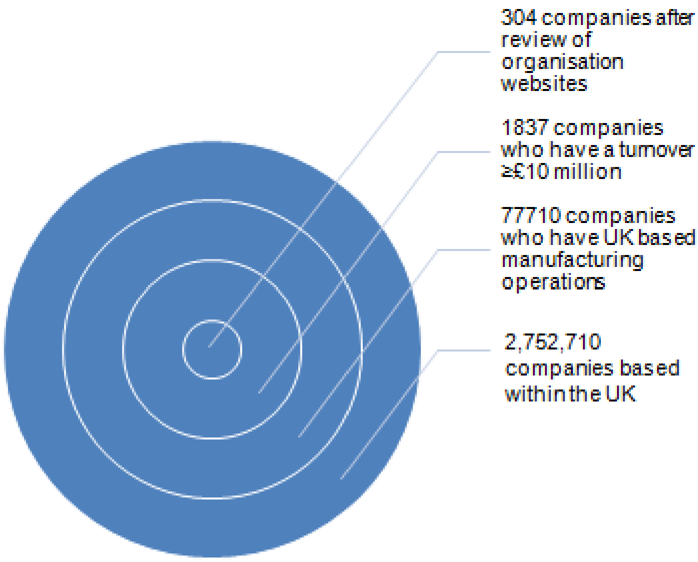

Figure 4-3: Identification of UK based manufacturing population within the scope of this research

The final stage in defining the population involved a review of the company websites for all 1837 organisations identified to ascertain if they complied with the earlier parameters entered into the database whist offering a complex product and additional service provision. To minimise the risk of incorrect identification of organisations to be included/excluded within the target population the review of all websites was undertaken by two practitioners with many years of experience within the manufacturing sector (*the author being one*) and one post doctorate academic researcher. Each reviewed the list of 1837 websites independently and where doubt existed as to the suitability of an organisation's operations and offerings to the focus of the research it was included within the final population. The three independent lists were then collectively reviewed and a single population of 304 companies identified to which the survey could be issued.

Whilst the resultant list of organisations is a stratified sample of the total population of companies recorded within the primary and secondary databases consulted, (FAME®, Applegate®, NEXIS-UK®), it is offered as the population of all UK based manufacturing companies with a turnover ≥£10 million and offering complex products (in line with the definition above) offered across all sectors as identified by the SIC codes identified at the time of conducting this research.

4.3.1 Considerations relating to data types

When collecting data using survey techniques, an understanding of sampling theory is a prerequisite to the effective use of these methods if the results are to be valid and without exhibiting bias. The target sample is the population of UK based manufacturing companies as defined at the time by the parameters specified. Coded questionnaires were sent to every company within this population. Had the population been significantly larger, then the principles of simple random sampling would have had to be employed to ensure that any conclusions and statements drawn from the data were valid, and that confidence levels could be given to the results. In addition, randomness is a prerequisite for any investigation into correlation between variables and significance testing. By adopting the whole population the integrity of the study is assured and conclusions can be drawn from the surveys providing that a sufficient return rate is achieved.

When seeking to select the correct method of reporting, and the tools to be used, an understanding as to the character of the data returned is essential. This ensures that the correct statistical tools and techniques are employed and that the results are reported in the correct manner. Using guidance offered by Saunders et al (2007), (see figure 4-4), it is seen from the questionnaire that the data returned is categorical in nature with the data being descriptive (dichotomous), descriptive (nominal), and ranked ordinal. This understanding of the nature of the data returned is significant as it informs the method of analysis and will be discussed further in (section 4.5).

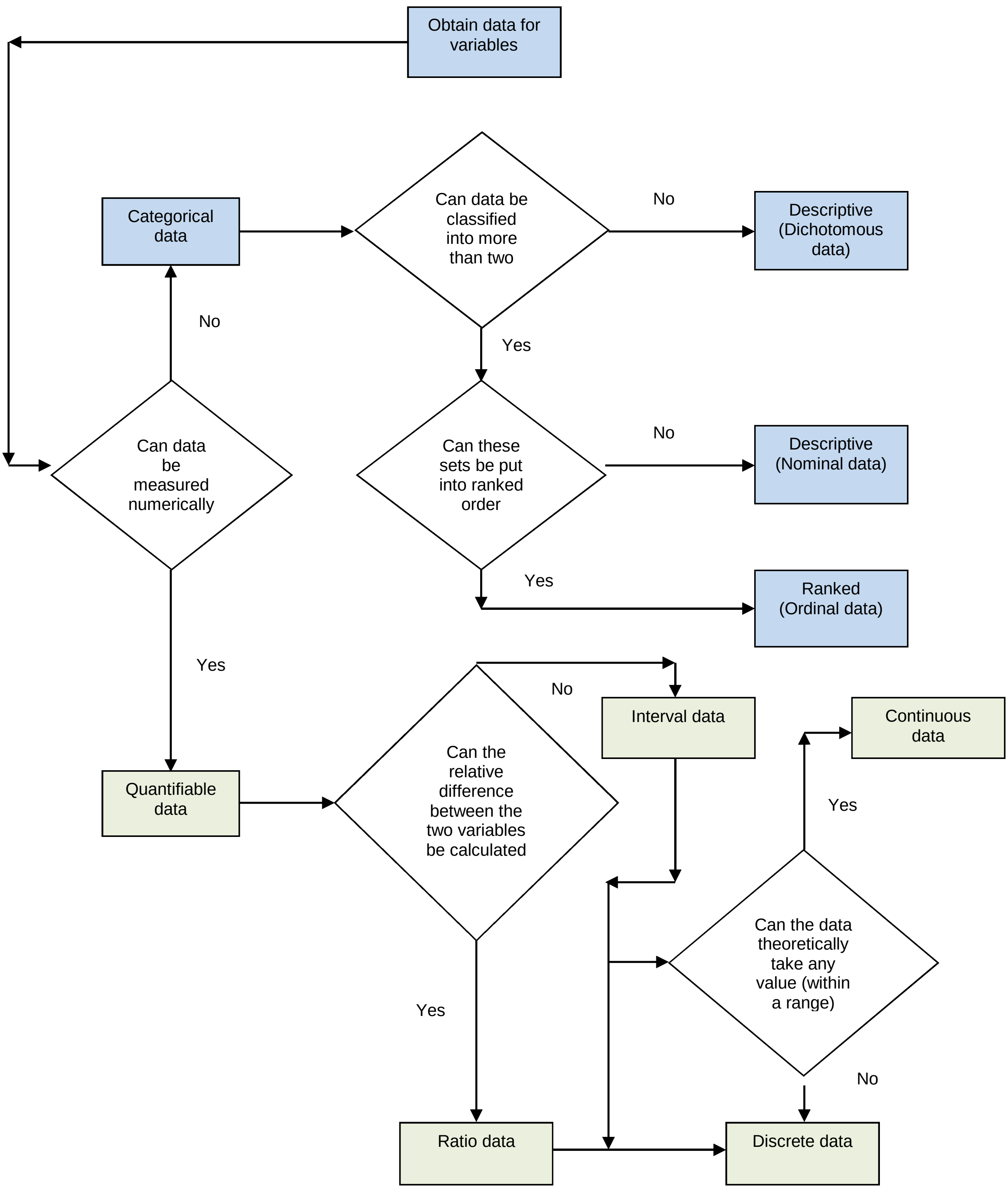

Figure 4-4: **Understanding of data types and decision upon level of assessment [Adapted] (Saunders et al., 2007).**

4.4 Questionnaire design, content, and execution

This section presents the design, method, content, and execution of the survey seeking to understand the level of awareness of IVHM facilitated intelligent/informated products within the UK manufacturing base.

4.4.1 Questionnaire design and content

The design of the questionnaire, the considerations undertaken, the strengths and weaknesses of the method chosen, and the limitations experienced in the method's execution are discussed within this subsection.

Why choose the survey as the method used to acquire primary data from which further research is to be built? The literature states that "...researchers administer questionnaires to.......a..[sample or]....population to learn about the characteristics, attitudes, or beliefs" (Frankfort-Nachmias and Nachmias, 2005; Marshall and Rossman, 1999). The review of the literature has identified little by way of contribution to the research objectives and the use of the survey is an "appropriate mode of inquiry for making inferences about a large group.....from data drawn on a relatively small number of....[respondents]....from that group" (Frankfort-Nachmias and Nachmias, 2005).

When reviewing the company records and web sites for each organisation it is observed that in some instances the names and positions of key personal had different descriptors. In choosing the delivery method for the questionnaire, [namely telephone, interview or postal mail], the latter mode of delivery was selected addressing the survey to managing directors. This ensured that a constant initial approach to each organisation was undertaken.

In designing the format of the questionnaire, consideration was made as to the format, layout, sequence and structure of the whole survey and each question in order to elicit the information sought whilst motivating the recipient to respond. Typically, surveys take the form of being trend studies, panel studies, or in this case, a cohort study where the focus of the research is taken to be a bounded population (Frankfort-Nachmias and Nachmias, 2005). The survey's role is to partially address the research objectives defined in chapter 3 with its design translating those research objectives into specific questions, the answers to which would inform analysis and synthesis of the resultant data. Additionally, it should be seen as a further stage of the framing process, as the resultant dataset serves as a sample from which structured interviews can be dawn.

Questions within the survey are of three forms, close ended, open ended, and contingent. The defined answers offered within the close ended questions were informed by the literature using the identified gaps therein which are subsequently coded for ease of future analysis. However, the primary aim of the exercise is to understand the level of ‘*awareness’* of the concept within the population chosen without introducing bias to the response resulting from the “forcing....[of]... the respondent to choose from given alternatives or by offering alternatives that might otherwise come to mind” (Frankfort-Nachmias and Nachmias, 2005). For this reason, the closed questions were subsequently ‘opened’ to allow for respondents to enter additional comments, opinions, and observations to each question which would can be subjected to additional encoding.

As one of the objectives is to seek awareness of IVHM and $CBM_{1\&2}$, care is taken to ensure that this terminology is not referred to within the questionnaire or accompanying cover letter, opting to offer a neutral definition for the concept and then referring to it as the ‘*approach*’ throughout the body of the questionnaire.

Supplementary to the use of ‘open’ and ‘closed’ ended questions, the survey sought to measure the opinions of the respondents as to the level of importance or significance of attributes to the success or failure of the approach. This is done by requesting that the responses be put in order or priority. The purpose of this request is to inform the analysis of the subjective opinions relating to the benefits, drivers, or inhibitors, or objective opinions where identified KPI’s exist.

The questionnaire structure and design is defined by the research objectives identified from gaps within the literature as discussed in chapter three of this thesis. Namely:

1. What characteristics do companies who plan, or are currently using condition based management technology, possess?
2. What drives these companies to develop and adopt this approach and what benefits are expected from its introduction?
3. What factors enable and/or inhibit the technical and commercial success of the technology development and introduction?
4. What characteristics (nature, complexity, lifestyle) do products for which the technology is developed have?
5. What are the current levels of maturity and complexity behind the technology and what functionalities does the technology provide?
6. Are there successful applications of this approach documented and what capabilities are required to maximise potential?

There are 47 questions sub divided into five sections. Section 1, seeks to gain a basic level of understanding about the respondent business and requests information relating to the sector in which it operates, the position within the supply chain, type of products manufactured, and if it is using, or plans to use the 'approach'. This is defined as a means to offer '*informated*' products as part of a competitive strategy.

Section two of the questionnaire seeks to identify the drivers and benefits for the adoption of IVHM/CBM technological applications, either perceived or actual, and the means of assessing these drivers and benefits from the organisation's position, and knowledge of those drivers/benefits from its suppliers and customers perspective. This is achieved by the use of both open and close ended questions and rating scales.

The third section aims to identify the enablers and inhibitors to the adoption if the approach to leverage both the commercial and technical success of the organisations, either perceived or actual, from those as identified within the body of the literature. Each question was again open to facilitate additional contributions which were then subsequently encoded.

Section four seeks to investigate the characteristics of the products manufactured by each organisation and the level of complexity that each product possessed in order to signify trends and categories of product sophistication. “This is seen as important as the research seeks to identify the level of complexity of the products to which such an approach is being employed and at what level. [i.e. System or sub-system level]” (Grubic. et al., 2009; Grubic et al., 2011).

Finally, section five of the questionnaire seeks to identify the opinions relating to the success of the approach if adopted, the level of evolution of that adoption within the company’s offering, [*monitoring, detection, diagnostics, prognostics, integrated decision support*], future plans of each respondent organisation, the relevance and impact experienced by adoption, and where they exists, the reasons for failure to adopt and/or failed attempts with the application to provide ‘intelligent’ products which inform competitive strategy. Having discussed the survey design the following subsection describes the method of survey execution.

4.4.2 Questionnaire execution

This sub section illustrates the process undertaken in the execution of the survey and is illustrated (figure 4-5).

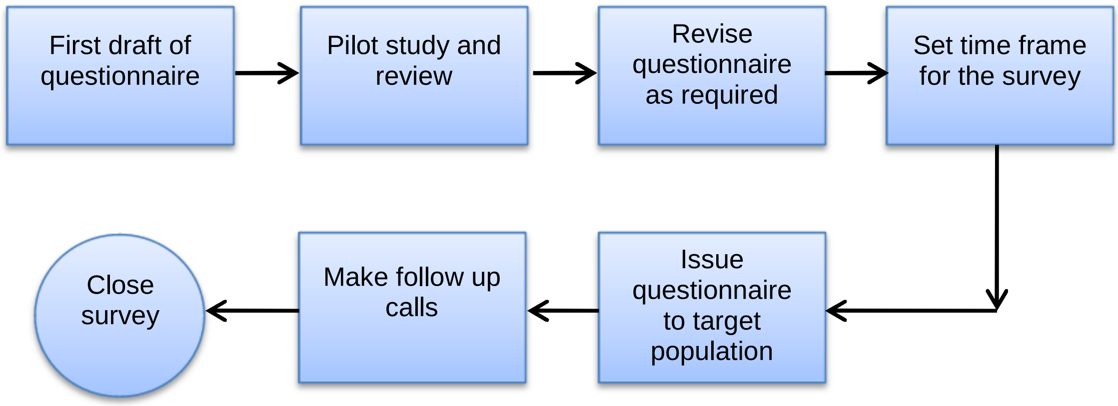

Figure 4-5 Illustration of process for survey execution

Upon completion of the questionnaire design the finished survey was subjected to review and ‘pilot’ by submission to the industrial partners of the Boeing IVHM centre at Cranfield university. The survey was reviewed for relevance to the research aim and objectives (section 3.2), to test for the ease of completion, and clarity of the accompanying instructions. Additionally, the survey was reviewed to test the ‘logic’ within its design ensuring it sought to answer the questions derived from the gaps recorded in the literature (section 2.8).

The time line for the questionnaire was defined as being from February 2009 to April 2009 and then distributed to the population. These dates were viewed to be significant as the timing between quarters one and two of the year were least affected by the holiday shutdown periods and would therefore help maximise the response rate. Follow up calls were carried out three weeks after distribution to ascertain that the questionnaire had been received. Care was taken to ensure that the contents of any discussion did not bias the outcome. Finally the survey was coded, recorded, and indexed.

4.5 Methodology employed for the analysis of survey results

The process undertaken upon receipt of the completed questionnaires to index, code, and '*cleanse*' the data returned and then carry out the analysis and synthesis is discussed within this section (figure 4-6).

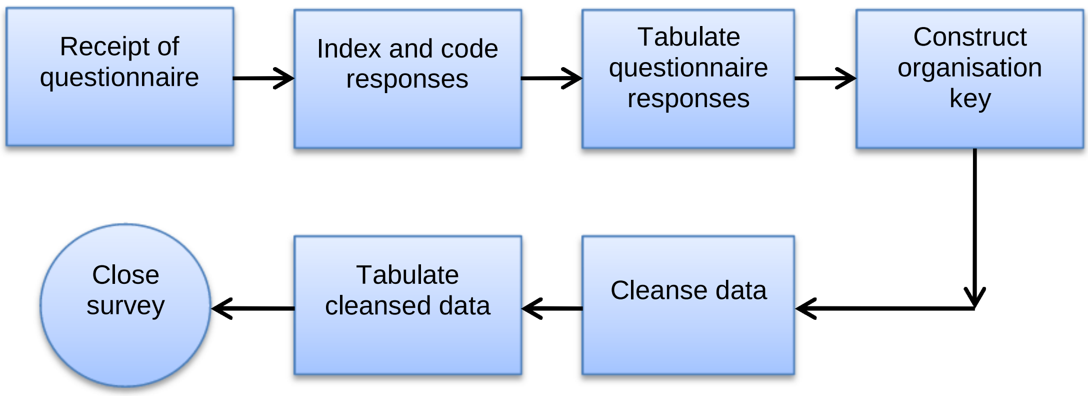

Figure 4-6: Illustration of the process for data tabulation and cleansing

Upon receipt of the returned questionnaires they were indexed by a unique identifier in order to preserve the identity and anonymity of the respondents and the identity key subjected to controlled circulation to only those immediately associated with the IVHM centre's 'mapping' project. The survey questions were coded and an MSExcel® matrix was constructed in which all the responses were tabulated. This table records the data exactly as it is collated from the questionnaires with indicators added to identify corrupt, incomplete, or additional data. A second worksheet within the MSExcel® file contains the identity key detailing the full contact details of all personnel and organisations responding to the survey.

The third worksheet records the data 'cleaning' process. In this worksheet is found a record of all the inputs made to the survey by question number and organisation where it is identified that inputs from the questionnaire required further attention. The actions taken against issue are recorded with an additional matrix listing any new 'coded' responses to be entered into the final dataset and assumptions made in generating the new codes. The thesis demonstrates clarity and openness within this worksheet by fully recording and assumptions and interpretations made when generating the final dataset.

Finally, the fourth worksheet illustrates the final ‘cleansed’ data that is used for the analysis conducted within phase one of this research. For the purpose of protecting anonymity, this information is not recorded within the appendices of this thesis but is made available for the purposes of *viva voce*.

When seeking to understand the results taken from the survey data it is important to understand the characteristics and type data returned (section 4.2.1) as there are strict rules as to the tools and techniques that can be employed to such data to ensure that the findings are valid. A review of the data types returned by the questionnaire following the framework offered by Saunders et al (2007) has illustrated that the data is categorical rather than being quantifiable in nature.

The categorical nominal and ranked ordinal data obtained by the questionnaire is used to study frequencies and proportions of the population parameters returned, thus descriptive statistics only are used to report the findings. Although statistical inference cannot be offered by the data, the findings presented in (section 4.6) do serve to illustrate the ‘pulse’ of the organisations responding to the survey whilst contributing to the research questions posed. Furthermore they serve to inform of potential areas of future in depth study by way of structured interviews and case studies within this and further research.

4.6 Results from awareness survey

This subsection of the thesis presents the findings of the survey of UK based manufacturers who produce complex products and offer, or have the potential to offer, differing levels of integrated service enabled or potentially enabled by the use of informated/intelligent products. The results returned by the survey are presented in (section 4.6.1) and a synthesis of the data is presented in (section 4.6.2).

4.6.1 Presentation of survey results

This subsection of the thesis presents the results returned by the survey data. From analysis of publically available data a population of 304 organisations is identified representing 0.01% of all industrial organisations within the UK; 0.4% of all manufacturing organisations and 16.5% of manufacturing organisations. The questionnaire achieved a response rate of 17% (52 responses).

The first section of the survey was designed to obtain an understanding of the business organisation. The data seeks to understand the position of each organisation and its manufactured offerings within the supply chain. When reviewing the sectors in which the organisations where operating, it is observed that there is a broad spread across all industrial and service sectors (Figure 4-7). It is seen that aerospace (17%), defence (15%), marine (11%) were the largest sectors represented within the survey result, whilst such sectors as rail (1%), utilities (1%), telecoms (2%), and food (2%) were surprisingly low..

When asked how each organisation would describe their relative position within the supply chain (Question 1.2), 39% stated that they were OEM's and/or system integrators, 35% stated that they were first tier suppliers, and 26% stated that they were service providers (Figure 4-8). Typically the type of products manufactured by the companies who responded (Question 1.3) reflected the sectors in which each organisation operate as illustrated in (Figure 4-9) with each respondent returning a description for their product offering which broadly fitted the definition of a complex product as offered in (section 4.2).

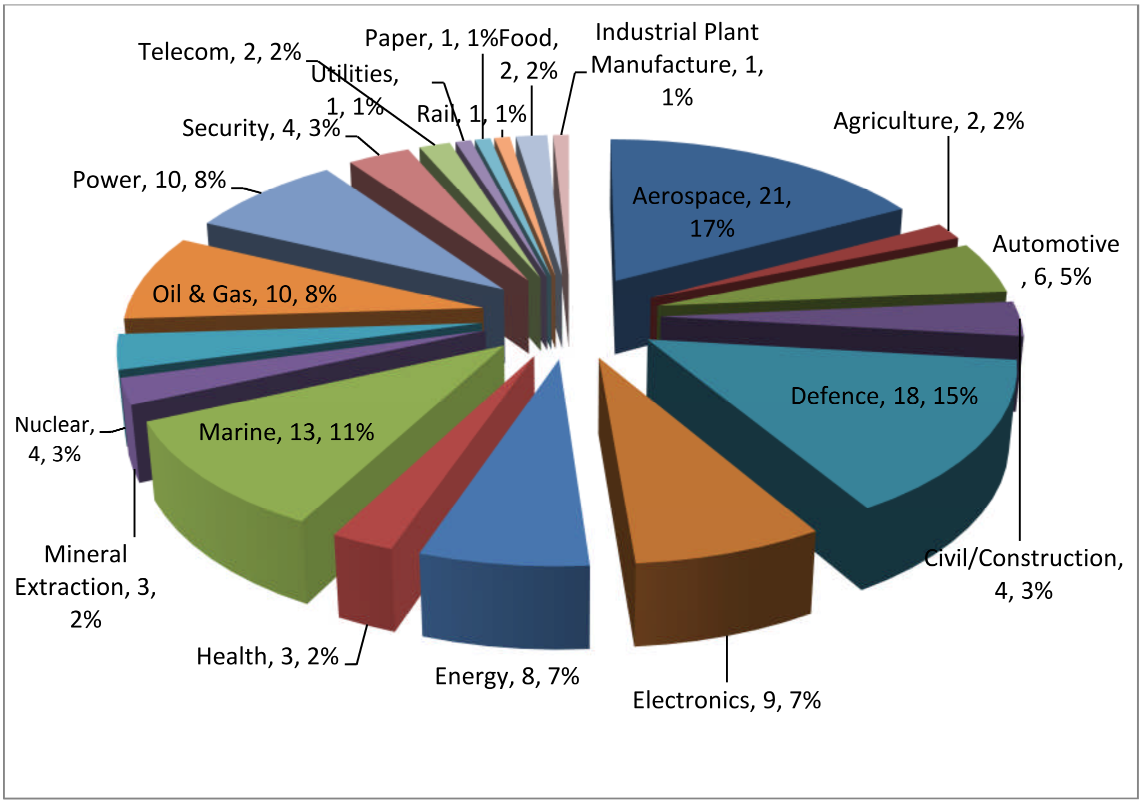

Figure 4-7: Question 1.1, Operating sectors for organisations completing the survey

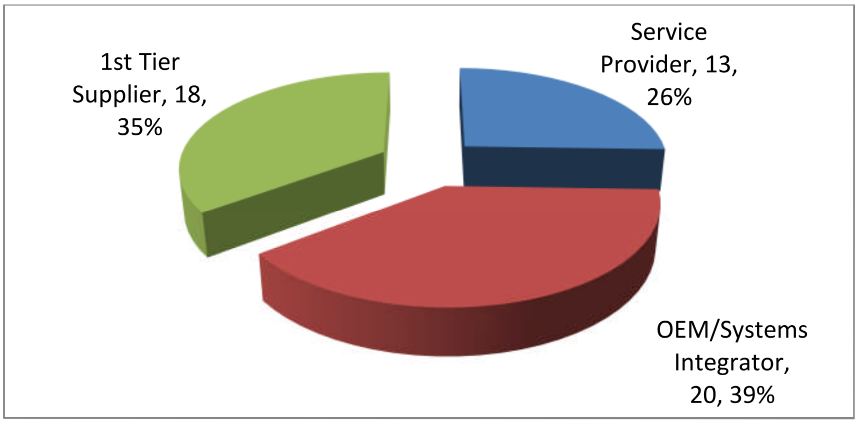

Figure 4-8: Question 1.2, Description of organisations completing the survey

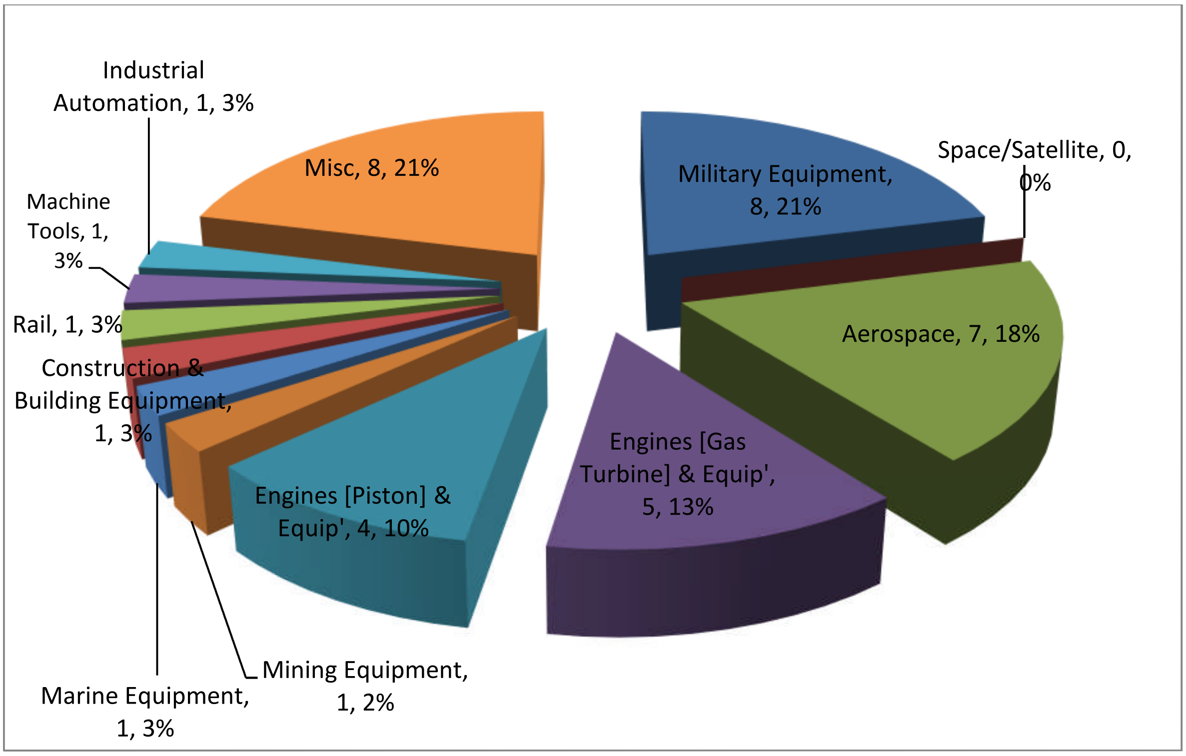

Figure 4-9: Question 1.3, Products manufactured by organisations completing the survey

The major customers for these organisations (Question 1.4) were industrial/commercial companies (65%), government agencies (31%) and direct consumers (4%) with the major end users of the manufactured products (question 1.5) broadly reflecting the same ratios (figure 4-11). However, as would be expected there is an observed increase in the number of consumers (by ratio) who are end users of the product.

Each organisation was then asked how they would describe their industrial customers (Question 1.6). The data illustrates for those organisations who submitted a response, that the majority of their customers (83%) were predominantly large enterprises with SME’s representing 8% and non industrial customers (presumably B2C) 9% (figure 4-12).

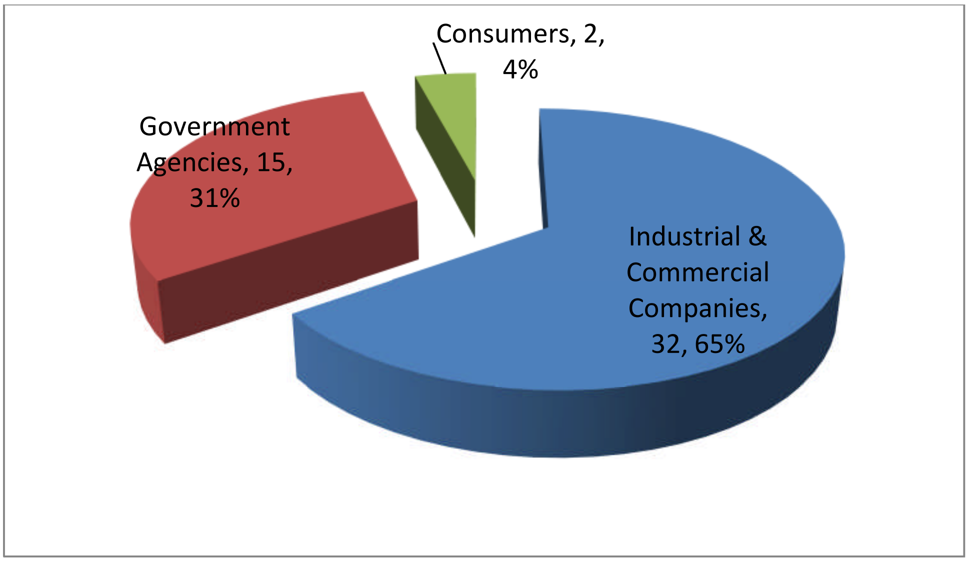

Figure 4-10: Question 1.4, Major customers for those completing the survey

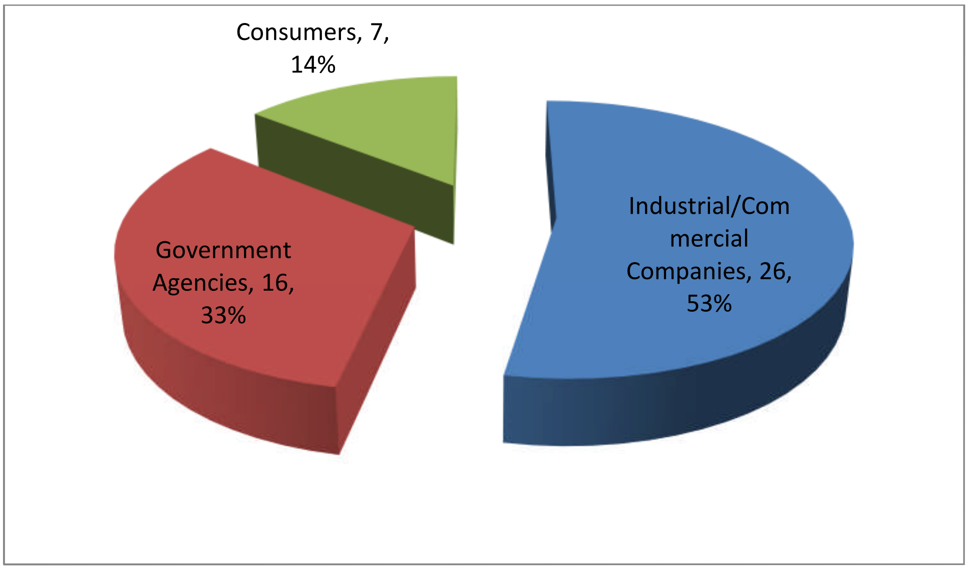

Figure 4-11: Question 1.5, Major end users of the products (if different from customers)

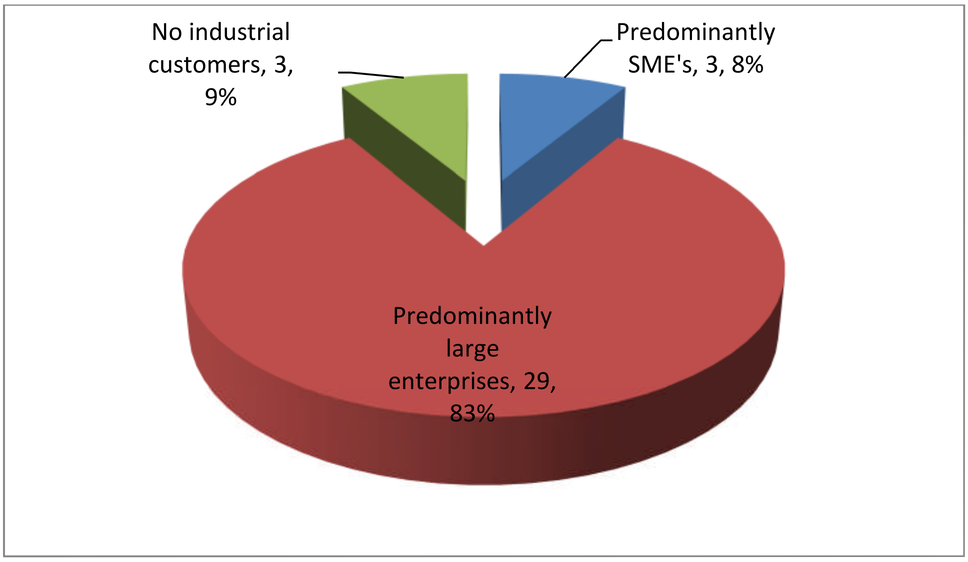

Figure 4-12: Question 1.6, Description of the organisation's customers

Finally, when requesting whether the organisations were using, planning to use, or had failed in their attempts to use the approach (Question 1.7) and if they planned to adopt the concept, over what timeframe? (Question 1.8), it was observed that half of those who responded (50%) were already using the concept at a level yet to be determined by the research, whilst 22% stated that they were not using but planned to use the concept. There were no returned data for the category of those organisations who may have attempted to use the 'approach' but had failed in their attempts. Of those who stated that it was their intent to use the 'approach' for their main product in the future, 64% were of the opinion that they would adopt the concept within 1 to 3 years, 29% within 3 to 5 years, and 7% in 5 years.

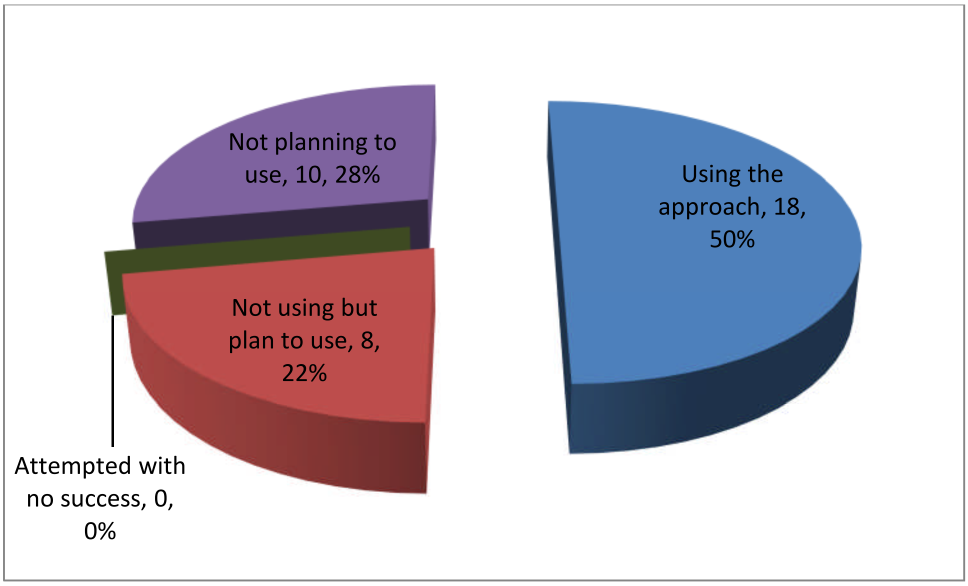

Figure 4-13: Question 1.7, Proportion of organisations using or planning to use 'the approach'

Section two of the questionnaire is concerned with seeking the views and opinions of those surveyed as to the drivers to, and benefits of, the adoption of the concept and approach (Figure 4.14). The data informs us that a 'reduction of the cost of ownership' of the product is seen as a less significant driver with a return of 2%. This is a surprising result as it would appear to be out of synchronisation with the views expressed within the servitization and PSS literature. This will be discussed further in (section 4.6.2) of the thesis.

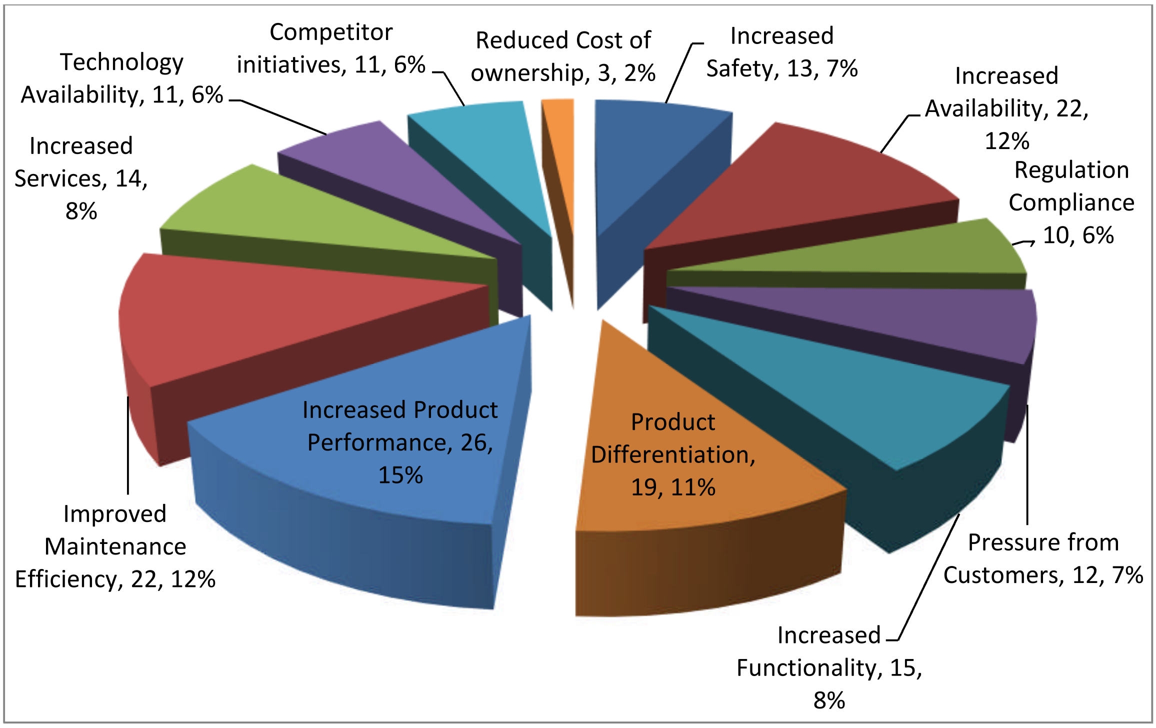

Figure 4-14: Question 2.1, Identified drivers to the adoption of the 'approach'

Having identified the drivers for the adoption as perceived by practitioners the survey seeks to understand how the organisations analysed the potential benefits relative to the stakeholders. (Question 2.2). It was found that 54% of the organisations responding did so in a formal way (for example using a business case proposal), whilst 38% used more informal methods and 8% recorded ‘not at all’ meaning that it was based upon the opinion and perceptions of completing the survey. When formulating these data (Question 2.3) seeks to identify which stakeholders (apart from those internal to the organisation) were consulted when formulating the organisation’s assessment. It is discovered that when consulting and soliciting opinions, 55% or organisations consulted their customers, whilst 21% discussed the issues with their supplier base and 8% with their service providers. It is noteworthy that 5% of organisations who responded formulated their opinions by a totally internal initiative with no input from external stakeholders.

When asked what the expected benefits to the organisation would be if the ‘approach’ was adopted it is observed that no clear single benefit emerges. A greater understanding of customer needs (14%), close relationships with the customer (14%), product/service differential (13%), and improved product functionality (13%) were all given relatively equal significance in expectation. Additionally increased revenue (11%), risk reduction (11%) and financial inflows (9%) and outflows (8%) were also identified as being important. It is interesting to observe that only 6% identify the relationship that the organisation has with it’s suppliers has being a perceived benefit. The data also suggests that increased changes in the company identity (i.e. branding etc) is a perceived benefit when adopting this approach (Figure 4-15).

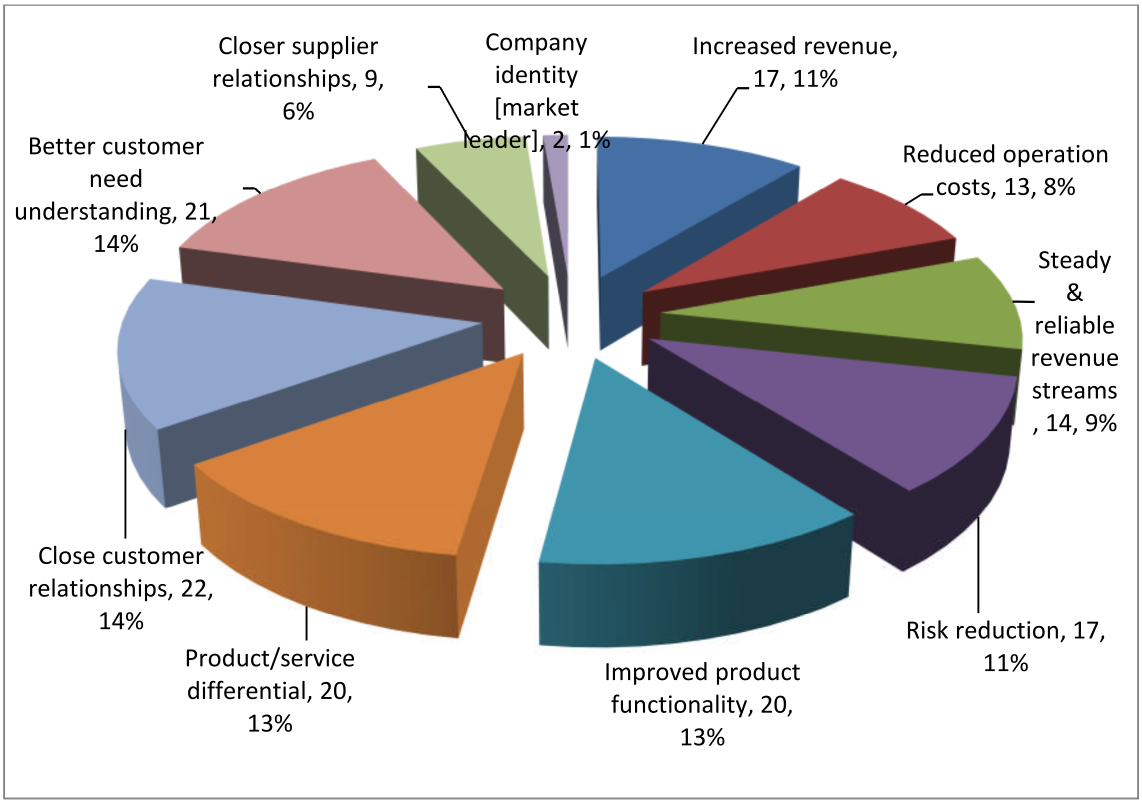

Figure 4-15: Question 2.4, The organisation's expected benefits from the adoption of the approach

In seeking to understand how the organisation would monitor the performance of the ‘approach’ when it is applied to the products and operations of the business, five specific indicators were offered from the literature for the respondents to select from with a facility for each respondent to add to the indicators as appropriate. (Question 2.5).

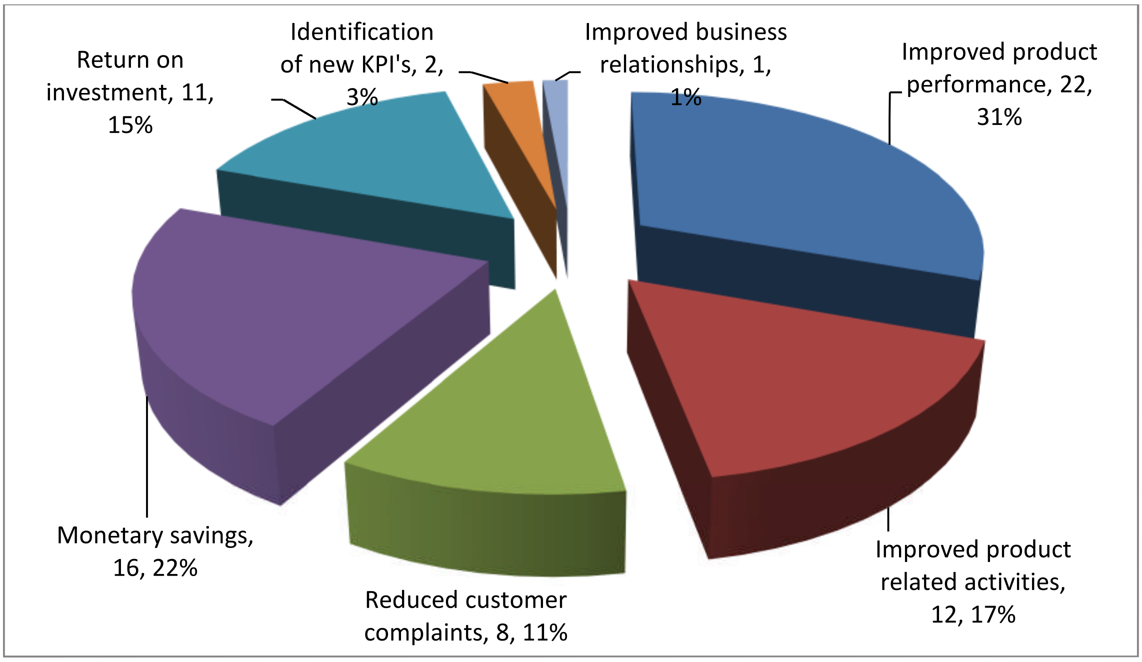

Figure 4-16: Question 2.5, Indicators used to demonstrate the realised benefits of the adoption of the 'approach'

It is seen from the data (figure 4-16) that an improvement in product performance is seen as the main KPI with monetary savings (22%), Improved product related activities (17%), RPI (15%) and reduced customer complaints (11%) all being significant indicators. Surprisingly only 1% stated that improved business relationships were seen as a significant KPI for measuring the realised benefits for adoption of the ‘approach’.

The survey then sought to ascertain the gaps between expectation of potential benefits and the benefits that were realised by the respondent organisations and to seek the factors that each business attributed the shortfall in expectation too (Question 2.6). The question was presented as an ‘open’ question aimed at seeking qualitative data by way of opinion. Of those respondents who stated that a gap existed (73%), the data suggests that the main reason for the gap is a lack of understanding of the perceived benefits (32%) whilst technical/engineering barriers account for 18% and change management issues 14% respectively. Issues relating to resources, data usage, and KPI's, whilst being acknowledged as factors contributing to gaps between expectation and achieved benefits were not seen as being as significant (figure 4-17).

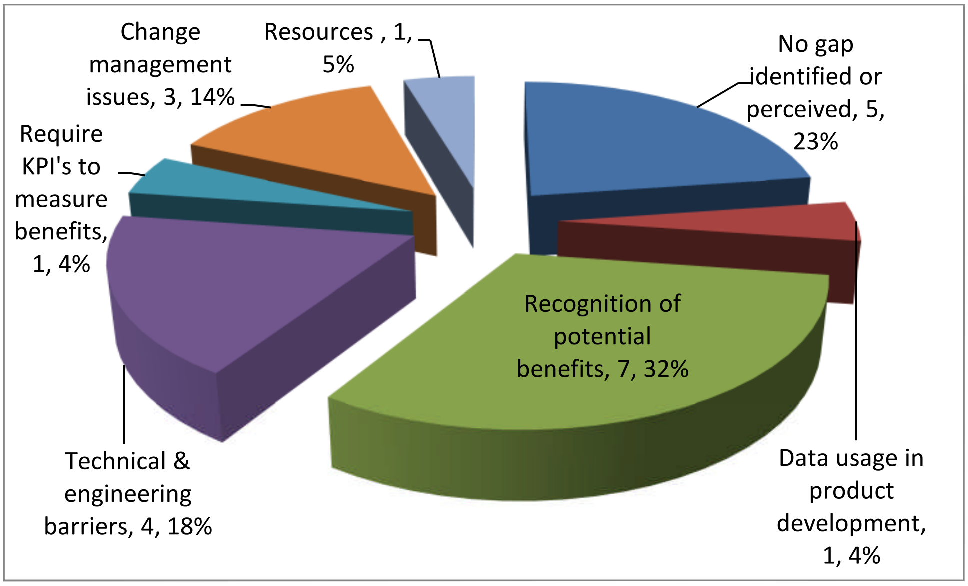

Figure 4-17: Question 2.6, Factors contributing to the gap between potential and realised benefits

Up until this point the questionnaire has sought to understand the benefits that are perceived to be obtainable by the organisation for the organisation, the factors that enable or inhibit the attainment of these benefits and the gaps between expected and actual benefits achieved. However, what about the benefits to both the organisation's customers and suppliers? It would be far beyond the scope of this research to survey the customer and supplier base of each of the respondent organisations, however such an activity would be a good foundation for several case studies or cross case investigation

When seeking to gain insight into this issue, the organisations were asked to answer the remaining questions within section 2 of the questionnaire from their customer's and supplier's perspectives. The author acknowledges that this is not ideal as it introduces an element of subjectivity to the survey and potential bias to the data from that of the answering organisations perspective but is seen as a means of gaining a more balanced understanding of the benefits, enabling and inhibiting factors to the successful adoption of the approach.

