Product-Service System Inventory Control: Manufacturing perspectives

by

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Abstract

This thesis explores the role of Inventory Control in Product Service System (PSS) applications within manufacturing contexts. This research led to a new approach for dealing with inventory control and contributes to understanding of the PSS paradigm in manufacturing industries. PSS embraces the product and service continuum as one system; meanwhile, Inventory Control has led to substantial improvements in performance across many industries. PSS and Inventory Control have for many years been recognized in the scientific literature and by industry as enablers of manufacturing operations. Most studies in the field of PSS and Inventory Control have only focussed on its individual scenarios; little is known about where the boundaries of PSS should lie as it needs to integrate both external and internal elements in managing PSS Inventory Control. To date, very little research has been reported related to inventory control in product-service systems from manufacturing operations perspectives.

Research has been done in three stages: (1) PSS characteristics were synthesised from the literature; (2) current industry example of PSS inventory were investigated through a survey; four case studies were developed; (3) uncertainty elements were identified from the literature related to the current PSS Inventory Control scenario and these were evaluated, developed and validated producing a generic model. The research carried out involved collecting primary data from qualitative research conducted through four case studies with companies in the United Kingdom and Malaysia; and information from secondary sources; utilising techniques such as survey, interview, matrix and modelling language method.

This thesis contributes to the current PSS research by developing a generic model of PSS Inventory Control from manufacturing operations perspectives and a PSS Inventory Control (PSSIC) Framework.

Dedication

My father, late mother and step-mother who have laid the foundation of my education. And to my siblings; Izzat, Eba, Ozal, Eja and Iffat. None of this would be possible without your prayer, love and inspiration.

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I would like to express my gratitude to my supervisors: Jenny Harding and Sue Morton; for their constant support and patience with me right from the first day I arrived Loughborough. You made my journey as a PhD student pleasant and made my dream to finish PhD on time come true. Also for your valuable help proof-reading and structuring this thesis. I am so proud to have studied under you. Thank you very much.

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Nomenclatures

PSS .... Product-Service System

GE .... General Electric

TPS...Toyota Production System

JIT .... Just-in-time

RMS .... Raw material stock

WIP .... Work-in-process stock

FGS .... Finished goods stock

IDEFØ ....Integrated Definition Methods for Function Modelling

UML .... Unified Modelling Language

CATIA ....Computer Aided Three- dimensional Interactive Applications

CAE.......................... Engineering Analysis using Computer-Aided Engineering

MPS.. Master production schedule

PP .... Polypropylene

HSE .... Health and Safety Executive

BHP .... Brake House Power

R&D .... Research and development

PDM .... Product Data Management

ERP .... Enterprise Resource Planning

BOM .... Bill of material

SPARCS... Self-pressurized-air rotor cooling system

PO .... Purchase orders

ITT .... Invitation to tender

MRP... Material requirements planning

DCS.. Distributed Control System

SAP................................Systems, Applications and Products in Data Processing

OEM.. Original Equipment Manufacturer

ICAM...Integrated Computer Aided Manufacturing

PSSIC... PSS Inventory Control

1. Introduction

1.1 Background of the study

Manufacturing organisations are facing new challenges as competition has become global. Customers are increasingly demanding greater value from their purchases and patterns of manufacturing are changing triggered by the turbulent and volatile expansion of global competition and fluctuations in raw material prices. This has necessitated new strategies and manufacturing paradigms. As manufacturing industry evolves, managers are challenged to formulate better methods to guide their companies. Typically, the development of new competencies can be achieved through investment whether inside the organisation, or through mergers and acquisitions. Improvement is challenging as there are variables that can potentially stall any development effort. Nevertheless, there are many reasons to be optimistic since organisations have the potential to modify their systems of production and improve overall performance. For example, The Foresight Programme in the UK Government Office and for Science (2013) claimed that:

“Manufacturing in 2050 will look very different from today, and will be virtually unrecognisable from that of 30 years ago. Successful firms will be capable of rapidly adapting their physical and intellectual infrastructures to exploit changes in technology as manufacturing becomes faster, more responsive to changing global markets and closer to customers… These developments will further emphasise the key role of physical production in unlocking innovative new revenue streams, particularly as firms embrace 'servitisation' and manufacturers make use of the increasing pervasiveness of 'Big Data' to enhance their competitiveness”

Today’s manufacturing companies must look for innovative ways to enhance competitiveness in order to remain profitable. Two popular approaches for enhancing competitiveness are deploying Product-Service System (PSS) and implementing an inventory control system. For instance, Wise and Baumgartner (1999) states that there is a significant opportunity to create a new competitive strategy by going downstream to sustain further business growth and generate more profits in manufacturing of products that are undifferentiated and commoditized, or from a wide product base. Managing inventory is a significant issue which affects many industries. Inventory control is the process of determining the amount of inventory which answers how often and how much to order within the procedures and frequencies of consumed quantities needed. Pong and Mitchell (2012) claim that inventory control through tactical purchasing and manufacture can generate cost saving. According to Nagarur et al. (1994) the inventory control design is required to provide the following:

- An easy update and retrieval of inventory information
- An efficient ordering system for replenishment
- More information for the management control of spare parts
- Accountability and accuracy of information

Manufacturing organizations have to make decisions at different levels on a regular basis. These decisions must also be made as quickly as possible in order to maintain competitiveness and to make the correct decisions, a solid basis of data, information and knowledge must be available. The task of collecting, sorting and analysing data is very time consuming if only performed manually. The data increases and eventually there will be such an enormous amount of data stored that retrieving what is required will become increasingly difficult. Problems within the system typically stem from the complex relationships inherent in the system. Operations in a factory involve a variety of information transformations on an internal and external basis. Without accurate, ongoing and correct information in real time, a factory is not equipped to foresee the potential issues or quickly respond to them when they are needed.

Variability is the often unpredictable deviation of processing that occurs in every real system. Variation exists because no production process is perfect. Often, controlling this variation is attempted during production when substantial effort and resources, e.g., time, money, and manpower, are required. The impact of variability is hard to predict and often is not intuitive in even the simplest systems. Anosike and Zhang (2006) point out that these changes allow variation in customer requirements, fluctuations in demand patterns, proliferation of niche markets, continuous increases in product mix, decreases in product life cycles, and increasing competition amongst manufacturers. For instance, typical production variability occurs when customers change orders with little notice given. This causes major disruptions to material suppliers, or production line stoppages as a result of breakdowns, or the effects of unresolved quality issues.

In 1988, Vandermerwe and Rada introduced the concept of servitization to describe the phenomenon of services in manufacturing which was taking place in several industries. Servitization refers to the transition process of adding services into a product-centric offering. Instead of viewing services and products from a traditional perspective, companies offer bundles of products and services to create value (Vandermerwe and Rada, 1988). An example of a firm that has implemented servitization is General Electric (GE); they developed new services rather than concentrating on selling existing products to more customers (Kumar, 2004). At the same time, Chase (1981) also discovered several approaches for manufacturing companies to enhance their competitiveness by using complementary services. Since the discovery of servitization in manufacturing, research in this area has grown extensively. PSS is another stream of studies related to servitization which originates from Scandinavian countries and is mainly related to ecological and environmental sustainability (Baines et al., 2009a).

The recent strong growth of manufacturing industry included transformations towards greater PSS. The term PSS conjures up a variety of interpretations; to reflect the field of the research PSS may be understood as, product and service that coexist jointly in one system. In its widest scope, this research relates to any manufacture of a product where services of some type are offered or integrated with the product. PSS is an integrated combination of products and services that deliver value in use and this includes both the tangible product and the intangible service as its basic elements (Baines et al., 2007). The definitions of product and service vary in the literature. Product is a well understood term in manufacturing for instance it is described as something tangible and certainly does not contain any intangible service elements. Goedkoop et al. (1999) describe product as "a tangible commodity manufactured to be sold and capable of falling on your toe and fulfilling a user's needs". In contrast, Wise and Baumgartner (1999) explained service in the manufacturing perspective as an add-on offering provided to the customer to ensure that the product being sold is able to operate in good condition and deliver its purported functionality. For example, services provided by a manufacturer to customers may include installation and warranty. There are numerous PSS definitions defined by scholars and practitioners working in this field.

The term manufacturing covers many topics including manufacturing strategy, manufacturing design, manufacturing operations and manufacturing knowledge systems. In the context of this thesis, manufacturing relates to manufacturing perspectives in manufacturing operations. Manufacturing operations require both individual and multiple processes including receiving customer orders, and delivery of the products or/and services to the customers. This research focuses on how manufacturing operations fulfil their products and services. The most common description of PSS is as a combination of product and service to reduce environmental impact. However, this research is solely from the perspective of manufacturing operations, and in particular examines PSS and inventory control, as this is complex in PSS. Inventory control is a crucial activity for many manufacturing companies as it has considerable influence on the profitability of most manufacturing organisations. A product-centric manufacturer is a manufacturer that only produces goods which may be referred to as a traditional manufacturer. As a product-centric manufacturer transforms to PSS, the strategies and methodologies of manufacturing companies will need to be enhanced. The enhancements must generate capability to operate in competitive environments where new market opportunities emerge but companies must deal with continual changes and uncertainty. The product-centric elements considered in this research are material storage, production and warehouse. The potential service offering in manufacturing operations can be divided into three main categories which are repair, maintenance and disposal although other potential areas of importance are: transportation and trucking services; system and solutions services; retail and distribution services; procurement services; outsourcing and operating services; leasing services; installation and implementation services; financial services; design and development services; and consulting services.

1.2 Problem statement

Improving global competitive and effective product development cycles increases pressure on manufacturing companies. Products must be designed, manufactured and distributed in greater quantities at lower costs, faster and of better quality. A PSS company is a transition type of company where products and services integrate into a single system. There has been considerable research into the PSS phenomenon however guidance on how companies can implement PSS is still very limited and the proposed frameworks and methodologies have seldom been validated. Mostly, PSS research empirically examines sustainability of company performance and growth. As a result, implementing PSS from a manufacturing perspective requires diverse approaches and techniques to be adopted. From a manufacturing perspective, case studies in PSS tend to be implemented in large sized companies and the research and knowledge gained from the studies are very confidential and seldom published so it is very difficult to understand the complexity and performance of PSS as a manufacturing paradigm.

In the product-centric manufacturing paradigm the manufacturer produces products and operates under its own specific organizational strategy to meet customer demands. A part goes through a sequence of procedures on the shop floor to become finished goods, but this sequential processing can result in high lead times before the product can be delivered to the customers. Procedures may be carried out "in-house" or may be outsourced. Outsourcing provides opportunities for a factory to move assets however it has not always been scalable, replicable and sustainable at all stages: raw materials, work in progress and finished goods. Any disturbance in the procedures may cause discontinuity of the main system. Each of these stages has a different view and requirements from inventory control. From the customer's perspective, when the product is sold, ownership lies with the customer and if any products are rejected or maintenance is needed the associated responsibility depends on the purchasing conditions and agreement. The common structure of all product manufacture delivered by product-centric manufacturing is summarised in Figure 1.1.

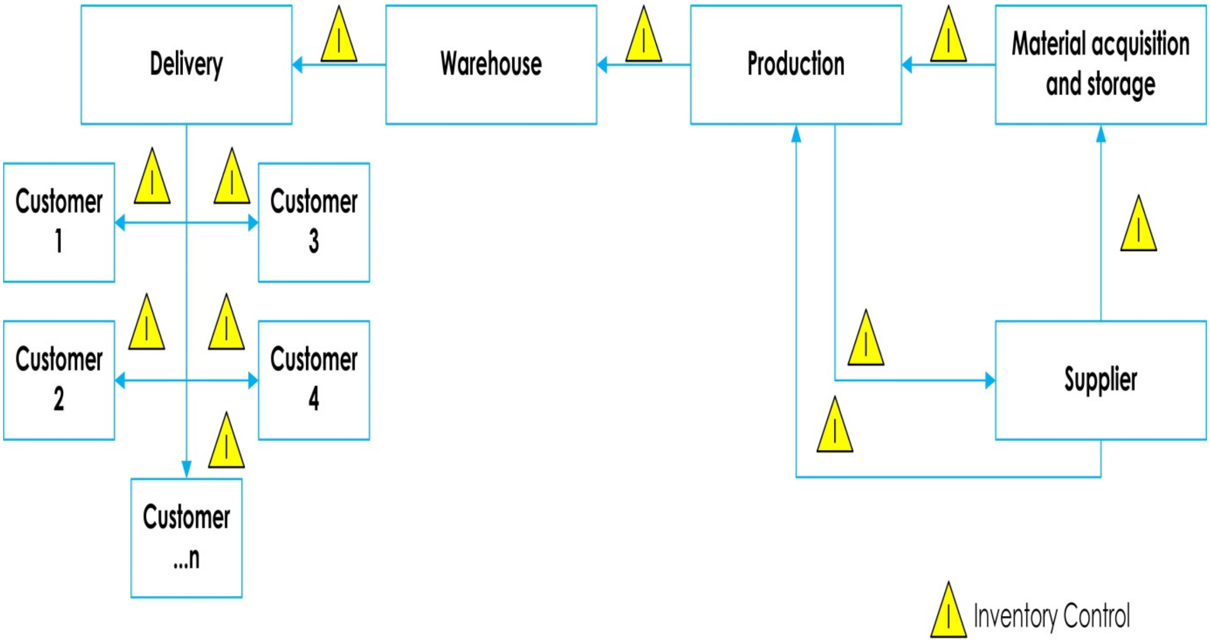

Figure 1.1 Phenomenon of product-centric manufacturing

The PSS paradigm means that products and services coexist jointly in one system. Inventory control adds a layer of complexity to PSS strategy. Challenges for PSS in manufacturing include uncertainty over condition of products and parts, maintenance requirements, remanufacture of parts or disposal aligned to keeping the supplied product operational. Dealing with system uncertainty whilst maintaining inventory levels as low as possible increases the complexity of knowledge management and decision support required to enable managers to handle multiple variations in production and manage the complex production flow to maximise profit. Another major problem is that the requirements and objectives for managing inventory for product and service phase are likely to be different. Examples of these are shown in Figure 1.2. Different manufacturing organisations have different levels of focus on the service elements of PSS which result in different characteristics and requirements which depend on the business strategy, customer requirements, technologies and ICT supports and other operational requirements.