The perceived benefits that can be obtained for the customers of the surveyed organisations (Question 2.7) are presented in figure 4-18.

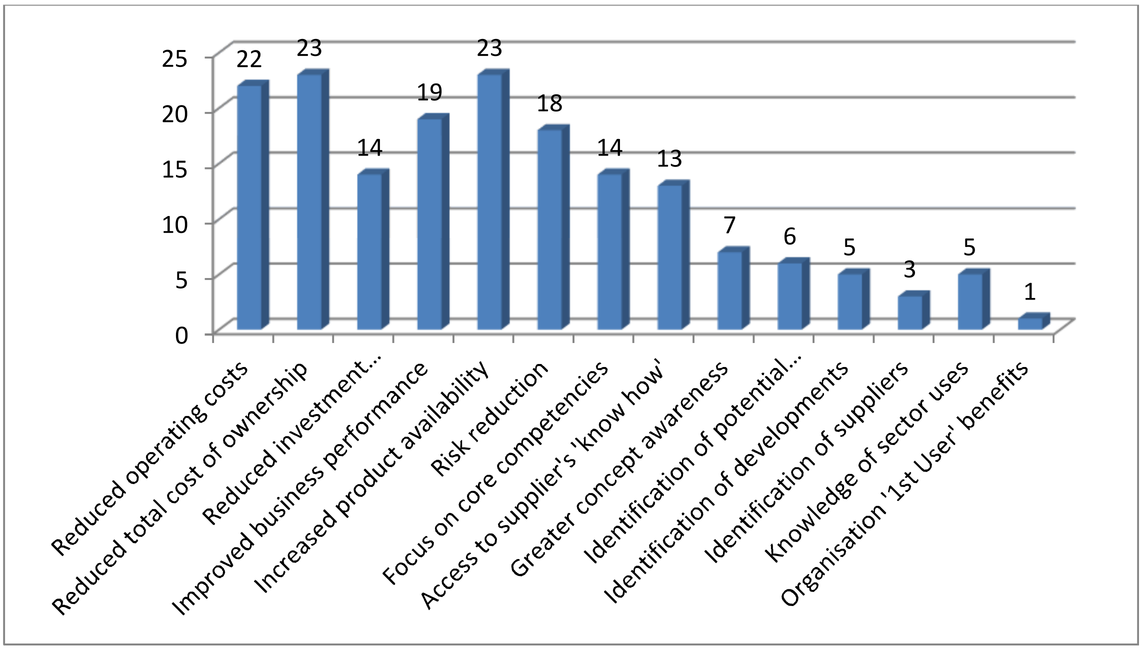

Figure 4-18: Question 2.7, Perceived benefits to the customer

The potential benefits listed within the question are informed by the literature (Section 2.6.1) with the final section of this question being left open for the addition of additional benefits by the respondents. It is seen that practitioner's views as to customer benefits broadly agree with those cited within the literature however it is interesting to note that only one organisation identified being the "1st user" as being a benefit. This is surprising as significant barriers of entry may be attained through the establishment of service infrastructures making it more difficult to compete for emergent organisations (Benedettini et al., 2009; Baines, 2010, [Unpublished]; Porter, 1979).

It is important that customers are able to see the benefits that are offered by the adoption of such applications so that alignment of customer expectation and organisation can be achieved. The methods employed by the respondent organisations to achieve visibility to the benefits of adopting the 'approach' where sought (Question 2.8). Of those organisations responding standard non fiscal methods seemed to be the most prevalent (figure 4-19).

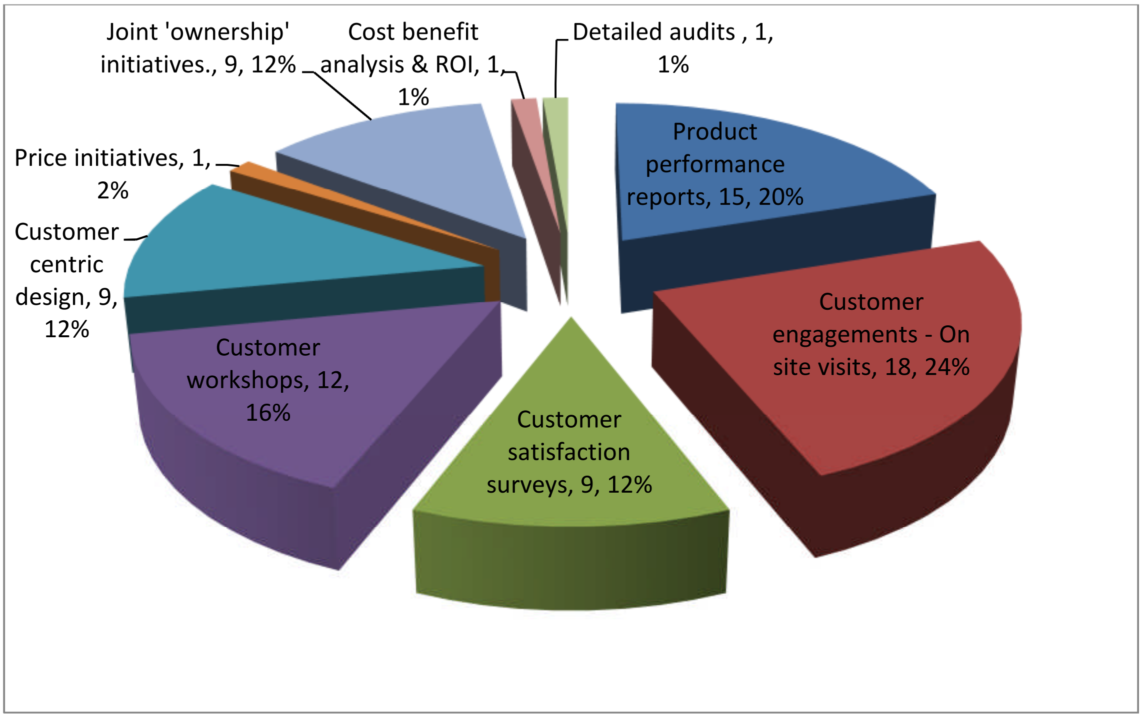

Figure 4-19: Question 2.8, Methods of obtaining visibilty of the benefits of the adoption of the approach to customers

It should be noted that traditional methods of fiscal analysis (e..g. cost benefit analysis and ROI) together with pricing initiatives for the product are not well represented within the returned data. However, when asked what indicators they use to demonstrate the 'realised' benefits of the approach to their customers (Question 2.9) the data records that 26% use monetary savings as a KPI whilst 3% offered no specific indicators (figure 4-20). This appears to offer conflicting data and offers the potential to investigate further the role of effective KPI's relating to the adoption and performance of IVHM generic technology within organisations and against stakeholder expectation.

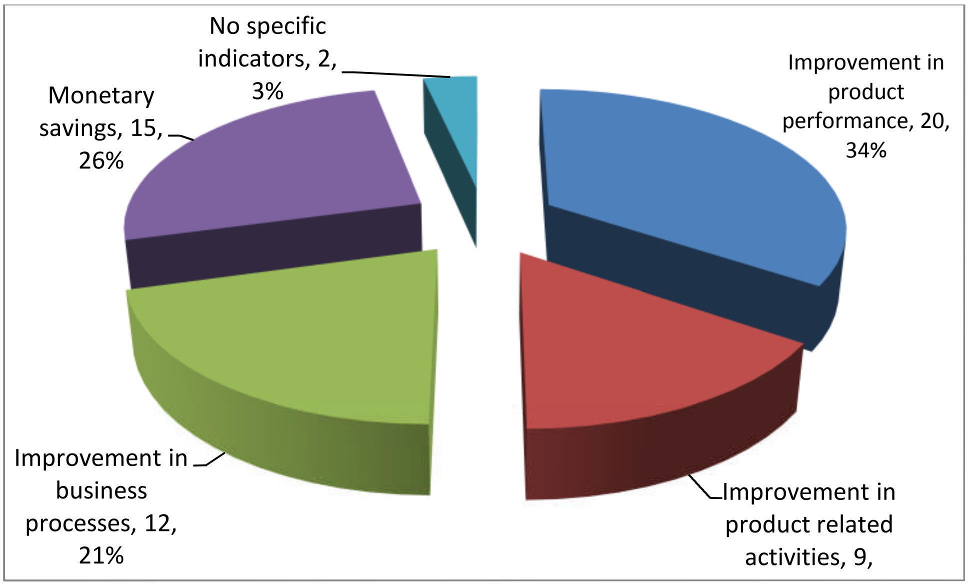

Figure 4-20: Question 2.9, Indicators used to demonstrate the 'realised' benefits to customers

The questionnaire then progresses to test if there are any gaps from the perceived customer perspective in the benefits that were achieved to expectation (Question 2.10). Again the question was presented as an 'open' question with the respondents free to record qualitatively any factors that they thought attributed to such gaps. (figure 4-21).

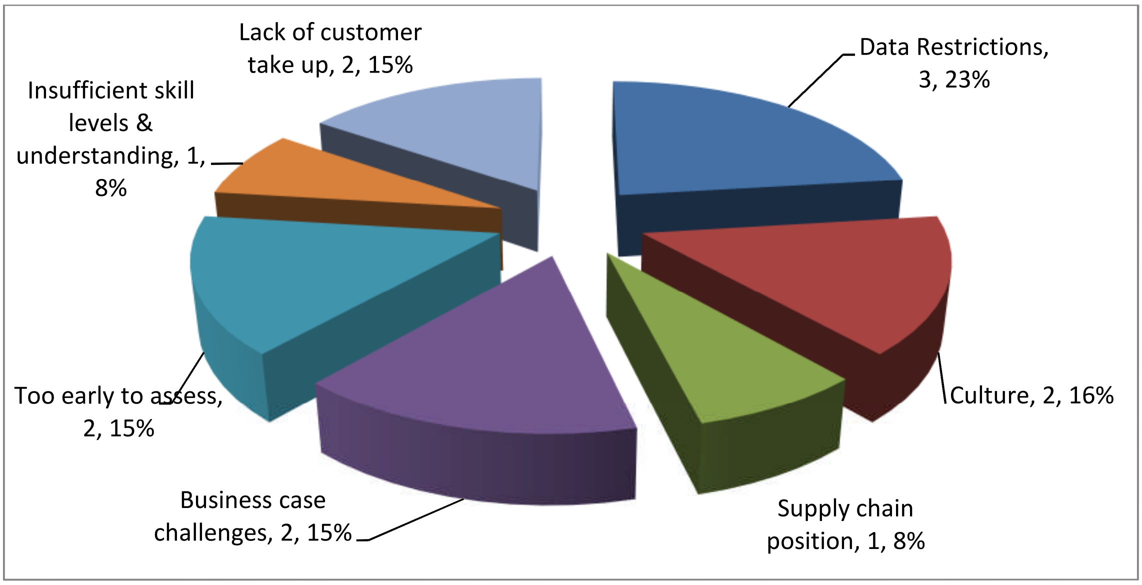

Figure 4-21: Question 2.10, Factors attributing to the gap between expectation and achieved benefits of the 'approach'

The data suggests that data restrictions (23%) are the majority factor contributing to the gap, although challenges in formulating the business case (15%), organisational culture (16%), poor customer take up of the concept (15%), and it being too early in the adoption cycle (15%) are all significant factors. Additionally, there is a lack of skilled personnel (8%) which also contributes to a shortfall in attainment against expectation, as does the organisations position within the supply chain (8%).

Finally within this section of the questionnaire, the position of the suppliers is also considered against the same focii. When asked what were the perceived benefits for their suppliers (Question 2.11), the respondent organisations returned the data as illustrated in (figure 4-22).

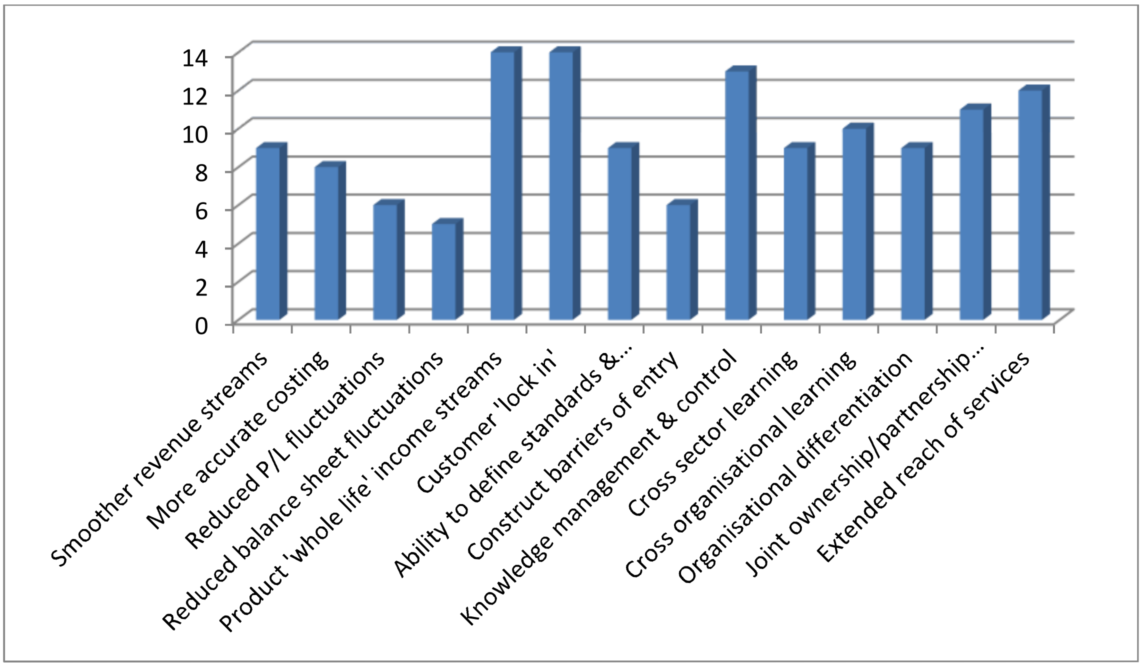

Figure 4-22: Question 2.11, Expected benefits for the organisations 'suppliers'

The benefits listed on the x-axis were again informed by the literature (section 2.6.1) with the question offering an 'open' section for the addition of additional categories to be added to the analysis. These benefits (Question 2.12) are made visible to the suppliers and service providers to the organisation by way of on-site visits (34%), workshops (30%), and active initiatives which seek to understand the needs of the supplier (23%) although the survey does not seek to identify or categorise the nature of such initiatives. Additionally, organisations state that they use periodic communications (newsletters, mail shots, press etc) (10%) received proposal offerings (3%) as methods to increase the visibility of the benefits offered (figure 4-23). This survey however, whilst identifying the mode of communication used by such organisations to disseminate such benefits does not offer an analysis of the effectiveness of such initiatives. In view of the emergent and early stage evolution of the concept within mainstream manufacturing (Chapter 2) further research should be carried out within this area.

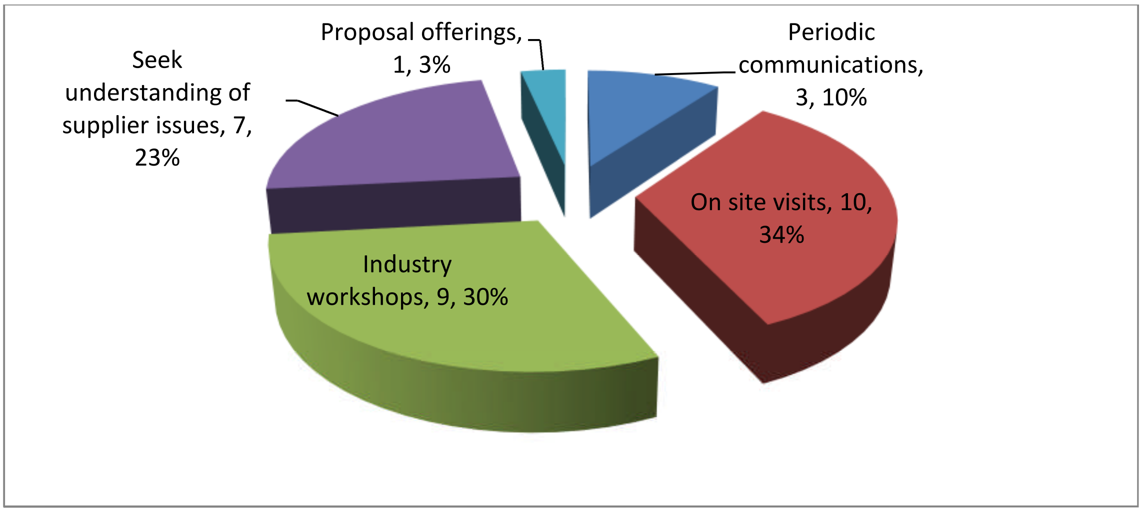

Figure 4-23: Question 2.12, Methods by which the benefits of adopting the 'approach' are communicated to suppliers and service providers

In communicating these benefits the indicators that were identified as being used were utilisation/downtime analysis (31%), 'fire fighting' reduction targets (19%), and joint ownership initiatives and procedures (15%). Significantly 12% of respondents stated that they were using the approach but offered no indicators to illustrate the benefits (figure 4-24).

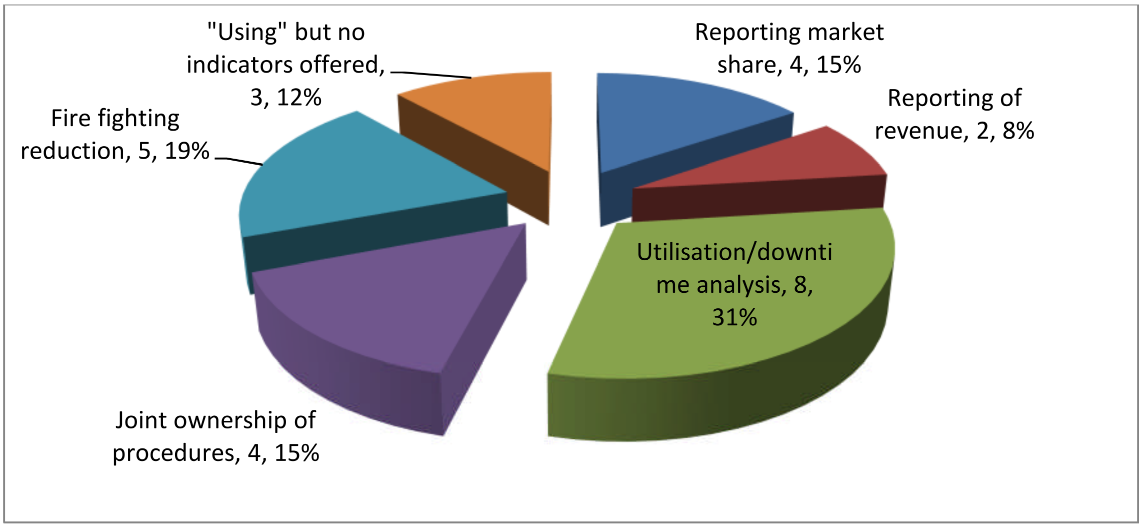

Figure 4-24: Question 2.13, Indicators used to demonstrate the benefits of the 'approach' to suppliers and service providers

Finally within section two of the questionnaire the respondents were again asked about the gap (if it exists) between the potential and realised benefits to their suppliers and service providers (Question 2.14) and what factors they attributed the gap to? The data returned the following results (figure 4-25).

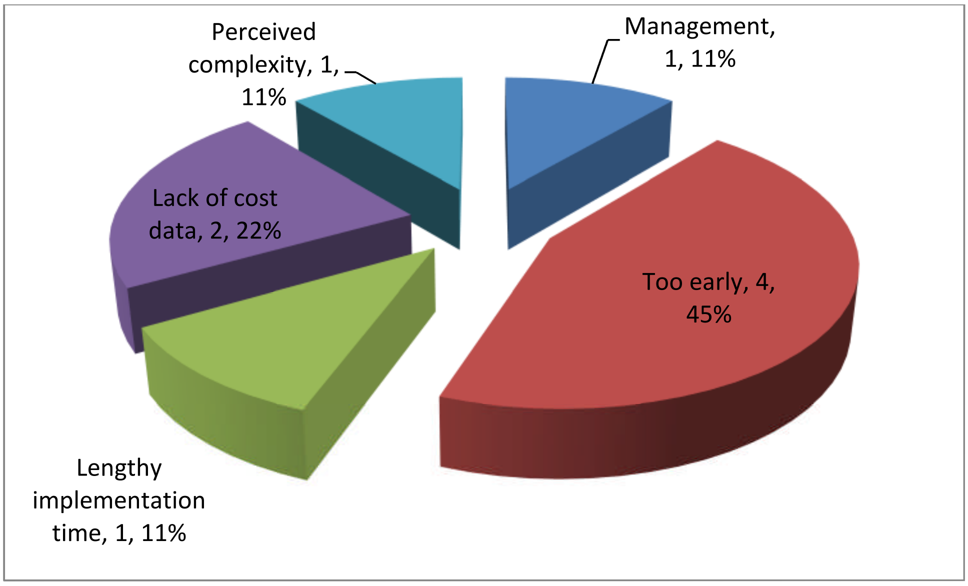

Figure 4-25: Gap between potential and realised benefits of the 'approach' to the organisation's suppliers and service providers

Section three of the questionnaire seeks to identify further the enablers and inhibitors to both the technical and commercial success of the ‘approach’.

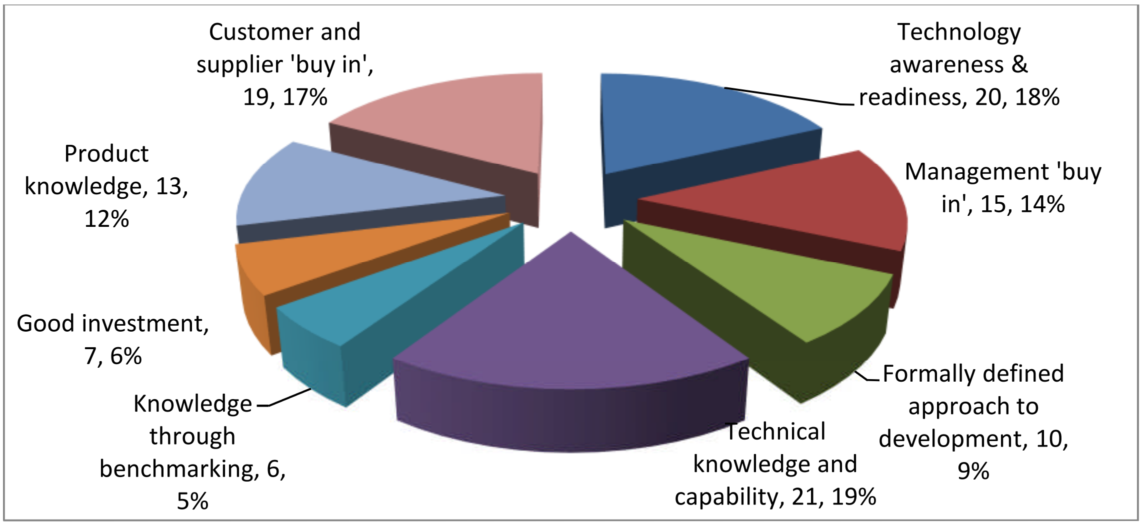

Figure 4-26: Question 3.1, Factors that enable the technical success of the approach

Organisations were asked which factors enable the technical success of the ‘approach’s’ development and introduction (Question 3.1). It is observed that the data returns a fairly even spread of the factors which were offered with a modal value of 8%. Of the factors listed, the data suggests that it is an understanding of benefits to the customer, or lack of it, (16%) which is the main factor to the technical success of the approach, whilst significantly an understanding of the technical benefits to the supplier only returns a value of 5%. (Figure 4.26). These two variables appear at the extreme opposite ends of the spectrum of data readings recorded. This shows that there appears to be a skewed interest in the needs of the customer rather than taking a more holistic and balance approach to ensure that there is alignment of demand, (the customer) and supply (the supplier). It is also of interest to observe that an understanding of the technical benefits to the organisation (12%) is mid way between that of the two previous readings. One observes that this lack of understanding results in organisations stating that the business case is also a factor to the successful application of the ‘approach’.

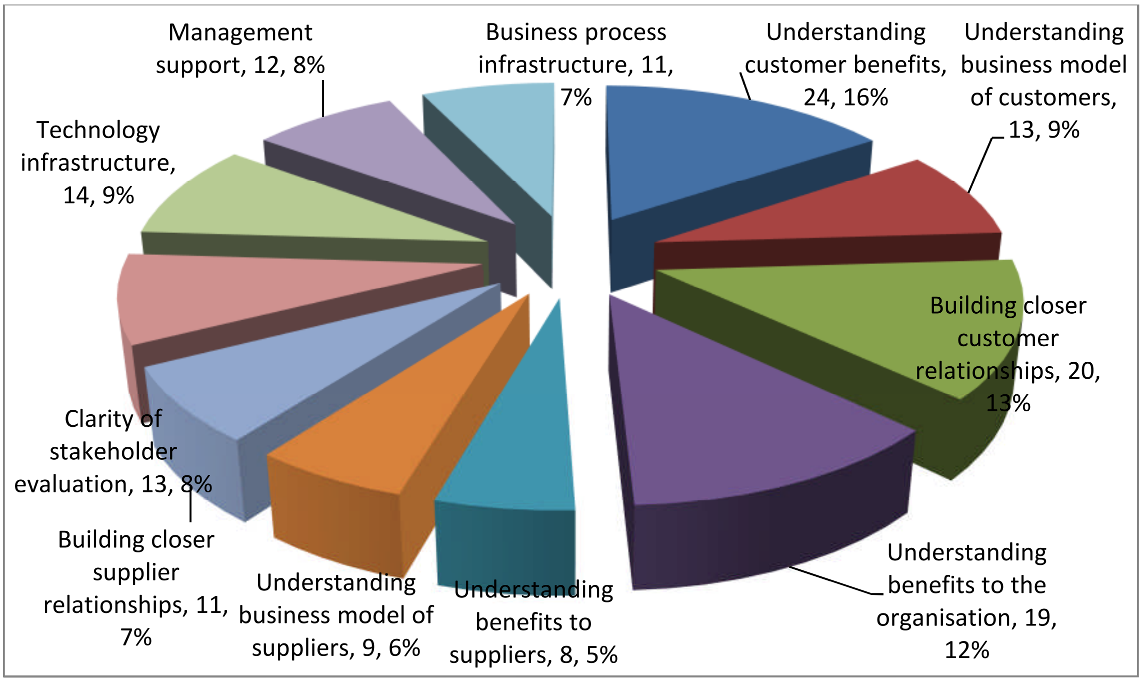

Figure **4-27: Question 3.1, Factors enabling the technical success of the 'approach'**

The questionnaire then asks the same question (Question 3.2) when seeking to gain an understanding of the factors which can enable '*commercial*' success.

The data returned an exact match for the factors returned. Whilst it is not surprising that the data should be similar is spread it is very surprising that the data sets should be the same. The data was rechecked for coding and data input and again the same result was returned (figure 4-28).

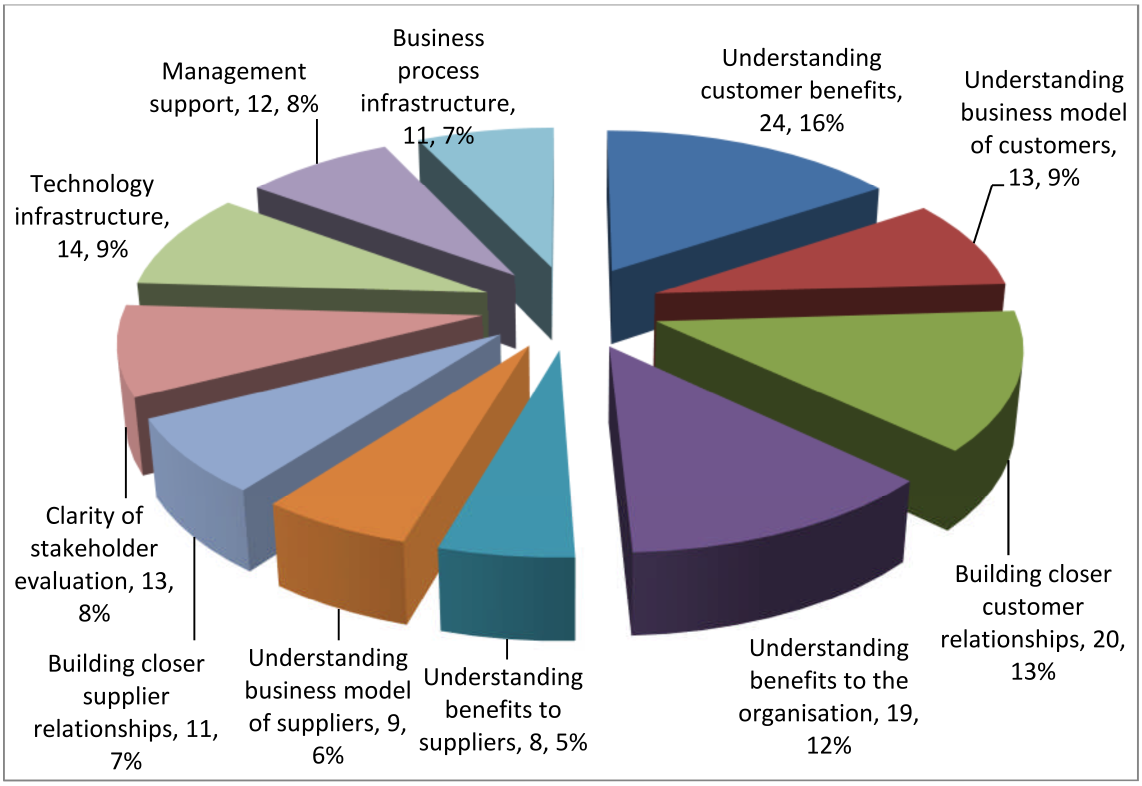

Figure **4-28: Question 3.2, Factors that enable the commercial success of the 'approach'**

Finally within this section of the questionnaire the same questions were asked to understand the inhibitors top both the technical success (Question 3.3) and the commercial success (Question 3.4) to the adoption of the approach. The data returned the following results respectively (figures 4-29 and 4-30).

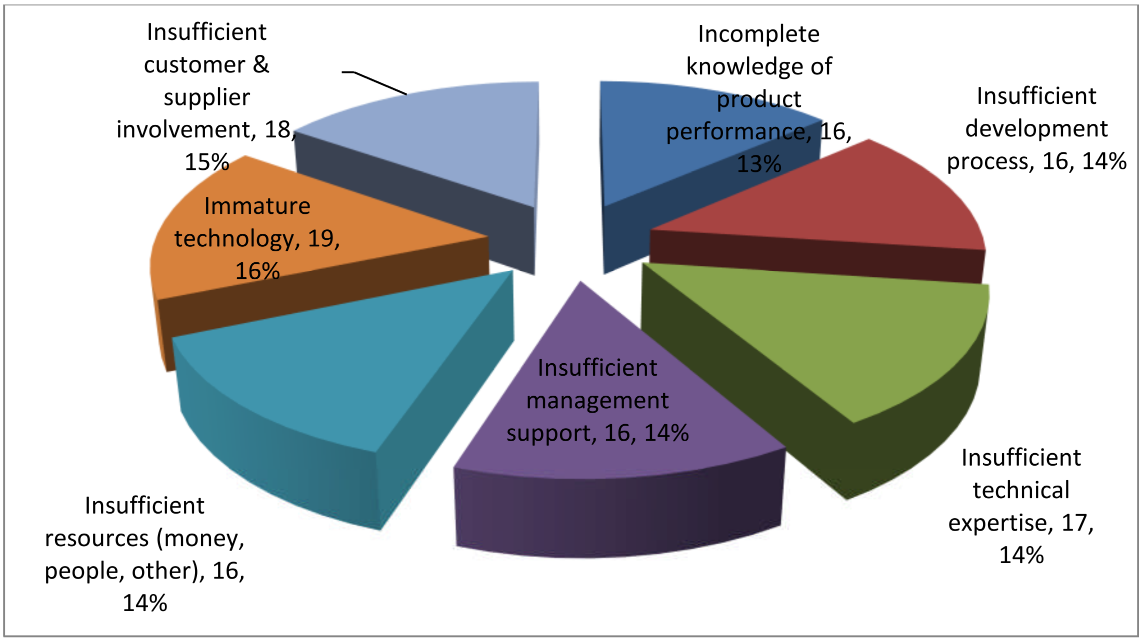

Figure 4-29: Question 3.3, Factors which inhibit the technical success of the adoption of the 'approach'

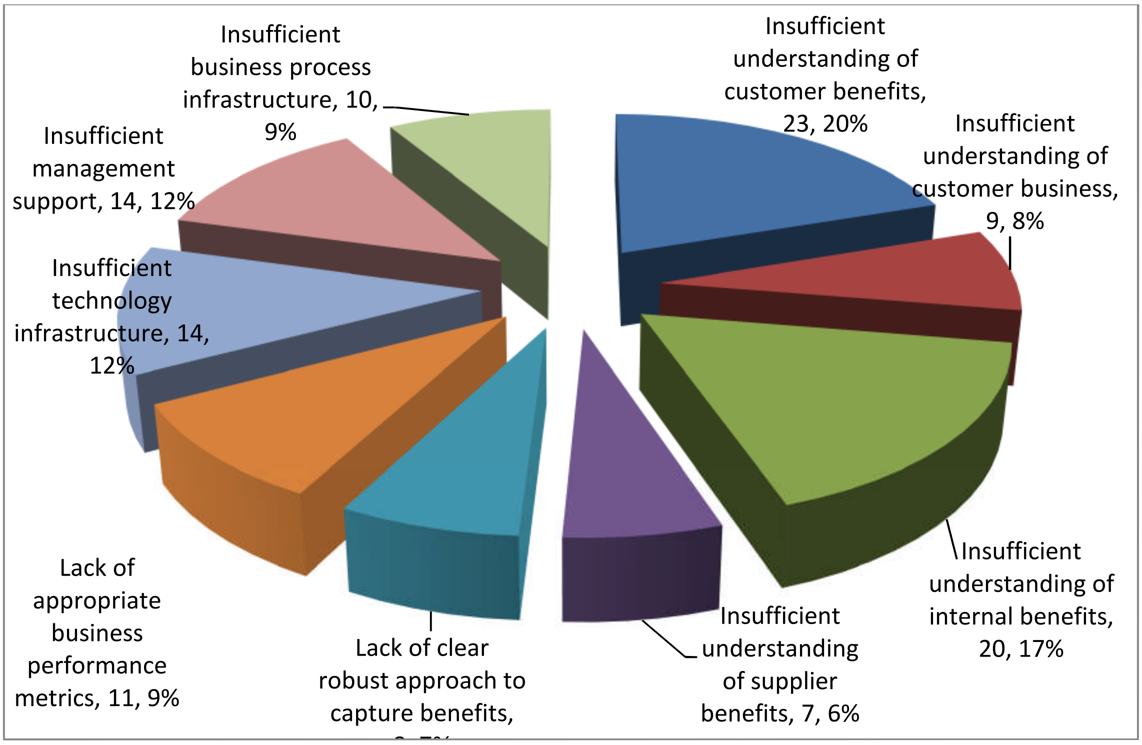

Figure 4-30: Question 3.4, Factors which inhibit the commercial success of the adoption of the 'approach'

Section four of the questionnaire seeks to gain knowledge relating to the product and the related approach. Typically the life cycle of the product (Question 4.1) was said to be within the ranges of 0-3 years (3%), 3-10 years (28%), 10-20 years (25%), and over 20 years (44%) with an installed base for the manufactured product (Question 4.2) being 0-100 units (6%), 100-1000 units (16%), 1000-10000 units (41%) and over 10000 units (37%).

It is observed that of the companies that responded to the survey they typically produce products that have lengthy life cycles and also a medium to high installed base. The survey revealed (Question 4.3) that the majority of organisations (77%) had few competitors (0-10), with those who had higher numbers of competitors 10-25 (10%), 25-30 (10%) and over 50 (3%) demonstrating that the majority of the organisations had an increased market position.

Of the products manufactured (Question 4.6) the majority were electro-mechanical in nature (45%), with mechanical products representing (29%), electronic products (21%) and electrical products (5%). This is in line with the literature review, the definition of a complex product (section 4-20) and the assumption that the majority of products would fall in line with the definition offered.

The data informs that products are multi system assemblies (Question 4.4 figure 4-31) and consist of multi component assemblies with the majority comprising over 100 parts (Question 4.5, figure 4-32). Of those companies that state that they are using the 'approach' it is seen that there has been a gradual increase in the application over the last 10 years which again substantiates the assertions made within the literature review and mirror the increase in research and academic interest over the same period (Question 4.7, figure 4-33).

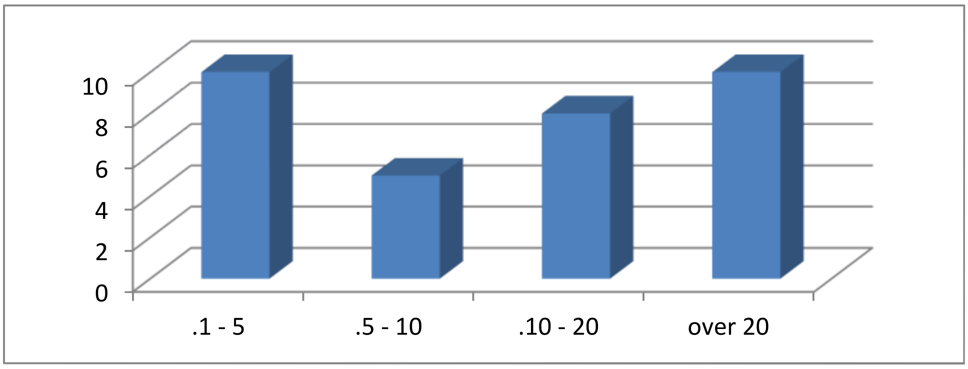

Figure 4-31: Question 4.4, The number of systems within the manufactured product

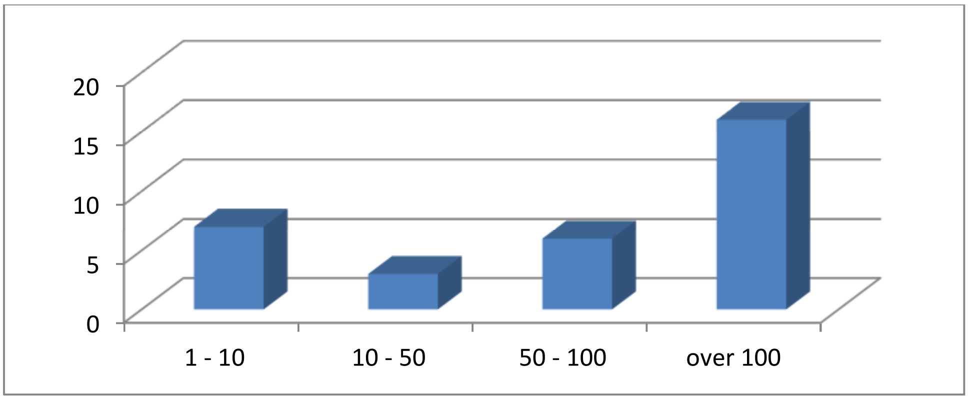

Figure 4-32: Question 4.5, The number of components in the manufactured product

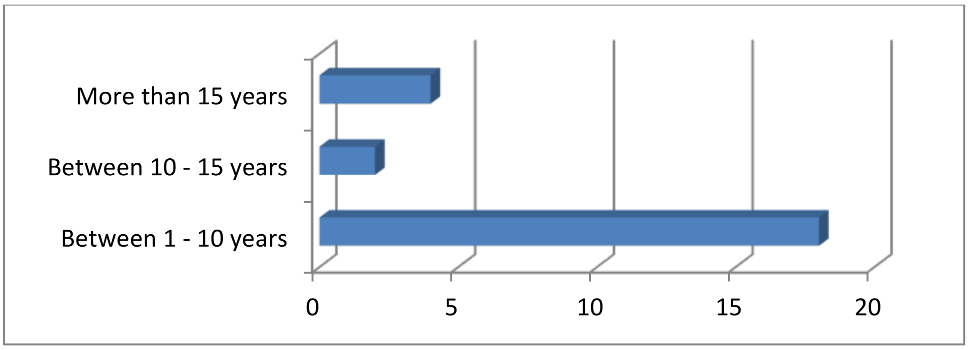

Figure 4-33: Question 4.7, The length of time the approach has been used within the product

Up until this point (Question 4.8), the survey made every attempt to be neutral in its description of the concept of informated products using the term ‘the approach’ in an attempt to prevent the respondents being too informed about the focus of the study. When asked to what level of complexity each organisation added technology to their products and for what purpose, the data illustrates that monitoring (26%), fault detection (20%), and diagnostics(23%) are the main functions. However prognostics (16%) and decision support (15%) are also functions built into the product for some manufacturers (Figure 4.34).

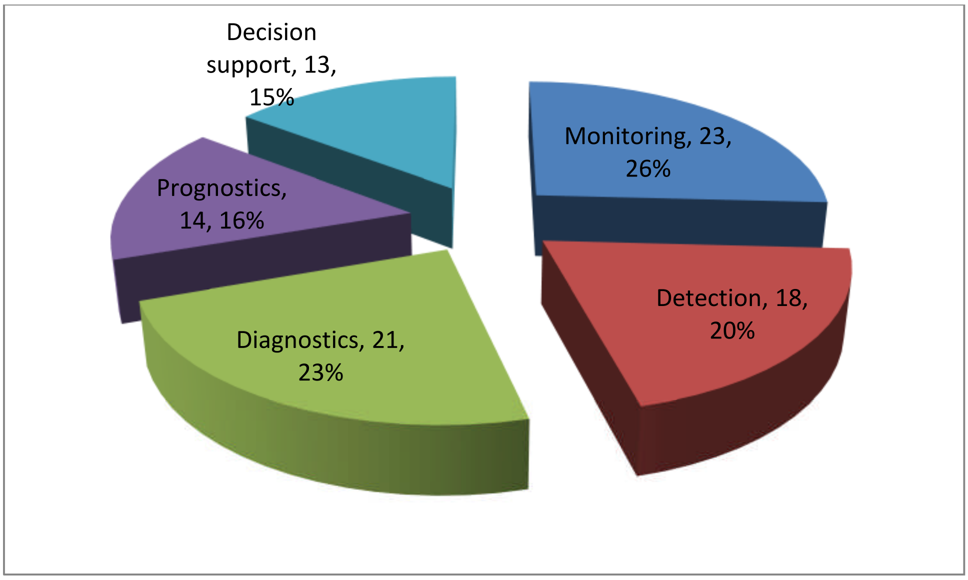

Figure 4-34: Question 4.8, Level of complexity supported by the 'approach'

The level of product support offered (Question 4.9) by the application of the approach is reported as part level (10%), assembly level (13%), subsystem level (32%) and full product coverage (45%). Typically the approach is applied to measure and monitor physical parameters (figure 4.35), the main ones being temperature, vibration, and power usage/ouput with on product configuration being limited to (16%), the majority being either off product support or a combination of off/on product support (84%) as determined by the specification and application of the product.

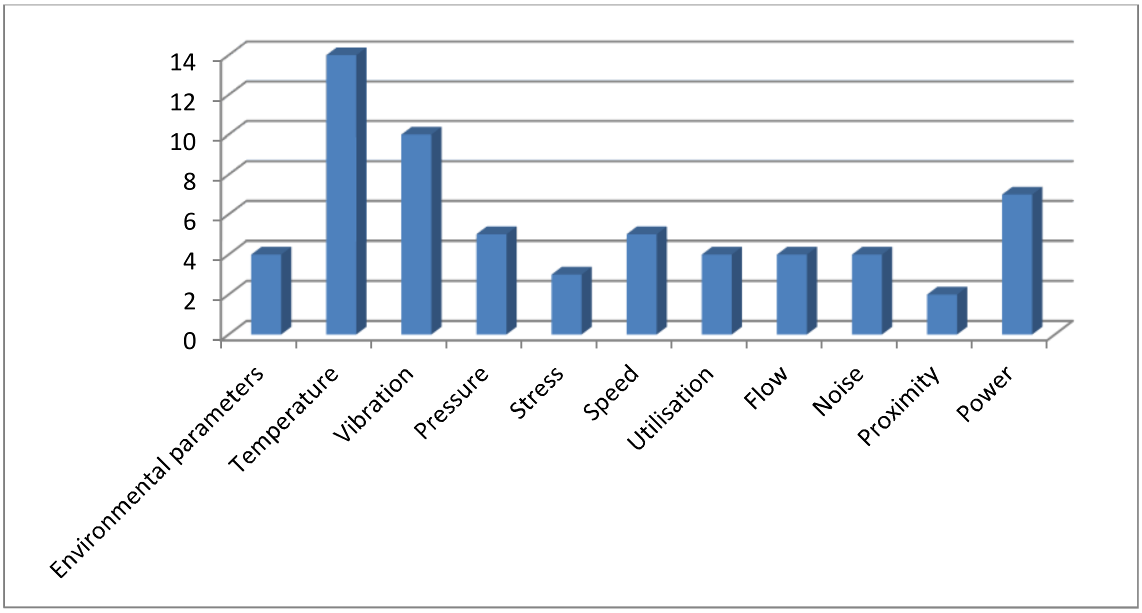

Figure 4-35: Question 4.10, Typical measured parameters

Finally in section four of the questionnaire each organisation was asked (Question 4.12) how they sourced the approach to measuring and managing product performance. In response the data recorded that of those who actively used the approach 75% undertook in house development whilst the remainder outsourced the initiate but by way of joint venture.

The final section of the survey seeks to understand what, if any, are the plans of each organisation for future applications. In asking organisations who stated that they had no plans for adopting or extending the application of the approach (Question 5.3), none stated that it was due to a lack of technical understanding. Of the few that did state that they had no plans, ‘economic reasons’, ‘customer fear of being ‘locked in’ to the supplier, and ‘customer currently satisfied’ all attracted a response but not in any level to be of significance (Figure 4-37).

The organisations that did respond to the survey stated that they were considering adopting or adopting further the approach (80%) either to different products within their offering, or to various levels of the system, assembly and/or component level (Figure 4-38). However each organisation also identified the perceived main threats to their plans to extend the approach and these are recorded within figure 4-40.