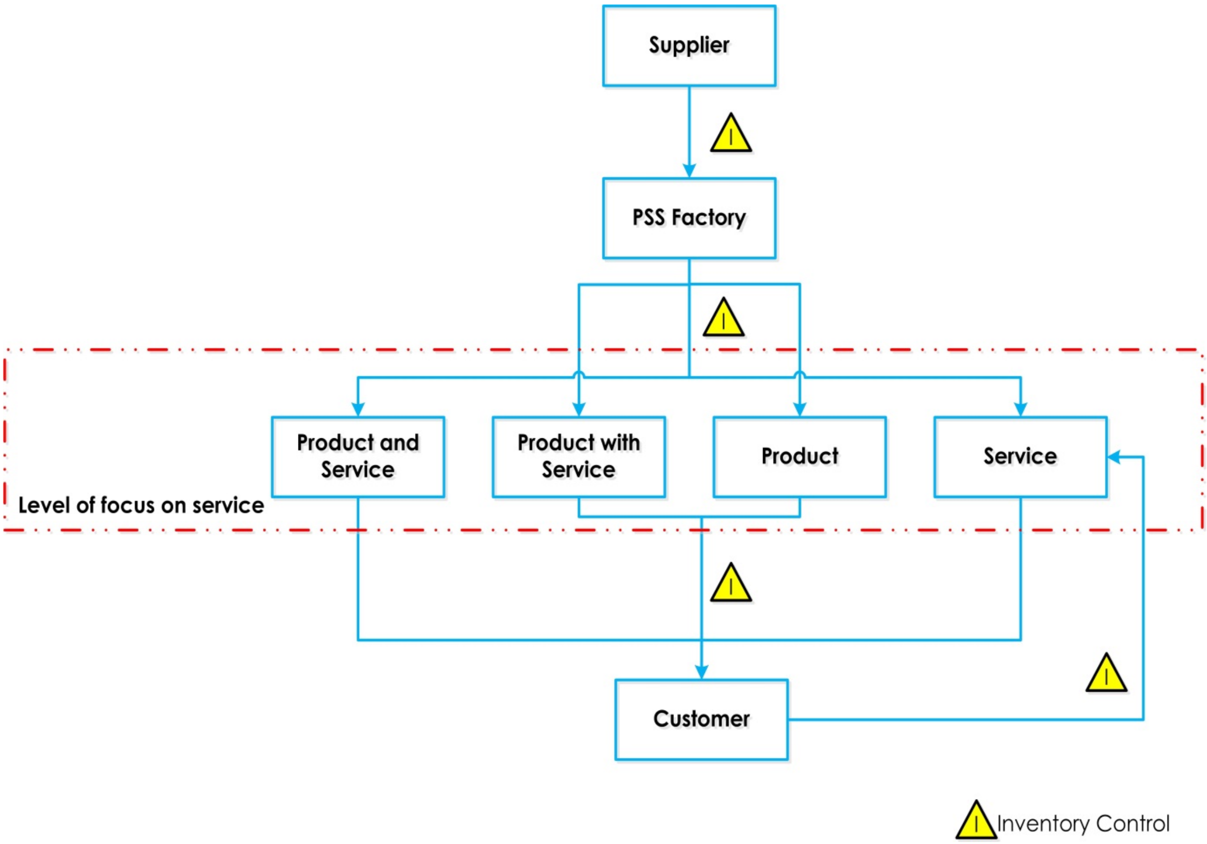

Figure 1.2 PSS Inventory Control

Inventory Control in PSS creates a larger set of uncertainties that the factory needs to manage, due to the enhanced scope and complexity of the product and service offering. Some of the areas to consider include assessing the performance and the requirements of the service delivery, and enhanced dependence on supplier. Driven by these aspects inventory control of product and service is less understood in PSS than in the traditional model of product-centric manufacture. PSS Inventory Control sets the context of this research whereby the focus is on the influence of uncertainty. In essence, when the manufacturer takes decisions to transform their manufacturing paradigm to PSS, they need to understand the implementation of the process. Inventory is a deciding factor in the management of assets which provide the stability of the organization and which lie at the heart of any business. Inventory control plays a crucial role in managing all products or services and also influences the generation of profit/loss. Inventory control provides useful information for managers to make more accurate and timely decisions. An important motivation of this research relates to its ambition to combine the two areas: PSS and inventory control which have not traditionally come together. Furthermore, from an industrial perspective there is not a standard approach to implement PSS Inventory Control.

1.3 Research questions

This research focuses on the PSS Inventory Control and the following research questions require detailed consideration:

1) What are the main debates related to PSS in manufacturing operations perspective?
2) What are the salient features of inventory control required for effective operation in manufacturing operations perspectives?
3) What are the main elements of uncertainty in PSS Inventory Control?
4) How can the key characteristics in PSS Inventory Control be modelled for practitioners?
5) How can a company manage the interface between product and service to successful inventory control?

1.4 Research aim and objectives

The aim of this research is to identify, analyse and describe the role of Inventory Control in PSS applications within manufacturing operations contexts.

To achieve this aim, the following research objectives have been set:

1) To identify, categorise and evaluate the system characteristics of PSS across a representative range of manufacturing operations contexts.
2) To determine the requirements for and related characteristics of inventory control in PSS and how these vary depending on the degree of focus on the service aspects of PSS.

3) To identify the key uncertainty elements relating to PSS Inventory Control.

4) To create a generic system model incorporating all the key characteristics and flows in PSS from a manufacturing operations perspective.

1.5 Thesis outlines

This thesis is divided into nine chapters, described as follows:

- Chapter 1 provides an overview and background of the research, the research questions, aims and objectives, outline of the work conducted and the structure of this thesis.

- Chapter 2 reviews the literature on manufacturing evaluation, servitization, product-service system and inventory control. In consequence, the research gaps are identified.

- Chapter 3 describes the methodology and methods adopted to conduct the research and explain the procedure and techniques employed in the study.

- Chapter 4 demonstrates the approach used in conducting a survey to identify PSS companies from different manufacturing operations contexts and how inventory control works in those companies.

- Chapter 5 presents the development of the PSS case studies in different manufacturing operations perspectives that have been conducted in the United Kingdom and Malaysia.

- Chapter 6 describes the uncertainty elements in PSS Inventory Control using a matrix method by evaluating the overall case study companies operations.

- Chapter 7 focuses on developing the generic model of PSS Inventory Control from a manufacturing operations perspective using the static process modelling language method, called IDEFØ.

- Chapter 8 discusses the key findings related to the material presented throughout this thesis.
- Chapter 9 concludes the work done in this research including: an explanation of how the research objectives were met and answer to the research questions; research contributions; research scope and limitations; and future research suggestions that could be conducted.

The schematic showing the overall thesis structure is summarised in Figure 1.3.

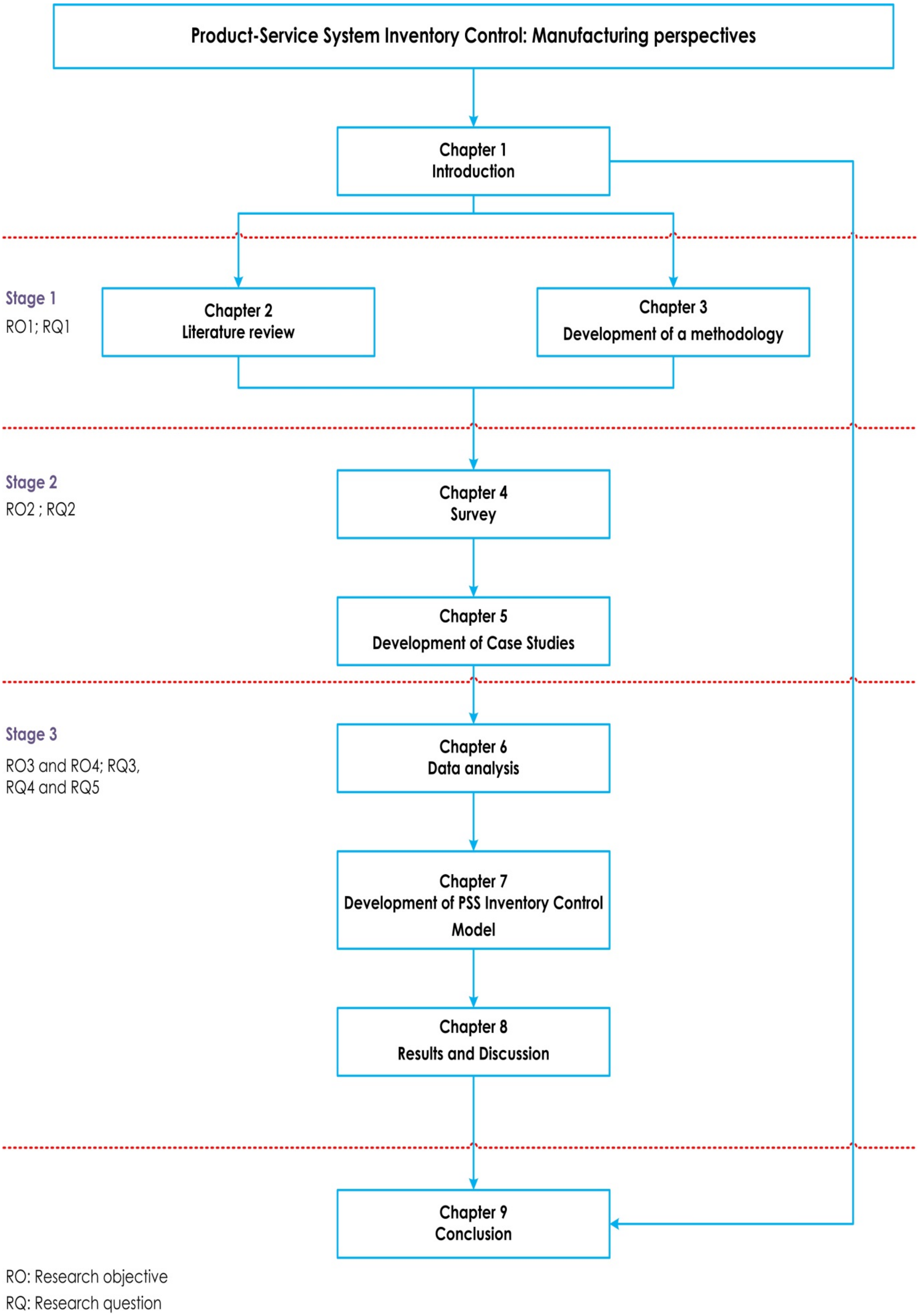

Figure 1.3 Summary of overall thesis plan

2. Literature review

The purpose of this chapter is to explore and summarise the literature related to this research. This literature review provides the basis for developing the research instruments and proposed methodology. It also identifies the research gap and provides the justification for the research.

2.1 Manufacturing evolution

Manufacturing is a series of activities to produce products, including design, material selection, planning, production, quality assurance, management and marketing (Blackstone and Cox, 2005). Manufacturing can be described as a transformation process to convert inputs into outputs (Williams, 1994). Manufacturing involves the production of physical goods by the processing of raw materials, then transforming these into components, subassemblies and finished products. The input elements are raw materials, energy and information, whereas outputs generally take the form of finished products, scrap and information. The input and output elements are limited by constraints on machines, processes, transport, handling for parts and tools and control subsystems.

Over several decades there have been profound changes in the ways in which manufacturing companies design, develop and produce products to offer on the global market. This has been caused by increases in global competition and demands and more recently by global financial pressures and increasing energy costs. Consequently, as manufacturing businesses face times of growth in demand for product, process, resources and plant, many firms may embark upon equally radical new paradigms of manufacturing. Some manufacturing firms may be widely distributed geographically and linked strategically in terms of dependencies. Each change of paradigm has to be accompanied by changes in the firm's strategy, organisation and manufacturing technology. It is crucial to understand the influences on manufacturing in order to chart out a future path for the manufacturing sector. For example, in the early stages of manufacturing evolution, the United States of America was the main player in the growth and development of manufacturing, then Japan hit the manufacturing world with its Lean paradigm and in today's global economic system China is the main player however to date this has not resulted in any new manufacturing paradigm contributions (Ismail et al., 2015). The main stages in manufacturing paradigm evolution are shown in Figure 2.1.

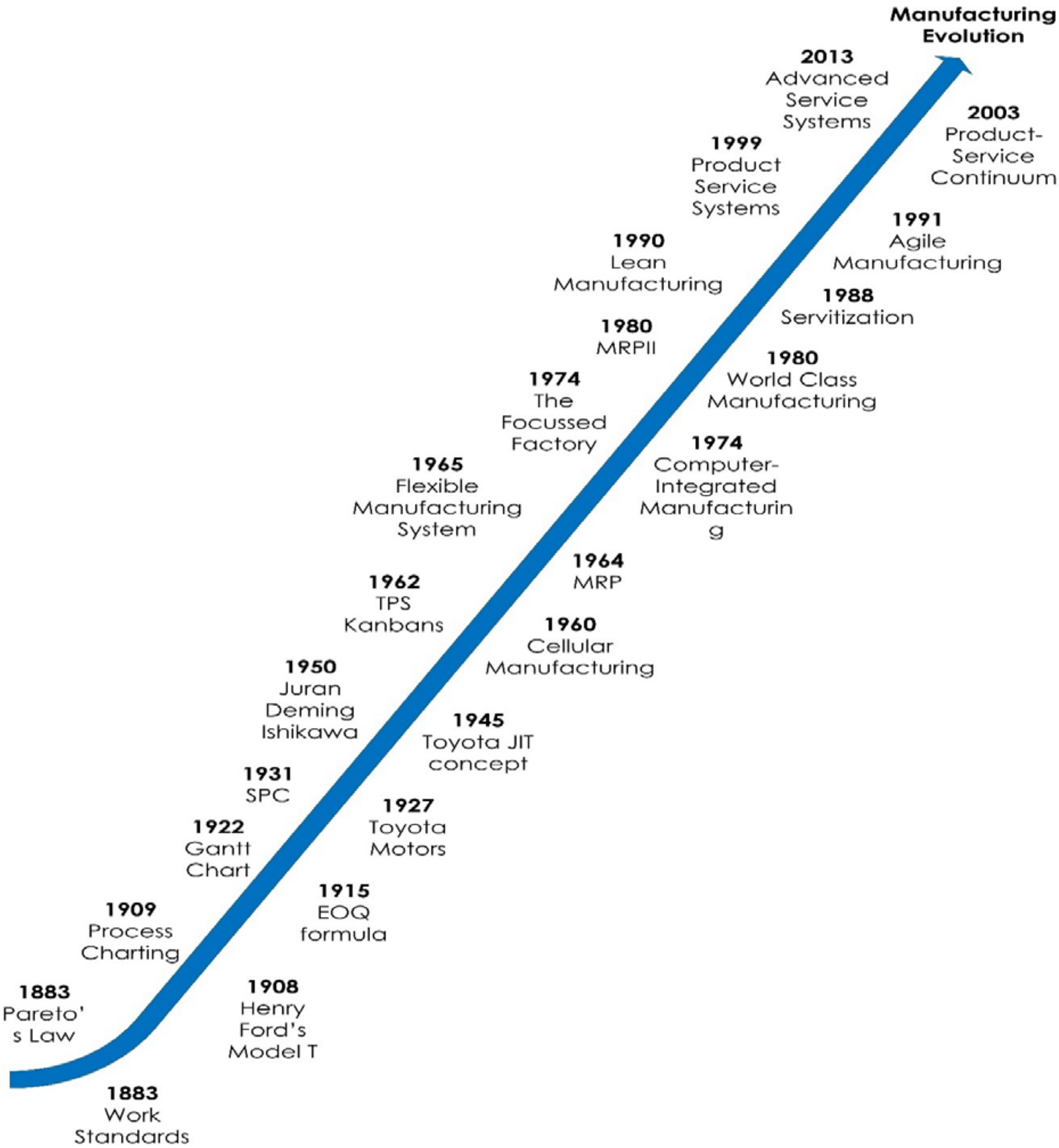

Figure 2.1 Evolution of the manufacturing paradigm (Ismail et al., 2015)

Each paradigm in manufacturing evolution has different functions and aims in terms of production volume, product variety, technologies used, and the dominant form of competition and countries of origin are recorded in Table 2.1 (cf. Ford and Crowther (1992); Ohno (1988); Vandermerwe and Rada (1988); Narasimhan et al. (2006); Gunasekaran (1999); and Goedkoop et al. (1999)).