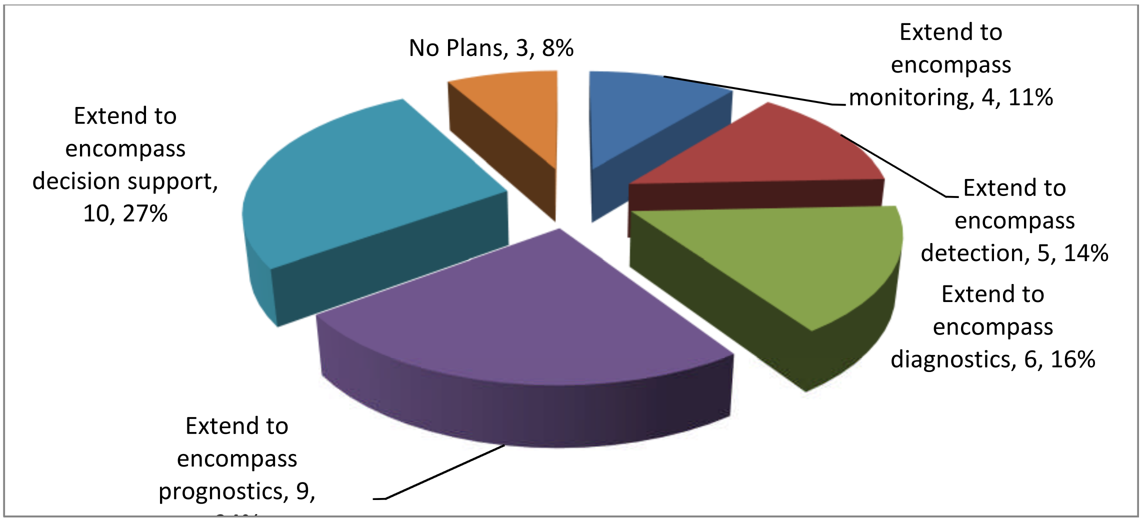

Figure 4-36: Question 5.2 Plans to extend the approach

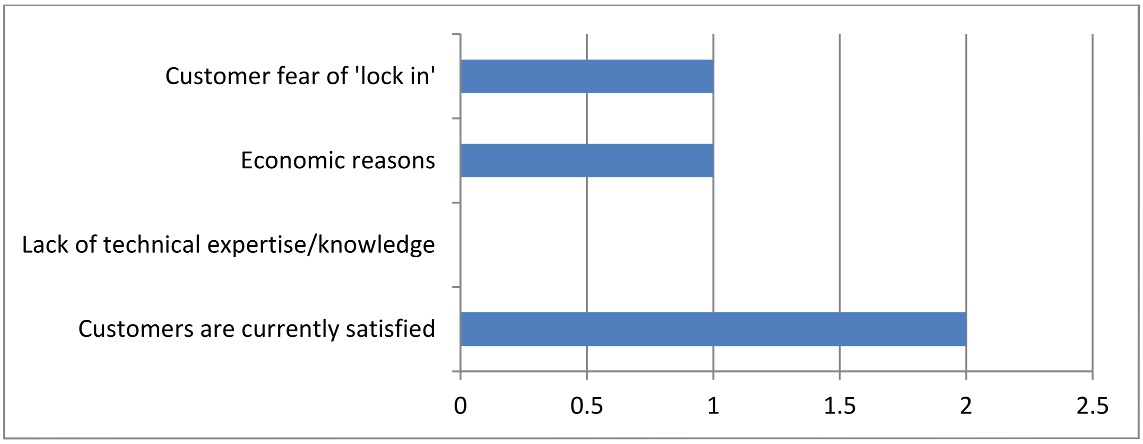

Figure 4-37: Reasons for not extending the approach

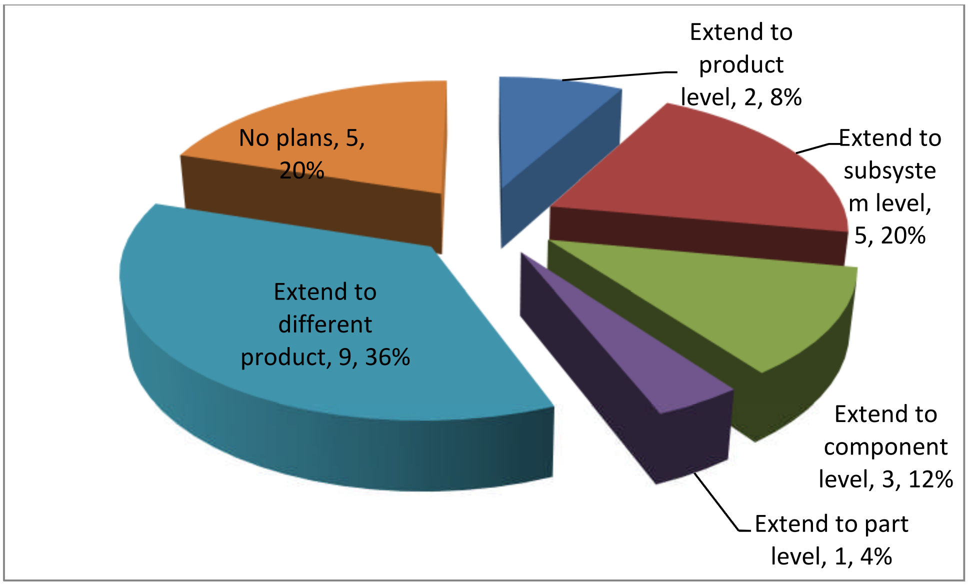

Figure 4-38: Respondent's plans to extend the 'approach'

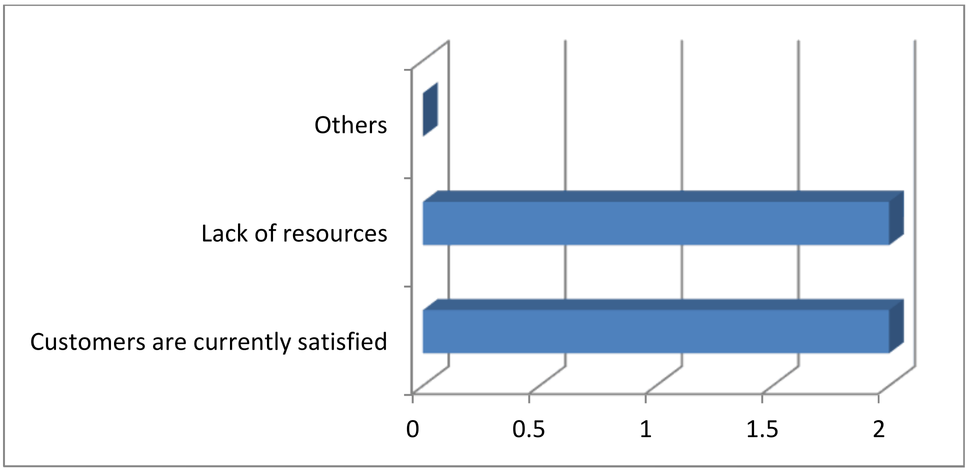

Figure 4-39: Respondent's reasons for having no plans to extend the approach

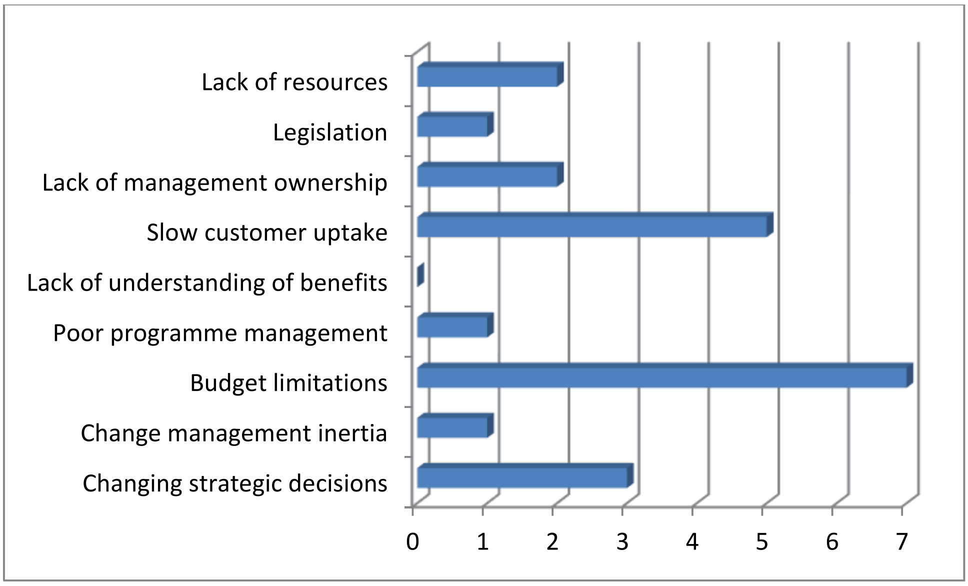

Figure 4-40: Main threats to respondent's plans to extend the 'approach'

The survey recorded that whilst the majority of organisations who responded to the questionnaire saw that the approach was relevant to their profitability and presumably their survival and future growth), (Figure 4-41), there were several skills and capabilities that each organisation needed to acquire in order to maximise the benefits that can be achieved through the adoption of the approach. These are illustrated in figure 4-42.

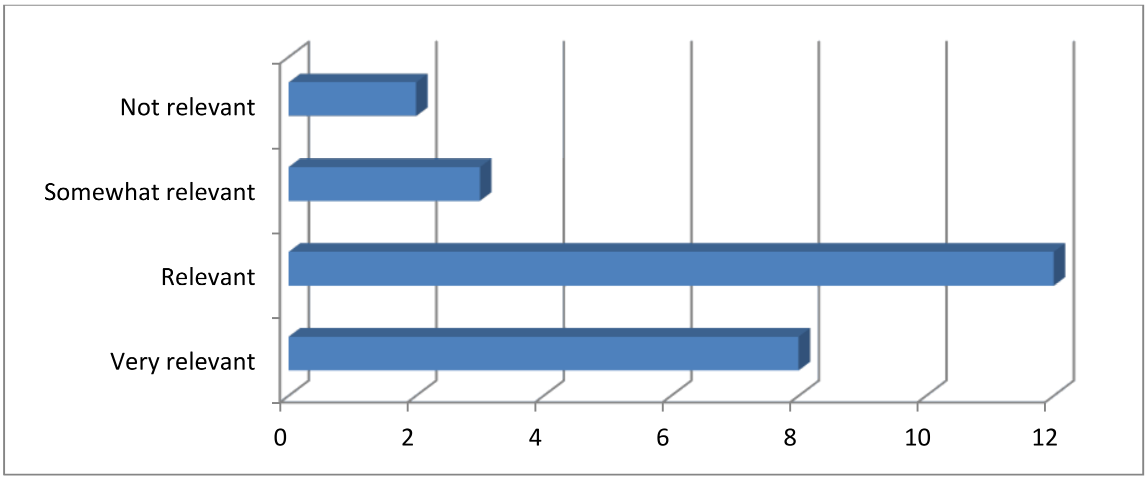

Figure 4-41: The relevance of the 'approach' to the profitability of the organisation

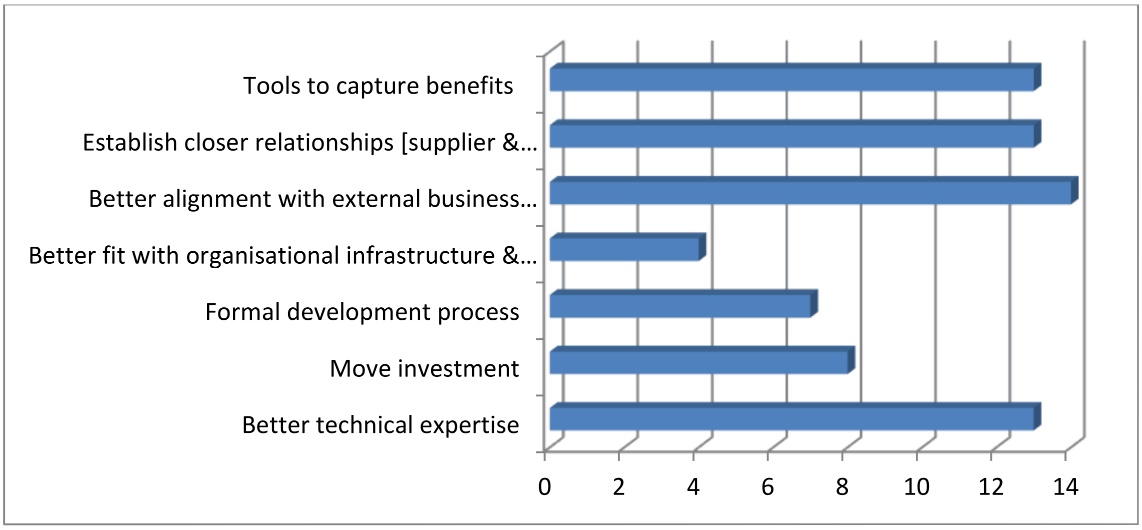

Figure 4-42: Required skills and capabilities required to maximise the benefits resulting from the adoption of the approach

This section has presented the results as recorded from data returned by the survey. The following section will offer a discussion relating to the findings of these results.

4.6.2 Synthesis of survey results

The literature review (chapter 2) suggests that there is limited understanding as to the state of the art adoption of IVHM generic technological applications outside of the aerospace and military sectors. This is particularly evident when seeking its application to product offerings by organisations seeking to compete through enhanced services (Section 2.8 Gap 1).

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5. This section reports the synthesis of the data reported within section 4.6.1. As previously advised (pages 76 & 80) , this stage of the research programme was conducted in conjunction with other researchers due to the need to complete this volume of work in the first quarter of the year (2009). This attempted to ensure that access to the targeted organisations did not become restricted due to the annual vacation periods. In addition the data and subsequent analysis was also required for the research focii of the other researchers. Although the author contributed significantly to the design, research protocols, data cleansing and tabulation and analysis, the results and synthesis of the findings reported are attributed to the collective but are included within this thesis as they are integral to the development of the research.

After conducting the literature review it is suggested that this limited understanding and fragmented focus is "...inhibiting the development and exploitation of these capabilities" (Grubic. T. et al., 2009).

To inform further this assumption a survey of organisations identified to be within the scope of the research focus (section 4.2) has been undertaken and reported (Grubic et al., 2011). The purpose of the survey was to further understand the extent to which these concepts have been adopted by practitioners, their motivations for seeking adoption/application of the technology, and the expected/achieved benefits and challenges experienced by such organisations through a wider business context lens. The previous section has presented the results as they are returned by the data. This section takes these results and presents the synthesised findings, yielding a deeper understanding of the issues from which ".... implications are drawn for both theory and practice in this area" (Grubic et al., 2011).

The extent of adoption of diagnostics and prognostics technology

The identification of the population and subsequent analysis of the data returned suggests a minority of manufacturing organisations are actively or have the potential to actively use IVHM generic technology applications to conduct diagnoses and prognoses of their product's current and future condition (Section 4.2). Of those organisations surveyed (304), and after a review of the data and each company website, it was found that 48% of them did not actively engage in the application. The study found that only 35% of the organisations actually applied IVHM, CBM_1, and/or CBM_2 generic technologies. A further 17% of organisations responding to the survey stated that they did intend to use these applications in the 'near future' (90% within the next 5 years). This implies that 10% (152) manufacturing organisations identified in the population are using, or are near to using monitoring, diagnostic, and prognostic technology within their business operations (Grubic et al., 2011). The point is made within the data and the thesis that number of companies is very small relative to both the population identified and the greater number of companies that were identified at each stage of the population identification. It is reported however that when the identity of some of the responding companies is known one sees that they are international market leaders within their sectors with many strategic business units throughout the UK. It is also important to note that only companies with a turnover greater that £10 million GBP are included. The subsequent appraisal of the data yields the following:

> *Finding 1: Almost 10% of UK based manufacturers targeted by this survey are applying, or are about to apply, diagnostics and prognostics within their business, and this trend is growing.*

Characteristics of adopting companies

The survey sought to further understand if there were any specific characteristics exhibited by the organisations who returned the survey and either presented a positive result (i.e. they did use or were expecting to use the applications) or a negative result (i.e. they did not and had no plans to adopt the application). The study focused upon 152 manufacturing organisations and the sectors in which these companies operated are illustrated in figure 4-7. It has been illustrated (section 4.6.1) that the majority of organisations who returned the survey work within defence, aerospace, marine, power, energy and electronics. Upon closer inspection of the organisations within these sectors one sees that they all manufacture relatively high value complex products with very few producing simple offerings at the component or assembly level (figure 4-9).

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6. The findings as reported within this section are referenced to Grubic, T., Redding, L.E., Baines, T., and Julien, D., (2011), “The adoption and use of diagnostics and prognostics capabilities within UK based manufacturers, Proc. IMechE, Part B, Journal of Manufacturer, Vol 225, pp. 1457-1470. This paper presents the findings of the survey. Whilst the work for this element of the research is the result of the collective effort of the authors it is also included within the thesis with all efforts acknowledged as significant elements of the work are the contribution of the author of this thesis.

It is seen that the majority of organisations are at the top of the supply chain (74%) (figure 4-8) who have a predominantly B2B relationship with their customers. Significantly the defence sector represents a nominal third of all the customers and end users for organisations returning the survey. This is reflected in the contributions to the literature (chapter 2) with a significant contributions relating to military aerospace and ground vehicle operations and logistics.

> *Finding 2: Of the UK based manufacturers targeted by this survey, and applying diagnostics and prognostics, most operate within the aerospace, defence, marine, electronics, power industry, oil and gas, or energy .....sector(s) and where government agencies play an important role*.

The characteristics of those organisations who responded to the survey may also be reviewed in terms of their position within the value chain. Of those organisations stating the they used IVHM generic applications 39% classified themselves as OEM's [or in the case of the aerospace sector, system integrators]. In addition 32% stated that they were service providers, 22% first tier suppliers, and 7% miscellaneous manufacturers. Of those organisations who stated that they did not use but did have an intention to use the application 47% were first tier suppliers, 33% OEM's, and 20% service providers.

When one reviews those organisations who do not use nor have any intention to use IVHM generic applications it is observed that 46% are first tier suppliers, 27% are other manufacturers, 18% service providers, and 9% OEM's. These findings suggest that the closer the organisation is to the product user/customer the greater the interest in technology applications that can deliver accurate fault diagnosis and a prognosis of remaining useful life.

Finding 3: *Of the UK based manufacturers targeted by this survey, and applying diagnositics and prognostics, most can be characterised as being positioned close to the eventual customer/end user.*

Drivers of diagnostic and prognostic technology development and adoption.

A review of the data identifies the following factors as being of significance when seeking to adopt IVHM generic applications, namely:

- Improving product performance
- Improving the availability for use of the product
- Improving MRO efficiency
- Improved product differentiation within the marketplace.

These factors are all important parameters/characteristics when seeking to inform the operational strategy of the organisation as they add value to the customer offering which is both explicit and implicit. This is relevant to the development and attainment of the research aim and will be dealt with in the following chapters (Chapters 5 & 6). Further study of the data and as reported in the associated paper relative to this chapter of this paper (Grubic et al., 2011), "….70% of companies associate increased and sustained revenues with adoption, whilst 84% expect this to be an enabler to building closer relationships with customers and better understanding of their needs" (Grubic et al., 2011). This concurs with the literature relating to PSS and servitization (Chapter 5) where such benefits as 'reduced total cost of ownership', 'low operating risk', and moving 'along the value chain, are well documented. It is seen therefore that commercial market pressures and increased product 'availability for use' are key drivers to the adoption of the concept.

Finding 4: *Of the UK-based manufacturers targeted by this survey, and applying diagnostic and prognostic technology, most are being driven by commercial market pressures and opportunities.*

Whilst these benefits are well documented within the IVHM and servitization literature they are not fully attained within the practitioner base (Figure 4-25) and surprisingly less than half of those who responded to the survey and stated that the used the application conducted a formal assessment of the benefits that they achieved against expectation.

Finding 5: *Of the UK-based manufacturers targeted by this survey, and applying diagnostic and prognostic technology, more than half have experienced a gap between potential and realised benefits.*

Enablers and inhibitors of diagnostic and prognostic technology development and adoption

The survey also aimed to identify and understand which enablers and inhibitors were present when organisations sought to adopt IVHM generic technology applications. This was approached by investigation through two lens, they being factors which enabled or inhibited both the commercial and technical success of the adoption of the concept. The results returned by the survey are illustrated in (Figures 4-26 to 4-30). It is seen that achieving an understanding of the benefits of the application is the greatest enabler to commercial success closely followed by closer commercial relationships between organisations although the spread of the ratios of all factors identified is quite ‘balanced’ with a difference of only 9% being observed. This is also true when considering the enablers for the technical success of the initiative. When viewing inhibitors to both the commercial and technical success of the adoption of IVHM generic applications again it is seen that the spread of factors is relatively ‘balanced’. Again it is an ‘understanding of benefits’ which returns the highest percentage for all factors identified.

Finding 6*: Of the UK-based manufacturers targeted by this survey and applying diagnostic and prognostic technology, understanding the benefits to customers is of the greatest importance for the commercial success of diagnostic and prognostic capabilities.*

Characteristics of products and diagnostic and prognostic solutions

When reviewing the types of product manufactured by those organisations who responded to the survey it is seen that they are high value complex engineered offerings that meet the definition of a complex product (Section 4.2) which have a long service life and high installed base. In reviewing the data and as reported in our paper (Grubic et al., 2011) it is seen that "…..the majority of products….[are]…..military (21%), aerospace (18%), engines (23%)…[gas or piston]……[and]….have an average lifecycle of 10 years or more" (Grubic et al., 2011). It is also noteworthy that typically the products identified were recorded as having an installed base of between 1000-10000 units although 41% had an installed base which was greater than 10000. This could imply that there are minimum levels for a product's installed base which could become either an enabler or inhibitor to the adoption of the application.

Finding 7*: Diagnostic and prognostic technology is typically deployed onto a mechanical or electromechanical product with a long life-cycle and a high complexity.*

In addition to the level of installation of the product to the market the research aimed to understand the level of technology applied to the product and its use. The findings obtained were consistent to the content of the literature review relative to levels of technology application based upon the open system architecture in that 69% of applications dealt with fault detection, monitoring and diagnostics, with a minority dealing with advanced concepts of prognostics and decision support.

Finding 8: *Most often the technology has both on- and off-product components, which provide functionalities of monitoring, detection, diagnostic, and to a lesser degree, prognostic and decision support.*

Current success of diagnostic and prognostic technology development and adoption

The adoption of this technology into the product's installed base appears to be very young with 65% of organisations stating that they had experienced only satisfactory results. Of those organisations returning the survey 56% stated that the application was very relevant to the future success of their business which appears to demonstrate that there is growing interest in IVHM generic systems.

Finding 9*: Of the UK-based manufacturers targeted by this survey, and applying diagnostic and prognostic technology, more than half felt this capability was very relevant to their future but the majority rated their current success as only 'satisfactory.*

It is seen that the challenges to be met are varied when considering the adoption of this concept. These range from commercial, technological, and managerial (organisation, culture etc.). The easiest of these issues to address is that of technology (Chapter 2). The commercial/business issues however require far more work and require further understanding relating to the business case, cost model, the method of delivery for the service. Underpinning all of these concerns appears to be the need for a 'roadmap' which can guide the organisation to inform it's operating strategy when seeking to adopt this mode of operating .

Finding 10: *Realising the benefits of diagnostic and prognostic technology will require addressing a range of challenges and developing a set of capabilities that relate to the business and cultural domain rather than advances in technology*.

4.7 Conclusions

This chapter has obtained and presented knowledge relative to the awareness of IVHM within the UK manufacturing base by way of a survey which has been informed by the literature. The objective and method of this phase of the research has been presented (Section 4.1). The population of UK manufacturing organisations to be surveyed has been identified and defined using scholarly, auditable and repeatable methods (Section 4.2) with due consideration being made to the types of data to be obtained and suitable analytical methods (Section 4.3) prior to the design of the questionnaire. The methodology applied for the design of the survey has been discussed (Section 4.3) together with the detail of the survey design and execution (Section 4.4). The methodology employed for the analysis of the data returned and the results are presented (Section 4.5) and (Section 4.6) respectively.

Having obtained an understanding of IVHM, its generic principles (Chapter 2) and the level of practitioner awareness of the application (Chapter 4), the following chapter revisits the concept of servitization and introduces the service delivery system prior to giving insight and understanding of operations strategy and the various methodologies for its formulation.

5 EXPLORING OPERATIONS STRATEGY FORMULATION METHODOLOGIES AND SERVICE DELIVERY SYSTEMS

For manufacturing organisations seeking to respond to competitive pressures the research has introduced the concept of the Product Service System (PSS) and the process of *servitization* (Sections 1.1 and 2.1) as innovative approaches through which competitive advantage may be obtained. Both approaches seek to establish ‘whole life’ added value to stakeholders by offering varying levels of post sales service and support which can also include end of life incentivized disposal of the product. The ability to provide such novel initiatives has been facilitated by a paradigm shift in maintenance strategies from time based and reliability based systems to condition based maintenance (CBM) using condition based monitoring (CBM_1) and condition based management (CBM_2) techniques. Whilst there are many contributions to the literature relating to condition based maintenance the research has identified IVHM has a key enabler to the *servitization* of complex products (Chapter 2).

A review of the IVHM literature identifies that there are no methodologies offering guidance on how to achieve alignment between the needs of the customer relative to services, the organisational structure to adopt, or the level of technology to employ when seeking to deliver a *servitized* solution (Section 2.8, Gaps 4,5, & 9). This need is also identified within the practitioner base through the analysis of data returned through a survey conducted within a defined population of the UK manufacturing base (Section 4.6.1). It is these findings that have confirmed the research aim and objectives (Chapter 3).

This chapter seeks to introduce the product of *servitization* to the reader, namely the Service Delivery System (Section 5.1). The concept of *servitization* is further discussed (Section 5.1.1) and then the product of the process, the service delivery system (SDS) is discussed (Section 5.1.2). The second half of the chapter (section 5.2) explores several operations strategy formulation methodologies that are within the literature to gain insight into the tools, techniques, and considerations relative to the design and use of such methodologies. An overview of the chapter structure is presented in Figure 5.1.

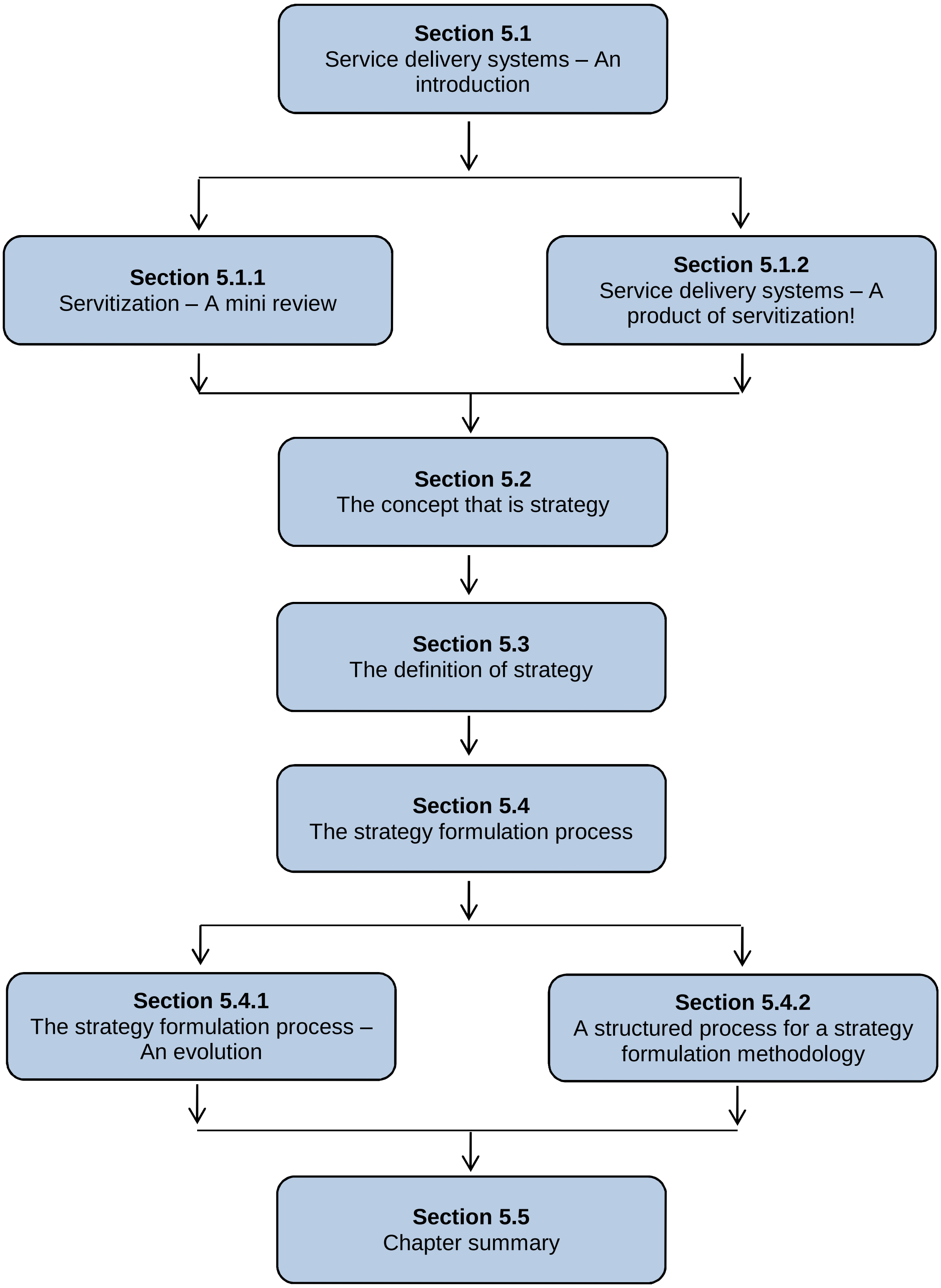


Figure 5.1 The structure of chapter three

5.1 **Service** delivery systems – An introduction

This section introduces the service delivery system as a product of the process of *servitization*. The service delivery system is an holistic solution to a service need which draws on managerial, organisational, and technical competencies which when applied together offer the ability to support the product in the field and the needs of the user/operator of the given product. An understanding of the concept of *servitization* and service delivery systems is required at this point of the research as the research aim (Chapter 3) is to develop and deliver a validated methodology which will "…..*inform the business and/or operational strategy of UK based manufacturing companies*". In developing this understanding a mini review of the literature relating to servitization is presented (section 5.1.1). This is followed by a discussion relating to the concept, identity and content of typical service delivery systems (Section 5.1.2).

5.1.1 Servitization – A review

The concept of servitization has been introduced earlier within this thesis (section 1.1, section 2.1, and in the introduction to chapter 5). However, these contributions have only offered brief references and referrals to this transitional process undertaken by manufacturing companies who seek to evolve their offerings from that of pure manufacturer to service provider or a hybrid of both. The research aim is to develop a decision framework that will inform the operations strategy of the organisation in seeking to achieve this transition either wholly or in part (Chapter 3). This section of the thesis discusses further the concept which is servitization and in the case of the following section (5.2), the product of servitization which is the *service delivery system*. This is achieved by a review of the literature relating to servitization and discussion of the concept in support of earlier work (Bandinelli and Gamberi, 2012; Martinez et al., 2010; Baines and Lightfoot, 2009; Neely, 2008; Almeida et al., 2008; Baines et al., 2007; Oliva and Kallenberg, 2003; Quinn et al., 1990; Vandermerwe and Rada, 1988). Whilst acknowledging that there are many more contributions within the literature relating to the concept, this section will base its discussion on the contributions cited.

The identification of servitization as being a 'powerful new feature of total market strategy' first appears in the literature in 1988 (Vandermerwe and Rada, 1988). The authors argue that in response to increasing competition and competitive forces "…it is no longer valid for ……[organisations]….to draw simplistic distinctions between goods and services or …[to]….assume that they…..[manufacturing organisations]….can do one without the other" (Vandermerwe and Rada, 1988). This view is common throughout all of the contributions (Oliva and Kallenberg, 2003; Baines and Lightfoot, 2009), (Neely, 2008) and is also well documented when reviewing the websites of organisations identified within the survey population identified earlier within the research (Chapter 4). The rationale for servitization offered by Oliva & Kallenberg is seen to be the consensus of opinion when reading further contributions, namely:

- "*Substantial revenue can be generated from an installed base of products with a long life,*
- *Services, in general have higher margins than products,*
- *Services provide a more stable source of revenue as they are resistant to the economic cycles that drive investment and equipment*
- *Customers are demanding more services………*
- *………services……….are more difficult to imitate thus becoming a source of competitive advantage*" (Oliva and Kallenberg, 2003).

Neely (2008) and Brax (2005) suggests however that this rationale is more simplistic and is purely based on improving competitive space by adopting (whilst not explicitly referring to it) an approach reminiscent of Porter (Bandinelli and Gamberi, 2012), namely:

i. Lock out competitors
ii. Lock in customers

iii. Increase differentiation

The literature offers several definitions for servitization however when analysed the contents of each definition are fundamentally the same. Table 5.1 offers an illustration (not exhaustive) of some of the definitions that are found within the body of the literature.

Table 5.1: Some definitions of servitization found in the literature (not exhaustive)

Vandermerwe & Rada (1988)	"…moving from the old outdated focus on goods or services to integrated 'bundles' or systems…..with services in the lead role"
Goedkoop et al (1999)	….a process of the combination of products and services together capable of meeting user needs
Tan & Gregory (2007)	"…a process of change of strategy where manufacturing companies opt for an orientation to services and/or develop more and better services with the goal of satisfying customer needs, obtaining competitive advantages and improving the company's performance"
Baines et al (2008)	"Servitization is the innovation of an organisation's capabilities and processes to shift from selling products to selling integrated products and services that deliver value in use".
Baines & Lightfoot (2009)	"Servitization is…widely recognised as the innovation of an organisation's capabilities and processes, to better create mutual value, through a shift from selling the product to selling Product Service Systems"
Bandinelli & Gamberi (2012)	"….the process of creating value by adding services to products"

The key point to note when reviewing the definitions is that *servitization* is seen to be a *transitional process.* It is the process of moving along a continuum which at one end resides the pure manufacturer and at the other one finds the pure service provider.

When considering the change drivers which result in servitization all contributions to the literature specify increased financial competition and to a lesser extent customer demand as key catalysts for this paradigm (Grubic et al., 2011; Neely, 2008; Baines et al., 2009b; Redding, 2011; Vandermerwe and Rada, 1988; Oliva and Kallenberg, 2003). However some authors also identify the evolution within the field of communications as a key driver to the adoption of added services to the product offering (Jennions, 2011; Baines, 2010; Neely, 2008; Quinn et al., 1990). Quinn et al propose that organisations are divided up into 'value chains' which focus internally on core competencies whilst subcontracting out other elements required to deliver the product and/or service offering. This is in stark contrast to earlier business models which saw vertical integration as the only way to provide service (e.g. Henry Ford and Ford Model T production) (Baines et al., 2011).

Organisations seeking to compete through advanced services do so by "….build[ing] their strategies not around products but around deep knowledge of a few highly developed core service skills" (Quinn et al., 1990). Although traditionally core competencies within the manufacturing organisation have been defined as the processes which facilitate direct manufactured value added, increasingly it is the supporting competencies that are becoming more of interest. Typically advancements in technology "…especially those associated with information and communication technologies" (Neely, 2008; Benedettini et al., 2009; Baines and Lightfoot, 2009). Neely cites $CBM_{1,}$ $CBM_{2,}$ and IVHM in particular as being noteworthy facilitators of servitization. However he goes on to state that "…servitization should not simply been seen as a variant of vertical integration, although clearly one way of adding services is through vertical integration" (Neely., 2008). The relationship between servitization and vertical integration is dealt with by on-going research which has been reported in a recent research note (Baines et al., 2011). Their research seeks to understand how the "pursuit of a services lead competitive strategy impacts the broader operations of a manufacturer" (Baines et al., 2011). They suggest that vertical integration is:

> "*taken as the extent to which a firm owns and takes responsibility for its upstream suppliers and downstream customers*" (Baines et al., 2011).

In conducting their research Baines et al suggest that vertical integration can be seen as being at two levels, they being:

- The macro level – forward or reverse vertical integration between companies, and
- The micro level – activities within the organisation itself (Baines et al., 2011).

In conducting their research they offer the following hypothesis:

> "Delivery of an advanced service contract is positively impacted by the vertical integration into capabilities for the subsystem design and production, as this ensures speed and effectiveness of response whilst minimising cost" (Baines et al., 2011).

These considerations become important when one takes an holistic view of a service delivery system and will be discussed further in the following section.

Section 5.1.2 Service delivery systems – A product of servitization

This section introduces the concept which is the service delivery system as applied to manufacturing organisations following the process of servitisation. It serves to inform the reader of the answers to the following questions:

i. What is a service delivery system?
ii. What does a typical service delivery system look like? (Design)
iii. How does a typical service delivery system operate? (Network)
iv. How does the service delivery system add value to its stakeholders? (Value)

v. What are the typical challenges that need to be overcome by the manufacturing organisation in seeking to adopt a service delivery system mode of operation? (Transformation).

Recent research (Tukker and Tischner, 2006) identifies that a Product Service System type business models can manifest themselves with differing levels of service integrated within them. For Baines et al these services may be categorised into three differing levels of service [Figure 5.2] (Baines & Lightfoot, 2012). At the base level one finds the pure manufacturer. This type of organisation has its core activity in the design and manufacture of its products and its relationship with its customers is purely transactional in nature. Typically such an organisation might offer bespoke spares and replacement equipment directly to the user (or independent maintenance/support business) on an ad hoc basis as it is approached for such. These organisations are found to the left of the servitization continuum and using Tukker's classification can be said to be pure product providers [Figuree 5.3] (Tukker and Tischner, 2006)

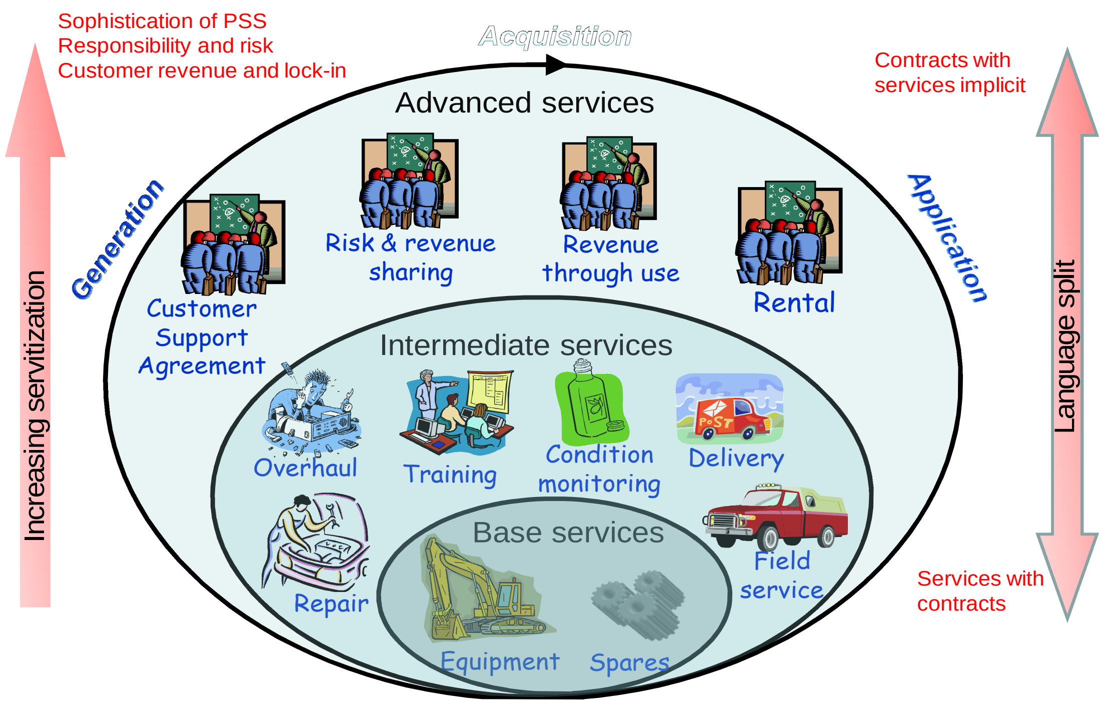


Figure 5.2: Increasing levels of service (Baines & Lightfoot, 2012)

The next level of service categorised by Baines et al is that of the intermediate level. Organisations within this level typically offer a more developed service which can include repair and service which can be either reactionary or preventative through warranty agreements etc. In addition training may be provided in product usage, service and repair. This is similar to that found within the automotive industry where product support can be through franchises, agencies and other third party/direct agreements. The emergence of condition monitoring ($CBM_{1,}$ $CBM_{2,}$ and IVHM generic technological applications) also emerge at this level although predominantly for monitoring rather than management of the product or asset. Such solutions would enable product oriented PSS business models to develop [Figure 5.3].

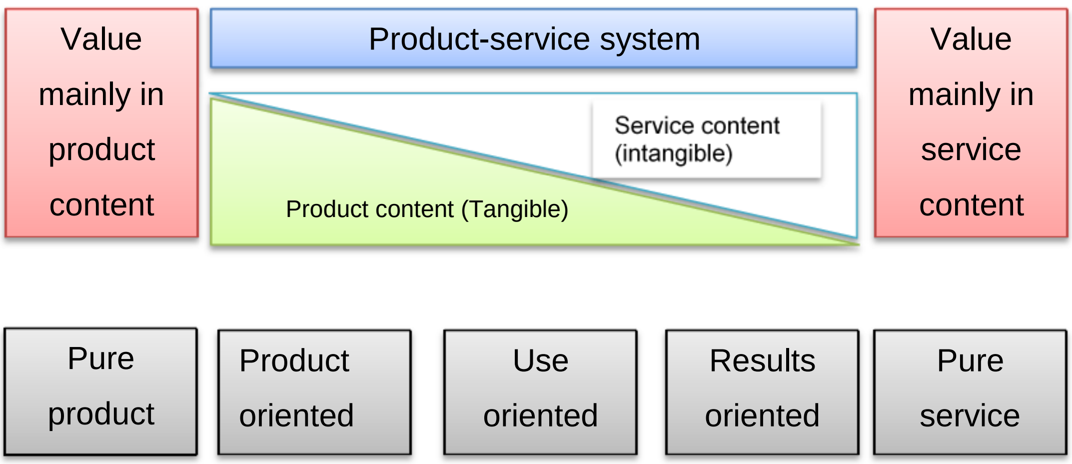


Figure 5.3: Categories and sub categories of product-services (Tukker and Tischner, 2006)

Finally there are the advanced services which include integrated customer support agreements, advanced rental and leasing solutions, and the facilitation of availability contracting as innovative solutions.

It is important to realise here that there are direct links between the levels of service offered by the organisation and the ability to offer alternative Product-Service business models. Service has to be delivered in real time (or as close to it as possible) in-order to facilitate these innovative business solutions. This relationship between the level of service, business model and the physical infrastructure that delivers the service, this research identifies as the *service delivery system*. There appears to be very little (or no) contributions within the literature seeking to understand the design, operation, and drivers for service delivery systems (Ponsignon et al., 2012) facilitated and driven by technology although there are examples referred to within the literature (Chapter 2).

Ponsignon et al state that there have been a plethora of contributions which seek to define and characterise services as distinct from manufacturing but "…unifying the field of services has been an enduring challenge and some semantic confusion remains about…." What is a service? (Ponsignon et al., 2012). In seeking to clarify this area these authors suggest that:

1) "Services can be thought of as a whole industry that encompasses an number of ….sectors,
2) Service can be seen as an outcome…. "What the customer receives" (Mohr & Bitner, 1995)….
3) A service can be described as a process…. "the manner in which the outcome is transferred to the customer" (Mohr & Bitner, 1995; Ponsignon et al., 2012).

In offering these three functions of a service Ponsignon et al suggest that "defining a service as a process has significant implication[s] from a service operations management perspective since the process view is seen as the dominant paradigm" (Ponsignon et al., 2012)".

Service delivery systems can exist at various levels ranging from organisations who manufacture goods and offer MRO facilities for their products to those offering full product support solutions whereby the supplier owns the product and carries the risk to revenue streams due to product degradation and failure, the user only paying for product use or availability for use. In seeking to design and define an operations strategy that will deliver an effective service delivery system an integrated holistic approach is required considering the needs of the customer, the level of service, and the system of delivery.

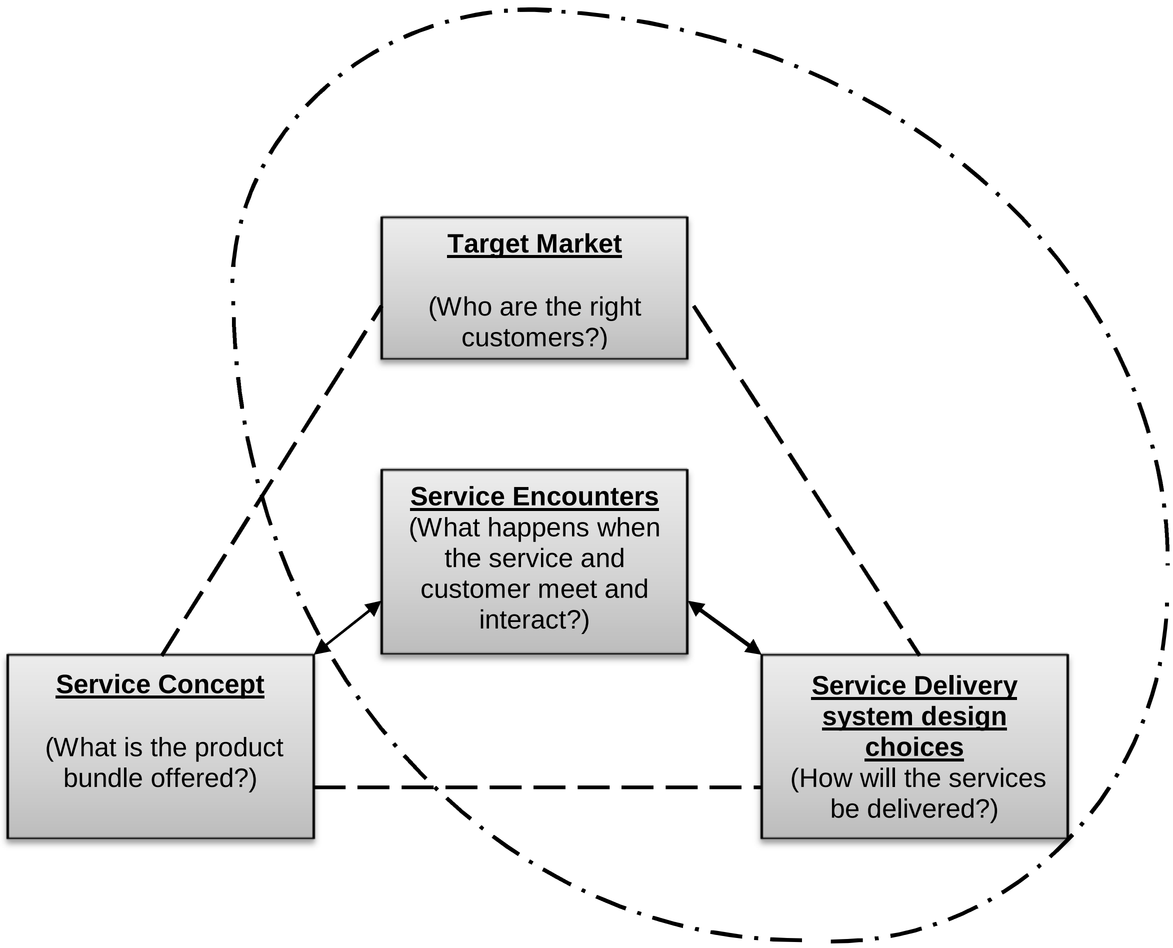


Figure 5.4: Looking at the big picture: the service strategy triad

(Ponsignon et al., 2012)

The questions arising for the organisation when deciding how far along the servitization continuum to travel are illustrated within figure 5.4 above. The answer to these questions and the resultant offering that delivers the service is the service delivery system. A good service delivery system possesses knowledge of who the real customers are and the exact requirements that need to be fulfilled. To put it simply it offers what the customer/user wants, when he wants it and also by a means that meets the expectation of the customer. For the organisation knowledge of what mix of product/service bundles to offer is also essential so as to ensure that these expectations are aligned with the competences of the business and/or its strategic partners. In addition the organisation needs to ensure that it has the correct infrastructure to deliver the service at the required time and place. The fulfilment of all these parameters define the service delivery system. It is the achieving of this alignment that is the goal of an effective operations strategy and the development of such a decision framework/methodology to inform such a strategy is the aim of this research.

This section has informed the reader of the concept that is servitization and that of the service delivery system. The following sections will give consideration to the concept of strategy itself and also seek guidance from some of the contributions within the literature relative to the processes used to inform operations strategy.

5.2 The concept that is strategy

The concept of strategy is not new. It finds its emergence within the military arena with the first contribution to the literature appearing in the “Art of War” written by Sun Tzu over 2500 years ago. A formal interest in the concept of strategy within the management arena first appears in the 1960’s with the appearance of Chandler’s “Strategy and Structure: Chapters in the History of Industrial Enterprise” (Chandler, 1962) and Ansoff’s “Corporate Strategy” (Ansoff, 1965). Since these early introductions there have been a plethora of contributions to the literature offering different ‘schools’ of thought relating to both strategy formulation and formation (Asmussen, 2007; Mintzberg et al., 1998). For Mintzberg this distinction manifests itself as *formulated* strategies being ones which are ‘intended’ or ‘deliberate’ strategies, whereas *formation* of strategy is the product of actions which facilitate ‘emergent’ strategies to develop (Mintzberg et al., 1998). This is eloquently demonstrated by the oft cited illustration in Figure 5-5. The author would assert at this point that it is Mintzerberg’s classification of formation of strategy which is the most significant for this research as any developed strategy that is the result of a formation methodology should be aligned to the drivers acting upon both the organisation and the process itself (ergo: it should allow emergence of initiatives and there assessment and possible adoption as they arise throughout the process).