Manufacturing Paradigm	Functions and aims
Henry Ford's Model T (1908)	Henry Ford's Model T "helped put America on wheels" by providing what Americans wanted in an automobile at a price most could effort.
Toyota production system (1945)	The Toyota production system arose from the ideas of the inventor of lean manufacturing and the development of certain strategies and tools such as Kanban, Just-in-time (JIT) principle, Zero defects to create a great company.
Servitization (1988)	Servitization is a process of transition by adding services to products-based offerings.
Lean manufacturing (1990)	Lean manufacturing minimises waste due to unneeded operations.
Agile manufacturing (1991)	Agile manufacturing changes operating states in response to uncertain and changing demands placed upon it.
Product Service System (1999)	Product Service Systems create value as outputs of combination of products and services as a system.

Table 2.1 Manufacturing paradigm phenomenon

2.2 Servitization

There is a need to clearly define the key terms of "product" and "service" at the beginning of this section since the extant literature is abundant with terminologies which are used to describe "product" and "service" almost identically. Vargo and Lusch (2004) argued that the difference is not in the characteristics of "product" and "service" but rather in the logic behind the business. The characteristics of material products compared to services can be categorised as intangibility, heterogeneity, inseparability, and perishability (Zeithaml, 1981; Anderson et al., 1997; Lovelock and Gummesson, 2004; Moeller, 2010). In most organisations, the aim for both products and services is the same i.e. to provide benefits and satisfy needs, but the characteristics of each are different. In the context of manufacturing; product and service are independent entities, where a service normally is an attachment offered with the product and organised by different departments. "Product is a tangible commodity manufactured to be sold, and capable of falling on your toe and fulfilling a user's needs" (Goedkoop et al., 1999). In contrast, Hill (1977) defines service "as a change in the condition of a unit or a person, or of a good belonging to some economic unit, which is brought about as a result of the activity of some other economic unit, with the prior agreement of the former person or economic unit".

"Within recent years there has been developing a noticeable tendency to define selling as a process of rendering service. Thus a manufacturer of automobiles does not sell automobiles; he sells transportation. And he uses as his strongest selling point the argument that the buyer of his car will have uninterrupted transportation. Similarly a manufacturer of tyres does not sell tyres; he sells mileage. And if one casing does not give satisfactory mileage he will furnish another."

Almost a century ago, Kitson (1922, p.417) documented the quote above; the manufacturer no longer focuses on solely on offering their physical products but is shifting their focus to also offer services to their customers'. In 1962, Becker made the suggestion to shift from products to services because the U.S. at that time was employing half of their total work force in the service sector (Fuchs, 1965). In 1969, Levitt claimed that *"…people don't want to buy a quarter-inch drill. They want a quarter-inch hole"*. This captured the trend of its nation in those days by focussing not on the products but on the expectation of benefits from the product. Hence the paradigm of embodying service provision within manufacturing organisations was recognised by both researchers and practitioners from USA and Western Europe over 40 years ago. In a renowned article in Havard Business Review, Levitt (1972) claims that *"Everybody is in service"*.

Thereafter, a handful of researchers have contributed very extensively to the identification and development of the phenomenon which appears in the literature as several topics: *"servitization"* (Vandermerwe and Rada 1988; Slack, 2005; Neely, 2009), *"after-sales services"* (Armistead and Clark, 1994), *"going downstream"* (Wise and Baumgartner, 1999), *"supplementary services"* (Anderson and Narus, 1995), *"servicizing"* (White et al., 1999), *"eco-efficient (producer) services"* (Brezet et al., 2001; Zaring et al., 2001), *"support services"* (Goffin and New, 2001), *"service engineering"* (Tomiyama, 2001; Shimomura and Tomiyama, 2005), *"product-service systems"* (Mont, 2002; Manzini and Vezolli, 2003; Tukker 2004; Baines et al., 2007), *"solutions"* (Miller and Hartwick, 2002; Galbraith, 2002), *"eco-services"* (Behrendt et al., 2003), *"solution oriented partnerships"* (Manzini et al., 2004), *"life cycle management"* (Takata et al., 2004), *"integrated solutions"* (Brady et al., 2005), *"industrial services"* (Brax, 2005), *"integrated solutions"* (Davies et al., 2006; Johnstone et al., 2008), *"winning in the aftermarket"* (Cohen et al., 2006), *"performance-based logistics"* (Kim et al., 2007), *"new service model"* (Antonacopoulou and Konstantinou, 2008), *"service infusion"* (Mathieu, 2001), *"service imperative"* (Bitner and Brown, 2008), and *"advanced services"* (Baines and Lightfoot, 2013).

The term servitization was first introduced by Vandermerwe and Rada (1988), and since the term was first coined, there have been plenty of other articles and papers addressing the various definitions of servitization in both research and practitioner literature. These are documented in Table 2.2.

Author	Definition connected to servitization
Vandermerwe and Rada (1988)	"Servitization is happening in almost all industries on a global scale. Swept up by the forces of deregulation, technology, globalization and fierce competitive pressure, both service companies and manufacturers are moving more dramatically into services."
Tellus Institute (1999)	"The emergence of product-based services which blur the distinction between manufacturing and traditional service sector activities."
Wise and Baumgartner (1999)	"...going downstream into more lucrative product related services."
Verstrepen et al. (1999)	"…Adding extra service components to core products."
Robinson et al. (2002)	"An integrated bundle of both goods and services."
Desmet et al. (2003)	"A trend in which manufacturing firms adopt more and more service components in their offerings."
Oliva and Kallenberg (2003)	"...transitioning from products to services."
Lewis et al. (2004)	"Any strategy that seeks to change the way in which a product functionality is delivered to its markets."
Davies (2004)	"...integrated solutions."
Ward and Graves (2005)	"Increasing the range of services offered by a manufacturer."
Slack (2005)	"...any strategy that seeks to change the way in which product functionality is delivered to its markets."
Lusch and Vargo (2006)	"…the application of specialized competences (knowledge and skills), through deeds, processes, and performances for the benefit of another entity, or the entity itself."

Ren and Gregory (2007)	"A change process wherein manufacturing companies embrace service orientation and/or develop more and better services, with the aim to satisfy customer's needs, achieve competitive advantages and enhance firm performance."
Baines et al. (2009b)	"…economic activity that does not result in ownership of a tangible asset."
Schmenner (2009)	"…the bundling or integration of services with products."
Cheng et al. (2010)	"…repair and overhaul."
Neely (2009)	"…innovating its capabilities and processes so that it can better create mutual value through the shift from selling products to selling Product–Service Systems."
Baines and Lightfoot (2013)	"Servitization is a term given to a transformation. It is about manufacturers increasingly offering services integrated with their products. Of these, some manufacturers choose to servitize by offering an extensive portfolio of relatively conventional services. Others move almost entirely into pure services, largely independent of their products, and provide offerings such as general consulting. Others still move to deliver advanced services which are a special case in servitization."