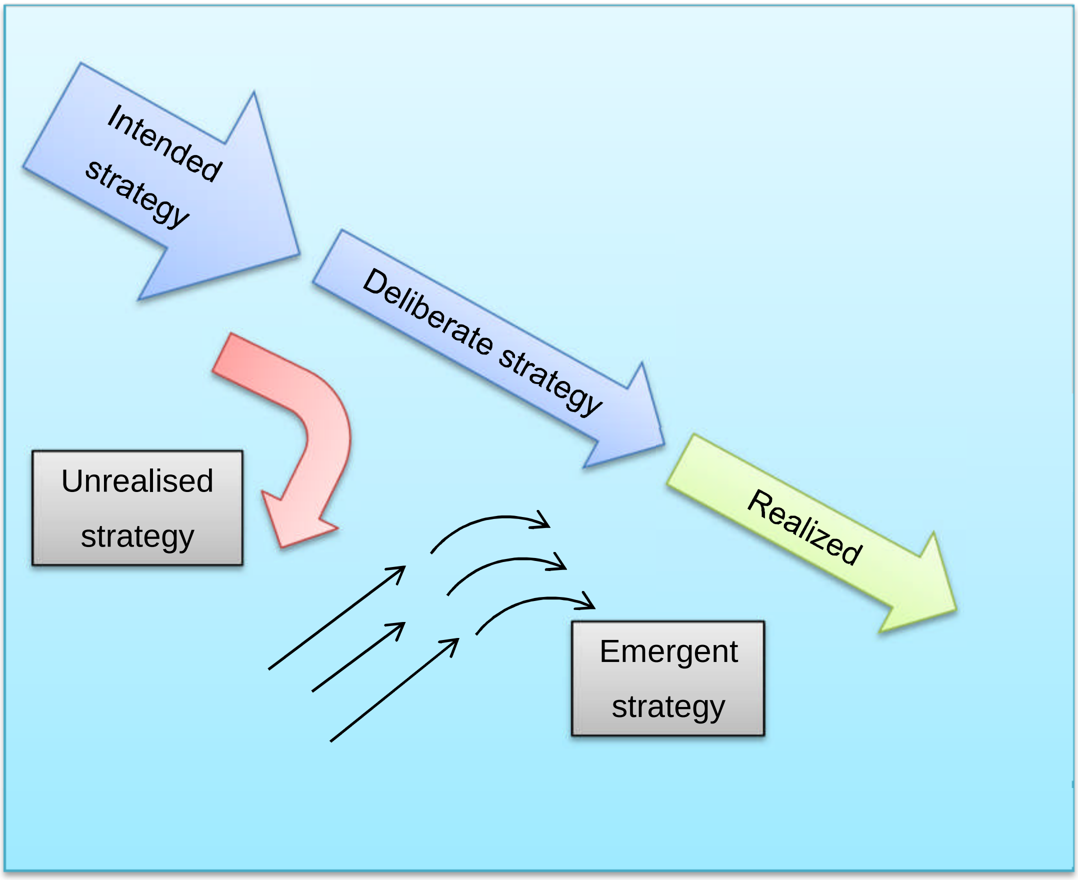


Figure 5.5: Strategies deliberate and emergent (Mintzberg et al., 1998)

Further contributions to the literature seek to define the elements that comprise the study of the strategy concept. Pettigrew et al (1993) and Petigrew (2004) refer to the dimensions of strategy in stating that any study of the concept should be approached through the lens of either/or content, context, and/or process (Figure 5.6).

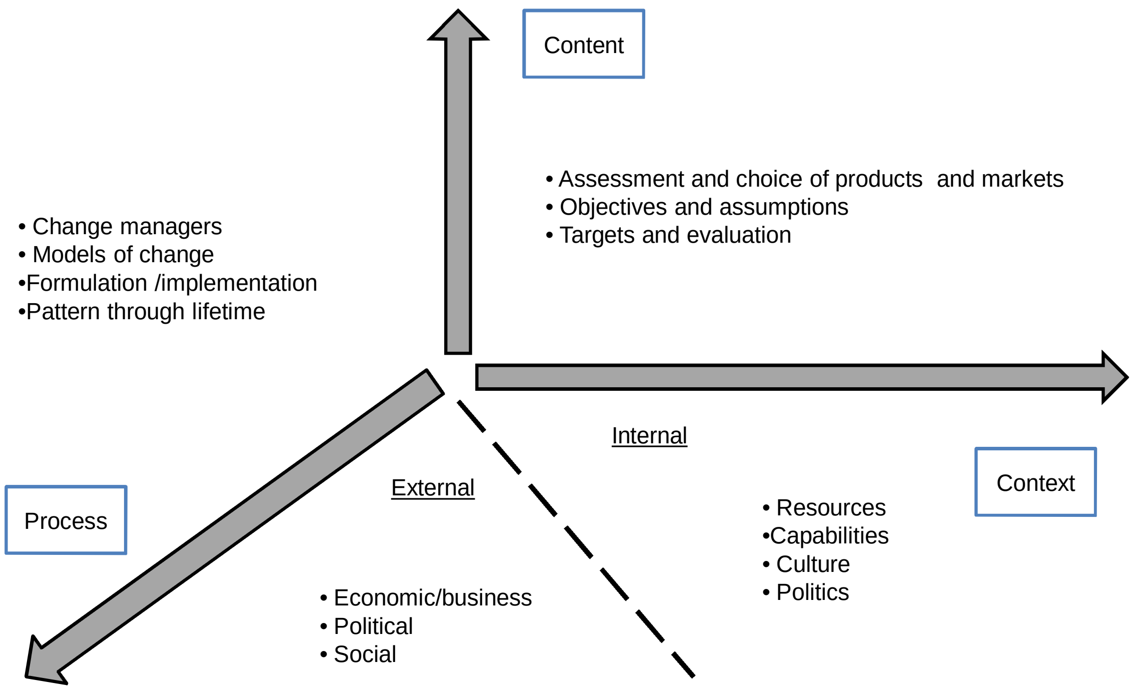


Figure 5.6: Understanding the dimensions of strategy [Adapted] (Pettigrew, 2004)

The literature also proposes that strategy exists at three differing levels (Hofer and Schendel, 1978; Wheelwright, 1984; Hunger and Wheelen, 2007), namely:

- Corporate strategy
  - The sector in which the organisation operates
  - Resource acquisition and apportioning throughout the organisation
- Business strategy
  - Boundaries of the business to be served
  - Identification of the competitive space in which the organisation will operate
- Functional strategy
  - Basis on which the organisation will achieve the competitive advantage

- o Integrating cross departmental functions and interfaces to achieve competitive advantage (Asmussen, 2007)

The aim of this research (Chapter 3) is to deliver a decision methodology that will assist in the formation (process of forming strategy) of an operations strategy for business level strategy whilst acknowledging that in some SME's an operating strategy can be common to all three levels cited. Having introduced and discussed the concept that is strategy the next section offers an identity (definition).

5.3 The definition of strategy

The literature has many contributions which have sought to define strategy. When reviewing the Collins Dictionary one finds the following;

> *"Strategy ….**1**. the art and science of planning and conduct of war. **2**. A particular long-term plan for success esp. politics, business etc. **3**. A plan or stratagem. [from F. strategie, Gk. Strategia – function of a general]…."* (Collins English Dictionary – 2007)

Mintzberg et al (1998) state that strategy is "a pattern that is consistent behaviour over time" (Mintzberg et al., 1998). The significance here is that the word pattern implies consistent repetitive behaviour and his statement informs that this behaviour is exhibited over a prescribed period. For Druker "…it is the theory of doing business" (Mintzberg et al., 1998). In furthering their definition Mintzberg et al state that for some strategy is *positional* in that it seeks to position the organisation's offering [products but could be services] within specified markets. For other contributors they suggest that strategy is a *perspective* in that it defines the "….fundamental way of doing things" (Mintzberg et al., 1998) within the organisation. Whilst both these approaches to a definition are equally valid this research suggests that the most effective strategies are the ones which take a hybrid position between these two viewpoints. In identifying these approaches Mintzberg et al propose that there are four definitions, namely:

- Strategy as an old position and old perspective
    - (Existing product position and methods)
- Strategy as an old position and new perspective
    - (Existing product position and new methods)
- Strategy as a new position and old perspective
    - (New products and existing methods)
- Strategy and a new position and new perspective
    - (New products and new methods)

They also point out that strategy can also be used as a ploy so as to induce a response within the market place by competitors.

Since the introduction of strategy as a managerial concept within an industrial setting (Chandler, 1962) most contributions seek to offer a definition for the concept. When reviewing the definitions identified (Table 5.2) there appears a common theme throughout. For Chandler (Chandler, 1962) and Kurien et al, long term goals and the allocation of organisational resources are key to his assessment. For other authors (Skinner, 1969; Porter, 1979; Porter, 1980; Quinn et al., 1990; Hayes et al., 1996) strategy is defined by sets of policies, sequences, and methods (Mintzberg et al's *perspective* approach) (Mintzberg et al., 1998).

Table 5.2: Definitions for strategy identified within the literature (1/3)

Author	Definition
Chandler (1962)	"....the determination of the basic long term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary to carry out these goals"
Skinner (1969)	".....a set of plans and policies by which a company aims to gain advantage over its competitors"
Porter (1980)	" ...strategy is a combination of the *ends* (goals) for which the firm is striving and the *means* (policies) by which it is seeking to get there"
Quinn (1980)	"...pattern or plan that integrates an organisation's major goals, policies and sequences into a cohesive whole"
Hayes & Wheelwright (1984)	"...a...... strategy consists of a pattern of decisions affecting the key elements of a ....[business] ... system".
Mintzberg (1987) and Mintzberg et al (2003)	"As a plan, strategy is some sort of consciously intended course of action, a guide to deal with a situation. As a ploy, strategy is a specific manoeuvre intended to outwit an opponent or competitor. As a pattern, strategy is a stream of actions demonstrating consistency in behaviour, whether intended or not intended. As a position, strategy is a means of locating the organisation in an environment. As a perspective, strategy is a concept or ingrained way of perceiving the world".

Table 5.3: Definitions for strategy identified within the literature 2/3

Author	Definition
Kerin et al (1990)	"...a fundamental pattern of present and planned objectives, resource deployments, and interactions of an organisation with markets, competitors, and other environmental forces."
Hax (1990)	"Strategy is a fundamental framework through which an organisation can asset its vital community while, at the same time, purposefully managing its adaption to the changing environment to gain competitive advantage. Strategy includes the formal recognition that the recipients of the results of a firm's actions are the wide constituency of stakeholders. Therefore, the ultimate objective of strategy is to address stakeholders' benefits – to provide a base for establishing the host of transactions and social contracts that link a firm to its stakeholders".
Platts and Gregory (1990)	"...a pattern of decisions, both structural and infrastructural , which determine the capability of a .... [company]..... and specify how it will operate in order to meet a set of..... objectives and which are consistent with the overall business objectives".

Table 5.4: Definitions for strategy identified within the literature 3/3

Author	Definition
Greenhalgh (1991)	"...strategy is not just about technology. It is also about people,....... direction,...... and focus. Apart from providing direction and focus a..... strategy also provides the vehicle to communicate to all levels of the organisation across all divisions just what the .... [organisation]..... is trying to achieve and how it intends to do it".
Johnson and Scholes (2002)	"Strategy is the direction and scope of an organisation over the long term which achieves advantage for the organisation through its configuration of resources within a changing environment and to fulfil stakeholder expectations.
Slack et al (2007) p63	"....concerns a pattern of strategic decisions and actions which set the role, objectives, and activities of the operation".

When reviewing the definitions offered within the literature in the table above this research offers the following definition the strategy concept:

> *Strategy is a determined, deliberate, or emergent (responsive) plan of actions and responses that aligns stakeholder drivers and organisational competencies in order to position the offerings of an organisation to achieve maximum competitive advantage.*

This section has identified and reviewed some of the definitions offered within the literature. This review has resulted in an holistic overview of those definitions offered from which this research offers a definition which is informed by the previous contributions. Having discussed the identity and definition for strategy the following section will look at the process for the formulation of an operations strategy.

5.4 The strategy formulation process

This section of the thesis discusses the process for the formulation and formation of an effective operations strategy. In so doing the section is divided into two sub sections. The first sub section (5.4.1) will give a brief overview of the evolution of the strategy formulation process, whilst the second sub-section (5.4.2) will review the structured process for a strategy formulation methodology.

5.4.1 The strategy formulation process – An evolution

In their research paper Mills et al state that "….fully identifying and representing a firm's manufacturing strategy is not a trivial matter: difficult issues are met…… What definition of strategy is being used? Whose perception of strategy is being taken? And how might the validity and comprehensiveness of the description be assessed?" (Mills et al., 1998). All these issues require careful consideration when seeking to inform operations strategy within the business. For the author the key word is '*alignment*'. When seeking to define a strategy there needs to be clear understanding of objectives (those of the organisation – *raison-d'etre*) and the needs of the customer (and stakeholders). It is essential that these are aligned and that the result of such an alignment can be met by the competencies of the organisation. The objective has to be clearly defined (and agreed) so that comprehensiveness and validity of the resultant strategy may be assessed. However, Mills et al cite Swamidass (2001) when stating that "manufacturing…. [and operations]….strategies in most firms were neither visible nor obvious" (Mills et al., 1998). In seeking to achieve such an understanding it becomes important to understand not only the content of strategy but also how such strategies are developed.

The literature offers very little by way of contribution to the understanding of strategy formulation processes from the early contribution from Skinner (Rusjan, 2005) although there is an awakening to this need within the literature. In their study of contributions to the literature relating to manufacturing strategy, Dangayach and Deshmuch (Anderson et al., 1991) reviewed 260 papers and classified them into content and process related issues. Of the 260 papers reviewed, 237 (~91%) related to the content of strategy with very little addressing the process issues. This continues to be the case with process related research only being addressed by few authors (Platts et al., 1998; Platts and Gregory, 1990; Platts, 1993; Platts, 1994; Platts et al., 1996; Platts and Tan, 2004; Tann and Platts, 2005; Tan and Platts, 2003; Mills et al., 1996; Mills et al., 1998; Baines, 1994; Baines, [Unpublished]; Baines et al., 1988; Baines et al., 2009a; Redding, 2011; Redding et al., 2010; Asmussen, 2007; Maslen and Platts, 1997).

The process of defining an operating strategy is a process which "describes …[and]…or prescribes a way by which the ….organisation creates strategy" (Maslen and Platts, 1997). Of the contributions dealing with the process of creating strategy Asmussen in his recent work states that such contributions are classified into those which offer descriptive works on such processes and those which discuss prescriptive offerings for "..the formation and formulation of….strategy" (Asmussen, 2007). He informs that the literature is further divided into those contributions which discuss the strategy process as a formation process and those that address the subject from the formulation perspective. In clarifying this distinction he states that the literature focusing on formulation processes address and describe the overall process by way of frameworks and operationalized processes. Again, a definition of the two classifications are offered:

- A framework – "…a conceptual structure which describes the main ideas of how to create a ….strategy"

- An operationalized process – as a framework but "…..provides the steps and tools for each step….. [or the process, which]….. might even include worksheets" (Asmussen, 2007)

Skinner (1969) and Wheelwright and Hayes (1979) offered the early frameworks but the first operationalized framework was presented by Fine and Hax (1985). Since then there have been few contributions relating to operationalized processes but of those that have appeared they have emerged in silos with the main contributors being Cambridge University (Platts et al., 1998; Platts and Gregory, 1990; Platts, 1993; Platts, 1994; Platts et al., 1996; Platts and Tan, 2004; Tann and Platts, 2005; Mills et al., 1996; Mills et al., 1998), Cranfield University (Baines, 1994; Baines, [Unpublished]; Swamidass et al., 2001; Baines et al., 1988; Redding, 2011; Redding et al., 2010; Ellson, 2002).

This research will seek to develop and operationalized process to meet its aim.

5.4.2 A structured process for a strategy formulation methodology

This sub section defines what is meant by a structured process relative to the research and seeks guidance from previous contributions to the literature relative to strategy formulation processes. In seeking clarity of task two definitions are sought, namely:

- Structure:
    - *Noun – the arrangement of and relations between the parts or elements of something complex*
    - *Verb – construct or arrange according to a plan; give a pattern of organisation to*
- Process:
    - *Noun - a series of actions or steps taken in order to achieve a particular end*

- *Verb - perform a series of mechanical or chemical operations on (something) in order to change or preserve it* (ref:- Oxford Dictionary)

In consulting the literature to obtain insight as to the previous offerings for structures and processes for the development of strategy "…there appears to be no single universal process for ….strategy development" (Swamidass et al., 2001). Skinner (1969) stated the one of the reasons why manufacturing organisations fail to have coherent manufacturing strategies is that "there is no textbook or article that would help manufacturing managers make strategic decisions to meet manufacturing strategic objectives" (Rusjan, 2005). Subsequent contributions are now starting to emerge which seek to fill this gap. The contributions to this area are few and this research refers to Swamidass et al, (2001), Platts et al (1998); Platts and Gregory (1990); Platts (1993); Platts, 1994) Mills et al (1998:1995) and Baines et al (1994:1988) for guidance.

Platts (1994) suggests that a when developing a methodology for the formulation of strategy four considerations should be made (Table 5.5). They go on to state that "..to be useful a process should specify how an organisation might be attracted to implement the process; who should participate in the process and how the project of implementing the process should be managed" (Mills et al., 1995).

Swamidass et al state that traditionally the formulation and development of strategy is achieved by "…matching manufacturing structure and infrastructure with business strategy through a formal planning process" (Swamidass et al., 2001). This reflects the opinion of Skinner (1969). They assert that this is essentially a top down approach to the formulation of a planned or deliberate strategy and makes little prevision for emergent strategy as introduced by Mintzberg et al (1995).

Table 5.5: Strategy formulation process considerations (Platts, 1994;Mills et al., 1995)

Point of entry	"It is necessary for the strategy process to provide a method of entry into the company …..and provide a platform to develop the understanding and agreement of the managing group"
Participation	This is the identification of who should participate in the strategy formulation process. Can be viewed as: • Width – who across the organisation should be involved • Depth – what level of staff should be involved • Position – should external stakeholders be involved in the application of the methodology/process
Procedure	Typically a three stage process: a) Audit current strategy against a set of objectives b) Formulation of a set of actions defined to address gaps identified in a) above c) Implementation of the action plans
Project management	Ensure that there are adequate resources and a well-defined time line for the completion of the process.

When reviewing the processes cited in (table 5.6) it becomes clear that they are all generically similar in structure when viewed through Platts' lens. There first needs to be a 'hook' at the point of entry that illustrates the need for the exercise and more importantly convinces the strategy team to continue with the process. All processes start with providing an awareness (if it did not exist) of the current strategic situation. This takes the form of either competitive profiling (Hofer and Schendel, 1978), developed arguments (Cohen and Cyert, 1973), or the formation of an issues statement detailing focus of the strategy study, issues to be resolved and the time line (Baines, 1994; Baines, [Unpublished]).

Table 5.6: Comparison of some leading contributions to the strategy formulation process

	Hoffer and Schendel (1978)	Baines (1994)	Mintzberg (2000)	Cohen & Cyert (1973)
Point of entry	• Competitive profiling	• Strategic positioning • Issues statement		• Develop arguments
Participation	• Marketing • Manufacturing • Balance skill and experience • Political heavyweights • External facilitators	• Directly – Internal executives and senior functional managers • Indirectly – external stakeholders	• Chief executive • Personnel who can fulfil one or all of four defined roles	• Coalition of top management
Process	1. Define corporate objectives 2. Select product families 3. Internal audit 4. External audit 5. Analyse gap between actual and desired performance 6. Prioritise the issues 7. Propose and evaluate 8. Implementation	1. Confirm how company competes 2. Conduct gap analysis between actual and planned competitive space 3. Establish decision criteria 4. Rank decisions 5. Implement strategy	1. Objective setting stage 2. External audit stage 3. Internal audit stage 4. Strategy evaluation stage 5. Strategy operationalization stage	1. Formulation of goals 2. Analysis of the environment 3. Assigning quantitative values to the goals 4. The micro process of strategy formulation 5. The gap analysis 6. Strategic search 7. Selecting the portfolio of strategic alternatives 8. Implementation of strategic program 9. Measurement feedback and control
Project management	• Adequate time scale • Resources	• Workshop • Facilitator • Several days • 5 years plus		

The authors cited in the above table broadly agree when addressing Platts' second point, namely who should participate? It is seen that representatives should participate from a broad spectrum of roles and functions. A balance of both internal perspectives is advocated and sought by some (Baines, 1994) (Hofer and Schendel, 1978) whilst Cohen and Cyert suggest a coalition of senior managers address the issue. This illustrates a contrast in approaches as implied within Cohen and Cyert's paper is a top down approach to the application of the strategy process, whilst Hofer et al, Baines, and Platts advocate a more balanced approach which when studied facilitates emergent strategies to appear which could be the product of any of Slacks's four perspectives of strategy (Figure 5.7) (Slack et al., 2007).

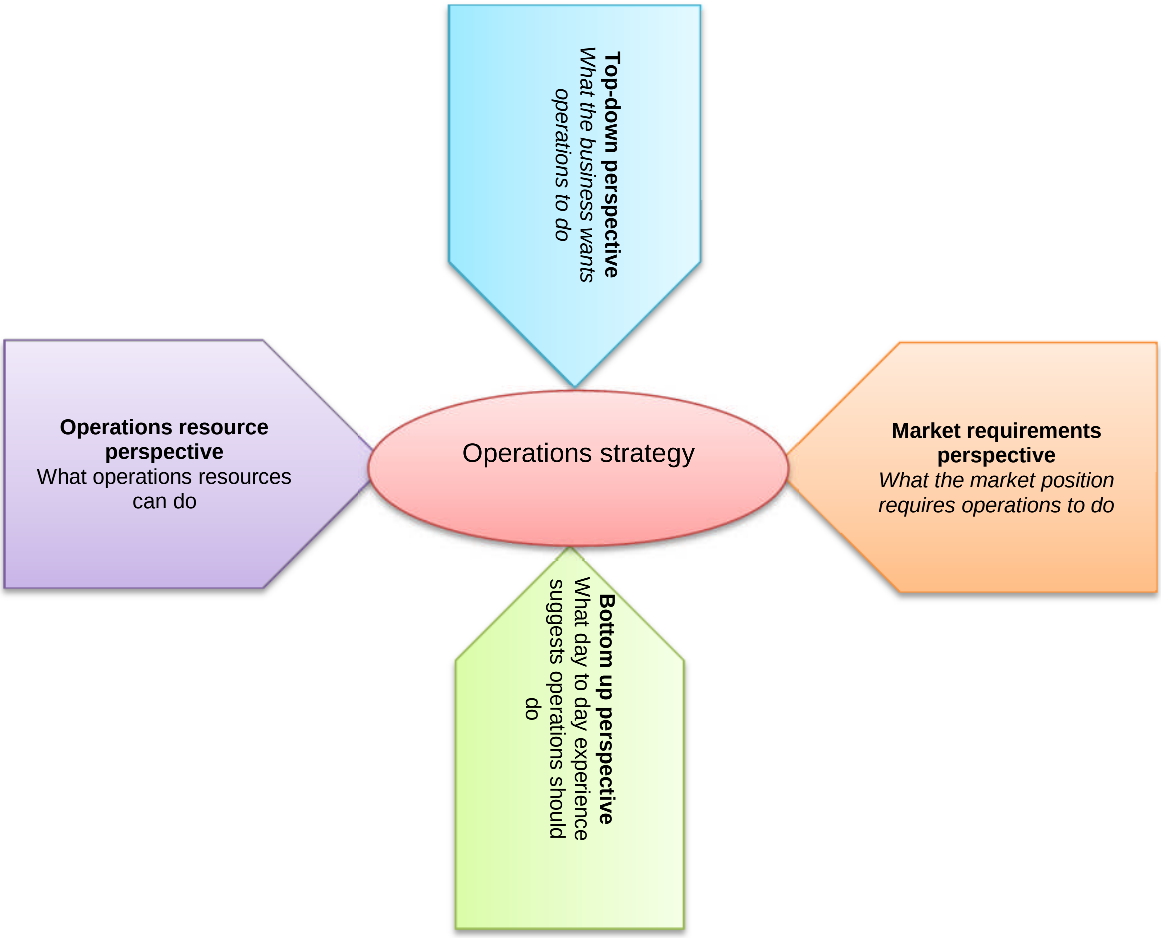


Figure 5.7: The four perspectives on operations strategy (Slack et al., 2007)

It is noteworthy that Mintzberg does not offer insight into who should participate in the process in the publication cited but does offer four roles for strategy "planners", they being (i) Finders of strategy, (ii) Analysts, (iii) Catalysts, and (iv) strategists (Mintzberg, 2000).

When looking at the processes offered by the literature it is seen that each contribution offers a sequential but iterative process that can be summarised in four distinct steps:

- Obtain situational awareness
- Identify performance gaps against planned/expected objectives
- Choose which initiatives to follow
- Disseminate the chosen strategy

Finally one arrives at Platts' project management. Here there are several perspectives observed. For Platts (1994;1996), Mills et al.,(1995) and Baines (Baines, 1994; Baines, [Unpublished]) they make the point that it is essential that sufficient time is devoted to the strategy formulation process. Typically this ranges from a couple of days to a week and is delivered via a workshop or workgroup remote from the normal operational function. This view is also revealed when analysing the survey of practitioners (Chapter 4). In addition the use of a facilitator is also seen as preferable (Baines, [Unpublished]; Swamidass et al., 2001), (Chapter 4). The final presentation of the developed strategy receives little coverage within the process strategy literature although there are innovations with QFD (Baines, [Unpublished]) and computerised processes (Tann and Platts, 2005).

This section has given a brief overview of the literature relating to strategy formulation, its evolution and process. The following section offers a summary of this chapter and signposts the next phase of the research.

5.5 Chapter summary

The chapter has revisited the concept of servitization (section 5.1.1) and then introduced one of the products of the servitization process, namely the service delivery system (section 5.1.2). The presentation of these sections at this stage of the thesis is seen as important by the author as the research aim seeks to deliver a decision framework/methodology (Chapter 3) which will assist the manufacturing organisation progress along the servitization continuum thus delivering an effective enhanced service delivery system. This progression will undoubtedly have an effect upon the operations strategy of the organisation as the application of the research deliverable will facilitate the assessment of intended strategy whilst not being so constrained as to restrict emergent strategies from being identified and considered. For this reason the research paused to gain guidance from the strategy literature. An understanding of the identity of strategy is offered by discussing it as a concept (section 5.2) and then seeking its definition (section 5.3). It has been seen the study of strategy can take place in one or several of three dimensions, namely *content, process* or *context*. This research falls within the strategy as a *process* dimension. The literature has been consulted in order to understand the evolution of the strategy formulation process (section 5.4.1) and then to seek guidance relating to structure of previous strategy formulation processes (section 5.4.2). The following chapter describes the adoption of an existing methodology as a pre-pilot, its testing and re-design so as to formulate a pilot methodology to satisfy phase 3 of the research (section 3.3.1).

6 FORMULATION OF PILOT METHODOLOGY

The research has introduced the concepts of the Product Service System and Servitization as methods by which manufacturing organisations may maintain and improve their competitive positions (Chapter 1). It has also been shown that the adoption of intelligent products offer the ability of real time product condition monitoring, diagnostic and prognostic capabilities which in turn can facilitate innovative maintenance, logistics and operational solutions (Chapter 2). The survey of UK based manufacturers whilst concurring the state of the art in integrated vehicle health management (intelligent products) confirmed and raised further points of interest (Chapter 4). This research has chosen to focus upon the need for a decision framework which can assist manufacturing organisations develop an operations strategy which aligns stakeholder needs and service/intelligent product offerings (Chapter 3). Such an operations strategy would deliver an effective service delivery system. The service delivery system and the concept of operations strategy techniques have been discussed in (Chapter 5).

This chapter fulfils phase three of the research programme. The formation/adoption of the pilot operations strategy formulation methodology discussed. The objective and method of achieving this phase of the research is presented (section 6.1). An existing strategy formulation tool is adopted as a *pre-pilot* study and discussed in (section 6.2). An evaluation of the performance of the adopted pre-pilot methodology is conducted by application and critique within two major manufacturers within their respective industrial sectors (section 6.3). The results of this evaluation are presented (section 6.4) followed by an analysis and discussion of the findings and observations resulting in a statement of requirements and specification for the *pilot* methodology (section 6.5). A summary of the chapter is presented (section 6.6) and the chapter structure is illustrated in figure 6.1.

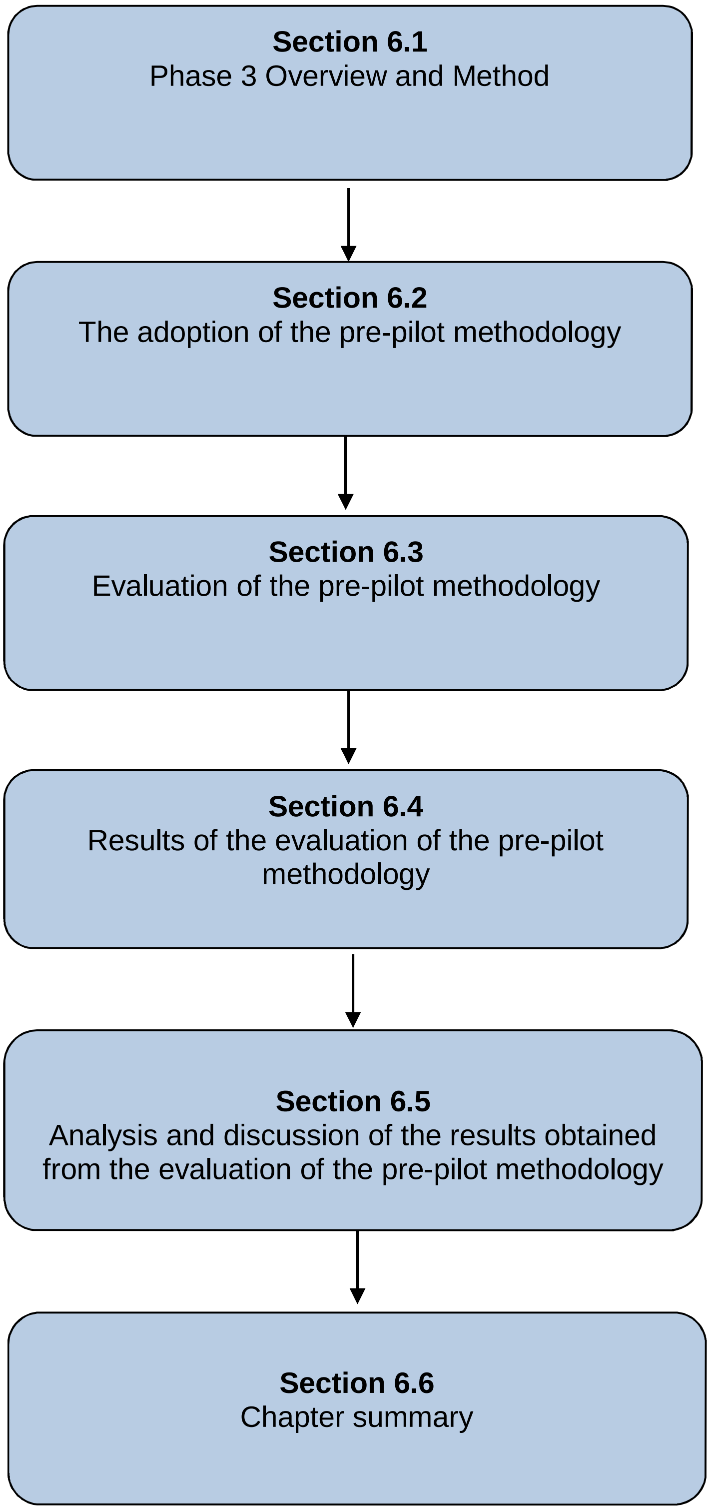


Figure 6.1 Structure of chapter six

6.1 Phase 3 overview objective and method

This section of the thesis discusses the objective and method followed in order to meet phase 3 of the research programme, namely the formulation of the pilot methodology. This is achieved by the adoption of an existing strategy formulation framework and its application to two industrial cases in order to observe its performance and ease of use. The chapter will present the adopted *pre-pilot* methodology (section 6.2) and through its application and assessment from academics and industrial experts in the field, a set of requirements will be established from which a specification for a pilot methodology is generated. The process for developing the specification for the pilot methodology is illustrated in figure 6.2.

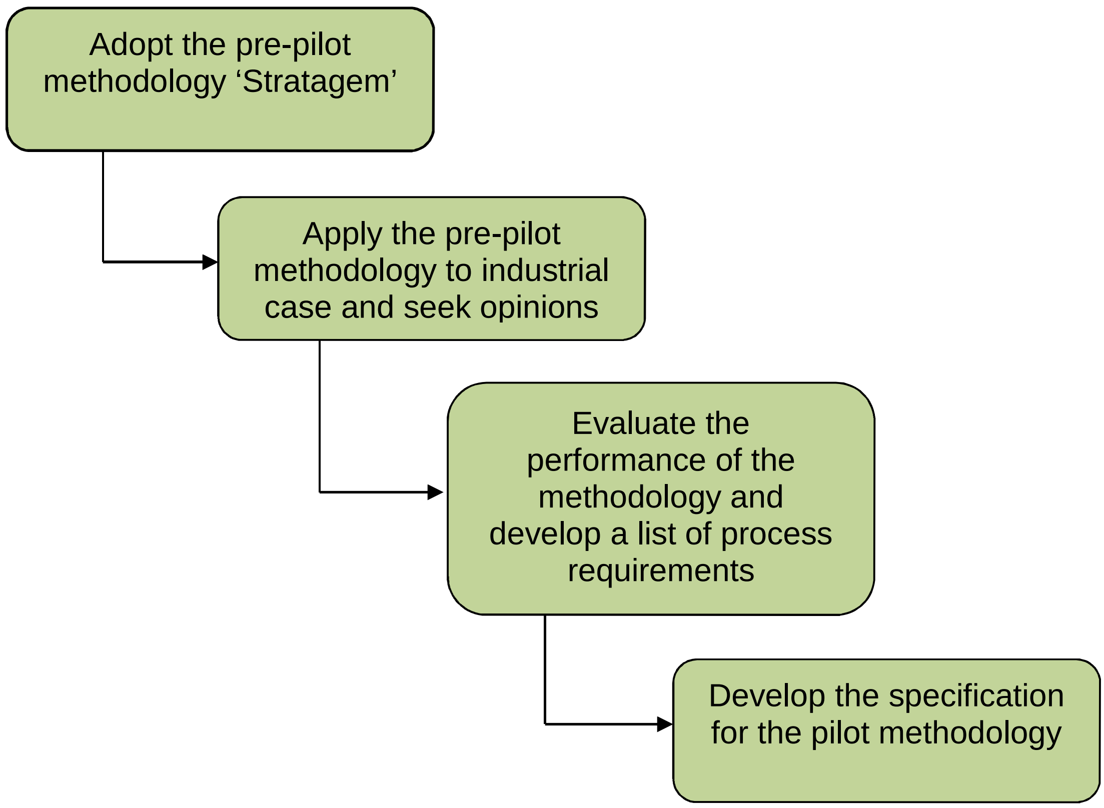


Figure 6.2 Process for developing the specification of the pilot methodology

6.2 The formation/adoption of the pre pilot 'Stratagem' methodology

Chapter 5 has presented the concept of operations strategy formulation techniques and discussed some of the various contributions which may be found within the literature. All the contributions, whilst valid offer no 'fit' when seeking to align the level of services to be offered and integrated vehicle health management generic technologies to deliver an effective service delivery system. The development of such a methodology requires a starting point and this research adopts the Stratagem methodology as its starting point for this development. The choice is opportunistic as this method was being used in parallel research relating to operations strategy by Cranfield University. The research could have chosen any of the methodologies listed within the literature as its starting point and applied the same development process to be followed. The ability to observe the testing and implementation of this methodology provided a unique opportunity to assess its merits and record areas which would require modification in order to provide a methodology which could deliver the required solution. This section presents the *Stratagem* methodology

6.2.1 Overview of the pre pilot 'Stratagem' methodology

The objective of this section is to present an overview of the pre pilot Stratagem methodology. This is achieved by describing the framework in terms of its structure and the stages within each phase of the structure. The section initially offers the overview of the structure of the framework with the subsequent subsections explaining each stage of the process. A four phase strategy formulation framework is adopted (Figure 6.3). The principle objective of the methodology is to guide practitioners through the process of formulating a strategy in response to an holistic understanding of existing or emergent forces acting upon the organisation.

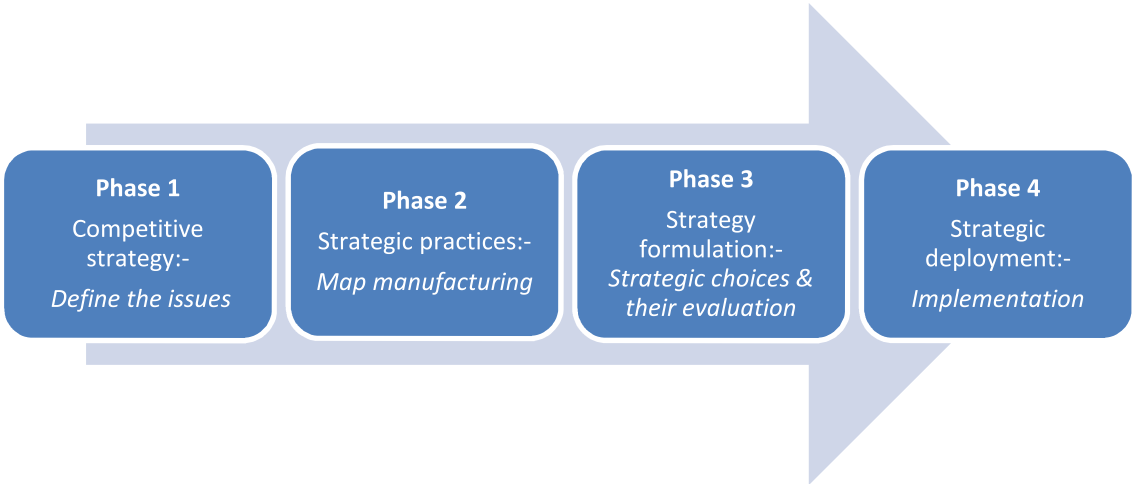


Figure 6.3: The stratagem formulation framework [Adapted] (Baines, Unpublished)

The phases of the methodology assume a sequential progression which facilitates an iterative approach to its application. The subsections following provide an overview of the four phases of the Statagem framework and associated sub-tasks within each phase.

Phase 1: Competitive strategy – Define the issues

In seeking to formulate strategy it is important to understand how the organisation actually competes. This can be a complex mix of varying strategies across the organisation with companies often having differing strategies based upon the manufactured product. For example, typically within the automotive industry, it is seen that differing strategies emerge based upon the position of the product within the organisation's operating markets. It is generally accepted that there are three competitive strategies that a company can adopt.

Figure 6.4: Alternative view of competitive strategy [Adapted]

(Treacy, M., & Wiersema, F., 1997)

When applying this model to the automotive industry it is seen that Nissan a best price strategy when offering its Nissan Micra to the market. This is achieved by tight control of methods and practices employed in its systems and operations within the manufacturing plant and of those of organisations within its supply chain. In contrast, BMW offer the Mini marketed upon a best product strategy within its market sector. It has a brand that is based upon a long historical heritage coupled with the resources and expertise applied by its parent company, BMW. Finally, Mercedes Benz offers entire customer satisfaction strategy by providing extensive fringe benefits of ownership. Such benefits as courtesy cars, enhanced service and support networks, and additional promotional packages are all offered to customers by way of strengthening the brand and customer '*delightedness*'.

In seeking to identify the strategic direction of the organisation it is important to understand these concepts and how they relate to the focus of the strategy formulation process. It is important to note therefore that when seeking to assess the internal and external factors affecting the strategy of the organisation a clear focus upon the scope of the exercise becomes essential.

This initial phase of the methodology requires an understanding of the current position of the organisation relative to its environment and to define the challenge(s) that face the business when seeking to meet the defined objectives of the company and ultimately its vision. This is achieved by undertaking the five steps within this phase of the framework.

Step 1: Scope the target business

This purpose of this stage of the process is to produce a strategy guidance document, or issues statement which is intended to be a single page document specifying which part of the business and/or its operations are being considered, the over-riding issues to be addressed, the performance gaps when compared against objectives, details of the changes being sought, and the time line for the implementation of the strategic initiative (Table 6.1).

The initial activity is to identify the main products and customers of the organisation. In so doing the identification of which part of the organisation and its operations to be focused on is obtained. This is achieved by taking an overview of the business by discussing and identifying concerns held by the stakeholders to the business. At this stage it is important that the investigation remains neutral when engaging with stakeholders seeking to observe and record emergent comments and issues from discussions and observations. This is aided by the construction of tabulated worksheets which record the opinions and responses to pre-determined questions or statements but also allow for emergent issues during this initial stage. In order to achieve a balanced picture all departments and interests should be reviewed by way of a top level review avoiding the temptation to drill down at this stage. Having undertaken this overview of the organisation the results can be analysed and the business area to be addressed identified and recorded on the issues statement template.

Step 2: Identify the over-riding issues

It is often the case that companies offer statements relating to their core competencies. To identify the over-riding issues it is important to seek the external view of the organisation which is achieved by direct contact with such stakeholders where possible. Typically, contact is sought from the company's customers, agents, contractors, franchises etc in order to seek responses to the same questions and in the same format as those used in task one. It is important that the investigation stays neutral during this step of the process and facilitate the emergence of issues and opinions as they are offered.

Step 3: Understand key performance gaps

The understanding of the gaps in performance between external expectation and internal realisation requires a means of scoring the responses offered to the questions asked of the stakeholders. Whilst the ranking of such responses is subjective the resultant scale does yield effective benchmarked results when applied to all respondents and returns significant insights as to the internal and external perception of performance against chosen attributes. The "value proposition model of Treacy and Wiersema (1997)......[defines]....... the strategic direction of the company and is similar to Porter's theory of competitive strategies (1980). [Asmussen 2007, Treacy and Wiersema 1997, Porter 1979, Porter 1980] and this proposition model used in this step of the framework builds further upon the work of Acur and Bititci (2004) and Baines (2007).

Table 6.1 illustrates a summary of the scores for each of the three strategic propositions identified by Treacy and Wiersema (1997) with two parameters being offered for each propositions namely, the current and desired positions of the organisation for each of the strategic propositions. This can then be graphically illustrated as shown in figure 6.5.

Table 6.1 Identification of gaps

Worksheet: Aggregate scores					
Customer Intimacy		Operational Excellence		Product Cost	
Current	Desired	Current	Desired	Current	Desired
11	28	17	21	24	30

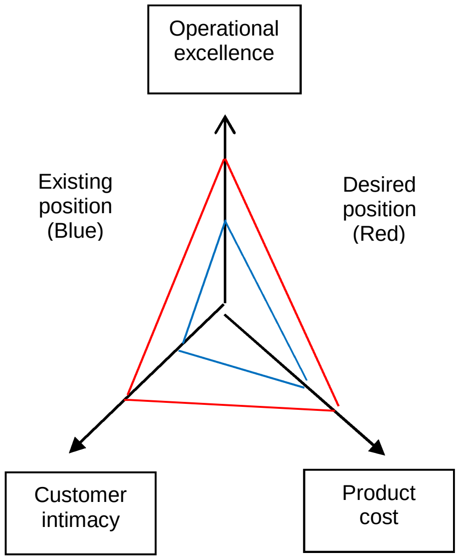


Figure 6.5 Gap Analysis

Upon completion of the gap analysis it is useful to repeat the same exercise focusing upon the position of the competitor. Whilst the internal position of the competitor remains unknown, useful data illustrates the benchmarked comparison when plotted against the current organisation's position illustrated in figure 6.5. This in turn produces yet a more informed decision. The addition of the competitor analysis could result in choosing a strategic direction which widens/closes the gap in performance compared to a competitor and not necessarily the one which illustrates the largest gap between internal performance and external expectation. Having identified such gaps the next step is the setting of strategic initiatives.

Step 4: Set improvement objectives

Authors in the fields of business strategy development, systems engineering and decision engineering (Bower, 1972; Mintzberg et al., 1976; Hofer and Schendel, 1978; Eisenhardt and Zbaracki, 1992; Nutt, 1993; Daenzer and Huber, 2002) agree that the effective formulation of strategy "requires the effective setting of objectives, the identification and evaluation of alternative actions and the implementation of the selected choice" (Tam and Platts, 2005).

In seeking to set the strategic objectives, a multi-discipline review should then be carried out to attain individual perspectives, (Nutt, 2004), informed by the gap analysis with the aim of identifying no more than five key objectives. Again it is important to link the customer (via the sales/marketing function) with that of manufacturing. The setting of such objectives will involve several functions within the organization and such a multi-discipline approach will reflect the insights offered by (Skinner, 1969) and (Hayes and Wheelwright, 1979) when asserting that all operational strategies should be aligned with the internal works functions. Once the objectives have been identified the final task within this phase is to produce the issues statement.

Step 5: Form issues statement

The '*Issues statement*' is a recorded single point 'snap shot' (scope) of the task that is to be addressed by the strategy formulation process. It communicates the area of the organisation under review, the overriding problem(s) to be addressed, the gaps to be closed, clear guidance of what it is that the initiative is seeking to achieve, the means of monitoring progress (KPI's), and the time line (usually greater than 3 years) (Table 6.2).

Table 6.1: Issues statement template

Business Area	Brief but clear description of the part of the organisation under consideration. (Need to define location, which products, which services are included).
Over-riding issues	Identification of particular challenges faced bt the business in the focus area. (These are at a general level – avoid detail here)
Critical performance gaps	Identify the performance gaps which are most relevant and critical to the strategy being developed
Issues statement	State clearly and succinctly what it is that the exercise is trying to achieve
Improvement objective	Clear indication of the objective(s) to be achieved with associated KPI's
Date for objective	Enter time line for strategy realisation (Typically 3-5 years)

Once the issues statement has been produced the organisation has a clear definition of the terms of reference for the strategy, scope of the process, sets of metrics by which performance of the strategy will be monitored, and the agreed time line for the initiative.

The next phase of the process is to assess the internal capabilities of the business within the scope of the issues statement and is discussed in (section 7.4.3).

6.2.1.1 Phase 2: Strategic practices – Map manufacturing

The second phase of the STRATAGEM formulation framework maps the internal capabilities of the organisation and it is important to ensure that any activities carried out within the mapping process of such activities remains within the scope the initiative as defined within the Issues Statement. The process within this phase of the framework consists of steps and is presented in the following sub sections.

Step 1: Form initial list of capabilities within manufacturing operations

In formulating a list of capabilities for the organisation it is important to look at the company holistically. A capability can be thought of as “physical resource that is active or key to the delivery of a product or service” (Baines 2010). Typically these are internal ‘*physical*’ activities within the production process, such as machining, fitting, assembly, pressing, moulding, welding, inspection, packaging, etc.

At this point, brainstorming techniques identify what the company actually does with more detailed mapping processes being avoided as a simple quick and general picture only is required. It is important to avoid ‘creep’ within the study by ensuring that only the capabilities associated with the section of the business being scoped as identified in phase 1 is undertaken.

A work sheet is used which seeks to prompt questions relating to such issues as suppliers, product range, infrastructure, technology, and customers issues/expectations when identifying the foot print of the manufacturing operations employed. This will result in a lengthy list of capabilities against these parameters which should be listed and placed on the capability map. The following section illustrates the process.

Step 2: Construct initial capability map

In carrying out step 2 of this phase of the framework the aim is to identify those capabilities that were listed in phase 2 step 1. Capabilities are chosen where a change in performance can significantly impact on the issue statement following the Pareto rule. To do this a combination of quantitative, qualitative and subjective assessment is required, a multi-discipline approach being best employed. All activities identified should be assessed for relevance to the strategic issue being addressed with each activity written down, preferably on a post it note or similar, identifying name, short description, and the impact on the objective then added to the capability map. The result would then resemble the illustration as figure 6.6. It is not important at this stage to have a clear process flow diagram, rather to have the information identified upon the map.

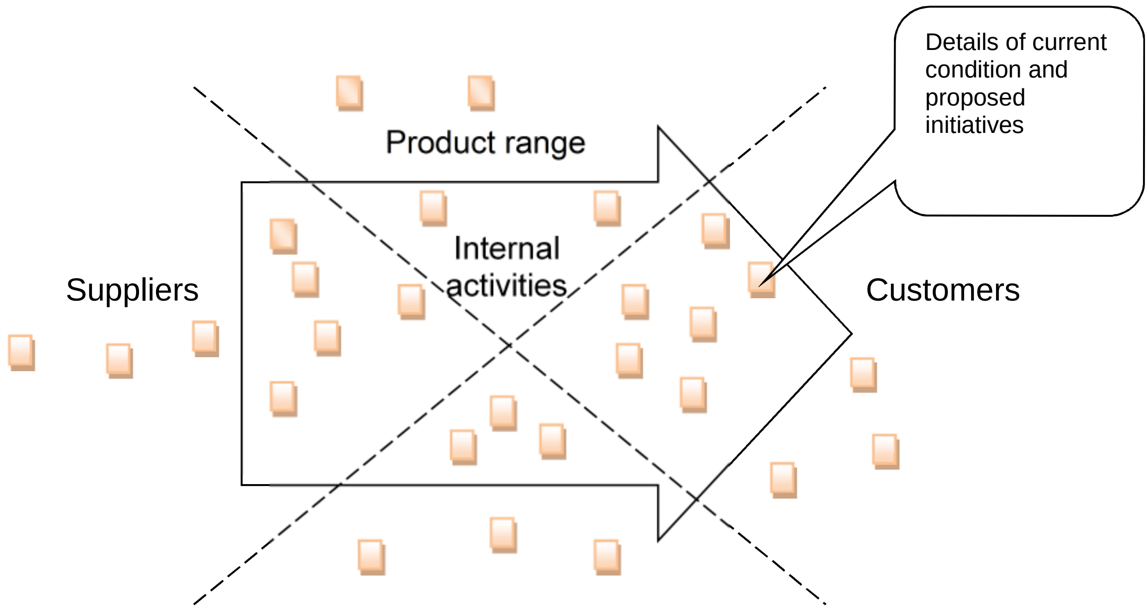


Figure 6.6: Initial capability map

Having constructed an initial capability map the next step will be to tidy the display up and add an informal sequential structure to the illustration with a logical process flow.

Step 3: Finalise the capability map

The final task in this phase of the framework is to finalise the capability map. Some of the capabilities will be at a very high level and will require breaking down into subordinate tasks. It is important to keep focused upon the capabilities at this stage and not the analysis of the identified issues. The objective is to construct an overview of capabilities related to the issues statement and not to construct and undertake a cause/effect analysis (Baines, [Unpublished]).

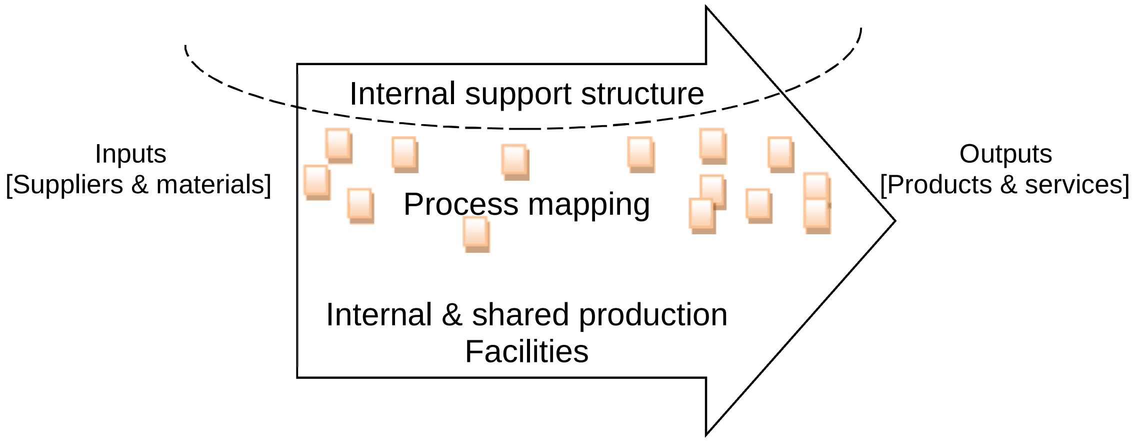


Figure 6.7: Completed capability map

Awareness of changes in capabilities within the organization, typically impending new technology implementation or decommissioning of obsolete technology should also be achieved and included within the process . The conclusion of this phase of the framework is the completed capability map.

6.2.1.2 Phase 3: Strategy formulation – Strategic choices and their evaluation

This phase of the framework seeks to "acquire,……manage… [and align the organisation's]........ resources that create internal manufacturing capabilities….. whose performance complements the external market and financial environment". (Baines, [Unpublished]). In so doing the framework scopes the breadth and depth of the current situation in line with the issues statement and formulates a strategy consistent with (Treacy and Wiersema, 1997). The formulation phase consists of three steps which are now described.

Step 1: Developing strategic initiatives

The process of strategy formulation requires an holistic and creative approach and is therefore not formulaic. In reviewing the capability map the team seek to identify where changes to identified manufacturing activities would yield positive impacts on capabilities. Such proposed changes should be specific and concise as this will facilitate estimation of the impact of such actions. This step should be done by further populating the capability map with strategic initiatives written on 'post it' notes as they appear so that a visual insight can be gained of potential changes. At the end of this step, the team should try and cluster/rationalise the initiatives in order to spot trends and interactions of the future change proposals. Once completed the team can then progress to the next step of the process.

Step 2: Identify key decision criteria

Step 2 in this phase of the process is to review the emergent initiatives to identify key changes. This is done by formulating a set of decision criteria focusing upon **F**inancial impact, **I**nternal acceptability to organization, **T**echnology fit, **S**trategic fit, (FITS). This is simply a structured filtering process to categorise the change initiatives into the four groups within the FITS criteria and is typically a balanced short list of key decision criteria used to achieve an objective evaluation of each proposal relative to how the organisation would usually assess project initiatives. The financial assessment would use standardise accounting tools such as return on investment (ROI), internal rate of return (IRR), net present value (NPV) etc with other quantitative and qualitative KPI's being used for the remaining categories. Once the criteria for scoring the initiatives is agreed, a tabulated decision framework can be implemented which ranks each initiative by assignment of calculated scores.

Step 3: Choosing strategic initiatives

The final step in this phase of the process is the construction of an evaluation matrix (Figure 6.8). The 'post it' notes can then be placed into this evaluation matrix. Positioning of these notes against the vertical axis is made by assessment of the relative impact of each initiative against the issue. The horizontal axis captures the FITS criteria calculated in the previous step.

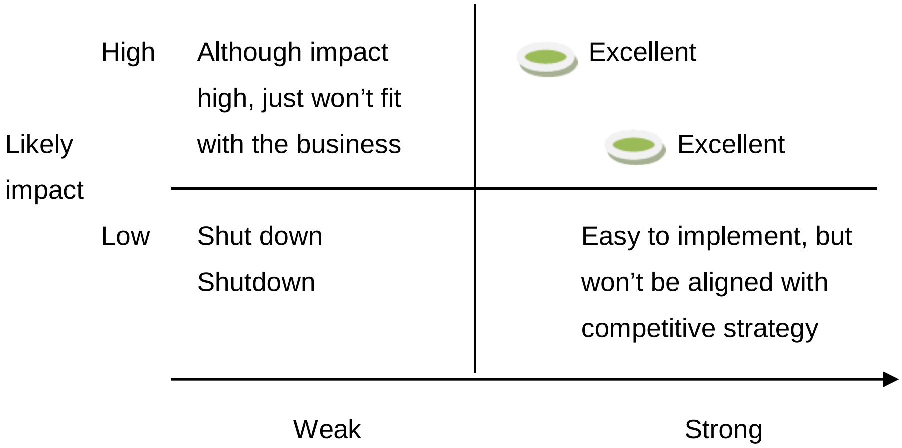


Figure 6.8: FITS criteria

In undertaking this stage a weighted matrix is used. Each initiative is assessed against each criteria and a total score is calculated. This enables the positioning of the initiatives relative to each other and the ones with a high impact and strong FITS score are taken forward for deployment.

Phase 4: Strategic deployment – Implementation

The final stage in the stratagem formulation process is deployment. If formulating the strategy to be followed "success is totally dependent on understanding the interplay between context, process, and content" (Baines, [Unpublished]). But success is equally dependent upon successful communication and presentation of the strategy. One such method of presenting the strategic plan is the Policy Deployment Matrix (PDM) (figure 6.9). Its use allows for a graphical overview to be presented in such a way as to allow audit of the progress towards the realisation of the objectives and vision at any time during its implementation

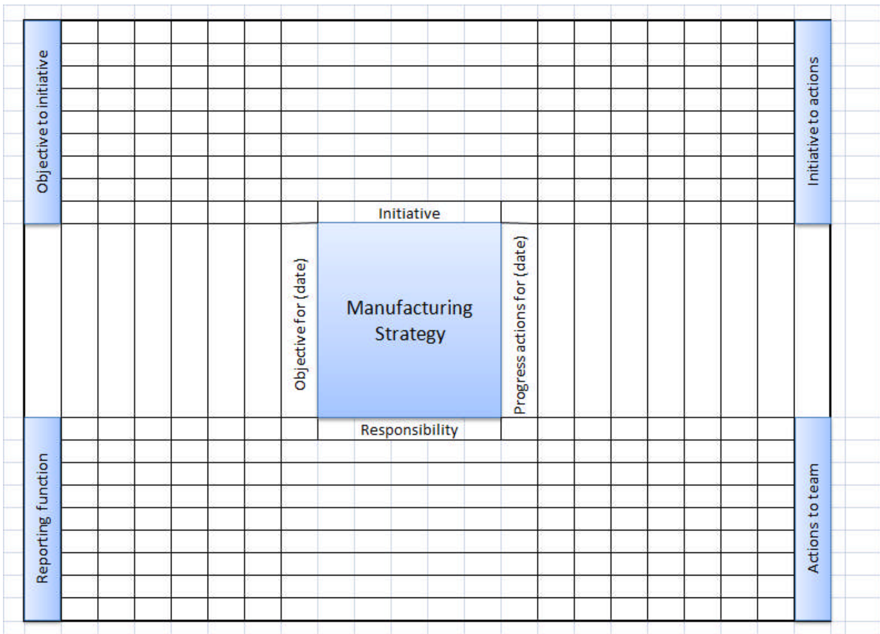


Figure 6.9: Policy deployment matrix template [Unpublished] (Baines 2010)

This section of the thesis has given an overview of the adopted pre pilot methodology process with the appropriate method for the delivery of the Stratagem framework being offered in (section 7.5).

6.3 Evaluation of the pre pilot 'Stratagem' methodology

The pre pilot methodology has been presented in (section 6.2). This section serves to evaluate the pre pilot 'Stratagem' methodology by way of case study. The section gives a description of the objective of the evaluation and method to be undertaken to complete this evaluation (section 6.3.1)

6.3.1 Objective and method of the evaluation of the pre pilot methodology.

The objective of this stage of the research is to evaluate the adopted pre pilot methodology by applying it to a manufacturing SME by way of industrial case study. The aim of this evaluation is to observe the application of the methodology and ascertain its usability, utility, and feasibility (Platts et al, 1996), to “determine whether it proves....[to be]..... a practical and procedural... .....[process]....” (Chandraprakaikul, 2008) in the formulation of operations strategy, and to identify such areas where improvements to the methodology can be made to meet the requirements of the research aim. (section 1.2).

The method chosen to undertake this evaluation of the pilot methodology is the case study. Firstly the design of the data collection protocol is undertaken which seeks to ascertain the data collection framework and instruments to be employed to gather the data, and the assessment criteria. (section 6.3.2). Secondly, the selection of the case study company is discussed (section 6.3.3) followed by a descriptive presentation of the execution of the case study (section 6.4). The observations and results are presented in line with the adopted assessment criteria in (section 6.5) with analysis and discussion of the findings presented in (section 8.6). Finally, the identified refinements from the evaluation of the pre-pilot methodology are discussed and presented in (section 6.7). An illustration of the complete evaluation process for the pre-pilot, pilot, and refined methodologies is illustrated in figure 6.10.

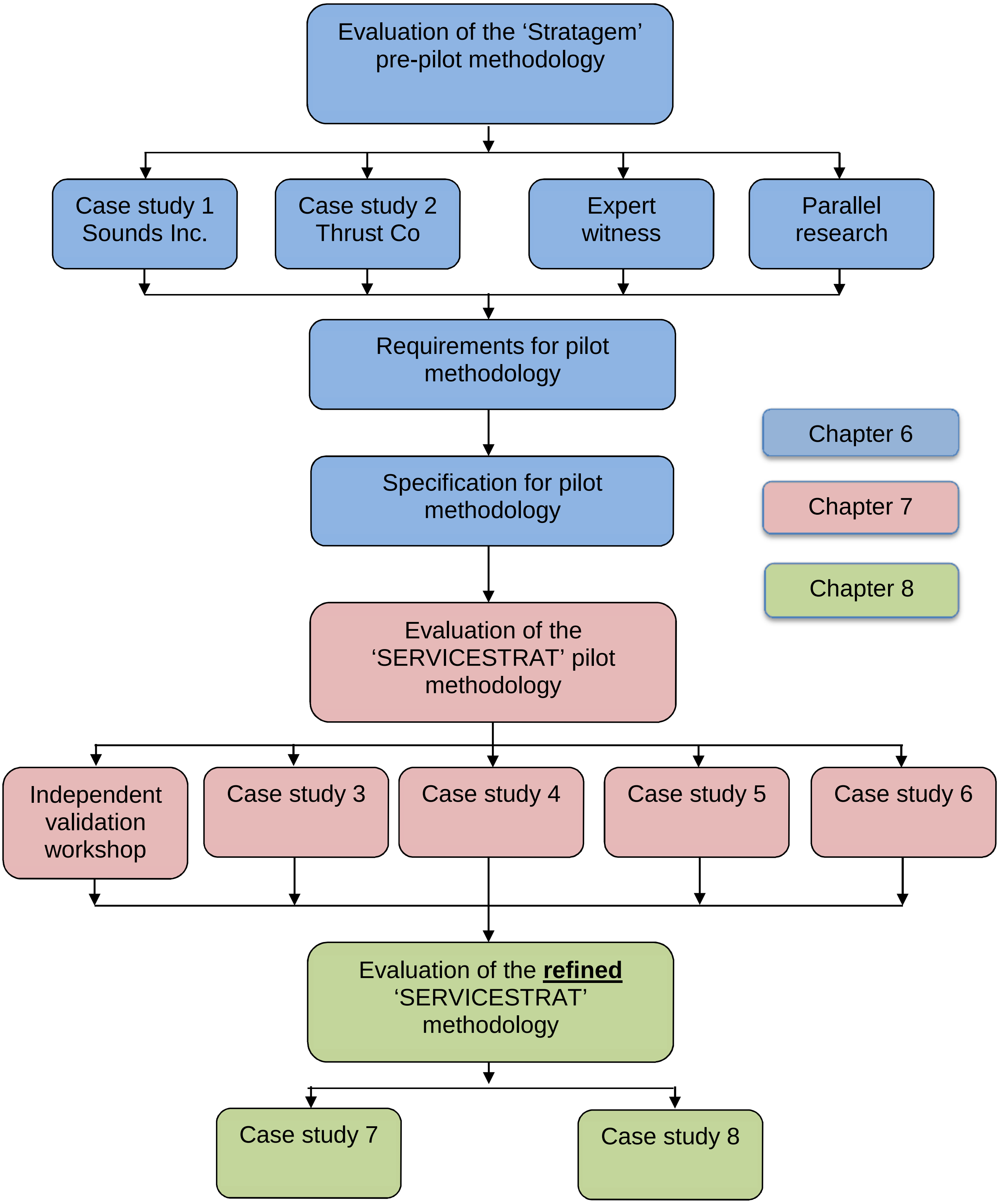


Figure 6.10: The methodology evaluation process

(Pre Pilot, Pilot and refined process)

6.3.2 Design data collection protocol (Pre pilot)

This subsection presents the method used for the undertaking of the evaluation of the pre-pilot methodology. In seeking to evaluate the methodology the focus of this research is upon the methodology's effectiveness as a defined strategy formulation process and NOT an evaluation of the resultant strategy itself. In so doing the research takes guidance from several contributions to the literature (Platts 1993; Adesola 2002; Bourne et al 2002; Tan et al 2004; Tan & Platts 2005; Lim 2007) when seeking a method for this evaluation. Collectively their contributions advise that an effective test for such a methodology is one which measures performance against three parameters, namely:

- Feasibility – Can the process be followed?
- Usability – How easily can the process be followed?
- Usefulness – Does the process yield useful results that satisfy expectations of the users? (Platts et al: 1990: 1993).

It is against these parameters that the methodology is evaluated. The framework for acquiring the data relating to the performance of the methodology is presented in table 6.3. It lists against each parameter the When? Who? And How? questions relating to the performance of the methodology should be asked. This follows the recommendations of Chandraprakaikul (2008).

In consideration as to the method to employ to acquire the data this research uses a 'Post Workshop Questionnaire' as its main source of information (*See Appendix B*). This survey was given to each participant after the pre-pilot study and the results, together with observational findings are used to assess the application of the methodology. Where a structured interview is carried out the survey questions form the script for the interview and each session is recorded and transcribed. The information acquired from these techniques is analysed and used to generate a requirements document from which a specification for the pilot methodology is to be formed.

Table 6.3. Data collection framework [Adapted] (Chandraprakaikul, 2008)

Categories of Assessment	Performance Questions	When to ask the questions	Who to ask the questions	How to ask the questions
In what ways can a methodology success be evaluated?	What questions should be asked to be able comment on each category of success?	When should the responses be sought?	Who should provide the responses?	How should the data be collected?
Feasibility	Could the methodology be followed?	Post completion of the methodology	Facilitators, participants, and expert opinion.	Survey, interview and direct observation.
Usability	How easily could the methodology be followed?	Each step of the methodology and post completion.	Facilitators, participants, and expert opinion.	Survey, interview and direct observation.
Usefulness	Did the methodology provide a useful output that meets expectation?	Post completion	Participants	Survey, interview and direct observation

6.3.3 Case study selection

This section describes the organisations selected for the assessment of the pre-pilot methodology and the reasons for their selection.

6.3.3.1 Case 1: Sounds Inc.

Sounds Inc is a UK based manufacturing company specialising in the design and production of amplification equipment for the music industry. From humble beings the organisation has grown over forty years to be a market leader with its product range of amplifiers being the product of choice for guitarists of the rock genre. When reviewing the organisations website the organisation state that it is the “unique marriage of technology with......[traditional].... hand building skills .... [that]..... ensure[s] ... the highest possible product quality” .. and an outstanding delivery of sound. The product brand is held highly by all levels of musicians being seen at the majority of rock venues and stadia, to the budding guitarist ‘jamming’ in their homes.

The organisation’s main production facility is in the UK having a floor space 70,000 square feet and employing circa 200. Supplementing this the company also places offshore its lower end products to Asian manufacturers in India, China, Korea and Vietnam. Today the company is experiencing ever stronger competition for its products from low cost economies and is actively seeking to identify and implement innovative strategic solutions.

6.3.3.2 Case 2: Thrust Co. plc

Thrust Co plc manufactures and supplies integrated power systems for use in both the civil and military sectors. Its main products can be found in aircraft, ships, power stations, mineral extraction plant, and industrial/commercial power plants. This manufacturing/service organisation [A ‘ManuService’ Company] has a range of offerings for its customer base ranging from the supply of a product/repair to the full integrated service delivery system driven by intelligent products

6.3.3.3 Expert Witness

The use of an expert witness is the result of an emergent opportunity that was not within the initial research programme as planned. The individual was a representative of a UK based multi-national organisation. The sector of the organisation in which he was employed specialised in marine thrust systems and ship monitoring equipment. The company offered an Integrated Vehicle Health Management enabled service delivery system to support its products and product users in the field. As someone whom had direct input into such operating systems and the ability to inform strategy his opinions were sought regarding the suitability of the pre-pilot to deliver an operations strategy supported by intelligent products. The methodology was presented to him and opinions sought through a semi-structured interview.

6.3.3.4 Parallel research

During this time period of this research, an MSc course in Operations Excellence served to understand how Operations Strategy could be developed through the use of a formal methodology. One such student offered the potential for the author to guide and observe the application of the Stratagem methodology through this parallel initiative. The author functioned as a complete observer during this activity, logging the performance of the methodology and the MSc students questions as to application of the process. This gave key insight into the feasibility, and usability of the process when applied by an individual who was not expert in the area of strategy formulation. Acknowledgement for the authors assistance and guidance is given within the MSc Dissertation (Viswanath, 2010).

6.3.3.5 Rationale behind the selection of companies

This subsection offers the rationale behind the selection of the first two case companies, the expert witness and the parallel research in the evaluation of the pre-pilot methodology. The population of companies from which the two companies were chosen was identified from those who responded to the awareness survey (Chapter 4). The companies in the respondent list were companies who manufactured complex products and fitted the defined scope of this research. Their qualification to be in the pool of possible companies was arrived at using a clear, rigorous and repeatable method (section 4.2). In making the final choice of which two companies to use at this stage of the evaluation two perspectives were sought.

- Select an SME who was a pure manufacturer, was operating in an intensely competitive space, and was proactive in investigating alternative solutions.

- Select an organisation that had made the journey along the PSS/servitisation continuum and was now operating as a 'ManuService' organisation utilising an established service delivery system enabled and facilitated by intelligent products.

Whilst the selection of the second organisation proved simple as there were only very few in that category, the first case company selection was both random and opportunistic. Case 1 was supporting existing research within the University and when approached were willing to be involved.

The 'expert witness' was a representative of an organisation who worked within the marine SBU of his parent company. His role was that of service manager for ship propulsion systems and he was responsible for informing the maintenance/service strategy of his organisation. Whilst based in Scandanavia, he reported directly back to his UK manufacturing organisation so fitted the defined scope of the work.

Finally, there was an opportunity to support and advise MSc research within the field of operations excellence. The group were also using the Stratagem methodology in their work and this research activity was able to guide, advise, and monitor their work during their case studies. This enabled this work to harvest data from their application of the methodology to gain a wider understanding of its application.

6.4 Results of the evaluation of the pre pilot methodology evaluation

This section presents and discusses the results of the evaluation of the pre pilot methodology as applied to the manufacturing SME Sounds Inc., and presents the findings using descriptive statistics (pie charts) and tabulations in a structured format based upon the feasibility, usability, and usefulness of the process. Using the data obtained by the post workshop survey, the review of the personal reflective reports submitted by the managerial team from Thrust Co. plc, and interviews (telephone or direct) the following findings are presented.

Reviewing the results returned by the post workshop questionnaire sees that of the 14 opinions sought there was a response rate of 8/14 (≈57%). This might have been improved had the questionnaire been issues immediately after the workshop, however at the time it was thought that a period of reflection would be beneficial prior to the request for the feedback and opinions sought. The survey was posted/emailed to all 14 participants but due to timing (industrial vacation period) and the repositioning of some of the personnel within their organisations resulted in a response rate that was lower than expected.

In addition to the questionnaire, personal reflections of the experience when applying the methodology was also sought which recorded opinions with regards to:

- What went well during the 1 week workshop?
- What did not go so well during the workshop?
- What would they do differently?

This qualitative data was deliberately left unconstrained and was reviewed to see what additional data could be obtained from the 'whole' experience gained by the cohort when seeking to apply this methodology to the case study SME within a constrained time frame of a week. The response rate for the written personal reflections was 13/14 (≈92%). The findings are reported in the following sections.

6.4.1 Feasibility of the pre pilot methodology

The results from the survey and the reflective summaries indicate that the methodology is a feasible process when seeking to formulate strategic initiatives. Of those who responded it is seen that all of the cohort from Thrust Co., plc succeeded in following the process with few exceptions (Appendix B: Q1) and that it was felt that the sequence of the stages was consistent (Appendix B: Q2). It was also the view of all of the respondents that the methodology could be applied to the case study company (Sounds Inc.) satisfactorily (Appendix B: Q3) but were unsure as to the ability of the framework to provide alternative solutions should the process encounter problems. (Appendix B: Q4).

6.4.2 Usability of the pre pilot methodology

The process was found to be easy to use within the cohort from Thrust Co., plc being able to complete the process within the 1 week workshop assigned to the assessment (Appendix B: Q5). All of the middle managers who applied the framework said that the workshop format was an effective means of undertaking the process when applying the methodology (Appendix B: Q6), however whilst all of the participants involved in using the framework successfully used all of the tools and techniques at each stage there does appear to be an element of doubt arising in the results. Of those who responded, 43% stated that they found the tools and techniques easy to follow whilst 57% stated '*mostly*'. This was further identified when the 'pre pilot' workbook was offered for review to a senior manager within a differing SBU within Thrust Co., plc. During this review of the workbook the following opinions were offered:

i. The workbook is too academic and not practitioner friendly

ii. Initial impression is that the balance between text and illustrations is not attractive. [Too text intensive].

iii. Greater use of signposting is required to enable the users to know where they are within the process throughout the whole execution of the framework.

[Reference: Executive - Thrust Co., plc.]

These comments could be an explanation as to why 57% of the users stated that they found the tools and techniques '*mostly*' easy to follow and explain to the employees of Sound Inc. whilst 71% stated that the aims and actions at each stage of the methodology were clear, again 29% stated that they were '*mostly*' clear. (Appendix B: Q8). During the delivery of supporting examples in the workshop to help with the understanding of the framework there was a mixed response (Appendix B: Q9).

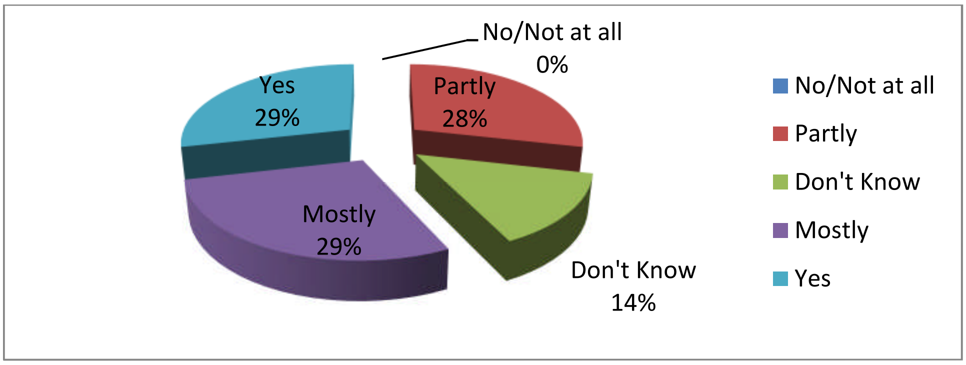


Figure 6.11: Question 9. Did the examples provided in the methodology help you use the methodology?

This is again assumed to be attributed to presentation and the need for more user friendly 'signposting' throughout the whole of the framework.

6.4.3 Usefulness of the pre pilot methodology

The response to this evaluation criteria was positive with all of those responding stating that the methodology was successful (worth doing) or very successful in providing results that meet with expectation (Appendix B: Q15). However, when asked if the methodology consumed excessive time and resources the response was inconclusive with 43% stating "not at all" and 43% stating that they did not know (Appendix B: 16) (Figure 6.12).

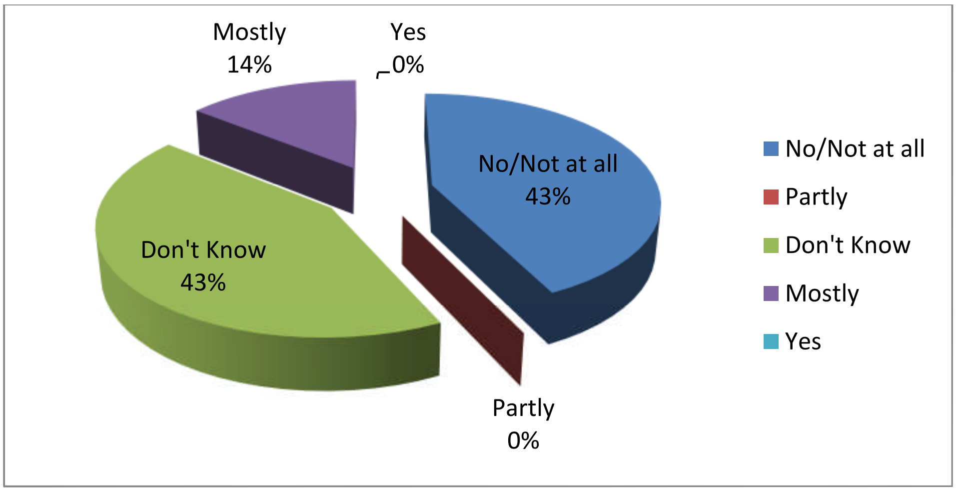


Figure 6.12: Question 16: Did the methodology consume excessive resources of time and people?

However all those questioned did state that the methodology did provide a practical process (Appendix G: Q17) and either fully (57%) or mostly (43%) met with expectations (Appendix G: Q21). When asked if there where lessons which could be learnt from the application of the methodology the results were again favourable with 50% stating yes, 33% who did not know, and 17% stating 'no/not at all'. (Appendix G: Q18). This issue is to be further tested during the evaluation of the refined methodology.

6.5 Analysis and discussion of the results obtained from the evaluation of the pre pilot methodology.

This section discusses the results from the evaluation of the pre pilot methodology and presents them in the format of strengths and weaknesses as identified during the application to the case study SME Sounds Inc. The strengths are firstly reported followed by an analysis of the weaknesses exposed in the application of the process.

6.5.1 Strengths of the pre pilot methodology

This section documents the main strengths of the pilot methodology as identified during and after the application of the framework upon the target company during the workshop.

Table 6.4. Strengths identified in the pre-pilot methodology

Criteria	Comments taken from personal reflections post workshop
Feasibility	"*...the methodology could be applied to the ...[casestudy].... and I feel that it could be applied to an industrial situation successfully"* *"We didn't seem to encounter any major problems...."* *"...the ability to revisit stages".* [i.e. iterative process]
Useability	*"....I think that the time allocated was fine to go through the...[exercise]....*" "*The workshop environment (practical) helped to embed the concept of STRATAGEM*". "*...follow the guidelines and....[the process]...gets easier*". "*Strength .....structured approach*" *"..the thing I found most beneficial is the physical steps you go through.........people are always looking for some form of visual representation and guide of how to feed back ata".* "*....highlights and identifies key goals and aligns them to he strategy being defined*".
Usefulness	"*The PDM is a very useful visual tool to show and control the resulting actions from the tool*". *"...the FITS criteria tool was useful in fully understanding initiatives. This tool allowed.....to understand the impact on different aspects of the business....[of strategies].... that may not have previously been considered*".

6.5.2 Weaknesses of the pre pilot methodology

This section records the weaknesses as identified during the post evaluation assessment and is split into 'primary' and 'secondary' areas for concern. The primary areas are taken to be major issues that need to be addressed to make the framework fit for purpose whilst the secondary issues are seen as refinements in order to make the framework easier for use.

6.5.2.1 Primary issues and weaknesses

When seeking to adopt a servitized solution manufacturers have an advantage as they can design and control the technology that is within the product and the functions and benefits that it can deliver to the organisation.

Limitations of the stratagem tool include:

1. Stratagem is primarily a market response tool seeking to establish a value proposition(s) which is in response to market centric analyses.
2. It does not consider how technology, by way of 'informated' products, may be employed as an enabler to deliver advanced services.
3. There is a clear link and interdependence between "Operational Excellence" and "Customer Intimacy" when technology is used as an enabler to the servitization of the organisation's offerings, which calls into doubt the assertion that to be a leader in the market you must seek to excel in one of the strategic initiatives defined by the existing model. Should a process of servitization be identified as a suitable strategic initiative the existing framework does not give insight into the following:
    a. How far along the product, product/service, to service continuum should the organisation seek to move?
    b. What can the application of technology by way of 'intelligent' products deliver for a company wishing to move along the PSS continuum?

c. What type of business model should the organisation adopt for a desired position along the servitization continuum? (i.e. level of contracting).

Secondary issues and weaknesses of the pre pilot methodology

During the application of the methodology by the cohort from Thrust Co. plc upon the case study company Sounds Inc., the following weaknesses were observed, noted, and recorded. This section tabulates the weaknesses recorded and are presented in table 6.5.

Table 6.5: Weaknesses observed within the pre pilot methodology observed during the evaluation of the pre pilot methodology

Criteria	Comments taken from personal reflections ‘post workshop’
Feasibility	“...*although there were subsequent stages through....*[process].... *the case study, the order was not consistent with ....* [delivery of supporting presentation].... *in fact the stages were revisited*”
Usability	“...*clearly from the questions and feedback at the end I think the target audience could also benefit from an overview of the framework and what it aims to deliver”.* *“I felt that there was too much of a rush at the end of the workshop”* *“The only difficulty...... was explaining how the process map fits into the process”.* *“....the complexity of the early stages of the process...* ...[and]... *subjectivity of the answers”.* *“....the aim of the methodology is to follow the structure as it is laid out and therefore it is not that* flexible*”.* The process was *“....too theoretical at times*”. “....*streamline stage 1, provide guidance on how competitive questions should be answered”.* *“The process map does not seem to fit the process. In the....case this was not a problem as the process was very simple. If this tool was being used in a complex industrial environment I am not sure that the effort to do a process map would be worth it”.* *“...make it clearer at an early stage.... that the process is aimed at being flexible allowing the user to jump from stage to stage as needed.*

Table 6.6: Weaknesses observed within the pre pilot methodology observed during the evaluation of the pre pilot methodology (continued)

Criteria	Comments taken from personal reflections 'post workshop'
Usefulness	"*The initial stage of assessing the current strategic position vs the desired position initially felt long winded however this was due to lack of understanding at.....* [that].... *point*"

6.5.3 Requirements of the pilot methodology

This subsection presents the requirements of the *pilot* methodology. A review of the performance of the pre-pilot methodology has identified its strengths and weaknesses when applied as designed to two case companies. In addition the view of an expert witness and direct observation of its application have facilitated the recording and tabulation of both strengths (Table 6.4) and weaknesses (Tables 6.5 & 6.6) of the pre-pilot methodology. When comparing the pre-pilot methodology's contents and performance against the needs identified in the literature (Chapter 2) and stakeholder requirements (Chapter 4), a set of requirements for the pilot methodology is identified and tabulated (Tables 6.7 & 6.8).

Table 6.7: Requirements of the methodology derived from the application of the pre pilot methodology process [Cases 1 & 2]

No.	Findings & observations from pilot evaluation of pilot methodology.	Requirements	Descriptions/Evidence	
1.0	Workbook presented too much theory which was said to be 'off putting' to practitioners when seeking to understand and implement the process.	Workbook should present adequate guidance notes throughout the process but should not present grounded theory and academic arguments	Feedback from post pilot personal reflective opinions and post pilot surveys.	
2.0	Workbook was too text intensive. This was found to be off putting and in a workshop environment too time consuming.	Methodology should have greater 'signposting' though out the process to ensure that the user has a full understanding of direction throughout execution.	Feedback given in post pilot study interview	
3.0	Stratagem is primarily a market response tool seeking to establish a value proposition(s) which is/are market centric	The ability to allow consideration as to how technology and informated products may become enablers of servitization strategies needs to added to the methodology.	Observation. During the pilot evaluation workshops, none of the participants identified the potential of informating products despite these methods being used within their own company.	
4.0	Poor time management during the execution differing tasks undertaken during the workshop.	Guidance as to timings for each activity may prove to be an advantage. This will facilitate better project management during the strategy formulation process.	Feedback from individual personal reflective studies submitted after the evaluation of the pilot methodology.	

Table 6.2: Requirements of the methodology informed by the literature (Platts 1994)

No.	Characteristics	Requirements	Descriptions
1.0	Procedure	Well defined stages	• Gathering information • Analysing information • Identifying improvements • Simple tools and techniques Written record
2.0	Participation	Individuals or groups to achieve:- • Enthusiasm • Understanding • Commitment	Workshop style to: • Agree objectives • Identify problems • Develop improvements • Catalyse involvement Decision making forum
3.0	Project management	Adequate resourcing	Identify: • Managing group • Supporting group • Operating group Agreed timescales
4.0	Point of entry	Clearly defined expectations	Understanding and agreement of managing group Commitment from managing and operating groups.

6.5.4 Specification of the pilot methodology

This section presents the specification for the pilot methodology. The requirements for the pilot methodology (Tables 6.7 & 6.8) are reviewed and compared against the needs of the stakeholders (Chapters 2 & 4). This review of requirements results in the formulation and definition of a specification for the pilot methodology which is presented in (Tables 6.9 & 6.10).

Table 6.9. Specification of the Pilot methodology.

No.	Category	Requirement	Evidence/Driver
1.0	Product	The ability to assess the suitability of the product to possess 'informated' functions.	• Not all products are suited to the application of '*in use monitoring/management*' solutions. • There are no frameworks identified which seek to map the 'type/level' of product, applied technology, to the level of service to be offered.
2.0 2.1.	Technology	The need to consider how technology might be employed as an enabler to deliver advanced services. To identify what level of technology to apply to the product to effectively support the desired level of service offering	• Although some organisations are aware of the potential of '*informated*' product to enable service, the evidence suggests that such awareness is not widespread within UK manufacturing. [Phase 1 Survey and descriptive literature review] • Consideration of the use such technology did not emerge during the primary evaluation of STRATAGEM workshops, [post workshop survey, observation, personal reflection or company interviews] • Existing methodology does not possess **<u>any</u>** technology assessment [Observation]

Table 6.10. Specification of the pilot methodology (continued)

No.	Category	Requirement	Evidence/Driver
3.0	Service Infrastructure	A greater understanding of the gap between the current service offering and market expectation is required. [Base, Intermediate, and Advanced] A clear understanding of how to achieve 'Alignment' between service requirements, technology enablers, and company structure/infrastructure. Knowledge of the preferred organisational structure for the deliverance of technology enabled enhanced services.	

Table 6.11. Specification of the Pilot methodology (continued)

No.	Category	Requirement	Evidence/Driver
4.0	Service	Knowledge of the optimum level of service to be taken on? What delivery system for the service should be adopted? Is the service demand pull or supplier driven?	• Documented in the literature (Treacy & Wiersema) (Interviews: RR Civil Aerospace, RR Marine, RR Defence, L3 Communications), • The literature supplemented by interviews and observations made during company visits indicate various service delivery systems ranging from OEM supply, franchise, dealerships etc.

6.6 Chapter summary

The third phase of the research programme has been presented in this chapter. An overview of the research method for the phase has been given. This has been followed by a detailed description of the adopted Stratagem methodology and an explanation of the rational for its selection for the pre-pilot study. The performance of the pre-pilot methodology has been assessed using a well-defined and widely accepted process (Re: Platts et al), the results of which have been presented. From the results obtained, and knowledge of stakeholder requirements identified during the literature review and industrial survey, a set of requirements for a strategy formulation methodology has been generated. Finally, a specification for a pilot methodology is defined. The following chapter will present and discuss the primary evaluation of the pilot methodology.

7 PRIMARY EVALUATION OF THE PILOT METHODOLOGY

The previous chapter adopted '*Stratagem*' as a methodology seeking to understand 'competitive space' as a starting point for the formation of the pilot methodology '*ServiceStrat*'. This chapter fulfils the fourth phase of the research programme (section 3.3.5) seeking to evaluate the pilot methodology by application with industrial 'case' organisations.

7.1 Phase 4 overview and research method

This phase of the research programme seeks to evaluate the pilot methodology by seeking application and review within industrial 'case; companies. The design of the data collection protocol is presented (section 7.2) and the case study method adopted (section 7.3). Feed back as to the 'feasibility', usability, and 'usefulness' is sought and the results (section 7.4) and analysis (section 7.5) presented. The required refinements identified from the analysis of the feedback from the 'case' participants are identified (section 7.6) and the refined methodology developed (section 7.7). An overview of the research phase (chapter structure) is shown in figure 7.1 and the case study research design in illustrated in figure 7.2 .

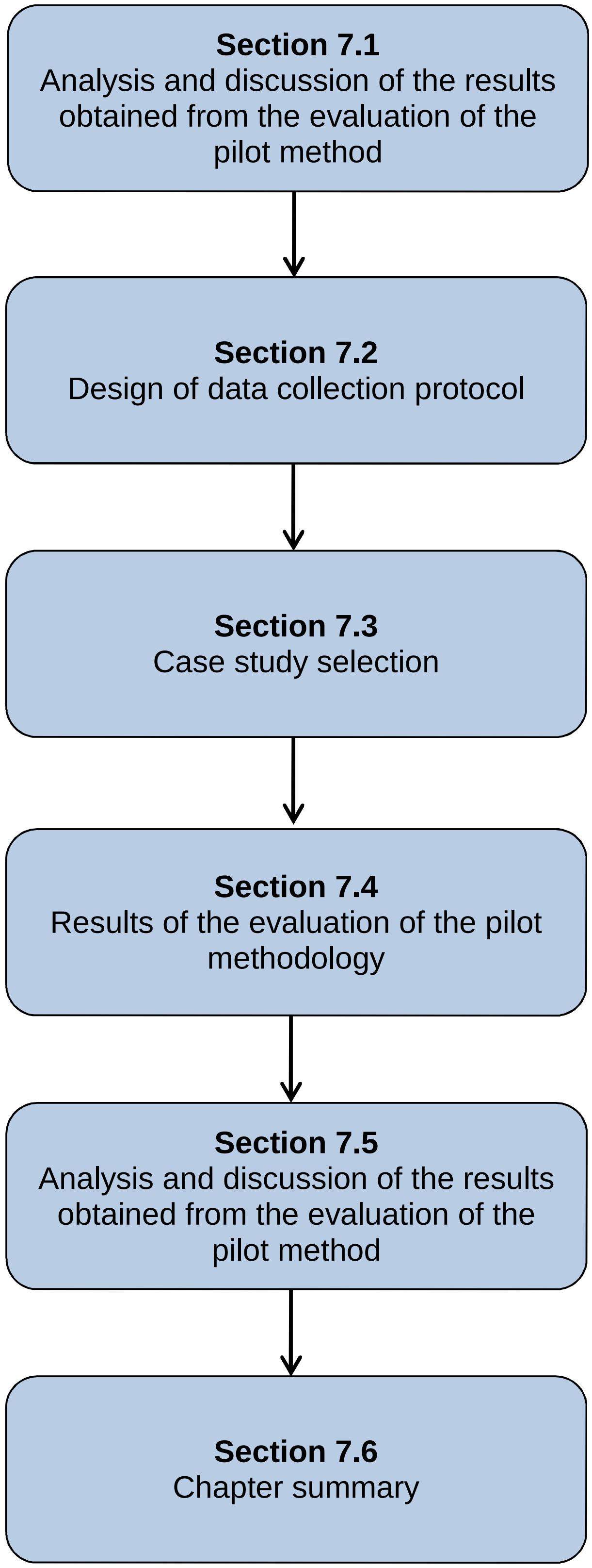


Figure 7.1: Structure of chapter seven

7.2 Design of data collection protocol

This section defines the assessment criteria and the data collection method for the evaluation of the pilot methodology (section 7.2.1). The data collection framework is presented (section 7.2.2) together a description of the tools and techniques to be employed during the evaluation of the pilot methodology. (section 7.2.3).

7.2.1 Defining the assessment criteria and data collection method.

This sub section seeks to inform the reader of the criteria used to evaluate the pilot methodology. The goal of the evaluation is to assess the ability of the pilot methodology to assist and guide the user in the formation of an aligned operations strategy.

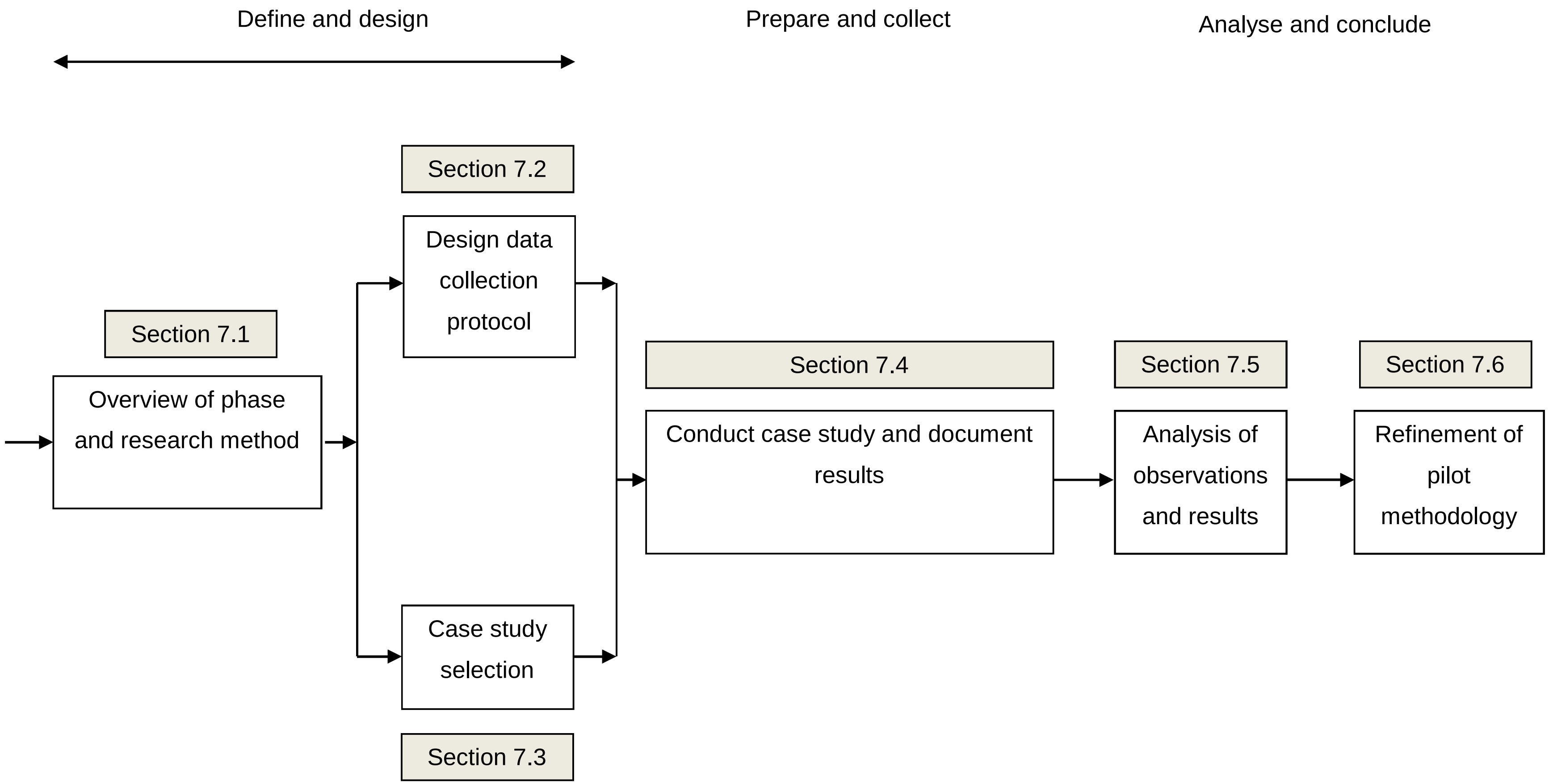


Figure 7.1: Overview of evaluation of the pilot methodology

The evaluation of the pilot methodology itself and not the outcome of its application is the purpose of this phase of the research programme. A review of the literature was undertaken and the evaluation methodology proposed by (Platts et al., 1998; Platts and Tan, 2004; Tann and Platts, 2005) is adopted. One of the possible sets of parameters which may be used for the assessment of such methodologies is defined by these contributions to the literature. Whilst there are many techniques that may have been considered it is the parameters offered by Platts et al’s contribution that are the adopted for this research. Namely:

- Feasibility: - Could the methodology be followed?
- Usability: - How easily could the methodology be followed?
- Usefulness:- Does the methodology provided results which were of use?.

These three criteria were presented by way of a coded questionnaire (appendix B) to enable easy cross case comparison by use of descriptive statistics. However, open questions and critique was also invited in order to harvest rich qualitative data should it exist.