Table 2.2 Definition related to servitization

The paradigm of servitization attracts many scholars and practitioners to investigate the contexts of transformation, principles, challenges and process of servitization. However, those scholars and practitioners are from different disciplines and use various conceptualisations and terminology to observe and explain the paradigm. As a result, servitization has been defined and conceptualised in various ways such as *"a trend"* (Vandermerwe and Rada, 1988; Lindberg and Nordin, 2008), *"a managerial philosophy"* (De Toni et al., 1994), *"a concept"* (Robinson et al., 2002), *"a generic term"* (Slack, 2005), *"a strategy"* (Ahlström and Nordin, 2006; Lindberg and Nordin 2008), *"a process"* (Brax, 2005; Ren and Gregory, 2007), and *"an innovation"* (Neely, 2009; Baines and Lightfoot, 2013). While a variety of definitions of the term servitization have been suggested, this research will use the definition provided by Baines and Lightfoot (2013) who saw it as a paradigm to coordinate a pure manufacturing company with their business competencies and strategy, product strategy and service offerings in close collaboration with suppliers to meet customer demands.

The literature on servitization covers a wide range of topics. The paradigm of servitization has been the focus of numerous studies such as defining servitization, evolution of servitization, features of servitization, drivers of servitization, adoption of servitization, service models, customer value, challenges facing manufacturing companies both on cultural and corporate level and success factors (e.g. Anderson et al., 2006; Spekman and Carraway, 2006; Storbacka et al., 2011; Tuli et al., 2007; Brady et al., 2005; Davies, 2004; Galbraith, 2002; Almeida et al., 2008; Baines et al., 2009b; and Storbacka ,2011; Gebauer and Kowalkowski, 2012). The paradigm of servitization can be clustered into five main principal communities; services marketing, service management, operations management, product service-systems and service science (Lightfoot et al., 2013). It should be noted that the literature addressing issues in these five main principal communities is vast and it is not the purpose of this thesis to provide a comprehensive review for each of the principals. However, as the aims revolve around the clarification of product service-systems (PSS), the definitions and viewpoints of PSS will be identified in the following sections.

Substantial amounts of discussion have been driven by the paradigm of servitization within manufacturing and this not only changes the offering point of view, but also impacts on the entire manufacturing organisation from their general business strategy, operations and production to delivery channels and marketing efforts. Most servitization studies are based on case study approaches that focus on car manufacturers, aerospace industry, machine tools, printing machinery and other capital equipment producers.

2.3 Product Service System (PSS)

2.3.1 Background of PSS

PSS is another stream of research related to servitization from the mid-1990s. PSS is a Scandinavian concept that is focussed on environmental sustainability and ecological impact of social, economic and industrial factors (Baines et al, 2009a; Baines et al, 2007; Manzini and Verzolli, 2003; Mont, 2002; Meijkamp, 2000; Goedkoop et al., 1999). The PSS paradigm has received increasing attention in the academic and practitioner communities in recent years. There is also other similar paradigms to PSS that use different terminology such as *"Integrated Product Service Offering"* (Nilsson and Lindahl, 2016) *"Product-Service"* (Tukker and Tischner, 2006), *"Extended Product"* (Thoben et al., 2001), *"Functional Sales"* (Lindahl and Ölundh, 2001), *"Post Mass Production Paradigm"* (Tomiyama, 2001), *"Product-Service Combinations"* (Behrendt et al., 2003), *"Functional Products"* (Kumar and Kumar, 2004), *"Total Care Products"* (Alonso-Rasgado et al., 2004), *"Industrial Product-Service Systems IPS2"* (Roy and Cheruvu, 2009) and *"Servicification"* (Lodefalk, 2010). Goedkoop et al. (1999) contribute to the early foundation of PSS on reducing environmental impact for the Dutch government. The term Industrial Product-Service Systems (IPS^2) is widely used to highlight PSS in the manufacturing-based business to business (B2B) context, (cf. Meier and Kortmann, 2007; Rese et al., 2009; Meier et al., 2010; Müller et al., 2012; Müller and Stark, 2010; and Meier et al., 2011).

Scholars and practitioners in PSS are from multiple disciplines such as engineering design (cf. Mont and Tukker (2006); Williams (2007) and Ulaga and Reinartz (2011)); business management (cf. Magretta (2002) and Tukker (2004)); and information systems (cf. Mont (2002) and Sundin et al. (2010)). As a result, cross-discipline research currently exists that emphasises different priorities and contributes to the PSS paradigm according to the focus of particular research projects. PSS is a mature paradigm, with a diverse range of terminology. It is therefore essential to identify the relevant research from the manufacturing operations perspective as the starting point for future research. Table 2.3

provides a list of definitions from the literature and these are listed according to the year of publication rather than by any significance ranking. To gain reliable insight into this research, the current researcher followed the terminology defined by Boehm and Thomas (2013).

Authors (Date)	Definitions of PSS
Goedkoop et al. (1999)	"A Product Service system (PS system) is a marketable set of products and services capable of jointly fulfilling a user's need. The PS system is provided by either a single company or by an alliance of companies. It can enclose products (or just one) plus additional services. It can enclose a service plus an additional product. And product and service can be equally important for the function fulfilment."
James et al. (2001)	"An eco-efficient service is one which reduces the environmental impact of customer activities per unit of output. This can be done directly (by replacing an alternative product service mix) or indirectly (by influencing customer activities to become more eco-efficient)."
Brezet et al. (2001)	"Eco-efficient services are systems of products and services which are developed to cause a minimum environmental impact with a maximum added value."
Mont (2002)	"A system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models."
Manzini and Vezzoli (2003)	"A Product-Service System can be defined as the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands."
Hockerts and Weaver (2002)	"A pure product system is one in which all property rights are transferred from the product provider to the client on the point of sale […] A pure service system is one in which all property rights remain with the service provider, and the clients obtain no other right besides consuming the service. A product service system is a mixture […] of the above. It requires that property rights remain distributed between client and provider, requiring more or less interaction over the life time of the PSS."
Brandstötter et al. (2003)	"A PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally, PSS tries to reach the goals of sustainable development."
Wong (2004)	"Product Service-Systems (PSS) may be defined as a solution offered for sale that involves both a product and a service element, to deliver the required functionality."

Mont (2004)	"A product-service system is a system of products, services, networks of actors and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and has a lower environmental impact than traditional business models."
Tukker and Tischner (2006)	"Product-service system (PSS): the product service including the network, technological infrastructure and governance structure needed to 'produces' a product-service."
Baines et al. (2007)	"A PSS is an integrated product and service offering that delivers value in use."
Boehm and Thomas (2013)	"A Product-Service System (PSS) is an integrated bundle of products and services which aims at creating customer utility and generating value."

Table 2.3 PSS definitions

2.3.2 PSS characteristics and classification

There are three elements of PSS which are product, service and system where a product is considered to be tangible, a service is intangible and a system provides interdependences and relations for product and service (Baines et al., 2007). Sakao (2009) established a list of product conditions to achieve higher effectiveness in the PSS derived from Tukker and Tischner (2006) research:

- Products with high costs to operate and/or maintain;
- Complex products that require special competencies to design, operate, manage and/or maintain;
- Products with considerable consequences or costs if not used correctly or appropriately;
- Products where operational failure or downtime is not tolerated;
- Products with long life; or
- Products with only a few major customers in the market.