7.2.2 Data collection framework

The purpose of this section is to define the data collection framework to be followed in the execution of the evaluation. Categories of assessment are defined together with the evaluation questions and identification of the ‘when?’, ‘who?’ and ‘how?’ identified. These are summarised in Table 6.3.

7.2.3 Data collection tools and techniques

In order to effectively evaluate the pilot methodology it becomes important to apply appropriate tools and techniques to observe and record performance, and to seek informed opinion and critique from appropriate stakeholders. Where the case study method is to be employed the researcher adopts the role of facilitator to the delivery of the process. The data sought in order to evaluate the performance of the pilot methodology is planned to be obtained via a workshop delivery supported by observation, interviews and a post application survey.

Survey

To ensure continuity and consistency with the evaluation technique used in the pre-pilot testing phase the same questionnaire is used [Appendix B]. Consideration as to the design and construction of the questionnaire as a survey technique has been discussed in (section 4.4) and the evaluation parameters discussed in (section 6.3).

Semi structured interviews (post workshop or when review sought)

Kahn and Cannell (1957) define the interview as "...a purposeful discussion between two or more people". In this phase of the research the interview seeks to illicit opinion on the feasibility, usability, and usefulness of the pilot methodology using a structured set of questions (guided by the survey) in the first instance, but also to adopt a secondary semi-structured format so as to enable additional critique and opinion relevant to the execution of the pilot methodology both in content (*of the process*) and context. Whilst the structured interview is scripted by a pre-defined set of questions which allow for consistent delivery of the questions and cross interview analysis, Saunders et al (2007) inform the researcher that semi structured interviews have sets of questions to guide 'themes' whilst leaving sufficient freedom for additional questions and information to emerge. This research employs a combination of both structured and semi structured interview techniques which are conducted either by telephone or face-to-face where clarification of points raised on the survey are required.

Guidance is also given in the literature as to the correct type of interview to employ depending upon the type of research being conducted. During the early stage of this research (the exploratory phase) semi structured interviewing was employed with organisations using IVHM to facilitate servitization strategies and PSS business models. This gave a greater understanding of the general area and guided the research focus. Now at the explanation phase (*seeking to evaluate and identify the performance of the pilot methodology*) a structured format is adopted to facilitate quantitative analysis and reporting using descriptive statistical methods whilst the semi structured approach is used to explore and identify themes emerging from weaknesses as identified within the review of the process. This approach is in compliance with the guidance within the literature (Table 7.1).

Table 7.1: Uses of different types of interview in each of the main research categories (Saunders et al., 2007)

	Exploratory study	Descriptive study	Explanatory study
Structured		xx	x
Semi-structured	x		xx
In-depth	xx		

XX = More frequently used X = Less frequently used

Observation

For this research observation is defined as "....the systematic observation recording, description, analysis and interpretation of.......behaviour" (Saunders et al., 2007) and the observer as a participant is defined as an "....observational role in which the researcher observes activities without taking part in those activities in the same way as 'real' research subjects. The researcher's identity and research purpose is clear to all concerned" (Saunders et al., 2007)

Saunders et al defines two methods of observation, participant observation (yielding qualitative data relating to the meaning of actions) and structured observation (yielding quantitative data relating to the frequency of actions). As with all research methods there are advantages and disadvantages to the selection of observation as a research method. These are illustrated in figure 7.3.

When selecting participant observation it requires an element of immersion into the study in order to gain an understanding of the context of the study. This enables delicate nuances to be revealed in the performance of the subject being evaluated (the pilot methodology) (Sekaran, U., 2003), (Saunders et al., 2007). The structured observation however requires a detachment from the object of study and seeks to inform of 'how' things happen rather than 'why' things occur.

Researcher takes part in activity

Participant as an observer

- Reveal purpose as a researcher
- Awareness of fieldwork relationship
- Gain trust to obtain access
- Key advantage – informants are likely to adopt a perspective of analytic reflection on the process in which they are involved

Complete participant

- Part of the group
- Does not reveal the true purpose
- Ethical issues
- Should not attempt this unless needed
- A detached perspective is lost

Researcher known **Researcher concealed**

Observer as a participant

- Researcher is a spectator
- Identity and purpose is known
- Advantage – can focus on the research
- Disadvantage – 'loose feet'

Complete Observer

- Does not reveal purpose
- Does not join in the group
- Exploratory stage of research
- Used as a precursor to structured observation

Researcher observes the activity

Fig 7.2 Topology of participant observation researcher roles [Amended] (Saunders et al., 2007)

It is important to note that "....all research methods have their place in an overall research strategy" (Saunders et al., 2007). In order to fully evaluate the performance of the pilot methodology a hybrid of research strategy is planned for this phase of the research and is illustrated below (figure 7.3).

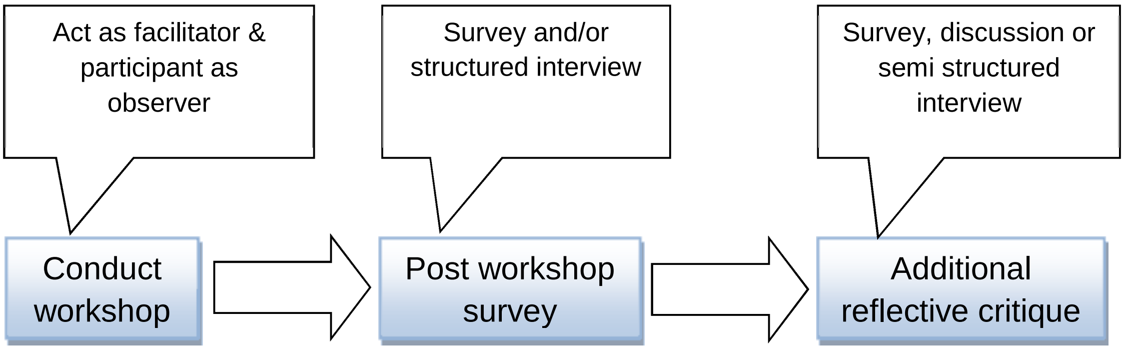


Figure 7.3. Process for obtaining pilot evaluation data

Contingent methodology

During the *pre-pilot* evaluation it became apparent that due to the current economic climate and issues facing the manufacturing sector, (recession and banking crisis), it proved difficult to get a commitment from organisations to participate in workshops. Organisations did however express interest in the methodology and did assert that if the climate was more favourable they would participate in the evaluation. The author presumes however that this may also be the case when the economy is buoyant as organisations could be too busy to engage fully with the research. The research risk analysis identified this probability and with this in mind a contingent evaluation process was defined as illustrated Figure 7.4.

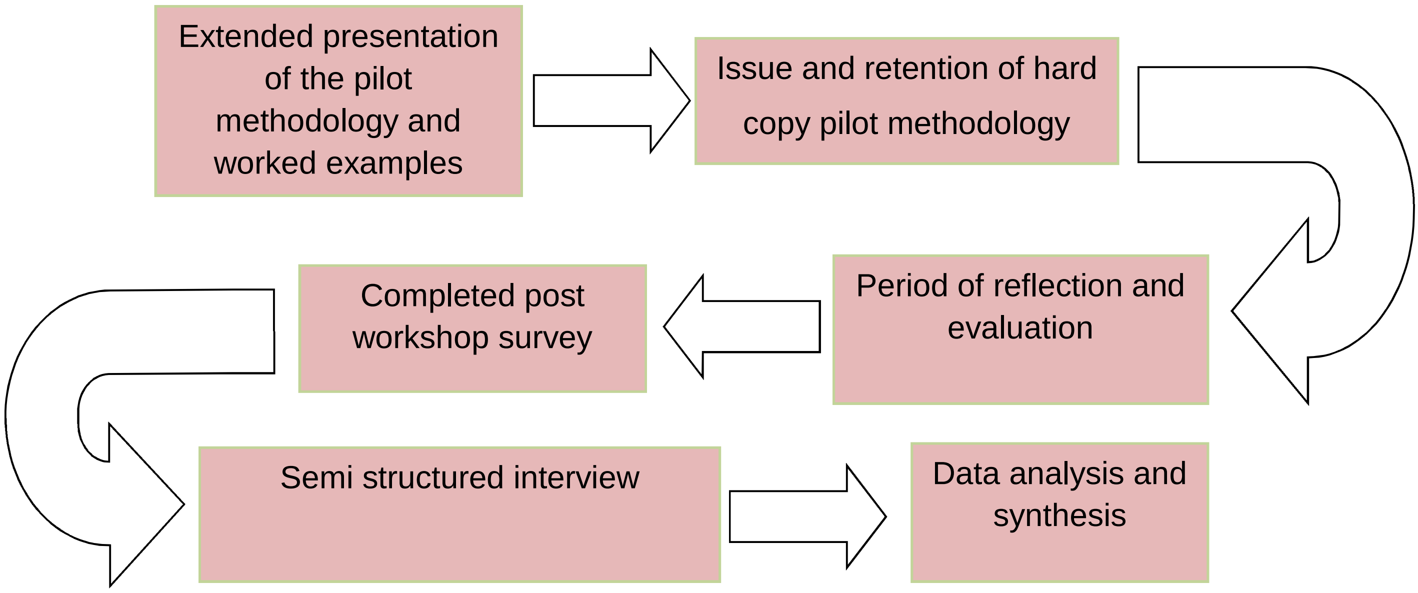


Figure 7.4. Contingent process for obtaining pilot evaluation data.

7.3 Case study selection

This section presents the company and research method selection criteria fro this phase of the research (section 7.3.1) and then gives a brief overview of the case organisations selected (section 7.3.2 to 7.3.7).

7.3.1 Company and research method selection criteria

In selecting companies to approach for assistance in the evaluation of the pilot methodology a justification for the selection of each organisation, the number of organisations to select, and the methodology to employ becomes apparent. In order to address these issues this research is guided by Yin (2003) when considering these issues.

The companies are chosen from those who responded to the awareness survey (Chapter 4). These were selected because the sampling procedure had already defined the population in which each organisation resides as relevant to the research containing a broad spectrum of organisations (OEM’s, SME’s, Sectors, and manufacturers).

When considering the method to employ for this phase of the research Yin informs that there are numerous types of research methods within the field of social science that may be employed. He lists experiments, surveys, histories, economic and epidemiological studies, case studies as potential options (Yin, 2009) and goes on to advise that when selecting the method to use three conditions need to be considered, namely:

- The type of research question being posed,
- The level of control that the researcher has over the behaviour of the events,
- A focus on the contemporary as opposed to historical events. (Yin, 2009)

Case studies are the preferred option when the research seeks to answer ‘how’ or ‘why’ type questions, when the researcher has little control over the development and nature of events as they unfold, and the investigation remains focused upon contemporary events (Robson, 2002; Creswell, 2007; Yin, 2009). When seeking to consider the type of investigating method to employ “....the first and most important condition for differentiating among the various research methods is to classify the type of research question being asked” (Yin, 2009)

Yin gives summarises his guidance as to what method to choose in tabulated form which is reproduced in Table 7.2.

Table 7.2: Relevant situations for different research methods (Yin, 2009)

Method	Form of research question	Requires control of behavioural events	Focuses on contemporary events
Experiment	How, Why?	Yes	Yes
Survey	Who, What, Where, how many, how much?	No	Yes
Archival analysis	Who, What, Where, how many, how much?	No	Yes/no
History	How, Why?	No	No
Case study	How, Why?	No	Yes

This phase of the research programme seeks to identify how the pilot methodology performs within a live situation with the researcher aiming to adopt the role as a facilitator, and the work is contemporary in nature thus fulfilling the requirements for case study selection..

When seeking guidance on the number of cases to adopt Yin (2009) states that "…..*single case works well if it represents a critical case or when it represents an extreme or unique case. Other rationales for single case design are when it is a representative case or a longitudinal case where studying a single case is done at two or more different points in time*". However, this study does not meet this criteria and therefore a multiple case approach is chosen.

In seeking demonstrate rigour and an unbiased position it is important to acknowledge perceived weaknesses within the case study method of research. In doing so this research is again guided by Yin who identifies four issues which often seek to relegate the case study as a method. The first criticism is one of bias as often data is extracted and adopts the bias of the researcher. In order to protect against this the evaluation adopted a standard set of criteria from the literature (Platts et al., 1998; Mills et al., 1998) and the survey questions were informed from this framework. The second criticism is that case studies provide a poor basis for scientific generalisation (Yin, 2009). The important defence here is that the case study is applicable to general statements relating to theoretical trends but does not seek to convey general theory to a population in the statistical sense. Thirdly, they are time consuming. The assumption is that case studies are ethnographical in nature or based upon extended participant-observer studies. This is not always the case as one "....*could even do a valid and high quality case study .....[using]... the telephone or internet... depending upon the topic being studied*" (Yin, 2009) Finally, case studies are often relegated as they cannot make assertions as to the cause and effect relationship. Whilst this is undoubtedly true, case studies can supply supporting evidence to 'true experiments' and should be seen as "valued adjuncts to experiments rather than alternatives to them" (Yin, 2009; Cook and Payne, 2002).

Having discussed the company and research method selection criteria that following subsections give a brief description of the organisations chosen.

7.3.2 Independent validation workshop

A half day lecture and workshop was conducted with a cohort of MSc students studying the concept, content, and processes relating to IVHM. The module presented the means by which an organisation seeking to formulate a service based operations strategy facilitated by informated products may chose to develop its response to the environmental forces acting upon it. The cohort consisted of mature students from various industrial organisations who held middle management positions within manufacturing companies producing complex products. During this session the methodology was presented in an 'open' lecture format followed by discussion and critique. The opportunity to seek constructive critique from this cohort was taken because of the identity of the community. As the methodology was not being applied to a specific case the focus was upon the process defined by the method itself. In addition the cohort offered a unique cross-sector perspective when considering their opinions as they all came from differing organisations and offered a different lens. The post workshop questionnaire (appendix B) was used as the main evaluation tool together with a request for written personal reflections. The data was then encoded and listed within the general findings. These findings were again used to generate the requirements document and specification for the refined methodology. Whilst the time allotted was not ideal, a longer period being required, it did offer valuable insight to delivery format and understanding of the concepts by the cohort.

7.3.3 Case study 3 Agricultural Solutions PLC

This organisation is a well-established manufacturer of domestic and commercial/industrial lawn mowers having been founded over 200 years ago. It has its manufacturing facility in the UK as well has numerous overseas SBU's. Its sales and service support is undertaken by agents and franchises where it has global market presence. Whilst the main products are termed grass cutting solutions it also manufactures and supplies a range of off road electric vehicles (e.g. Golf buggies).

The product is supported by differing levels of service provision ranging from parts, warranties, training (for operators and technicians), and also offers an 'End of Life Mower Disposal Programme' via a strategic alliance with a third party organisation which complies with the European End of Life Directive. (EELD).

> *"We have introduced this programme......long before legislation demands it.....because we think it is right to do so... [as] ...we have a moral duty to protect our collective environment. We have to be seen to be responsible for our products from the beginning to end of their lifecycle....and we have to be seen to be taking this responsibility seriously"*. (Managing Director – 2011)

This organisation was selected because it is a UK manufacturer and is providing intermediate level services. In addition it demonstrates that it is undertaking a process of sevitization (either as a proactive or reactive strategy) and has the same motivators as those that drive the PSS agenda, namely an environmental and sustainability consciousness.

7.3.4 Case study 4 Handling Company Inc.

The organisation was formed in 1956 in Japan with its UK SBU opened in 1982. The company manufacturers robotic solutions for various manufacturing sectors ranging from food, plastics, machines, automotive, glass, and the electronics sector to name but a few. Typically, the role of these robotic solutions are cited to be palletisation, packaging, handling, and metal removal.

The aim of the organisation is "*to make the robot evermore intelligent*" (Technical Director - 2011). The organisation was chosen because it manufactures a complex product (inline with the definition offered in this research) whilst offering intermediate levels of service and has the potential to be fitted with IVHM/$CBM_{1\ \&\ 2}$ enabled operational solutions.

7.3.5 Case study 5 Air Products PLC

This company is a multi-national manufacturer of helicopters formed by the merger of two major European manufacturers in 2001. With an SBU (production facility) based within the UK the organisation identifies itself as a "total capability provider in the vertical lift market" (Ref: Technical Manager). It operates internationally through a series of joint ventures, collaborative programmes and strategic partnerships within both the commercial and military sectors.

Whilst being an OEM manufacturing a range of helicopters it is also seen as progressing into the advanced service sector through use of HUMS, CBM, and various levels of IVHM. Technology is employed to monitor the usage of the asset by the operator as well as product condition through structural health management (SHM), engine health management (EHM) techniques.

The organisation was selected as it is seen as being to the ‘right’ of the servitization continuum, (it has servitized to the point where it is conducting active monitoring of the product in use), and as such offers the potential to critique the framework from the point of view of the organisation who has ‘embarked upon the journey’.

7.3.6 Case study 6 Ground Vehicles Ltd

Is an SBU of a major UK based OEM for the defence industry. The parent company supplies products, assets, and systems for all military theatres of operation (air, land, and sea) whilst the SBU specialises in land based fighting and transport solutions through the manufacture and support of innovative vehicles.

The organisation was selected as it is seen as offering advanced service solutions with its intelligent products offering designed levels of in-the-field operational autonomy. The manufactured vehicles also possess HUMS, IVHM, CBM, and EHM at differing levels of integration although data transfer is predominantly open loop in nature.

7.3.7 Community Assessment.

The pilot methodology was presented by two of the researcher’s colleagues at an established academic conference. The purpose was to introduce the methodology to the academic community and to seek feedback if offered from academics, researchers, and practitioners within the field. Whilst not an objective measure of the methodology and thus being of limited value due to the uncontrolled attendance, uncontrolled recording and the limited duration offered by the conference, it did act as a soundboard to introduce the methodology by way of publication and invite opinion from the delegates attending. No major critique of the methodology was offered and any such comments that were received are included within the findings.

7.4 Results of the evaluation of the pilot methodology

This section presents the results of the evaluation of the pilot methodology as applied to the case studies identified). The research design aims to conduct case studies informed by facilitated workshops which use the data collection techniques as previously defined (section 7.2.3). This research adopts an availability sampling approach. The methodology is delivered by way of presentation with copies of the pilot methodology being issued to each organisation with a request for cross departmental review. Each company was issued with copies of the workbook and allowed a period of time (*typically 4 – 5 weeks*) to digest and assess the contents. Feedback and critique is returned by way of the completed survey supported by invited comment by way of open written qualitative data.

7.4.1 Feasibility of the pilot methodology

The data returned reported that the majority of the organisations offered positive opinions as to the feasibility of the methodology with only one organisation (Case 5) stating that they did not think that it was feasible for their organisation. In offering this view Case 5 were of the opinion that it was their position in the supply chain (the OEM) and the market in which they operated (supply of military products) which made the feasibility questionable. Case 6 being also an OEM operating in the same sector as Case 5 stated that their strategy formulation process was reactive to government edicts by way of the ' Strategic Defence Review' (SDR) carried out by national executives and so the 'voice of the customer' was not typical. The feedback generally is seen to be positive with the majority view being favourable to the methodology when expressing opinions as to the consistency of the process stages and their ability to apply them.

When asked if the methodology offered contingency for problems encountered in the application of the methodology the consensus was neutral with 'don't know' being the main response. This was expected as in the review by 'experts', a full workshop (as research design) proved not to be possible. As such this could be the only opinion returned with Case 6 stating that "....our assessment was theoretical and so practical problems were not encountered".

7.4.2 Usability of the pilot methodology

The case organisations stated that the workshop is the best forum in which to conduct the strategy formulation process by use of the pilot methodology however the majority stated that they did not know if the process could be fully completed within the allotted time. Again this is to be expected as the evaluation was conducted by informed review rather than executed workshop. However, whilst the majority stated they did not know, two of the middle managers undertaking the MSc program gave positive answers with regards to the time to complete whilst one thought it was too ambitious to complete the whole process in the time allotted.

Of the tools and techniques supporting the methodology, the feedback was positive with the responses indicating that they were easy to use and follow at each stage of the process with the aims and actions easy to understand at each stage of the process. The use of the worked example (the fictional case within the workbook) also aided the use and understanding of the methodology and it was thought that the method may have sufficient flexibility within it to react to changes in circumstances during its execution.

7.4.3 Usefulness of the pilot methodology

When seeking opinion as to whether the process was worth doing the responses were inconclusive. This is to be expected as the evaluation was by expert review rather than by research design (the execution of a full workshop). However the majority of the MSc cohort did think that methodology was worth doing whilst the industrial organisations stayed neutral in their opinion. Of the resources (time and number of people) required to undertake the full process no clear feedback could be obtained as the responses were evenly spread ranging from 'very' excessive, 'average', 'to not at all'. Again this is to be expected as the responses are based upon individual perceptions of the time it would take to conduct the exercise within their respective companies however the methodology was thought to be a practical process.

7.5 Analysis and discussion of the results obtained from the evaluation of the pilot methodology

This section discusses the results from the evaluation of the pilot methodology (section 7.4) and presents them in the format of strengths (section 7.5.1) and weaknesses (section 7.5.2) as identified from the survey and additional qualitative data that was gained by additional comments from the Independent Validation Workshop, Cases 3 to 6, and the Community Assessment.

7.5.1 Strengths of the pilot methodology

This section records the strengths as reported during the evaluation of the pilot methodology and are presented in Table 7.3.

Table 7.3: Strengths of the pilot methodology as identified during pilot evaluation

Criteria	Comments taken from surveys and additional qualitative data offered by comments from cases and MSc cohort.
General	"........*there are many similar products on the market......the key selling point for this one seems to be the use of servitization (provision of total service rather than a product) through 'informating' (deriving data directly from the service or object delivered to the customer to enhance market penetration) as the main way of saving or expanding a business*".
	".....*could see that some of the methodology works for us and that the theory seems sound, but because our strategy is largely imposed, then some steps were not followed*"
	"....*the logic of the sequence of the stages was good*"
	".....*we feel that additional stages are required that ask the questions surrounding affordability of our service and the willingness/ability of the customer to pay more for better quality*"
	"....*a facilitated workshop would probably be the most effective means of undertaking the study as the reasoning and impetus to undertake each stage would be directly available to those participating*".
	"..*it is good to get some structure and traceability back into the decision making process....[the methodology].....forces us to follow a defined path towards the development of a strategy*"

Table 7.4: Strengths of the pilot methodology as identified during pilot evaluation (Continued)

Criteria	Comments taken from surveys and additional qualitative data offered by comments from cases and MSc cohort.
General	*"...I do not think that the ...[methodology]...holds all the answers, especially for an organisation of the complexity of.....[ours]. It is however a very logical approach......this is very a very useful aid to clear thinking and strategy development. It is the stages of the process and the thought process that the tool forces you down that delivers the real benefit*".

7.5.2 Weaknesses of the pilot methodology

This section records the weaknesses as reported during the evaluation of the pilot methodology and are presented in Table 7.5.

Table 7.5: Weaknesses of the pilot methodology as identified during the pilot evaluation

Criteria	Comments relating to weaknesses taken from surveys and additional qualitative data offered by comments from cases and MSc cohort.
General	“......*I wasn’t sure if the ServiceStrat is a general tool for overall business strategy, or a tool focussed on strategy making for servitization*
	“........*I was confused about the part HUMS or IVHM plays in ServiceStrat. It is alluded to in the preface but does not then re-appear until section 9”*
	“.....*I did not understand the overall structure of the four houses model. I can see why the four houses are there, and I can see that the first house has to come first! But I did not understand the hierarchical progression thereafter. I don’t see why the organisational aspect drives the technical aspect (or product), to me they are equally important elements that contribute to how the service requirements are met and could almost be considered independently*”.
	“.. *wondered whether the Technical and Product houses were the right way around – my thought was that the service requirement informs the product requirement (and organisational requirement), and the product requirements define the technical/technology requirements that support/underpin/realise the products*”.
	“....the relationships between the various elements of the ‘house’ structure were not clear to me”

Table 7.6: Weaknesses of the pilot methodology as identified during the pilot evaluation (Continued)

Criteria	Comments relating to weaknesses taken from surveys and additional qualitative data offered by comments from cases, MSc cohort.
General	"....*In the Quality House part, it is not clear if box A is about customer requirements or business requirements. I found this confusing, especially as box C is defined as the 'voice of the customer'*.....".
	"...*Box E, the 'Correlation Matrix' is only briefly summarised on page 19, but is not mentioned thereafter – it is not clear what this part of the process is about, or what value it has*".
	"......collectively, steps 3.1 thru 3.5 seem to represent a significant preliminary to being able to construct the Quality House, but I could not understand how they fed into 3.6 – this needs to be much more clearly explained. I also thought 3.1 thru 3.5 overlapped in terms of the issues they were trying to expose".
	".....I wonder if a servitization strategy development can be performed without a more intimate involvement of customers. My limited understanding is that it is usually customers that push their suppliers for servitization, rather than the other way around. This might mean that the final conclusion, and maybe the intermediate steps, need to be exposed to customers to get there buy in/approval?"
	".....*because this tool is a generic tool, its use may very well not lead to the implementation of servitization, which is only one of the possible outcomes. Close the business, sell the business, retrench into core markets, simplify, expand buying a bolt on; can all be valid outcomes of your......[process]......without going near servitization*".

Table 7.7: Weaknesses of the pilot methodology as identified during the pilot evaluation (Continued)

Criteria	Comments relating to weaknesses taken from surveys and additional qualitative data offered by comments from cases and MSc cohort.
General	*“.....a generic tool should be scalable. This one might work for a single department in a big business, or for a small-medium enterprise. It is unlikely to work in a large organisation where politics, silos, lack of corporate direction, time-serving and complacency all mitigate against getting the movers and shakers together in a room for 5 days with a common set of goals, common understanding of the business, adequate data and most of all the authority to commit to strategic change*”.
	“....*I can’t find much emphasis on process analysis and improvement*” “....*ditto for human capital*.....”
	“....*the worked examples are confusing and hard to follow*”
	“........the sudden appearance of HUMS on page 60 was baffling until I realised that you had to introduce it. I am not sure that suppliers of simple components can ‘informate’ them unilaterally simply by altering them to include sensors, or even holes for sensors. Surely the engine or vehicle manufacturer would specify the sensor system, its holes, pick up points, inputs and outputs etc, leaving the sump man to merely adjust his press tooling”.
	“........*I did find it difficult to read and to be honest lost concentration the further I went. I don’t wish to be negative but......as an academic piece of work it would hold water, but has for its practical application in a larger business I am not convinced*”

Table 7.8: Weaknesses of the pilot methodology as identified during the pilot evaluation (Continued)

Criteria	Comments relating to weaknesses taken from surveys and additional qualitative data offered by comments from cases and MSc cohort.
General	"....*the applicability depends largely on the complexity of the company*"
	".....*we did wonder about the flexibility of the process to respond to sudden external influences*"

Having presented the results, observations and comments obtained from the evaluation of the pilot methodology in the previous section, the next section identifies the refinements to be undertaken in order to align the methodology to the needs specified.

7.6 Refinement of the pilot methodology

This section presents the refinements to be undertaken to the pilot methodology as identified during its evaluation. From the surveys and tabulated data, and the additional qualitative data obtained from returned critique a list of refinements has been tabulated and is presented (Table 7.9: Changes to the pilot methodology. When reviewing some of the comments it becomes apparent that the refinements can be broken down into presentation, identification of purpose, structure, and usability.

Whilst the weaknesses identified in the pilot methodology are tabulated in the previous section which inform the refinements offered in the following table, the research wishes to draw attention to two of the comments offered.

i. *".....I wonder if a servitization strategy development can be performed without a more intimate involvement of customers. My limited understanding is that it is usually customers that push their suppliers for* *servitization, rather than the other way around. This might mean that the final conclusion, and maybe the intermediate steps, need to be exposed to customers to get there buy in/approval*?"

ii. "*.....because this tool is a generic tool, its use may very well not lead to the implementation of servitization, which is only one of the possible outcomes. Close the business, sell the business, retrench into core markets, simplify, expand buying a bolt on; can all be valid outcomes of your......[process]......without going near servitization*"

When considering statement (i) the response was expected. The literature (chapter 5) gives a plethora of examples and guidance relating to the need for alignment of operations strategy to the needs of the stakeholders, one of which is the customer. The question arises as to who is the customer? .A customer could be the end user of the product or service within the market place (B2C), or in a B2B relationship it could be the next organisation down the supply chain (or SBU within a corporate structure). In order to have an aligned strategy it is important that it is customer 'pulled' not business 'pushed' although the research does acknowledge that this may not always be so if the operations strategy relates to breakthrough technologies and emergent products thereof.

The pilot methodology is offered as a 'neutral' process that does not seek to be prescriptive but does facilitate the option of an operations strategy based upon the concept of servitization to emerge. Whilst all the options offered in statement (ii) above are valid, the methodology seeks to ensure that such options are not default positions to a changing environment. There is an alternative solution to these traditional *remedies* and the pilot methodology facilitates the emergence and consideration of added services and PSS as an effective operations strategy.

Table 7.9: Changes to the pilot methodology

Criteria	Changes to the pilot methodology
Presentation	Remove references as it was the opinion of practitioners that the workbook appeared too ‘academic’ and was therefore off putting
	Needs better sign posting throughout the workbook
	Need to use the example ‘case’ more throughout the process to facilitate better understanding
Purpose	Be more explicit and clear as to the target users of the methodology. Who should use it and what does it hope to deliver?
	State what it does not deliver! The methodology is to assist in the formulation of an operations strategy for the organisation...it is not for the formulation and analysis of the business case. This distinction needs to be explicit.
	Better explanation of the servitization, organisation, technology links as some of the participants of the evaluation registered confusion..
Structure	Requires a better description of the house structure.
	Requires better description of the reasons behind the choice of hierarchy of the houses within the methodology
	Remove ‘roof’ of the house as it is not providing added value to the process.
Usability	Workshop structure was thought to be the best forum but perhaps a structure should be illustrated.
	Clear demonstration of tools and techniques in the last two houses

7.7 Chapter summary

This chapter has presented the evaluation of the pilot methodology, the fourth phase of the research programme. The pilot methodology evaluation process has been presented (section 7.1) together with the design of the data collection protocol (section 7.2). The case study selection and structure was then described (section 7.3) and a quantitative and qualitative analysis of the data returned from the evaluation presented (section 7.4). A subsequent analysis of the data (section 7.5) identified the recorded strengths and weaknesses of the pilot methodology as perceived by the participants from which required refinements are tabulated (section 7.6). The analysis was conducted against the criteria of feasibility, usability, and usefulness together with qualitative 'open' critique offered by participants of the evaluation process.

Whilst the research design aimed to deliver a case study analysis the current economic climate proved to be too challenging in that organisations were concerned with survival due to the macro financial climate and were unwilling to release key staff and personnel to conduct the planned workshops. Whist not optimum for the phase of the research, the companies identified were willing to receive the methodology via presentation and retained hard copy of the workbook from which a detailed internal review of the process was conducted and data returned to the researcher. This approach does have the benefit of being able to give insight as to the ability of the process to be stand-alone methodology, (one that can be used without the need for a facilitator). The feedback received illustrated a positive evaluation the pilot methodology with suggestions to further refinements. The refinements were incorporated into the pilot methodology which is presented for verification and validation. (Chapter 8).

8 SECONDARY EVALUATION OF THE REFINED METHODOLOGY

The previous chapter (8) has presented and discussed the primary evaluation of the pilot methodology. This chapter addresses phase 5 of the research methodology whereby the refined *post pilot* methodology is applied to two further case study companies by way of validation and verification. The output of this phase of the research is the final operations strategy formulation methodology.

8.1 Phase 5 objective and method

The objective and method of the final phase of the research programme is presented in this section. The objective of this phase of the research is to test the post pilot methodology and through the identification of further requirements obtained by use and/or professional critique, produce an operations strategy formulation methodology that has been verified and validated. The design of the data collection protocol (section 8.2) is presented followed by a summary of the selection criteria for the two case companies (section 8.3). A description of the evaluation of the methodology is offered (section 8.4) with the results of this evaluation presented in (section 8.5). The analysis and discussion of the findings is seen in section (section 8.6). Following the final amendment /refinement of the methodology (section 8.7) a summary of the chapter (section 8.8) is offered. An overview of the structure of this chapter is illustrated in Figure 8.1.

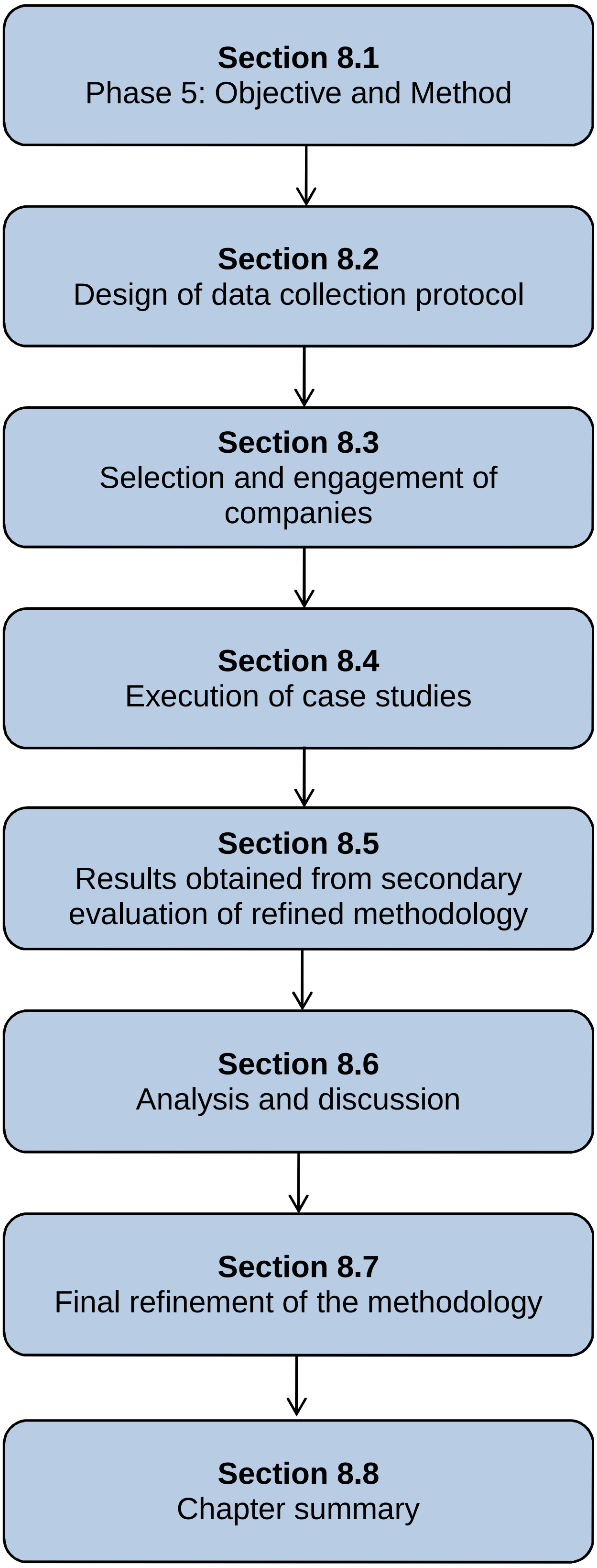


Figure 8.1: Structure of chapter eight

8.2 Design of data collection protocol

The design and data collection protocol is the same as in the evaluation of the pilot methodology (section 7.2) to ensure continuity of research method. The definition of the assessment criteria and data collection method has been discussed in (section 7.2.1). The data collection framework (section 7.2.2) and the data collection tools and techniques (section 7.2.3) as used in the previous phase of the research programme are repeated in this final evaluation phase with the contingent process for obtaining evaluation data remaining in place.

8.3 Selection and engagement of companies

This section presents the rationale for, and the selection and engagement of companies to be used for the final cases. All the considerations discussed in (section 7.3.1) are adopted for this phase of the research. It was noted that two competing companies operating in the same sector were part of the population of organisations identified as within the scope of the research (Chapter 4). The companies had the same products, offered similar services and had the same customer and supply chain for their products. For these reasons the research felt that these organisations would provide interesting insights into the feasibility, usability, and usefulness of the methodology whilst giving a quasi-standard assessment approach when seeking comparisons in the data.

Case study 7 Railtech PLC

This UK subsidiary of a multinational organisation specialises in the design and manufacture of rolling stock and locomotives for the railway sector. It has and continues to experienced difficult trading conditions and has sought to increase the value added to its customers by adding advanced services through an evolving service delivery system. The organisation offers the design and manufacture of its products supported by condition monitoring technology (CBM_1) although full integrated management solutions are in their early stages of evolution. This organisation is chosen because of its position as a key railway infrastructure supplier and the stage it is in when considering the evolution and development of the organisation. The company fits the scope of the research by having a recorded interest in Product Service System type availability contracting driven by IVHM generic technology (identified from survey return and company website). It's current evaluation of its trading position ensures that this organisation is relevant to the research.

Case study 8 Express Trains PLC

This organisation is a competitor of Railtech PLC (Case 7) and is currently experiencing the same market and stakeholder pressures. As a design and manufacturer of railway rolling stock and locomotives it operates in a highly competitive market which is currently evolving. It is subject to rapidly advancing technology and evolving business models. The organisation is also adopting Product Service System modes of operation however it lags behind Case 7 in the area of CBM_1 with no evidence of condition based management (CBM_2) being observed. As with Case 7, it is the position relating to the organisation's evolution (i.e. advancing technology, commercial pressures, and their response) that makes this organisation one which is relevant to this research. In addition it offers the opportunity to compare the responses for the two organisations as they operate in the same sector, make similar products and offer similar services.

8.4 Execution of case studies

This section presents the execution of the case studies. The research design allowed for two workshops to be undertaken with the researcher taking the role of participant as observer. There was planned to be one workshop with each organisation. When senior directors were approached, whilst they were very positive and wished to engage with the research, the response was that they (and their key staff) could not attend a week long workshop due to current time constraints. In response to this the contingent methodology was adopted (Figure 7.4).

8.5 Results obtained from the secondary evaluation of the refined methodology.

This section presents the results of the secondary evaluation of the refined post pilot methodology. The process of evaluation adopted the contingent method as defined in Figure 7.4. The documented methodology was issued to the directors of each of the case organisations for their review and critique. The final evaluation was undertaken using a structured interview format which was informed by the post workshop questionnaire. Whilst the research would have benefited from the workshop[approach the views and opinions expressed by the interviewees are of significant value as each person responding held a key senior position within their respective organisations and were regularly involved within the strategy formulation process. This research sought the opinions of each executive (four in case 7 and two in case 8) and their responses were recorded (audio) and transcribed. The responses are summarised in Tables 7.1 to Table 7.10.

Table 8.1: Key points raised from semi structured interviews (Case study 7)

Question	**Interview 1**	**Interview 2**	**Interview 3**	**Interview 4**
Q1. Do you think that the methodology could be followed in its entirety?	• Basic building blocks are sound • Facilitated process • Thinks there needs to be an element of training	• "It is more of a strategy document than a detailed flow chart showing inputs and outputs. That level of detail is really missing to me" • Gives good guidelines but not prescriptive	• Does not see a problem…..it is relatively easy	• No problems following it. • Strategy objectives defined • Sign posting good • Likes definitions • Thorough
Q2. Do you think that the sequence of the stages is consistent?	• Yes it is consistent • Can't think of a better way of sequencing it • There is a level of consistency	• Flows logically and did not see anything wrong	• The whole process is QFD. The process is designed not to miss steps but this ties up far too much time	• Sequence of stages is good and can't foresee any problems
Q3. Do you think that the method could be applied satisfactorily?	• We are both a manufacturing and service business • We do not do this at the moment • "can see value in this about operating strategy against core requirements and skills"	• No – Our company is way to complex for this – could not get all the influences into the process • This would work for an SME but for a global organisation there would be far too many variables	• Not a yes/no answer • There are elements applicable to various parts of the organisation	• Theoretical structure no problem • "Bang on in trying to sort out what we have to offer in services within the UK"

Table 8.2: Key points raised from semi structured interviews (Case study 7)

Question	**Interview 1**	**Interview 2**	**Interview 3**	**Interview 4**
Q4. If problems are encountered do you think the method can provide alternative solutions?	• Did I make sense? – Yes • Are there any 'howlers'? – did not see any •	• This made me think – especially the 'shifting sands' and the first pillar.	• Down to the use of a facilitator and the facilitation of the process and the words used. • The example did not show anything 'left of field' emerging.	• Yes the way it is structured you have the basis for negotiation
Q5. Do you think that the method can be undertaken in the allotted time?	• Easy to complete but may struggle to get executives for 5 days • Here you would get 3 days and work extended days in a hotel	• Could do with 5 days as long as teams chosen wisely. • If there were 20+ in a team there may be issues	• Yes – undoubtedly • It could be done in a shorter time – needed for SME's	• Facilitation is paramount • "as long as people understand the time they have available and the process……" • Facilitator to guide
Q6. Is the workshop an effective means of delivering the methodology?	• Has to be as environmental issues make it impossible to use any other way	• Best way of doing it • Brainstorming etc	• Only option you have to get success • No viable alternative	• Yes definitely • Pull people from their normal roles

Table 8.3: Key points raised from semi structured interviews (Case study 7)

Question	**Interview 1**	**Interview 2**	**Interview 3**	**Interview 4**
Q7. Are the tools and techniques easy to follow?	• Need to re-read and think about it • Need to revise QFD • Good audit trail	• Perhaps the tools should be enhanced more and related to case study • Workbook not strong enough as a 'stand alone' document but fine as a facilitated process.	• Depends on backgrounds • Sign posts are good • Needs prior knowledge • References are good • Thought the workbook lengthy.	• No problem as presented • Need to use
Q8. Are the aims and actions of the method clear at each stage?	• Yes	• Not totally clear • This is down to who is reading it	• Yes at each stage • Sign posts good • "You told them what you were going to tell them, then told them what you had told them"	• Yes – the introduction and structure, and then down into each stage is very clear indeed".
Q9. Did the example provided help you use the methodology?	• Interesting case study • It does help • "sufficiently displaced as not to confuse" • Good, not too complex	• Yes it helps but needs more depth in example	• Example helped • Would be difficult without it • Should have shown something left of field	• Always good to have a case study • Brings it alive
Q10. Did the method provide flexibility?		• The way the process is pitched helps • Does not constrain so as to negate emergence	• Generic enough • Boundaries with each step • Technology levels are a given – need to say why!	• Yes see previous comments • Depends on audience

Table 8.4: Key points raised from semi structured interviews (Case study 7)

Question	**Interview 1**	**Interview 2**	**Interview 3**	**Interview 4**
Q11. What are the major strengths and weaknesses?	• Strengths – process oriented and intuitive • Weakness – Back end, work through the thing and then what? • Facilitated process helps • Needs to finish off – so how to apply the findings	• Nice to see a method like this • Brings in other concepts • Did not see problem elements • Weaknesses – none offered	• Strength – leaves documented audit trail • Points of reference • Weakness – the relevance of going through the whole process step by step	• Strength – clear structure • Combination of structure of ideas • Auditable trail
Q12. What changes would you make if you ran this process?	• I would like this to be computerised • Takes a scientific approach to strategy formulation	• Don't know well enough to answer	• Process is NOT missing a trick • Can't find anything wrong	• Very comprehensive do not see additions • Could be useful to have web based portal/process
Q13. What stages would you modify or combine?				• Cannot comment for the sake of it • I am not an ops man

Table 8.5: Key points raised from semi structured interviews (Case study 7)

Question	**Interview 1**	**Interview 2**	**Interview 3**	**Interview 4**
Q14. What else in the method structure would you like the stages to define?		• Do not know well enough to comment • Maybe more depth		
Q15. How would you rate its potential success?	• Hunch would be that it would be successful	• Confident that a strategy would come out of the process • How successful that strategy would be - cannot tell!	• Would not be worth doing as you would not get support in this company • We have a strategy in place so would not be used	• It would work • Needs faciliator
Q16. Does the methodology consume excessive resources, time, people?	• No when you look at what we are dealing with - £300 million turnover	• Neutral – would take the appropriate length of time	• 1 week @ 6 people needed = 6 working weeks • A lot for an SME • Can you shave days of it without compromising the process	• No – the time is defined and the process fits the time

Table 8.6: Key points raised from semi structured interviews (Case study 7)

Q17. Does the method provide a practical process?	• Yes			• Yes, very much so
Q18. Are there any lessons learnt?				• Could be basis for a book • "It would produce a good output, I am absolutely sure"
Q19. Which stages were found to be the most useful and why?	• Liked the whole process • Not unique as it can be applied across areas	• Foundation of the model is the most useful • Do not know the least useful	• Shifting sands	• Need every stage to produce the temple • Least useful – organisational structure
Q20. Is there anything else you wish to offer?		• A good read • Huge amount to read • 1st section – is it fluff? • 'meat' is at the back….follow the case study	• Nothing springs to mind	• Well produced and polished peace of work

Table 8.7: Key points raised from semi structured interviews (Case study 8)

Question	**Interview 5**	**Interview 6**
Q1. Do you think that the methodology could be followed in its entirety?	Yes could follow it ok but needs a facilitator – depends on the level of material on how you develop strategy in the first place.	You need a facilitator – need to have someone who is used to the process. It is different to what we do! The scope of this we cover in 1.5 days of our 3 day review. Without a facilitator I feel you would get lost.
Q2. Do you think that the sequence of the stages is consistent?	I thought the formulation of the steps to get to the end was 'cool'….it is pretty simple – practical steps A,B,C,D – good points!	Service – technology – product – it does come back to the organisation at the end. We offer service of loco's across America. 'They' looked at service but not the product! Consequently when products go 1000's of miles across the USA……. Hundreds of trucks get abused. There is no monitoring – they come back at a certain time but (we) have no idea of their condition. We do not know how to track the loco. They missed the product house completely.
Q3. Do you think that the method could be applied satisfactorily?	Though it could be applied in part. We do have some of these points……but not with such formality.	Yes it could but need time to devote to this. We suggest a week. We do 3 days every 6 months with an additional 2 days to cascade.

Table 8.8: Key points raised from semi structured interviews (Case study 8)

Question	**Interview 5**	**Interview 6**
Q4. If problems are encountered do you think the method can provide alternative solutions?	Perceived problems! Did not see any obvious ones…..We would do this but not with such formality and supporting tools.	Can emergent solutions appear as you go down this route? …it is very thorough and would not rule things out.
Q5. Do you think that the method can be undertaken in the allotted time?	Allotted time. Can be done easily. Can be done in three days. We would hit it hard and fast. Maybe all in a hotel.	If facilitated then yes…..the facilitator needs to be strong so as to maintain balance.
Q6. Is the workshop an effective means of delivering the methodology?	Yes a workshop. Give them three days in a hotel then they can't escape. A quick dirty analysis first.	Yes. If you do it a different way then you do not get them owning the process or the outcome.
Q7. Are the tools and techniques easy to follow?	They are not bad….nothing jumped out at me …….	Yes they are …..[But this person is an operations manager and knows QFD well].
Q8. Are the aims and actions of the method clear at each stage?	This is important….referred to work of Nigel Slack and the importance of rigour in systems….method demonstrated this.	Its appears so…..appears to be clear.
Q9. Did the example provided help you use the methodology?	Case study helps….I am sure this is the case.	It did help to have a case study ….[supporting the methodology].

Table 8.9: Key points raised from semi structured interviews (Case study 8)

Question	**Interview 5**	**Interview 6**
Q10. Did the method provide flexibility?	It is not too rigid….nothing prevents you wondering off to do other things. You need a framework to keep focus else people would just have a 'moan'	If you dropped out a stage would this still work? Yes…it is all about the facilitator…when they do PDF they could cut out staff and still get results.
Q11. What are the major strengths and weaknesses?	Strengths – depends on the maturity of the people and their discipline. It is an 'ops' thing. You need to be aware of the competition and who they are. Weaknesses – none offered by interviewee	Strengths • Structure • Has all the questions there • We don't do any customer work when we do PDF • Have regular review • Would not miss much out if followed Weaknesses – none offered by interviewee
Q12. What changes would you make if you ran this process?	Unsure but there is nothing that springs out here. I think that the tool is great but the sector …[Rail] …needs to evolve – custom and practice. The auto sector is light years ahead….we need a real culture shock. The tool is …. • Very powerful • Very good • Problem is with this sector	
Q13. What stages would you modify or combine?	Question not asked	Question not asked
Q14. What else in the method structure would you like the stages to define?	Question not asked	Question not asked

Table 8.10: Key points raised from semi structured interviews (Case study 8)

Question	Interview 5	Interview 6
Q14. What else in the method structure would you like the stages to define?	Question not asked	Question not asked
Q15. How would you rate its potential success?	Worth doing and having a framework offers every chance of success	Successful and worth doing
Q16. Does the methodology consume excessive resources, time, people?	Perhaps it could be squeezed into an more informal session	Substantial investment but then if you are trying to change the business……….
Q17. Does the method provide a practical process?	Yes it does	It is practical and straight forward
Q18. Are there any lessons learnt	I cannot answer this question until I have used the methodology	Question not asked
Q19. Which stages were found to be the most useful and why?	It is good, you can use it and if you put a group of guys together you would get a solution	The first house would be the most useful but cannot state which would be the least useful
Q20. Is there anything else you wish to offer?	No other comments were offered	No other comments were offered

8.6 Analysis and discussion of results from the secondary evaluation of the refined methodology

This section discusses the findings recorded in (section 8.5). The feasibility, usability and usefulness of the methodology are first discussed followed by the strengths and weaknesses as observed by the industrial executives in the two case companies.