Service in the PSS includes spare parts; repair, reconditioning (reconditioning is more extensive in scope than repairing); retrofit (performance upgrade; retrofitting is more extensive in scope than reconditioning); inspection; maintenance; technical support; technical consulting; performance audit;

operation related services; and customer training (Henkel et al., 2004). However, as an overview of the most important characteristics of PSS from a manufacturing perspective is still missing, the work by Minguez et al. (2012) which provides the characteristics of PSS for an architecture context will be used as reference:

1) The first specific characteristic is integration with the external factor customer. This characteristic is driven through a PSS service component and, is not limited to the creation process only. The consumer in addition has to be integrated with the product to ensure customer oriented solutions. Consequently, the event and creation processes of a PSS should be driven by internal (e.g. the product) and external factors (customers), whereas the roll-out of traditional products are mainly driven by internal factors.

2) The second characteristic is individualization potential. This is implied through the first characteristic but the amount of individualization is a consequence of the level of integration of the customer. The greater the degree of integration then the greater the level of individualization will be.

3) The third characteristic is the technical integration of a PSS product and service. The definition of technical integration refers to the functional connection of product and service. The more product-specific the service is then the level of integration will also be greater. The status of the technical integration indicates the level of the interdependencies which exist between the involved product and service.

4) The last characteristic is the output of third characteristics. The range of characteristics, caused through the heterogeneous constituent parts (product and service) and their interdependencies, results in the larger amount of complexity.

Different types of PSS exist therefore there is a need to identify the convergence points and boundaries between product and service in manufacturing perspective. Various classifications of PSS have been proposed (cf. Chase (1981);

Brezet et al. (2001); Olivia and Kallenberg (2003); Behrend et al. (2003) and Wang et al., (2011)). In another major study, Tukker (2004) outlines the classification of PSS which is cited most often in PSS literature that gives perspectives of integration between product and service in PSS. Tukker (2004) presented eight-types of PSS as illustrated in Figure 2.2; in early stage of PSS development Hockerts et al. (1995) there were three categories of PSS: product-oriented, use-oriented, and result-oriented (Mont 2002, citing Hockerts et al. 1995).

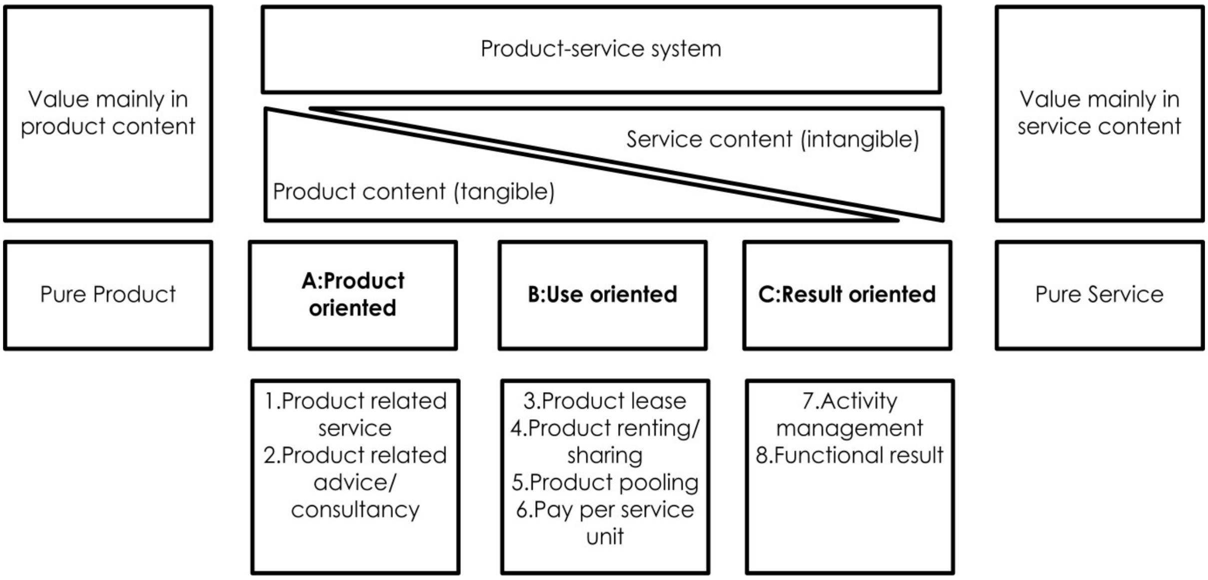

Figure 2.2 PSS classification (Tukker, 2004)

There are two different types of services in PSS: product related service which focuses on products; and advice, training and consulting service which are focussed on both products and processes (Tukker, 2004). Product-Oriented Service provides PSS elements that focus on sales of products with an additional service; the ownership of the tangible product from provider is transferred to the customer (e.g. the provider offers a maintenance contract). Use-Oriented Service is a type of PSS that aims to sell the function of products throughout the specific distribution and payment systems; the ownership of the tangible product is retained by the provider (e.g. the provider provides a car for rental). Result-Oriented Service is when the tangible products from the provider are replaced by intangible services; there is an agreement between the provider and customer on a result without any involvement of pre-determined products (e.g. the provider promises the customer an effective weight loss programme rather than selling weight loss supplements). This type of classification of a PSS model is very useful from a manufacturing perspective as it identifies the boundaries between product and service and the main elements in each category. Each of the elements in the model has certain criteria however the model does not provide details of how the integration between each category works.

2.3.3 PSS application

A variety of guidelines for PSS developments have been produced for the sustainability field for longevity, recycling and implementation phases in design such as UNEP's Design for Sustainability manual (Crul et al., 2009). Research into PSS is discussed largely using case study approaches for instance rental of office space by Morelli (2003), leasing in office furniture by Besch (2005), rental for forklift trucks by Sundin et al. (2005), leasing in Baby prams by Mont et al. (2006), performance-based construction by Gruneberg et al. (2007), material efficiency services (chemicals) by Halme et al. (2007), food delivery services with online ordering and waste management by Evans et al. (2007), healthcare equipment supply and withdrawal by Tonelli et al. (2009), vertical integration of an ultra-precision by Azarenko et al. (2009), service contracts for defence equipment by Ng et al. (2009), car sharing by Kriston et al. (2010), leasing in solar power sell by Shih and Chou (2011), service-oriented computing by Minguez et al. (2012), green Product-Service offering by Gaiardelli et al. (2014) and IT supported services by McLaughlin (2015).

In addition, the most prominent examples of PSS are Rolls-Royce Total Care and Xerox document management. Rolls-Royce offers full responsibility for repair and maintenance of products, such as a jet engine for an agreed period of time in the aerospace industry to contracted airlines, with the customers only paying a fixed cost. Previously, Xerox sold products such as photocopiers to customers and customers had the responsibility for the repair and maintenance of the equipment. However, within the new paradigm, Xerox provides document management where customers' only pay for the number of pages printed; Xerox is responsible for all of the repair and maintenance activities. In addition, the ownership of the equipment remains with Xerox (Baines et al., 2007).

2.3.4 Uncertainty in PSS

The transformation of PSS from traditional manufacturing or expanding PSS elements in operation or business exposes many uncertainties to the company. Uncertainty is defined as "State of deficiency of information related to a future event" (Sakao et al., 2008). This research is interested to identify different types of uncertainty in PSS to help a company in planning and developing their PSS strategy in manufacturing operations perspectives; uncertainty is a critical factor in decision making. There are a wide range of uncertainty discussions in manufacturing operations such as calculating and communicating uncertainty; key enabler for reducing uncertainty; and factors causes uncertainty however these will not be discussed in this thesis as this research focuses solely on uncertainty within PSS. The research by Hepperle et al. (2010) was used as a basic platform for identifying uncertainty elements in PSS since to date, their publication is the only available work that explains uncertainty in PSS. There were two categories of PSS uncertainty: planning phase; and design and development; PSS uncertainty elements in both phases will be elaborated in Table 2.4.