Feasibility of the process

When reviewing the results recorded in the previous section the consensus of the six executives approached within the two companies was that the methodology offers a feasible process although the majority of opinion stated that the method is best delivered and supported by use of a facilitator. The process defined by the methodology is easy to follow and has adequate signposting although some level of training would also benefit the users of the process depending on the level of understanding of strategy formulation techniques. The basic building blocks identified within the methodology follow a logical sequence consistent with the objectives of its use and offers good guidelines to the formation of an operations strategy without being prescriptive. The use of the QFD technique within the field of operations strategy, whilst being innovative is designed not to miss detail. It offers a logical and auditable process offering value when seeking to align core skills with strategic objectives with one respondent stating that the methodology was "……'bang on' in trying to sort out what we….. [they]….. have to offer in services within the UK". (Table 7.1: Case study 7, Interview 4). There were no perceived issues regarding the feasibility of the methodology and it was sufficiently flexible to allow emergent solutions to be developed.

Usability of the process

The data obtained from the interviews of executives within case study companies 7 & 8 informs the research that the methodology is usable. The presentation of the methodology was designed to be self-supporting and whilst the majority opinion was that it could be followed and easily used the documented method is not strong enough to be a stand-alone methodology. Its application would benefit from the use of a facilitator to guide its users. The main consideration is that of the time taken to fully apply the methodology. Whilst the exercise can be completed within the five day allotted time several executives stated that it may prove difficult to retain the key personnel for five consecutive days, three extended days within a neutral setting being their preferred option. This was seen as being particularly relevant when the methodology is used by SME's. Although the problems to be addressed may be significantly smaller within the SME, such organisations may not be able to release key staff for such periods.

The workshop means of delivering the methodology is seen as the "..the only option ……to gain success…. there is no viable alternative" (Table 7.2: Case 7, Interview 3). This ensures that the application of the methodology is not impeded by the operational demands of the users whilst undertaking the process and also ensures that those conducting the study 'own' the resulting strategy.

The supporting tools and techniques aid the usability of the methodology and the case study also gives valuable guidance "..which is sufficiently displaced not to confuse" when seeking to understand how to apply the method however the inclusion of the case does make the documented methodology lengthy for one respondent. The understanding of the QFD process is dependent upon the backgrounds of those applying it but there are sufficient references and guidance notes to aid the application. The usability is also aided by the flexibility of the process as it does not constrain so as to negate emergence of alternative considerations throughout.

Finally several responses did suggest that the methodology should be computerised and/or offered as a web based solution. However, the literature suggests that senior executives and managers are cautious and reluctant to adopt solutions unless there is explicit clarity relating to methodology employed to derive such solutions. In general the methodology is seen as being usable with the process “Not missing a trick” (Table 7.4: Case 7, Interview 3) and being very comprehensive (Table 7.4: Case 7, Interview 4).

Usefulness of the process

In seeking to assess the usefulness of the process it is important to note that the research is seeking to assess the usefulness of the methodology when delivering an operations strategy and not an assessment of the outcome to the organisation of the application of the resultant strategy itself. Whilst this is undoubtedly of interest to all in the field it is not within the scope of this research. The data returned states that the methodology if applied would be successful although would benefit from the use of a facilitator although one respondent did voice doubts as to the outcome when applied to his organisation. Whilst seeking to remain neutral and avoid bias within reporting and acknowledging the opinions it is significant to note that this view was not concurred by his colleagues during a review of the transcripts when asked the same explicit question. It was also the view of the executives that the process would not consume an excessive amount of time when one considers the value of the business and the need to have an aligned strategy. This view may need revision when applying the methodology to a smaller organisation but elements of the process might also be omitted without jeopardising the ability to identify and inform and emergent or planned strategy. The usefulness of the methodology is aided by the structure of the process being sequential, ordered and iterative. All the stages of the methodology assist in making it useful although the opinions sought suggest that the first phase, the identification of the ‘shifting sands’, (organisational awareness) and the laying of the ‘foundation’ (stakeholder requirements) where perceived to be the most beneficial.

Strengths of the process

In taking an overview the comments made by the interviewees the following strengths relating to the methodology are noted. The feasibility, usability, and usefulness of the methodology when seeking to define an operations strategy are supported by the following:

- The methodology offers a structured approach which is clearly signposted
- The process defined within the methodology is iterative and allows for feedback loops and reconsideration during its application.
- It offers a clear and auditable ‘trail’ so that the question of ‘how did we come to this decision’ can be seen and answered.
- The application of a facilitator ensures that time is spent upon the objective of the process (the formulation of strategy) and not translation of the methodology itself.
- It takes an product development approach which is seen as aligned to the needs of a typical manufacturing organisation.
- There is a clear and concise road map throughout with explicit objectives at each phase and stage of the methodology.
- It ensures alignment of effort and results to the needs of stakeholders.

Weaknesses of the process

When considering the weaknesses of the process it is noteworthy to observe that very little recommendations are offered by the opinions sought for modification of the methodology. The validation process explicitly asked of the executives if they perceived any weaknesses or room for improvement (Question 11) with only one opinion seeking to question the relevance of going through the whole process ‘step by step’. The process does allow for certain steps to be omitted although the four house methodology does allow for consideration relating to level of service, technology, organisational structure and product suitability and they alignment to the requirements of the stakeholders and the economic and competitive space in which the organisation operates. Additionally, the methodology does rely on being able to bring together a suitable team for as significant length of time so that due consideration of the issues through a workshop delivery can be achieved. Whilst this mode of application is seen as the optimum it could be difficult to achieve. Careful scheduling would have to be considered.

8.7 Final refinement of the methodology

This section records the final refinement that is undertaken prior to presenting the final methodology in the following chapter. (Chapter 9) and are recorded in Table 7.11.

Table 8.11: Modifications to presentation of the methodology

Mod 1	Add definition of complex product to definitions page
Mod 2	Review methodology deliver programme to illustrate that days do not have to be consecutive
Mod 3	Accreditation • add EPSRC to front cover • remove written accreditations as not required in the methodology document
Mod 4	Remove pages for user notes in document
Mod 5	Modify figure 6 in document describing methodology to clearly show the process

8.8 Chapter summary

This chapter has fulfilled the final phase of the research programme by conducting the secondary evaluation of the post-pilot refined methodology. It has sought the advice and opinions of experts within the field of strategy formulation within two case organisations who hold executive positions within their companies. The evaluation has retained the same test parameters of feasibility, usability, and usefulness thus adopting and maintaining a well-established technique for the assessment of such a methodology throughout the research. The case organisations have stated that the methodology is feasible, useable, and is of usefulness and would deliver a viable operations strategy. The following chapter presents the ServiceStrat methodology.

9 PRESENTATION OF THE METHODOLOGY

This chapter presents an overview of the ‘ServiceStrat’ methodology which is the fulfilment of the research aim. The previous chapter detailed the evaluation of the refined post pilot methodology and the final validated operations strategy formulation process is presented here. The chapter offers an review of the final research objective and the method employed (section 9.1) and then presents an overview of ‘ServiceStrat’ methodology (section 9.2).

9.1 Overview of the research objective and method

This phase of the research presents the final validated ‘ServiceStrat’ methodology. It is the main deliverable and meets the research aim and the final research objective (section 3.2) and has been achieved by following the defined research programme (section 3.3). The development of the research programme delivered the following research process.

- Phase 1: To understand the principles of IVHM and to gain knowledge of the level of practitioner awareness of the concept. (Chapters 2 & 4).
- Phase 2: To introduce service delivery systems and to gain an understanding of the operations strategy formulation process (Chapter 5).
- Phase 3: The formulation of the pilot operations strategy formulation methodology (Chapter 6).
- Phase 4: Evaluation of the pilot operations strategy formulation methodology (Chapter 7).
- Phase 5: Validation of the refined post pilot operations strategy formulation methodology (Chapter 8).

This section has presented an overview of the objective and method which has been undertaken to deliver the final methodology which is the result of the five research phases recorded above. The following section presents an overview of the ‘ServiceStrat’ methodology (section 9.2). Finally the phases which have been followed to achieve this methodology are presented in figure 9.1.

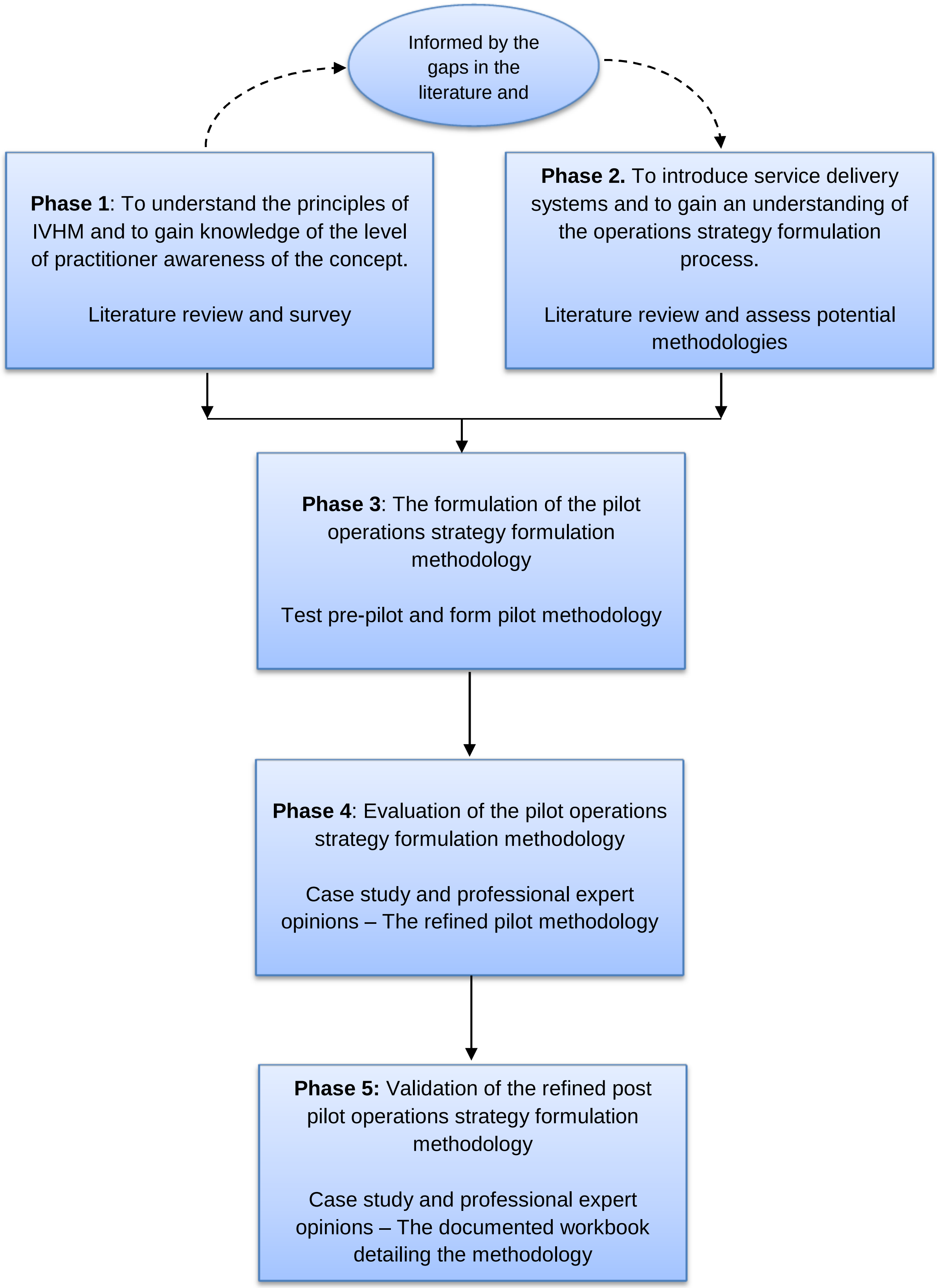


Figure 9.1 Phases leading to the final methodology

9.2 Overview of the 'ServiceStrat' methodology

This section presents an overview of the validated 'ServiceStrat' methodology. The methodology is presented by way of a workbook the structure of which is discussed in section 9.2.1. There follows an overview of the validated methodology (section 9.2.2) and a description of each of its phases and stages (section 9.2.3).

9.2.1 Structure of the workbook

The validated methodology is presented by way of a workbook which is divided into three parts. Part 1 of the workbook introduces the concepts of Product Service Systems, servitization, operations strategy and poses the rationale for conducting a review of operations strategy. Part 2 presents an overview of the ServiceStrat process, whilst Part 3 gives details of each stage of the methodology together with a worked example for guidance.

The structure of the workbook is illustrated in the figure below (figure 9.2).

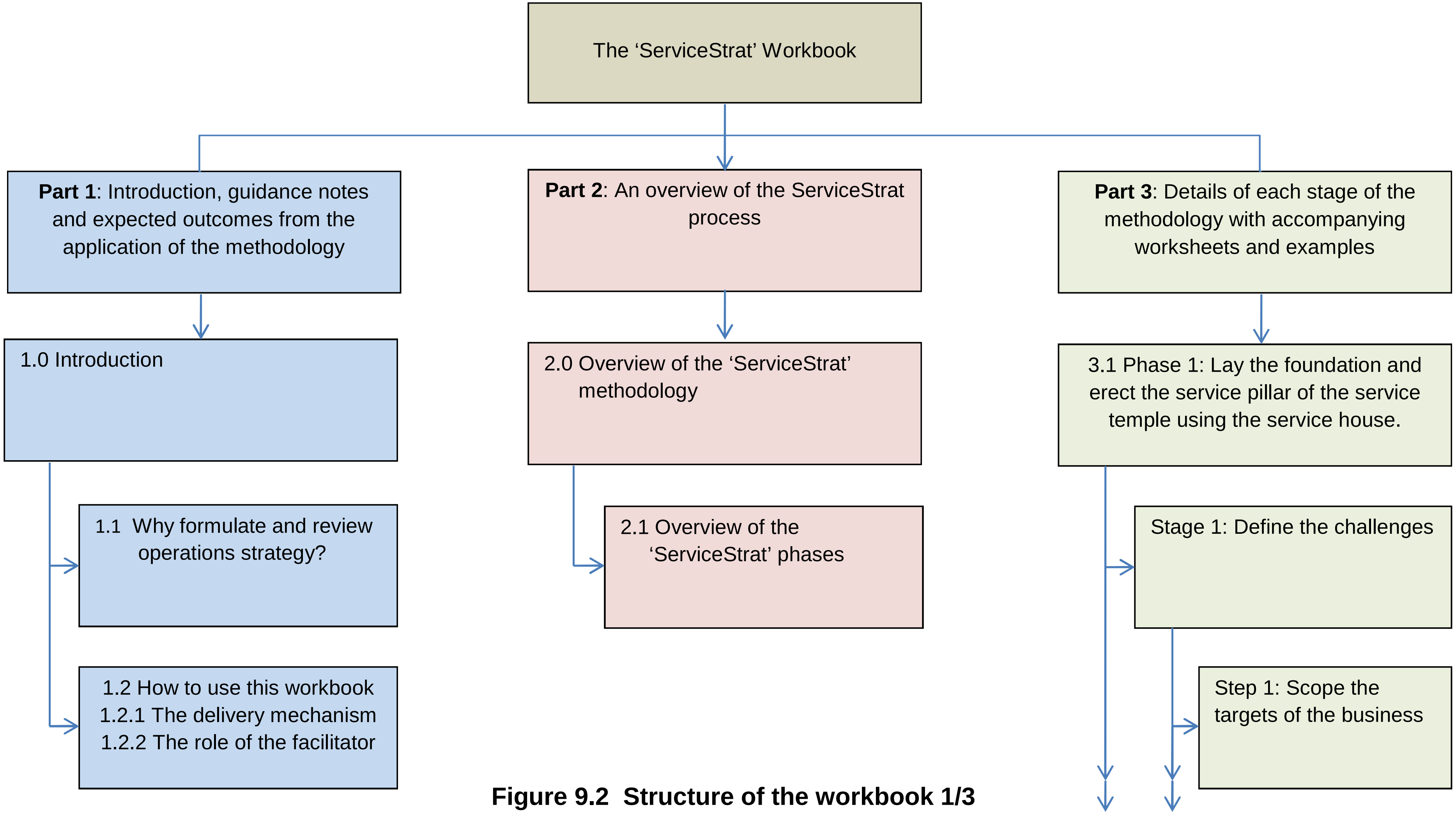


Figure 9.2 Structure of the workbook 1/3

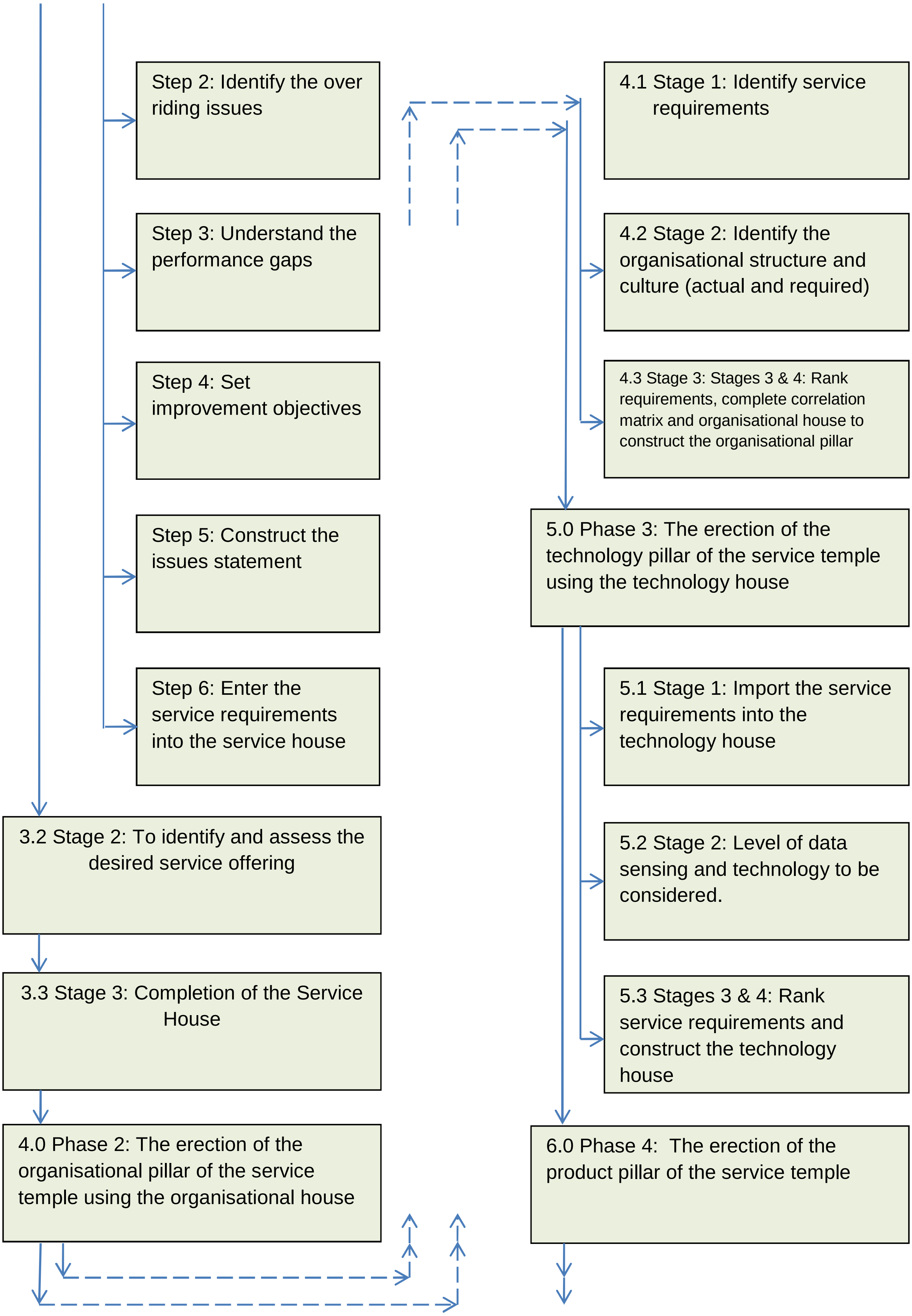


Figure 9.2 Structure of the workbook 2/3

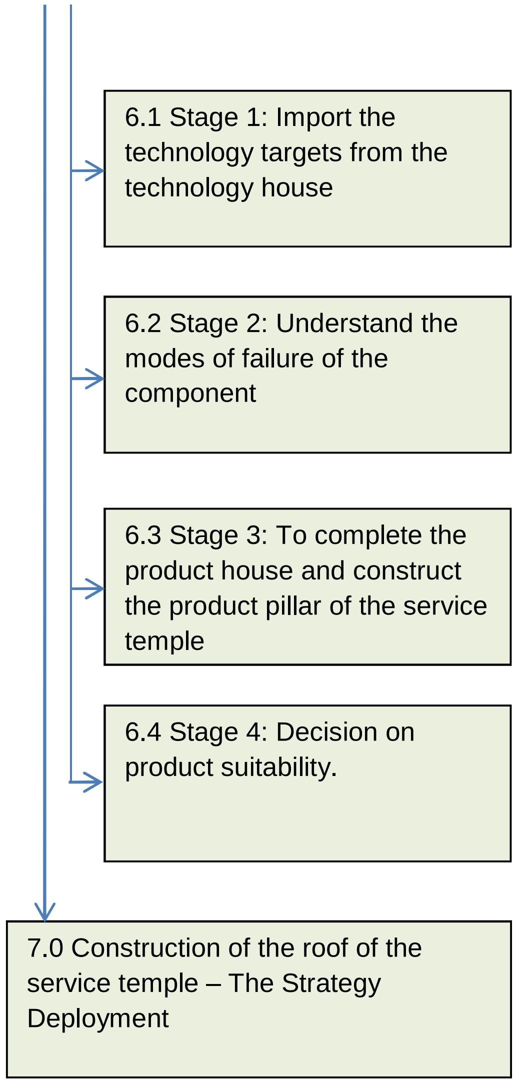


Figure 9.2 Structure of the Workbook 3/3

9.2.2 Overview of the final 'ServiceStrat' methodology

This subsection presents an overview of the final validated 'ServiceStrat' methodology. This overview gives a description of the content and structure of each of the phases and stages of the methodology as they appear in the methodology. It is designed to be used by senior directors and managers who have a responsibility for defining the operations strategy of their organisations. It facilitates an understanding of how the organisation actually competes within its market sectors by seeking stakeholder opinions.

Whilst not offering a prescriptive solution the methodology allows through a structured gap analysis the emergence of alternative operating strategies one of which is enhanced services. It allows for the assessment and understanding of the organisational structure of the company, and the level of technology to adopt by way of offering intelligent products, when seeking to align their operations strategy to stakeholder requirements.

In order to guide the user through the methodology use is made of the construction of a 'service temple' as a means of sign posting the progress through the strategy formulation process. An illustration of the 'temple' is seen in Figure 9.3.

It is seen that the structure comprises seven elements which if assembled correctly will deliver an operations strategy which is aligned to stakeholder needs, whilst possessing the best suited organisational structure and level of technology inbuilt to the product and support system. It also allows for a test to see is the product is suitable for such an initiative finally delivering a strategy which if followed will deliver an operations strategy which facilitates competitive advantage through the adoption of enhanced service delivery systems.

When seeking to construct the structure various tools and techniques are provided within the methodology. The research has adopted earlier the premis that an operations strategy is the product of strategic thinking and as such product development tools have been used to guide the process. The main tool

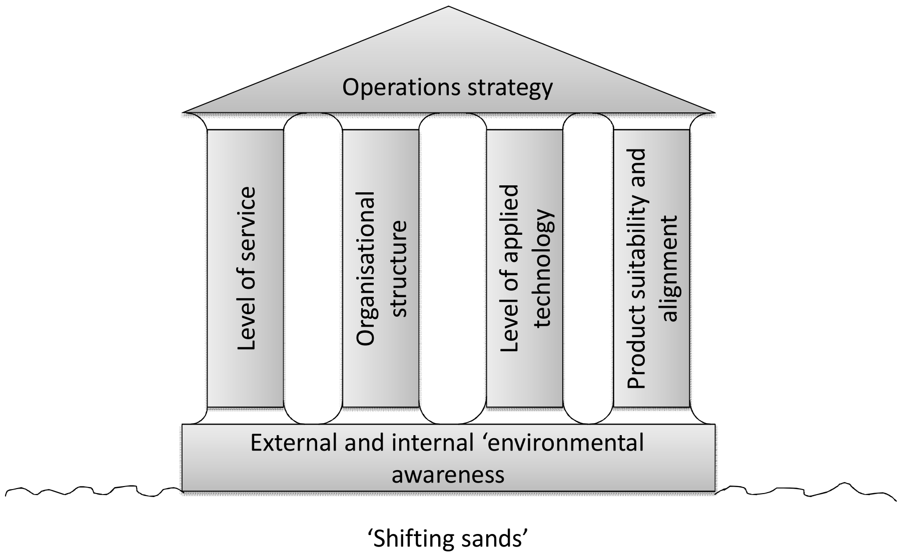


Figure 9.3 The 'Strategy Temple'

used to support the user(s) of the methodology in the construction of the 'temple' is the House of Quality. This is an established tool within the product development literature and is now applied to guide the thought processes in forming an operations strategy. It will be seen that it is also supported by additional tools and techniques throughout the process. An overview of its use and iteration in forming the temple structure is shown in figure 9.4.

Finally an overview of the aim, rationale and outcome of each phase of the 'ServiceStrat' methodology is presented in table 9.1.

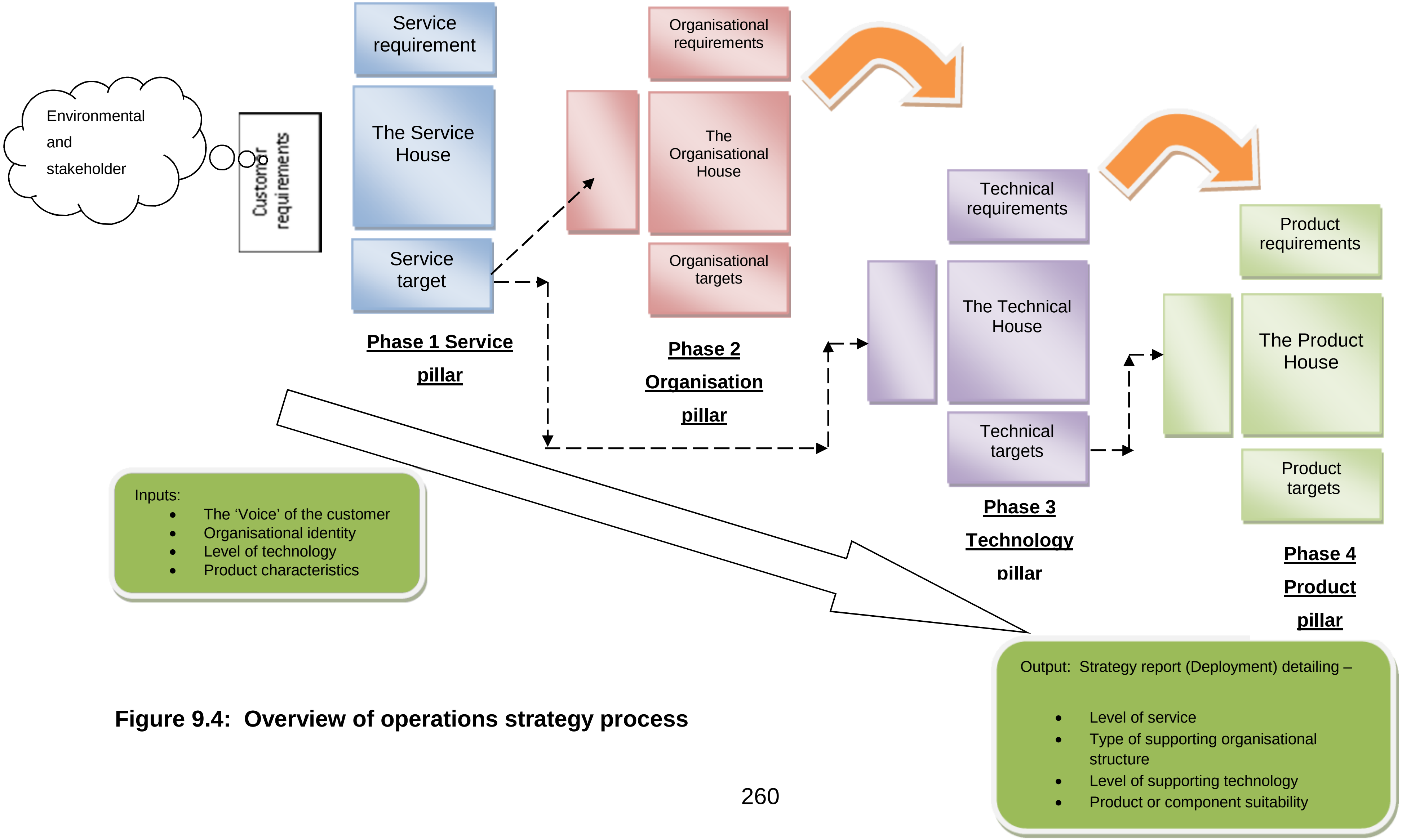


Figure 9.4: Overview of operations strategy process

Table 9.1 Aim, rationale and outcome for each phase of the methodology

	House of Service (The Service Pillar)	The Organisational House (The Organisation Pillar)	The Technology House (The Technology Pillar)	The Product House (The Product Pillar)
Aim Service strategy	To understand which forces and drivers are acting upon the organisation, and align the operations strategy to these forces.	To understand the optimum organisational structure required to deliver the service expectation within the service house	To understand the level of technology to adopt in order to support the organisation to deliver the required level of service as identified within the service house.	To assess the manufactured offering for suitability and purpose to deliver data by way of '*intelligent*' product.
Rationale Technology strategy	The need for an holistic methodology which identifies threats to the organisation and aligns operations strategy to that threat (considering initiatives other than cost or lean)	There needs to be alignment between the service expectation and the organisational structure in order to deliver the service offering	As the company moves through the service continuum, greater knowledge of the product's performance in the field is required	Not all products are suited to the application of IVHM type technology. It may be necessary to increase the product offering in the value chain.
Outcomes Product strategy	To set service targets and levels to be offered by the company to align with customer, market, stakeholder expectations	To align the organisational requirements of the business with the service expectations.	To align the technology requirements by way of 'intelligent' product to that of the organisational requirements and service expectations	Assessment of the product's suitability to be fitted with required technology and to what level to deliver the desired 'in filed' data.

Phase 1: Lay the foundation and erect the service pillar of the service temple using the service house.

The objective of phase one of the methodology is to identify the current issues which are faced by the company, to define which area of the company and its operations are to be reviewed and the change sought to the organisation. The results of this preliminary analysis are then presented in a documented issues statement. This is achieved by seeking further an understanding of the following:

- the definition and scope of the area of the organisation to be considered.
- the definition of the area of operations and/or offerings that are under review.
- an understanding of the environment in which the organisation competes and to gain knowledge of the drivers for change.
- To gain a clear understanding of how the company really achieves competitive status.
- To consider how the competitive status may be improved giving due consideration to the emergence of servitization as an alternative strategy.

This phase is the longest phase within the methodology and consists of three stages which lead to an understanding of the environment in which the organisation operates (*shifting sands*), the definition of the true means of achieving competitive status (foundation gained by the environmental awareness), and the erection of the service pillar through the use of the service house.

Stage 1: Define the challenges

This stage of the methodology guides the user through a series of **six** sequential tasks which if followed will assist the user in identifying the area(s) of the business to be considered and the performance changes required. The sequence is not meant to be rigid and the methodology allows for stage iterations as emergent drivers and required operational changes are identified.

Step 1: Scope the targets of the business

This step requires the multi-departmental and/or multi-disciplinary team to review the organisation, strategic business unit (SBU), or department under consideration and to generate a defined scope of the area of the business under review.

The process to be undertaken when carrying out this task is as follows:

i. The review team should convene in an area remote from their normal place of operations (work departments) to ensure uninterrupted diligence to the review process.

ii. The purpose for the review should be communicated by a short presentation explaining the theme and rationale behind the principles of operations strategy.

iii. A brief overview should then be given of the organisation's area of operations to be considered, its position in the value chain, and the reasons for the review. Care should be taken by the facilitator here to ensure that any emergent issues deemed to be important by consensus are also discussed. This is typically the organisations range of product and service offerings. Their alignment to the customer's requirements and fit to organisational competence are also discussed. It is important to resist to the temptation to do analytical detail at this point as the methodology is concerned with the appraisal and identification of strategy, <u>not</u> tactics.

Step 2: Identify the over-riding issues

This task identifies the over-riding issues which are affecting the organisation/business/SBU previously chosen. These should be kept at a general level (avoiding going into detail) so as to allow the process methodology to undertake an holistic review without limiting its ability to let alternative solutions emerge. In discussion(s) with the team the issues should be very obvious from the key existing performance indicators (KPI's) that are operating within the company. For example:

a. Falling market share
b. Increasing costs
c. Reduced revenues
d. Reduced profits
e. Customer complaints
f. Service issues

Step 3: Understand the performance gaps

When seeking to formulate operations strategy it becomes important to understand how the organisation achieves competitive advantage. This can be a single strategy or a complex hybrid of varying strategies across the organisation differing when based upon the product or market (niche/sector). Theory suggests that there are three basic competitive strategies that the organisation can adopt (Chapter 5) (Treacy and Wiersema, 1997; Porter, 1980).

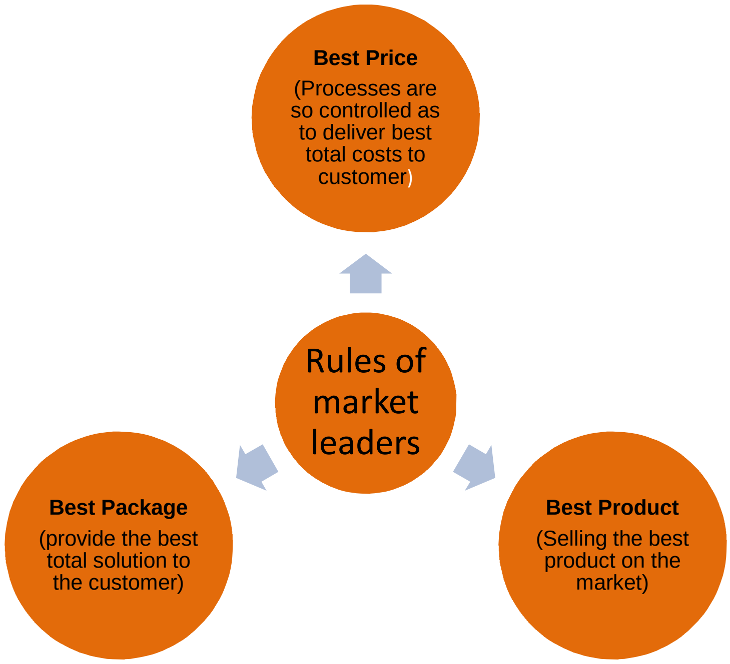


Figure 9.5: Alternative view of competitive strategy [Adapted] (Treacy and Wiersema, 1997)

The methodology uses this model and supporting tools to identify where the organisation's competitive space is placed. When seeking to understand and identify the operations strategy being used by the organisation it becomes important that these concepts are understood. The point to note is that when assessing the internal and external factors which can affect (and inform) strategy a clear focus relating to the scope of the study becomes essential. To understand the gaps in performance between internal expectation and external realisation of the company's performance relative to these parameters, a means of scoring performance and opinion becomes apparent. A series of worksheet are provided to assist in the gathering of data relating to the identification of this competitive space which enable a ranked score to be given from both internal and external perspectives. Whilst the ranking of the responses is subjective, the resultant scale does yield effective benchmarked results when applied to all the data and as such, returns significant insights to the internal and external perception of performance against chosen attributes.

Step 4: Set improvement objectives

This step uses empirical scores based upon a structured gap analysis to identify which of the three strategic approaches the organisation should pursue in order to gain, or maintain competitive advantage. It follows that to make the greatest improvement in strategic performance the strategy which exhibits the largest gap is addressed. By using such an approach the user of the methodology is assisted in selecting and setting improvement objectives to gain advantage in one of the approaches identified in step 3. Authors in the fields of business strategy development, systems engineering, and decision engineering (Bower, 1972; Mintzberg et al., 1976; Hofer and Schendel, 1978; Eisenhardt and Zbaracki, 1992; Nutt, 1993; Daenzer and Huber, 2002) agree that the effective formulation of strategy "*requires the effective setting of objectives, the identification and evaluation of alternative actions and the implementation of the selected choice*" (Tann and Platts, 2005). When selecting which of the improvement objectives to pursue Nutt (2004) advises that a multidiscipline approach should be adopted in order to obtain the perspective of the initiatives identified which are informed by the structured gap analysis. This approach ensures alignment of the operational strategy to be pursued with internal works functions and external expectations of the organisation, and reflects the insights offered by leading academics within the field (Skinner, 1969; Hayes and Wheelwright, 1979)

Step 5: Construct the 'issues' statement

This stage of the framework summarises the output of the ServiceStrat process so far by way of a single document offering a focused and concise statement of the challenges that are under review. This is done by way of the 'issues statement' (Table 9.2). The issues statement gives the team a clear definition of the area of the company that is under review and the over-riding issues that are to be addressed. Additionally it gives a statement of the critical performance gaps that have been identified from the application of a structured and systematic approach and not just based upon gut feelings of individuals.

Whilst intuition is deemed to be important and is taken into consideration during this stage, it is the findings of a well defined analytical process that should be used to inform strategy as the cost of misalignment to the environmental, market, and financial drivers can be catastrophic to the performance of the business.

Table 9.2: The issues statement.

The Issues Statement	
Business area	The location of the company or SBU and the internal location of the initiative is entered here. (e.g. The manufacturing operation at site X.Y.Z.)
Over-riding issues	Typically – diminishing market share and received enquiries due to fierce competition from low cost economies.
Critical performance gaps	The organisation lags behind customer expectation and/or competitor performance within one of the competitive fields.
Issues statement	To increase the level of one of the competitive fields to a level of excellence.
Improvement objectives	To increase customer service and customer intimacy through enhanced services
Target date to meet objectives	This would be typically 3 to 5 years for a strategic intent.

Step 6: Enter the service requirements into the service house

The final step in this stage of the methodology is to identify which initiatives align with the strategic direction chosen. The identification of such initiatives is achieved by harvesting internal and external expectations (Ask the stakeholders). These initiatives are then tabulated and ranked in order of perceived importance. In so doing the service house construction is started (Figure 9.7).

No	Improvement initiative	Organisational offerings	Importance ranking
1	To increase customer satisfaction	Correlation Matrix	1
2	Greater understanding of customer needs		5
3	Faster response		2
4	Field service		7
5	Knowledge of product in use		3
6	Knowledge of product performance		4
7	Faster diagnostics		6
8	Ability to predict failure		8
		Service Targets	

Figure 9.6: The partially completed 'service house' (1)

Referring back to the ‘Service Temple’ (Figure 9.4), the methodology, whilst intensive, serves to deliver an understanding of the environment and forces acting upon the organisation (*the shifting sands*) thereby achieving a situational awareness for the strategy team. This awareness enables the construction of an issues statement (Table 9.2) which gives a concise definition of the focus, scope and aim of the exercise from which, using a prescribed set of tools and techniques, an aligned set of improvement initiatives can be generated. This forms the *foundation* of the service temple.

Stage 2: To identify and assess the desired service offering.

This stage of the methodology seeks to identify the current and potential enhanced service offerings of the organisation and to then input them into the service house. This is achieved by seeking the views of the market (customers, franchises, agents etc) and then to tabulate them and import into the house of quality. These views are best achieved by either market research or to quite simply ask the customer base. It may also be useful to enquire how the organisation’s offerings compare to that of its competitors within the area of advanced service offerings.

Research (Baines, 2010) reports that service offerings can be categorised into three categories, namely base, intermediate and advanced levels of service offerings. These can then be further broken down into sub groups describing the types of service provision (Appendix I). Although these subgroups are not substantive and may vary depending upon the findings of the methodology they are adopted for the purpose of dissemination of the process. They are then entered into the service house has illustrated in figure 9.7.

		Service offerings												
		Base		Intermediate						Advanced				
		Spares	Equipment	Repair	Overhaul	Training	Condition monitoring	Delivery	Field service	Customer support	Risk & revenue sharing	Revenue through use	Rental/lease provision	
No	Improvement initiative													Importance ranking
1	To increase customer satisfaction													1
2	Greater understanding of customer needs													5
3	Faster response													2
4	Field service													7
5	Knowledge of product in use													3
6	Knowledge of product performance													4
7	Faster diagnostics													6
8	Ability to predict failure													8
	Service targets													

Figure 9.7: Partially completed 'Service House' (2)

Service offerings

No	Improvement initiative	Base: Spares	Base: Equipment	Intermediate: Repair	Intermediate: Overhaul	Intermediate: Training	Intermediate: Condition monitoring	Intermediate: Delivery	Intermediate: Field service	Advanced: Customer support	Advanced: Risk & revenue sharing	Advanced: Revenue through use	Advanced: Rental/lease provision	Importance ranking
1	To increase customer satisfaction	2	2	2	2	2	2	2	3	3	2	2	2	1
2	Greater understanding of customer needs	2	2	1	2	2	3	2	2	3	3	3	2	5
3	Faster response	2	2	1	1	2	3	2	3	3	3	3	2	2
4	Field service	3	2	3	1	1	3	2	3	3	0	0	0	7
5	Knowledge of product in use	2	1	3	2	2	3	0	2	2	0	0	0	3
6	Knowledge of product performance	2	1	2	2	3	3	1	2	2	3	3	3	4
7	Faster diagnostics	2	1	2	2	2	3	2	2	2	3	3	2	6
8	Ability to predict failure	2	2	1	1	2	3	2	3	3	3	3	2	8
	Service targets	79	59	67	55	73	111	62	90	81	77	77	56	

Ranking (R)
0 = Not important
1= Low importance
2= Medium importance
3= High importance

Weighting (W)

To order the service targets (T) in each column the following equation is applied.
T = $\sum_{i=1}^{n}(Ri \; x \; Wi)$
where:
R = Ranking
W = Weighting

Figure 9.8: Completed 'Service House'

Stage 3: Completion of the service house.

The final stage in phase one of the methodology is to complete the service house and thus erect the service pillar. The strategy team first complete the correlation matrix. This is done by assessing the intersection of each pair of listed parameters within the matrix and ranking the importance that each has upon the other as illustrated in figure 9.9. This is a subjective assessment to some extent but its limitations are mitigated by the collective experience of the team. Once complete, the values in each column are multiplied by the assigned weighting (per row) and the resultant sum of all the values within a given column are entered into the service targets box. This will result in all the service offerings having a ranked level which is aligned to the stakeholder needs and is balance with requirements and capabilities. It is apparent that not all the initiatives can be achieved within a given time so decisions regarding the choice of targets can be made based on capability and the ranked scores. The list of chosen initiatives (targets) forms the service pillar of the service temple.

Phase 2: The erection of the organisation pillar of the service temple using the organisational house.

The objective of the second phase of the methodology is to identify the current and required organisational structure which is, or needs to be, aligned to the service initiatives identified in phase 1. The process of identifying the aligned organisational structure is generic to that undertaken in phase 1. The outcome is the definition of the organisational pillar within the service temple through the use of the organisational house. This is done by achieving the following phase objectives.

- To understand the organisation structure of the company or business unit under review.
- To assess by holistic review and analysis the suitability of the organisation to deliver the service requirements identified in Phase 1 of the methodology, the Service House

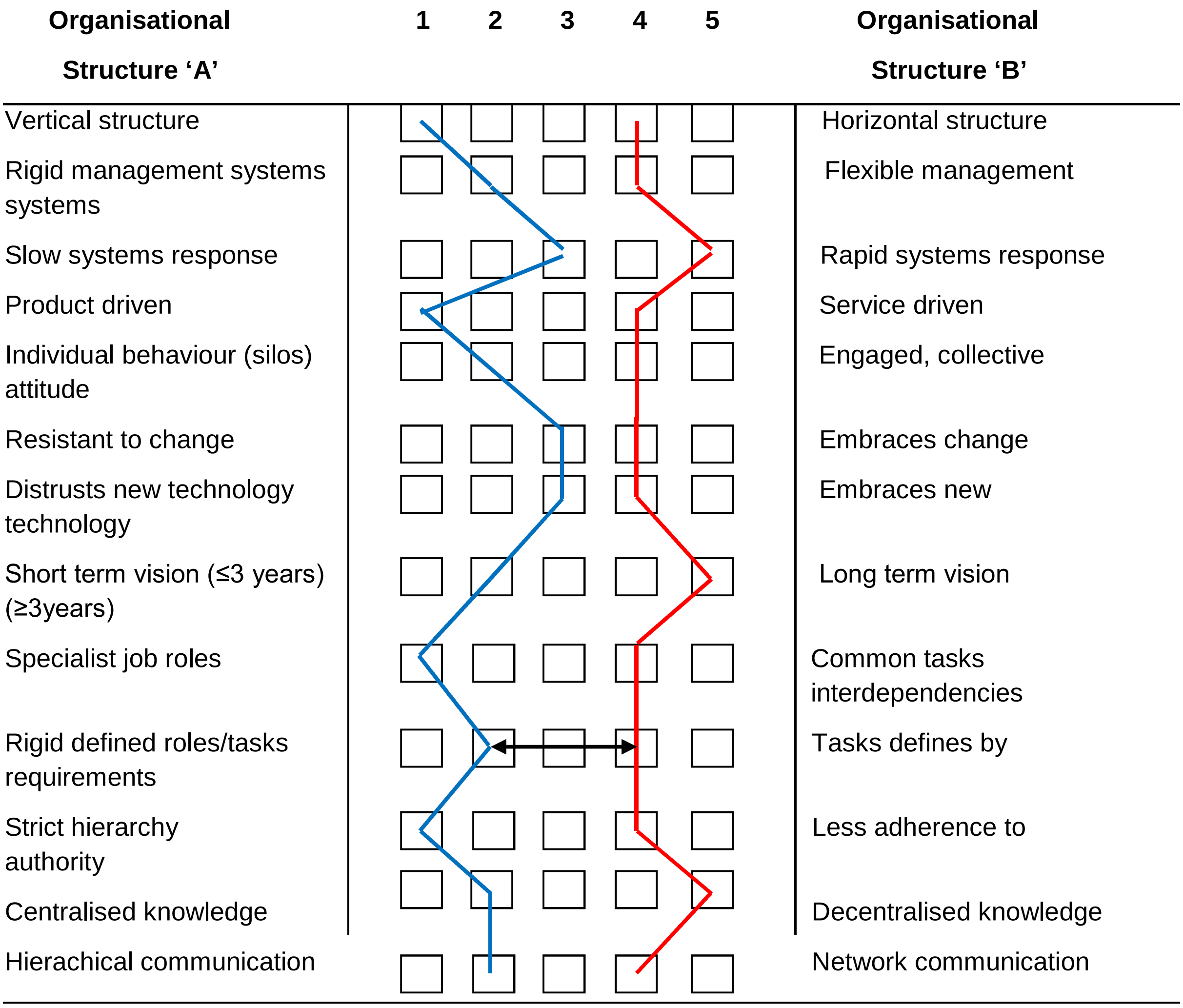
To achieve these objectives and thus construct the organisational pillar a five stage process is followed.

Stage 1: Import the service targets into the organisational house

This stage of the methodology informs the organisational house. This is achieved by importing the identified service targets from the service house into the organisational house. The next stage is to understand the nature of the organisations structure and culture.

Stage 2: Identify the organisational structure and culture of the organisation

This stage of the process aims to assist the strategy team in understanding the type of organisational structure that exists within the organisation in which they work. A worksheet (Figure 9.10) is provided for this purpose. The aim is to compare the current structure and culture of the business unit with that of the desired structure. The worksheet is offered as an indication of categories for comparison and is **NOT** meant to be exhaustive. It is assumed that the strategy will populate the questionnaire with additional attributes which are specific to the focus of the study. Such attributes can be identified from either an internal or external perspective (i.e. ask the customer or other stakeholders in the market). The aim of the exercise is to identify the gaps that exist between current and desired organisational characteristics. In order to achieve a balanced and unbiased opinion it may be necessary to collect stakeholder perspectives. The value of the results obtained from the use of the tool is dependent upon the opinions sought. Whilst it may not be possible, an external perspective will improve the quality of the output from its application.



Current organisational characteristics – Blue line

Desired organisational characteristics – Red line

Figure 9.9: Organisational characteristics

When comparing both the current and desired characteristics of the structure and culture of the organisations a series of gaps are observed. These gaps are then recorded and given a rank by way of the magnitude of the gaps observed (Table 9.3).

Table 9.3: Organisational characteristics – gaps to be addressed by priority

	Gap		Rank/Priority
Vertical structure	3	Horizontal structure	1
Rigid management systems	2	Flexible management systems	2
Slow systems response	2	Rapid systems response	2
Product driven	3	Service driven	1
Individual behaviour (silos)	2	Engaged, collective attitude	2
Resists change	1	Embraces change	3
Distrusts new technology	1	Embraces new technology	3
Sort term vision (≤3 years)	3	Long term vision (≥3years)	1
Specialist job roles	3	Common tasks, interdependence	1
Rigid defined jobs/tasks	2	Tasks defined by requirements	2
Strict Hierarchy	3	Less adherence to authority	1
Centralised knowledge	3	Decentralised knowledge	1
Hierarchical communications	2	Network communications	2

Stage 3: Rank the gaps identified to establish requirements.

Clearly the requirement to address all these attributes may prove prohibitive within the time constraints laid out within the issues statement (*see phase 1*) and resources available. Due to resource and time limitations it is suggested that only those displaying a priority '1' are carried forward for consideration. The process is iterative and such attributes not included can be considered at a later time.

Stage 4

This stage of the methodology serves to complete the organisational house and therefore erect the organisational pillar. The process undertaken in completing the organisational house is the same as that for the service house. Using the matrices within the framework the service requirements and the initiatives relating to the structure and culture of the organisation are entered. The correlation between the two sets of parameters are then assessed by the team and entered into the relevant matrix. Finally the prioritised and aligned organisational targets are identified and recorded using the same process as previously used (i.e. T=$\sum_{i=1}^{n}(Ri\ x\ Wi)$).

Phase 3: The erection of the technology pillar of the service temple using the technology house.

The objective of the third phase of the methodology is to identify and determine the level of technology that could be adopted in order to facilitate an ‘intelligent’ product. An intelligent product (*see definitions*) enables data to be collected relating to performance, usage, and/or location which may then be used to make maintenance and operational decisions. The methodology seeks to align the necessary level of technology to the service requirements in order to assist the organisation deliver the service offering.

Stage 1

This stage of the methodology requires that the service requirements identified within the service house are imported into the technology house as per the previous phases. Here it is important to note that the input is from the service house and NOT the organisational house.

Stage 2

This stage seeks to identify the levels of sensing and integrated systems that may be offered by the organisation to facilitate the service requirements. The literature suggests that when building ‘*intelligence*’ into the product which may be employed to monitor and manage a product’s performance in the field, such applications are seen to follow the OSA-CBM architecture (Chapter 2). Here we have seen seven layers of potential applications of sensor and monitoring technology ranging from level 1, the fitting of simple sensors to measure pre-designated parameters, to level 7 which offers a fully integrated management system, which may be either open or closed loop, and offers real time presented data and management of solutions for the product in the field. These layers (or levels) of technology application are taken and imported into the technology house as technology requirements. As per the previous phases, the correlation matrix is then used to align the level of technology to the level of service

Stage 3

The final stage in this phase of the methodology is to complete the technology house and thus erect the technology pillar of the service temple. The strategy team again complete the correlation matrix by assessing the intersection of each pair of listed parameters within the matrix and ranking the importance that each has upon the other. Once complete, the values in each column are multiplied by the assigned weighting (per row) and the resultant sum of all the values within a given column are entered into the service targets box. This will result in all the service offerings having a ranked level which is aligned to the stakeholder needs and is balance with requirements and capabilities. It is apparent that not all the initiatives can be achieved within a given time so decisions regarding the choice of targets can be made based on capability and the ranked scores. The list of chosen initiatives (targets) forms the technology pillar of the service temple.

Phase 4: The erection of the product pillar of the service house.

The fourth phase of the methodology serves to ascertain if the product (component or sub-assembly) is best suited to the level of technology being proposed by the technology house. It has deliberately been left as the last stage of the process as it is desired for the resultant strategy to be informed by alignment to stakeholder requirements (strategy pulled) rather than to generate a solution looking for a problem (pushed). To achieve the erection of the product pillar several objectives are proposed. Namely:

- To review the product’s suitability to be fitted with sensor technology and associated systems.
- To understand the failure modes of the products and their impact.
- To understand the level of sensors and systems to adopt.

To achieve this understanding this phase of the process comprises a four stage process for completion.

Stage 1: Import the technology targets into the product house

This stage requires that the technology requirements identified in the technology house are input into the product house as the starting point. It follows the same sequence as all the previous stages and these requirements are entered into the box on the left side of the correlation matrix.

Stage 2: Understand the modes of failure for the product.

This section draws upon product performance knowledge which can be found by the organisations existing ‘in house’ systems or by talking to end users in the field. Typically the data would be found by service departments, design departments, and shop floor personnel who carry out repairs. The external data can be found by talking to the customers using the products, and to third parties, typically agents, franchises etc. There are several tools that can be used to support the identification of the failure modes for the product, a few of which are listed below.

Table 9.4: Quality tools to assess modes of failure

Tool	Known as
Failure modes & effects analysis	FMEA
Failure modes, effects & criticality analysis	FMECA
Event tree analysis	ETA
Fault tree analysis	FTA
Cluster analysis	-
Decision tree analysis	DTA
ISIKAWA Diagrams	Fish bone diagrams

These tools are well known and documented within the literature so are not discussed further within this thesis. The use of such tools does facilitate an accurate and in depth understanding of the modes of product failure and the impact of such occurrences.

Stage 3

This stage of the methodology constructs the completed product house and hence the product pillar. Having used one or several of the tools and techniques listed in table 9.4 an understanding of the product failure modes and their impact is achieved. These failure modes are ranked by order of impact and the resultant list forms the input into the product house. (The box to the left of the correlation matrix). The workbook gives a fictional case study for clarification and guidance throughout the workbook detailing the process (Appendix I). For ease of illustration and based upon the author's 30 years experience within the field of automotive die design and manufacture, a list of associated failure modes is offered by the case study and entered into the product house. The levels of technology that may be applied to the product to mitigate against these failures (Chapter 2 – the OSA-CBM architecture) forms the basis of the company's offering and is the input into the product house. As per the previous stages of the methodology the correlations are ranked and the cumulative sum of the product of these ranks and weightings are recorded within the product target box. This gives a ranked list of OSA-CBM offerings which would be required to mitigate against the failure modes. The next stage is to decide upon the products suitability to be fitted with such technology to meet the requirements.

Stage 4: Decision on the suitability of the product.

This final section entails a review of the solutions achieved and the following questions and considerations are addressed.

- Is the product suitable for the fitment of sensors and associated technology?
- Should the sensors be fitted directly to the product or the associated equipment?
- Is the company's offering correctly positioned within the added value chain for the application of extended services. (i.e. Should the company move up the added value chain and supply a more complex product?)

An assessment of the findings is conducted by all to ascertain the products suitability. If this is positive then the strategy can be presented and disseminated. However the assessment may yield a negative result. This can then trigger further investigation as to the product offering's position in the value stream which may include modification of the production of a more complex solution.

Having completed this phase of the methodology the product pillar is erected. The final stage is to present the strategy by way of a clear and concise document. Having completed the four phases of the methodology the information is now available which is aligned to the forces acting upon the company from which the operations strategy if formed. The tool for communicating the strategy is presented in the following section.

Construction of the roof of the service temple. The Strategy Deployment

This final phase of the methodology serves to present the formulated strategy. It is important that any such presentation is clear and concise and illustrated in such a way as to be easily understood and assimilated as it is only by such considerations with willing ownership of the strategy be adopted. To this aim, this methodology adopts the Quality Function Deployment (QFD) matrix as the means of communication of the strategy to be followed.

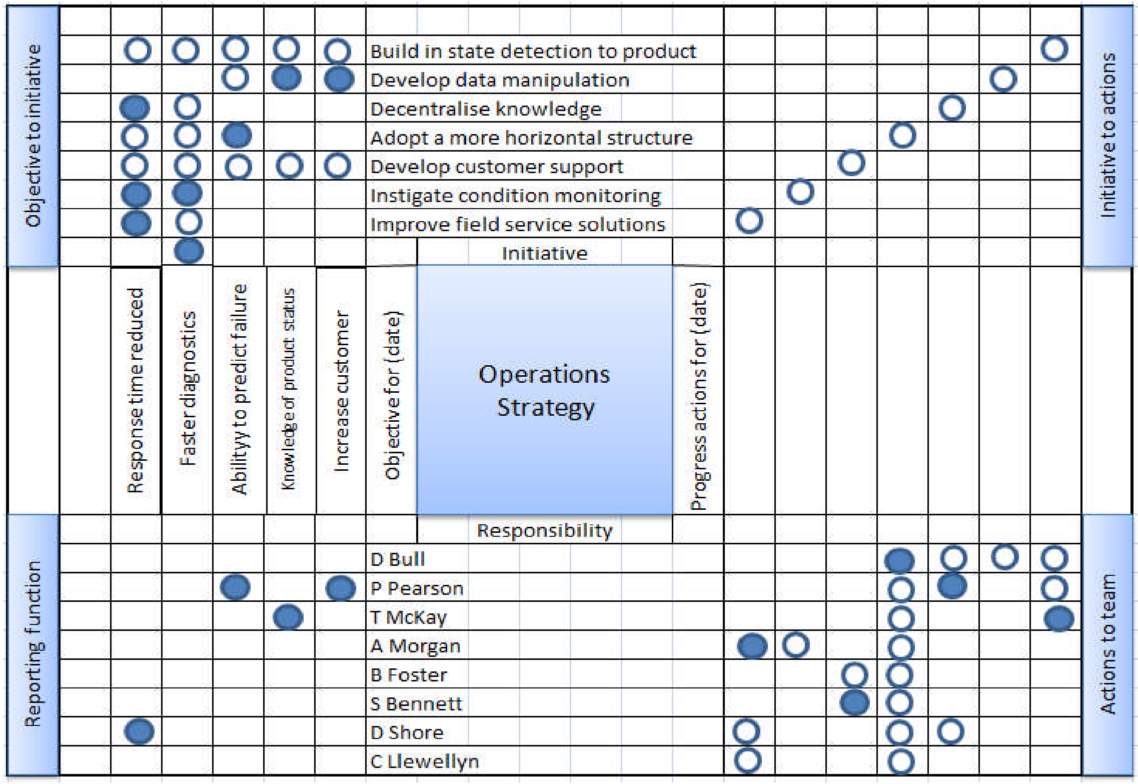


Figure 9.10: Completed policy deployment matrix

Having followed the process laid down by the methodology the management of the organisation will have produced an operations strategy which is the product of an holistic review of all external expectations and internal offerings of the business. The process will have considered the following:

- What are the external drivers acting upon the company?
- How does the company compete to meet these drivers?
- How should the company modify its operations to align with planned or emergent strategy?
- Should the organisation adopt a strategy based upon greater customer integration?
- Does the company have the 'best fit' organisation to suit its chosen strategy?
- Should the company adopt 'informated' products and at what level?
- Is the manufactured product best suited for 'informated' solutions.

In undertaking such a strategic review and formulation process the output is a clear statement of future direction for the organisation. This is presented in a ‘Strategy pack’ containing the following:

- The issues statement – definition or purpose and scope
- Service House and Service Pillar
- The Organisation House and Organisational Pillar.
- The Technology house and Technology Pillar
- The Product House and Product House
- The Quality Function Deployment

The above can be presented either by a strategy file of via poster for review.

9.3 Chapter summary

This chapter has presented the ‘ServiceStrat’ operations strategy formulation methodology. It is the completion of the research aim and the primary contribution to the body of knowledge. The methodology is presented as a work book and offers a structured, iterative, and procedural process for manufacturing organisations who wish to develop an operations strategy. It guides the user(s) through a process which helps them understand how they actually compete within the market place and perform against stakeholder expectation and competitor performance. Through a conducted gap analysis it allows for emergent strategies to be formed. The methodology seeks alignment between expectation and offerings as the level of service, organisational structure, and technology (if appropriate) are considered. The following chapter will offer concluding remarks for this research whilst presenting the contribution that this work has made to the body of knowledge. The limitations of the research and future opportunities for further research are also discussed.

10 CONCLUSIONS

The research recognised that manufacturing organisations are seeing the emergence of innovative business models and initiatives which if adopted can assist in the maintaining and improvement of their competitive position. Two such initiatives identified are Product Service Systems (PSS) and Servitization. (Chapter 1). The literature has identified Integrated Vehicle Health Management (IVHM) as one of several applied technology applications which if adopted can facilitate Condition Based Management (CBM_2) and Health and Usage Monitoring (HUMS) (Chapter 2). The adoption of IVHM generic technologies can further facilitate the emergence of an aligned and effective Service Delivery System (SDS) (Chapter 5). The review of the IVHM literature and a survey of UK based manufacturing organisations has identified that there is a need for a decision support framework (or guidance) which if followed will help practitioners identify their competitive space and assist in the formulation an aligned operations strategy to deliver a technology enabled Service Deliver System (Chapter 5). This chapter presents an overview of the research aim, objectives and research programme followed (Section 10.1). The research contribution is discussed (Section 10.2). The limitations of the research (Section 10.2) and future research opportunities (Section 10.3) are also presented. Finally the research offers concluding remarks (Section 10.4).

10.1 Overview of the research aim, objectives and programme

The aim of this research was developed in (Section 3.2) and is:

> "*To understand the landscape relative to the condition based management of products whilst in use within the field and identify potentially high value IVHM enabled applications and operations. To develop a strategy formulation methodology which seeks to target such applications to deliver an aligned service delivery system. The methodology will deliver an understanding of the organisations competitive position and its performance gaps. It will guide the user in assessment of stakeholder requirements,*

levels of technology, and organisational structure required to deliver an aligned operations strategy delivering an effective service delivery system".

In seeking to achieve the research aim several research objectives were identified and completed. These served as way marks to the deliverance of the research aim and are listed below.

i. To study a broad range of industrial sectors and the literature to identify the state of the art of emerging, and if they exist, failed IVHM applications.

ii. To identify and understand the factors which have enabled or inhibited the technical and commercial effectiveness of the adoption of the concept.

iii. The creation of a decision support tool that incorporates key factors and transforms them into business performance measures.

iv. The validation and verification of the decision framework through case exemplars.

The development of a five phase research programme has been presented (Section 3.3) which was followed to achieve the research aim and objectives. This in turn has delivered a decision framework/process for the development of an operations strategy to deliver an IVHM enabled Service Delivery System. The programme is as follows:

- Phase 1: To understand the principles of IVHM and gain knowledge of the level of practitioner awareness of the concept.
- Phase 2: To gain an understanding of a Service Delivery System (SDS) and the operations strategy formulation process
- Phase 3: The formulation of the pilot operations strategy formulation methodology

- Phase 4: The evaluation and refinement of the pilot operations strategy formulation methodology
- Phase 5: Validation of the refined operations strategy formulation process.

The validated and verified strategy formulation methodology has been presented in chapter 9. This section has presented an overview of the research aim, objectives and the research programme followed. The following section will present the major contributions of the research and this thesis.

10.2 Summary of the contribution to knowledge

This thesis presents a five phase research programme which has resulted in several contributions to knowledge in the areas of the formulation of operations strategy, the aligned strategy for the implementation an Integrated Vehicle Health Management (IVHM) enabled service delivery system, and a greater understanding of the state of the art in both. In achieving these main contributions additional contributions have been achieved and will be highlighted. This section summarises both the primary and secondary contributions that have been achieved when undertaking this research.

10.2.1 The primary contribution to knowledge

The primary contribution to the body of knowledge has been the development and presentation of a validated and verified practical and iterative methodology for the development of an operations strategy. The research has developed a methodology which can formulate the links between IVHM and operations strategy to facilitate a service delivery system which is aligned to the needs of stakeholders. The methodology can be used by organisations seeking to adopt, develop, or review an IVHM enabled service delivery system and fills a gap identified in the literature (Chapter 2: Gap 5). The application of this methodology will produce an aligned strategy thus aiding the elimination of the gap between potential and realised benefits when adopting IVHM (Chapter 4: Finding 5). It also goes part way to addressing a range of challenges and developing a set of capabilities that relate to the business and cultural domain (Chapter 4: Finding 10).

The research sees an operations strategy as a *product* of strategic thinking. It has identified a product development tool from the engineering and quality tools 'tool box', and applied this to the strategy problem. Through the adoption of this tool, and with the support of several developed additional tools and techniques, an iterative sequential (but flexible) methodology has been developed. This offers an holistic solution through a well-defined structured process to develop and assess an operations strategy. The methodology, through the use of this structured approach (and with the support of well documented worksheets) also facilitates the future audit of the thought and decision processes undertaken to deliver the given strategy thereby enabling quality assurance of the whole process. It is this methodology that is the primary contribution of the thesis and is developed by the research programme (Section 3.3). The results from the testing of the pre/post pilot methodologies and the refined post pilot methodology show that the final 'ServiceStrat' methodology can deliver an effective operations strategy. This is achieved by the holistic understanding the organisation's competitive position relative to the needs of its stakeholders and its competitor performance, and the alignment of the organisation's offering to those needs (re-level of service provision, organisation and technology). The final methodology fulfils the research aim.

10.2.2 The secondary research contributions

In the undertaking of this research to achieve the aim and objectives of this study there have been several advances to the body of knowledge which are within themselves an important contribution. These are documented within this subsection.

A greater clarification as to the concept and identity of IVHM

Section 2.2 of this thesis gives greater understanding as to the concept, content and identity of an IVHM system. It asks the fundamental questions. What is IVHM? What comprises an IVHM system at its base level? How does one define IVHM? In order to do this the literature has been reviewed and definitions relating to IVHM have been recorded and analysed. Most definitions relate to the focus under consideration with little by the way of a generic identity being offered which can be applied across all centres. This research builds upon the definition offered by Benedettini et al (Benedettini et al., 2009) and through analysing the various contributions gives a generic definition that is not constrained to any particular industrial sector or application.

A greater understanding of practitioner awareness of IVHM generic solutions

Whilst the literature offers a substantial body of knowledge relating to 'hard' engineering theory, science, practice and applications of the component elements that make up IVHM, (namely sensors, systems, telecommunications, computer science, and decision support technology), there is found to be very little relating to a business focus and virtually nothing which gives guidance as to the means by which a company can inform its strategy when seeking to align service, IVHM and the organisation. This finding within the literature leads to seeking to understand the level of awareness of IVHM's potential within UK industry.

This research has shown that this awareness is located in silos within the manufacturing sector. The awareness and knowledge rests mainly with OEM's and systems integrators of complex engineering products and is adopted mainly by organisations within the aerospace and defence sectors although it is also evident in other sectors where single large commercial enterprises supply such technical solutions across sectors (i.e. Marine, Energy, Medical).

A better knowledge of how IVHM can facilitate the Service Delivery System (SDS)

The research has illustrated through identified examples (and resultant publications), how IVHM is being used as a facilitator for the delivery of advanced services through ever complex service delivery systems. This is seen to range from simple product monitoring (which can be periodic or continuous), through to complex management support systems. Such systems offer the potential for whole life product management ranging from effective maintenance, service, and repair (MRO) initiatives, to availability and usage contracting. In addition the study of the field has shown the to minimise physical and operational risk, increase safety, and have the potential to offer a paradigm shift in the logistics and supply chain of the SDS.

Identification of the major focii of interest and application of IVHM has also been achieved through the review of the literature and the practitioner survey (Chapter 4).

Identification of the population of manufacturing practitioners who apply or have the potential apply IVHM enabled service delivery systems.

This research has applied a rigorous and repeatable procedure to identify and record within a database the population of UK based manufacturing organisations who have, or possess the potential to have IVHM generic enabled service delivery systems. Whilst the data stored is time specific, (companies evolve and even perish over time), the information stored and the documented and repeatable method applied provide a valuable resource for further related research within this field.

Knowledge of the requirements of a methodology for the formulation of an operations strategy for an IVHM enabled service delivery system.

Through the testing of the pre-pilot and pilot methodology (Chapters 6 & 7) the requirements of such a methodology for the formulation of an operations strategy for an IVHM enabled service delivery system become known. These requirements are fully documented within this thesis (section 6.5.3 and section 7.5). Knowledge of these requirements enable the specification for such a methodology to be documented (Section 6.5.4). The recording of both the requirements and specification for such a methodology can provide valuable insight for future research within this area.

10.3. Limitations of the research

This section highlights the limitations that are identified relating to this research. The section is split into two subsections, they being the limitations identified within the research programme (section 10.3.1) and the limitations of the research findings (section 10.3.2).

10.3.1 Limitations of the research programme

The research structure as followed a well-defined programme (Chapter 3) which sought to understand the application of IVHM generic applications within the landscape of PSS and *servitization*. This understanding and awareness of the IVHM concept was sought through literature review and practitioner survey. The gaps identified within the body of knowledge sought to identify and validate the research aim, namely, the development of a methodology to formulate a strategy to deliver a service delivery system enabled by IVHM enabled '*informated*' product (Chapter 3). Having identified and validated the aim, the research identified a pre-pilot methodology as a starting point and applied this to an industrial case and evaluated its performance. Guidance was sought from the literature as to methods of evaluation of strategy formulation methodologies and process and a widely accepted method adopted throughout the research to ensure standardisation process and repeatability of findings. The development of the final research method is the result of a clear process of test, evaluate, modify and re-test throughout the pre-pilot, pilot, and refined evaluation stages. This iterative process is seen as the foundation for the development of the final deliverable. There are three limitations within this research which require discussion.

i. <u>The number of cases</u>. The evaluation at each stage of the development process is based upon case studies and assessment by senior managers from industrial organisations (4, pre-pilot, 5, pilot, 2, refined method). Whilst all interviewees held positions of responsibility relative to the scope of the work within their organisations the findings cannot be assumed be representative of the industrial population. The cases were drawn from organisations who responded to the survey (17%) which is a minority of those from within the identified population.

ii. The content of cases. The research was designed to evaluate the methodology at each stage of its development by applying it as a workshop within each of the cases with the researcher acting as either facilitator or observer. During the evaluation of the pre-pilot method the researcher adopted the role of observer. For the evaluation of the pilot and the refined methodologies it was not possible to conduct full workshops with any of the organisations identified with each company citing difficult economic conditions for not being able to engage in the activities and designed. The contingent evaluation methodology was adopted with the evaluation being conducted by means of seeking the expert opinion of executives using semi-structured interviews with each participant having time to study the methodology. Whilst the final evaluation method adopted is not as robust as a full application of the methodology using the workshop method, the observations and findings remain valid.

iii. Time constraints and length of cases. The length of each interview and discussion was typically 1.5 hours with each interviewee having had time (at least a week) to study the method. The evaluation of the methodology would have been improved if the workshop had of been conducted but also would have benefited by several longitudinal studies to monitor the execution and performance of the resultant strategy. Whilst the purpose of the test was to evaluate the methodologies ability to formulate an aligned and coherent strategy the findings would have been enriched should such longitudinal studies have been possible. The execution of the evaluation process has delivered a validated methodology that is feasible, usable and useful.

10.3.2 Limitations of the research findings

This sub-section identifies concerns that should be considered relating to the findings of this research.

i. Incomplete and corrupt survey data. The data returned from the practitioner awareness survey (Chapter 2) was (with some respondents) incomplete. In addition some respondents failed to answer all of the questions with others responding to requests for 'ranked' opinions incorrectly when completing the questionnaire. This introduced a requirement to 'clean' the data.

ii. Bias. Care has been taken throughout the research to avoid bias. Throughout the practitioner awareness survey IVHM specific statements were deliberately avoided in preference to such neutral references and 'generic concept' when seeking the opinions of organisations. However the data cleansing required interpretation of incomplete survey returns and incorrectly answered questions. The data was cleaned by the researcher who had in-depth knowledge of the concepts and as such elements of subconscious bias may exist within the final data.

    In addition there could be structural bias within both the practitioner awareness survey and also the post workshop evaluation survey data as those responding do so as they seek to actively engage within the research. As such the findings, whilst remaining valid, provide only informed insight and opinion as to the awareness of the IVHM concept and the evaluation of the methodology. Greater confidence would be achieved with fully observed workshops (as research design) but full engagement with this proved difficult to achieve due to organisational time and resource constraints.

iii. Case study data gaps. Several questions within the post workshop questionnaire could not be answered as they were based upon the interviewee having taken part in the designed workshop. As such the respondents could only offer informed opinion as to the methodologies performance if the workshop had been completed. The choice of whom to interview was carefully chosen to ensure that they held key positions of authority (senior managers, directors, executives) within their respective organisations and could influence the strategy decision. Although this was achieved the findings are still based on professional judgement of several persons holding such positions.

iv. The case evaluation employed. Finally the method chosen for the evaluation of the case studies is widely documented and accepted within the literature for the evaluation of such methodologies. Whilst the adoption of such an evaluation technique offers a standardised approach and comparisons within future research it focusses upon three parameters only, namely feasibility, usability, and usefulness. The research is informed the literature on this point. However, further work could be undertaken to ascertain if these are the only suitable parameters for such evaluation, thus building on earlier contributions. The time constraints for this research prevented this but such an initiative offers scope for further research.

10.4 Directions for future research

First, the assessment of the ServiceStrat methodology has taken the form of case study (if available) and rigorous critique by practitioners who are experts in the field of operations strategy and its formulation. It is however suggested that further work be carried out by way of case study research relating to the application of the methodology. Such case studies could be both longitudinal and cross-sectional in nature. A longitudinal case study would allow for an assessment of the strategy and its formulation over an extended period (suggested 5 years) as this would enable several reviews by iteration to ascertain the long term performance of the process. Whilst this methodology does not contain assessment tools for the measurement of the performance of the resultant strategy (*not within the scope of the original research*), that is not to say that assessment could not be incorporated prior to the feedback loop within the iteration.

A cross case analysis will enable the methodology's performance to be assessed when applied to similar organisations within a given sector, or groups of sectors. This may reveal if there are common features observed when applying it to similar groups or indeed significant considerations resulting from identified differences.

Second, this research has been focused upon UK based manufacturing organisations who seek to understand their competitive space and their performance therein. From that understanding, the methodology enables emergent operating strategies to emerge, one of which is enhanced service provision enabled by IVHM applications (i.e. intelligent/informated products). The methodology could be applied to service providers, typically energy, and infrastructure (e.g. transport) by way of asset management. The application of such intelligent products would allow for availability contracting, usage, and condition monitoring of power plants, and civil engineering structures for example. Again such an initiative could have an impact on the final operating strategies of such organisations who applied the methodology.

Third, the methodology could be applied with a sustainability focus. It has been stated that one of the initiatives being considered by organisations is the Product Service System. This initiative emerged from the interest and concern for diminishing finite resources due to increased consumption. The application of the methodology could yield an emergent PSS strategy whereby the emphasis was taken away from product ownership and greater importance given to the purchase of use. (Typical examples are car rental/lease, London bicycle initiatives etc). Typically with such initiatives a level of product monitoring to enable the service is inevitable. Therefore the methodology could be applied within this scenario and its ability to deliver a coherent and workable strategy assessed.

Fourth, this research and the resultant methodology has been focused upon the formulation of an operating strategy for the given organisation. That is however only part of the process of forming operations for the organisation. Following such an exercise there then follows the business assessment of the identified and required strategy. This can be either financial, non-financial or a mixture of both sets of KPI's. Inevitably it comes around to the assessment of the business case when considering the implementation of the operations strategy. Further research could be conducted therefore in the relationships and business performance of such strategies.

Fifth. This research has shown how IVHM technology can have an impact upon product maintenance, repair, and overhaul (MRO) strategies through the use of both CBM_1 and CBM_2 applications through intelligent/informated products. Further research is suggested in regards to the nature of the feedback mechanisms, and substance of such data. The data harvested through the use of IVHM generic technology applications can have significant impact upon the design and manufacturing functions if used correctly. Such data can enable continuous improvement in Through-life Engineering Services where the product is designed for service using data fed back from existing product usage in the field. Interest can be in either 'hard' engineering issues, or the 'soft' systems approach.

10.5 Concluding remarks

This chapter has given an overview of the research aim, objectives, and the programme followed. The research contribution, both primary and secondary, have been presented together with the limitation identified relating to both the research programme and the research findings. In turn recommendations are made for future research within this area of interest. Finally, this work has made a significant contribution to the body of knowledge within the area of methodologies for the formulation of operations strategy.

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APPENDICES

Appendix A Questionnaire – Competing through intelligent products

Competing through intelligent products

UK manufacturers are applying increasingly innovative ways to enhance competitive advantage. An emerging trend is the employment of condition based management technology (referred to in this survey as *'the approach'*) to support business models where the performance of the product in service is paramount rather than simply the product. This approach combines hardware and software technologies to identify current and predicted 'health' of a product. This survey should identify the extent of the adoption of this approach as an element of competitive strategy within UK manufacturing. We have conducted research on UK manufacturing and believe that your organisation is one that can help to further 'UK plc' in a challenging business environment.

We need your help, please!

We are surveying a broad spectrum of UK manufacturing to identify applications of this approach and to understand the motivations, challenges and benefits and invite you to participate by completing this questionnaire. This questionnaire is gathering information from businesses which are using, attempting or are planning to use condition based management technology. We would be very grateful if you could complete the questionnaire or forward it to the most appropriate individual in your organisation.

Our commitment to you

In return for your help, you will receive an executive report of our survey, and you will be invited to attend an industry networking event which will take place at Cranfield University in October 2009.

What is involved?

The questionnaire will take no longer than 15 minutes to complete. Blank text boxes are included in some questions for further explanations. Please complete as many questions as possible and return the questionnaire in the envelope provided. You will find suggested (hopefully helpful) definitions in footnotes on a number of pages.

Your response will be treated in the strictest confidence. Responses will not be published unless we have prior written consent, and information provided will not be shared with any other body. To receive the report and invitation to feedback at Cranfield, please provide contact information and/or business card.

Name:
Company:
Position:
Job description:
Plant/Building/Department:
Address:
Phone:
Email:

Many thanks for your help.

L. E Redding, Cranfield IVHM Centre, Cranfield University, Cranfield, Bedford, MK43 0FQ

Q1.1 Please indicate the sectors in which your business operates. (Tick all that apply.)

Aerospace	[ ]	Marine	[ ]
Agriculture	[ ]	Mineral Extraction	[ ]
Automotive	[ ]	Nuclear	[ ]
Civil/Construction	[ ]	Oil and gas	[ ]
Defence	[ ]	Power	[ ]
Electronics	[ ]	Security	[ ]
Energy	[ ]	Telecom	[ ]
Health	[ ]	Others (Please specify below)	[ ]

Q1.2 How would you describe your business?

Service provider	[ ]	First Tier Supplier	[ ]
OEM/Systems integrator	[ ]	Other (Please specify below)	[ ]

Q1.3 Is your business a:

Division of a company	[ ]	Sole business unit	[ ]
Subsidiary of a company	[ ]	Private company	[ ]

Q1.4 What kind of products do you produce/manufacture? (Please specify below)

Q1.5 Who are your major customers?

Industrial Companies	[ ]	Consumers	[ ]
Governmental Agencies	[ ]		

Q1.6 Who are the major end users of your products (if different from customers)?

Industrial Companies	[ ]	Consumers	[ ]
Governmental Agencies	[ ]		

Q1.7 How would you describe your industrial customers?

Predominantly SME's	[ ]	No industrial customers	[ ]
Predominantly large enterprises	[ ]		

Q1.8 Are you currently using or planning to use *the approach* on your main[1] product?

Using	[ ]	Have attempted but no success	[ ]
Not using but plan to use	[ ]	Not planning to use	[ ]

[1]By _main product_ we refer here to a product supplied by your company/business unit that for example: has the biggest revenue per unit and/or market share, is the most representative of your business or has the most advanced *approach* deployed. This product should provide a context to questions being asked here.

Q1.9 When (<u>if you plan to use the approach</u>) are you planning to use/develop *the approach* for your main product?

Between 1 – 3 years [ ] In more than 5 years [ ]

Between 3 – 5 years [ ]

Section 2: Tell us about drivers and benefits

Q2.1 What are the drivers behind the attempt to develop *the approach*?

		Priority
Increasing safety	[ ]	[ ]
Increasing/improving availability	[ ]	[ ]
Complying with regulations	[ ]	[ ]
Request/pressure from customers	[ ]	[ ]
Providing more functionality	[ ]	[ ]
Differentiating from competitors products	[ ]	[ ]
Improving product performance (for example reliability)	[ ]	[ ]
Improving maintenance efficiency and effectiveness	[ ]	[ ]
Providing more services	[ ]	[ ]
Technology availability and readiness	[ ]	[ ]
Competitors developing similar solutions	[ ]	[ ]
Other (Please specify below)	[ ]	[ ]

Q2.2 Before attempting to introduce *the approach* how did you analyse the potential benefits to relevant stakeholders?

In a formal way, for example a business case [ ] Not at all [ ]

Only in an informal way [ ]

Q2.3 Apart from your own business, which stakeholders were included in your analysis?

Customers [ ] Service providers [ ]

Suppliers [ ] Others (Please specify below) [ ]

Q2.4 In your opinion, what benefits should your business expect from *the approach*?

Financial

Increased revenue [ ]

Reduced operating costs [ ]

Steady and reliable income streams [ ]

Strategic

Risk reduction [ ]

Improved product functionality and reliability [ ]

Enabling differentiated product/service offering [ ]

Marketing

Building closer relationships with customers [ ]

Better understanding of customer needs [ ]

Building closer relationships with suppliers [ ]

Others (Please specify below) [ ]

Q2.5 What indicators do you use to demonstrate the realized benefits of *the approach* in your business?

Improvements in products performance [ ]
Improvements in product-related activities [ ]
Customer complaints [ ]
Monetary savings [ ]
Return on investment [ ]
No specific indicators [ ]

Others (Please specify below) [ ]

Q2.6 Is there a gap between potential and realized benefits to your business and what factors would you attribute this gap to?

Q2.7 In your opinion, what benefits should your customers expect from *the approach*?

Financial

Reduced operating costs [ ]
Reduced total cost of ownership [ ]
Reduced investments in people and equipment [ ]
Improvement of their business performance [ ]
Increased product availability [ ]

Strategic

Risk reduction [ ]
Allowing them to focus on core competencies [ ]
Access to supplier's "know how" [ ]

Marketing

Greater awareness of the concept [ ]
Identification of potential applications [ ]
Identification of developments [ ]
Identification of suppliers [ ]
Knowledge of sector uses [ ]

Others (Please specify below)

Q2.8 How do you make the benefits of *the approach* visible to your customers?

Periodic product performance reports	[ ]	Customer centric design initiatives	[ ]
Customer engagement - On-site visits	[ ]	Price initiatives	[ ]
Customer satisfaction survey	[ ]	Joint 'Ownership' Initiatives	[
Customer workshops	[ ]	Others (Please specify below)	[ ]

Q2.9 What indicators do you use to demonstrate the realized benefits of *the approach* to customers?

Improvement in product performance [ ]
Improvements in product related activities [ ]
Improvement in their business processes [ ]
Monetary savings [ ]
No specific indicators [ ]
Others (Please specify below) [ ]

Q2.10 Is there a gap between potential and realized benefits to your customers, if so what would you attribute this gap to?

Q2.11 In your opinion, what benefits could suppliers expect from *the approach*?

Financial
Smoother revenue streams [ ]
More accurate costing [ ]
Reduced P/L fluctuations [ ]
Reduced balance sheet fluctuations [ ]
Product 'whole life' income streams [ ]

Strategic
Customer 'lock in' to supplier [ ]
Ability to define standards and procedures [ ]
Construction of barriers to entry [ ]
Knowledge management and control [ ]
Cross sector learning [ ]
Cross organisational learning [ ]

Marketing
Organisational differentiation [ ]
Joint ownership/partnership initiatives [ ]
Extended reach of services [ ]

Others (Please specify below) [ ]

Q2.12 How are benefits of *the approach* made visible to suppliers and service providers?

Periodic publications	[ ]	Seek understanding of supplier issues	[ ]
On site visits	[ ]	Other (Please specify below)	[ ]
Industry Workshops	[ ]		

Q2.13 What indicators do you use to demonstrate the benefits of *the approach* to your suppliers and service providers?

Reporting of market share	[ ]	Joint ownership of procedures	[ ]
Reporting of revenue	[ ]	Reduce the need for fire fighting	[ ]
Utilisation/downtime analysis	[ ]	Other (Please specify below)	[ ]

Q2.14 Is there a gap between potential and realized benefits to your suppliers and service providers, if so what do you attribute this to?

Section 3: Tell us about enablers and inhibitors

Q3.1 What factors can enable technical success of *the approach* development and introduction?

		Priority
Technology awareness and readiness	[ ]	[ ]
Management buy-in	[ ]	[ ]
Formally defined approach development process	[ ]	[ ]
Technical knowledge and capability	[ ]	[ ]
Knowledge of "*the approach*" through benchmarking	[ ]	[ ]
Good investment	[ ]	[ ]
Knowledge about your product	[ ]	[ ]
Buy-in and early involvement of customers and key suppliers	[ ]	[ ]
Others (Please specify below)	[ ]	[ ]

Q3.2 What factors can enable commercial success of *the approach* development and introduction?

		Priority
Understanding the benefits to customers	[ ]	[ ]
Understanding business model of our customers	[ ]	[ ]
Building closer relationship with customers	[ ]	[ ]
Understanding the benefits to our business	[ ]	[ ]
Understanding the benefits to our suppliers	[ ]	[ ]
Understanding business model of our suppliers	[ ]	[ ]
Building closer relationship with key suppliers	[ ]	[ ]
Clarity of evaluation of stakeholder benefits	[ ]	[ ]
Technology infrastructure	[ ]	[ ]
Management support	[ ]	[ ]
Business process infrastructure	[ ]	[ ]
Others (Please specify below)	[ ]	[ ]

Q3.3 What factors can inhibit the technical success of *the approach* development and introduction?

		Priority
Incomplete knowledge about the product performance	[ ]	[ ]
Insufficient approach development process	[ ]	[ ]
Insufficient technical expertise	[ ]	[ ]
Insufficient management support	[ ]	[ ]
Insufficient resources (money, people, and other)	[ ]	[ ]
Immature technology	[ ]	[ ]
Insufficient customers and key supplier involvement	[ ]	[ ]
Others (Please specify below)	[ ]	[ ]

Q3.4 What factors can inhibit commercial success of *the approach* development and introduction?

		Priority
Insufficient understanding of the benefits offered to customers	[ ]	[ ]
Insufficient understanding of customers’ business	[ ]	[ ]
Insufficient understanding of the benefits to our business	[ ]	[ ]
Insufficient understanding of the benefits provided to suppliers	[ ]	[ ]
Lack of a clear/robust approach to capture stakeholder benefits	[ ]	[ ]
Lack of appropriate business performance metrics	[ ]	[ ]
Insufficient technology infrastructure	[ ]	[ ]
Insufficient management support	[ ]	[ ]
Insufficient business process infrastructure	[ ]	[ ]
Others (Please specify below)	[ ]	[ ]

Section 4: About your main product and the related 'approach'

Q4.1 What is the average lifecycle of your main product?

0-3 years	[ ]	10-20 years	[ ]
3-10 years	[ ]	Over 20 years	[ ]

Q4.2 What is the installed base (units currently in use) of your main product?

0 -100 units	[ ]	1000 -10000	[ ]
100 -1000 units	[ ]	Over 10000	[ ]

Q4.3 Approximately, how many main competitors do you have on your main product?

0-10	[ ]	25-50	[ ]
10-25	[ ]	Over 50	[ ]

Q4.4 How many subsystems does your main product contain?

1 – 5	[ ]	10 – 20	[ ]
5 – 10	[ ]	Over 20	[ ]

Q4.5 Approximately how many components/parts are in each of these subsystems?

1 – 10	[ ]	50 – 100	[ ]
10 – 50	[ ]	Over 100	[ ]

Q4.6 How would you describe your main product?

Mechanical product	[ ]	Electrical product	[ ]
Electro-mechanical product	[ ]	Electronic product	[ ]

Q4.7 How long has (or when have you attempted to develop) *the approach* been used on the product?

Between 1 – 10 years	[ ]	More than 15 years	[ ]
Between 10 – 15 years	[ ]		

Q4.8 What is the level of complexity[2] supported by *the approach*? (Tick all that apply.)

Monitoring	[ ]	Prognostics	[ ]
Detection	[ ]	Decision support	[ ]
Diagnostics	[ ]		

Q4.9 What level of your product does *the approach* support?

Overall product level	[ ]	Component level	[ ]
Subsystem level	[ ]	Part level	[ ]

Q4.10 What measures does *the approach* provide? For example: vibration, temperature, pressure, stress, etc.

[2]By *monitoring* we refer to hardware and software resources deployed to collect data about a product, subsystem, component, or a part with no subsequent resultant action.
By *detection* we refer to hardware and software resources deployed to collect and process data to provide information regarding the occurrence of a fault and/or failure in a product.
By *diagnostics* we refer to hardware and software resources deployed to provide much earlier fault and/or failure detection and subsequent fault and/or failure isolation, in order to determine the capability of a product to perform its function(s).
By *prognostics* we refer to hardware and software resources which enable prediction and determination of the remaining useful life of a product
We define *decision support* as the use of data gathered through monitoring, detection, diagnostics and/or prognostics and its use to enhance operational decisions.

Q4.11 What is the overall configuration[3] of *the approach*?

Has both on-product and off-product components	[ ]	Other (Please specify below)	[ ]
Only on-product component	[ ]		

Q4.12 How do you source *the approach*?

Completely outsourced	[ ]	In-house developed	[ ]
Outsourced, but joint venture	[ ]		

Section 5: Future plans

Q5.1 In your opinion, has *the approach* been successful?

Very much	[ ]	No	[ ]
Satisfactorily	[ ]		

Q5.2 Do you have plans to extend *the approach*?

Extend to encompass monitoring	[ ]	Extend to encompass prognostics	[ ]
Extend to encompass detection	[ ]	Extend to encompass decision support	[ ]
Extend to encompass diagnostics	[ ]	No plans	[ ]

Q5.3 What are the main reasons (if you have no plans) for not extending *the approach*?

Customers are currently satisfied	[ ]	Economic reasons	[ ]
Lack of technical expertise/knowledge	[ ]	Others (Please specify below)	[ ]

Q5.4 Do you have plans to extend *the approach* to another level of your product or to different product maybe?

Extend to product level	[ ]	Extend to part level	[ ]
Extend to subsystem level	[ ]	Extend to different product	[ ]
Extend to component level	[ ]	No plans	[ ]

Q5.5 What are the main reasons behind having no plans to extend *the approach* to another level of your product or different product?

Customers are currently satisfied	[ ]	Others (Please specify below)	[ ]
Lack of resources	[ ]		

[3] *On-product* components represent hardware and software resources (e.g. sensors, communication technology, artificial intelligence, etc.) deployed on a product for the purpose of monitoring, detection, diagnostics, prognostics and/or decision support.
Off-product components are hardware and software resources deployed to remotely monitor, collect, process, and analyse condition or health of a product.

Q5.6 In your opinion, what are the main threats relevant to your plans?

Q5.7 Overall, how relevant is *the approach* to your business's profitability

Very relevant	[ ]	Somewhat relevant	[ ]
Relevant	[ ]	Not relevant	[ ]

Q5.8 Overall, how relevant do you foresee *the approach* to be in your sector?

Very relevant	[ ]	Somewhat relevant	[ ]
Relevant	[ ]	Not relevant	[ ]

Q5.9 Overall, what skills and capabilities would you like to develop to realize most from *the approach*?

		Priority
Better technical expertise	[ ]	[ ]
More investment	[ ]	[ ]
Formal approach development process	[ ]	[ ]
Better fit with existing organizational infrastructure and processes	[ ]	[ ]
Better alignment of existing business processes with those of our customers and suppliers	[ ]	[ ]
Establish closer relationships with customers and suppliers	[ ]	[ ]
Tools to capture benefits of its introduction	[ ]	[ ]
Other (Please specify below)	[ ]	[ ]

Appendix B Post Workshop Questionnaire (Pre Pilot, Pilot, and Final Evaluation)

Post – Workshop Questionnaire

The ‘STRATAGEM’ Methodology

The aim of this questionnaire is to identify from those who have used the framework potential improvements that can be made to the process. The questionnaire is constructed in four sections.

Section 1: Feasibility

Section 2: Usability

Section 3: Usefulness

Section 4: Comments

Please add any additional comments that you may wish to offer in section 4

Thank you for your time and co-operation in completing this questionnaire. Your input into the process is important to the assessment of the STRATAGEM methodology and will be used to improve and validate the process.

FEASIBILITY: Could the methodology be followed?

The purpose of this section is to discover if the methodology could be followed. Please tick the answers which best reflect your opinion. Please add any comments as necessary

1. Completeness: Was the methodology followed in its entirety?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   If the methodology lacks in completeness, please indicate where you feel there are omissions or where additional stages should be added.

   Comments: ____

2. Consistency: Did you feel that the sequence of the stages was consistent?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   Comments: ____

3. Applicability: Did you find that the methodology could be applied satisfactorily?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   Comments: ____

4. Contingency: If the process encountered problems, did the methodology provide alternative solutions?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   Comments: ____

USABILITY: How easily could the process be followed?

The purpose of this section is to discover how you structured and followed the methodology.

Please tick the answer(s) which best reflect your opinion. Please add comments as necessary.

5. Time: Could the STRATAGEM methodology effectively be undertaken in the allotted time?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

Comments: _

6. Delivery: Is the workshop delivery an effective means of undertaking the process?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   Comments: _

7. Ease of use: Did you find the tools and techniques at each stage easy to follow and explain?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   Comments: _

8. Understanding: Where the aims and actions of the methodology clear at each stage?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

   Comments: _

9. Understanding: Did the examples provided in the methodology help you use the methodology?

   No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐s ☐

   Comments: _

10. Flexibility: Did the methodology provide flexibility during application?

    No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

    Comments: _

11. Modification: Please state what you would consider to be the major strengths and weaknesses of the methodology?

    Comments: _

12. Modification: What changes would you make if you were to repeat the overall methodology?

    Comments _

13. Modification: Which of the stages would you like to modify or combine?

    Comments: _

14. Modification: What else in the methodology structure would you like the stages to define?

    Comments: _

USEFULNESS: Did the methodology provide useful results that met with expectation?

The purpose of this part is to discover how useful the methodology was. Please tick the answers that best reflect your opinion.

15. Please rate the success of the overall process of the 'STRATAGEM' tool.

    Most unsuccessful (waste of time) ☐ Not successful (not worth doing) ☐

    Successful (worth doing) ☐ Very successful ☐

    Don't know ☐

16. Efficiency: Did the methodology consume excessive resources of time and people?

    No/Not at all ☐ Partly ☐ Average ☐ Quite ☐ Very ☐

17. Practicality: Did the methodology provide a practical process?

    No/Not at all ☐ Partly ☐ Average ☐ Quite ☐ Very ☐

18. Benefit: Are there any lessons learnt from the application of the STRATAGEM process?

    Comments

    ____

19. Which stages of the STRATAGEM process was found to be most useful and why? Please provide examples. _

    _

    _

20. Which stages of the STRATAGEM process was found to be least useful and why? Please provide examples. _

    _

    _

21. Satisfaction: Did the process meet your expectation?

No/Not at all ☐ Partly ☐ Don't know ☐ Mostly ☐ Yes ☐

22. Satisfaction: Would you use the STRATAGEM methodology again in your organisation and why?

☐ Yes ____

☐ No ____

23. Additional comments.

Thank you for your time and co-operation