Phase	Uncertainty elements	Descriptions
Planning	Market	Market uncertainty involves changes in customer needs and market segmentation.
	Company	Company uncertainty is related to the organizational structure of the company which is stakeholders, human resources, capital and production capability.
	Environmental	Environmental uncertainty is a technology change and market shift in order to meet the standard and regulations of industrial or government bodies such as European Union.
Design and development	Reliability	Reliability uncertainty is to do with the breakdown of the products during the contract or warranty period; provider may have to pay in term of financial penalty.
	Product function	Product function uncertainty arises when the standard products of the company need to be modified, upgraded or removed by the variable functions to meet the customer requirements or new technology.
	Innovative service	The uncertainty in innovative service is addition of new service for the advantage of revenue generation of the company.
	PSS integration	PSS integration uncertainty happens during the integration between product and service to develop value for the customers.
	Supplier coordination	Supplier coordination uncertainty could arise due to lack of cooperation between company and it supplier.
	Communication	The lack of adequate knowledge sharing in communication between internal or external stakeholders could lead to communication uncertainty.
	Remanufacturing	The uncertainty in remanufacturing is related to the re-usage of materials; reconditioning the original products; or manufacturer that involves in reverse engineering.

Table 2.4 Uncertainty elements derived from Hepperle et al. (2010)

2.4 Inventory Control

Inventory is used to describe the items used by a manufacturing company to produce its product. It can include many items from raw materials, components, partially manufactured sub-assemblies to finished products. Inventory can represent many costs to a firm, and can also provide useful indicators of process capability and production efficiency. Continuous inventory availability is a vital requirement for uninterrupted work flow within a factory. However, it is also in the interest of the factory to keep the inventory holding at the lowest level consistent with the customer demand as high inventory, or unbalanced inventory is wasteful and causes unnecessary expense. Every production task will incur some level of inventory and this requires collection and processing of both physical and information elements. Inventory management and inventory control are well-discussed fields, not surprisingly there are a high number of publications with diverse focus (cf. Avșar et al. (2014); Berling and Marlund (2013); Marklund and Rosling (2012)). However, the main principles behind inventory management are similar throughout the literature, i.e. to ensure optimum value to meet customer demands and gain profits.

The following clear definition of inventory management is taken from a financial encyclopedia website; "*Inventory management can be defined as overseeing and controlling of the ordering, storage and use of components that a company will use in the production of the items it will sell as well as the overseeing and controlling of quantities of finished product for sale*" (Inventory management, 2016).

The interest in inventory control stems from real manufacturing operations issues. Inventory control is the process of tracking and tracing the quantity and location of inventory within the procedures and frequencies of consumed quantities. It is focused on questions such as when and how much new material should be ordered, produced or delivered? Inventory control is interdisciplinary and spans financial accounting as well as operational and logistics factors. There are three categories of stock: raw material stock (RMS) - incoming area; work-in-process stock (WIP) - assembly area and finished goods stock (FGS) - outgoing area.

Inventory control is crucial to many organisations because profitability is often linked with the effectiveness and accuracy of inventory control systems. Inventory control is required in a variety of contexts and is carried out by applying a number of theories, methodologies and tools that depend on the complexities and issues which arise in different organisations. Often studies in inventory control are conducted explicitly and are confidential for one organisation. Therefore, identifying the scope for the problem that is relevant and of interest is an essential pre-requisite in undertaking the analysis. Typically inventory control issues include inaccurate quantities, storage locations, pricing and identification, tracking and tracing inventory flows, capacity in managing inventory, damage inventory and inventory identification (cf. Andersson et al. (1998); Marklund (2011)). The solutions are often obtained by using methods such as probability theory, queuing theory, control theory, statistical inference, mathematical optimization, computer science and programming.

2.5 A reframing of PSS paradigm (manufacturing perspective)

The literature review in this research was set out to provide a clarification of PSS Inventory Control in manufacturing operations perspectives to help researchers and practitioners understand the core phenomenon as shown in Figure 2.3.

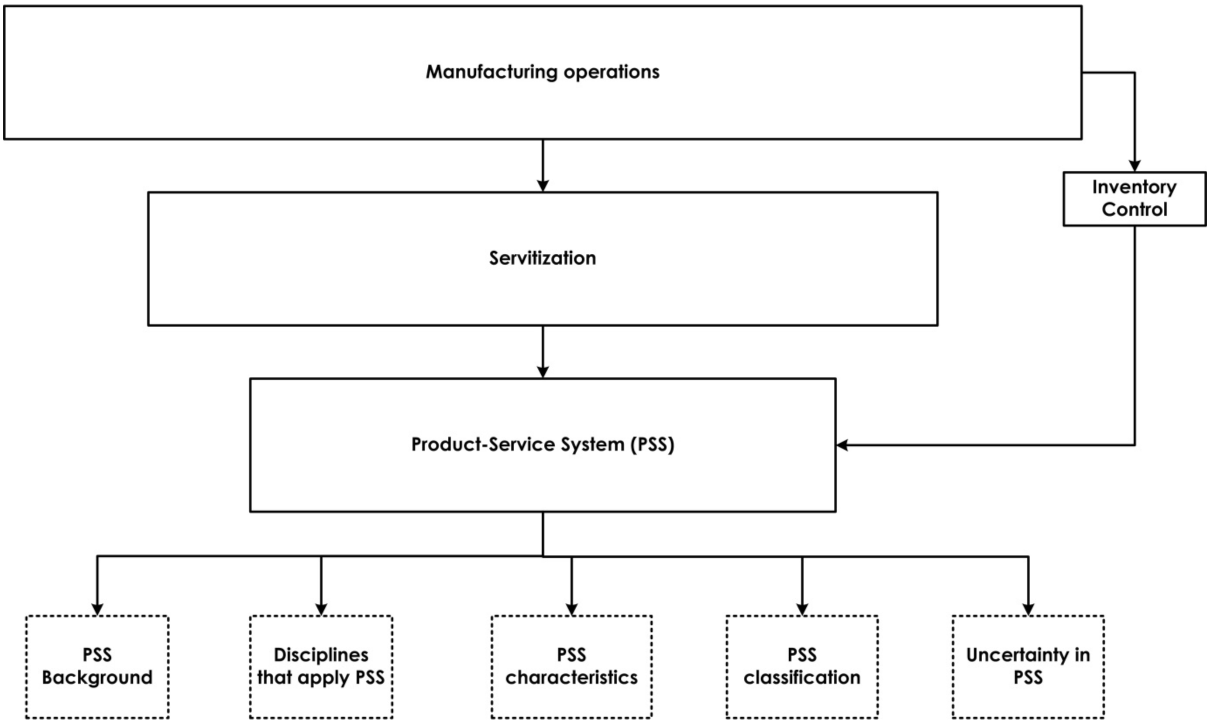

Figure 2.3 PSS Inventory Control in manufacturing operations **perspectives related literature**

The following are a personal summary of critiques of the approaches presented by previous researchers.

1. Based on the literature, a number of academic and industrial practitioner publications were identified that clarify the terminology of the PSS paradigm. The definitions contained in these publications, however, have a lack of focus on the manufacturing operations perspective and those definitions listed from the formative years of PSS do not differ fundamentally from each other. However, recent work by Boehm and Thomas (2013) defines the perspective of PSS in the specific context of manufacturing operations, in terms of product, service and system to meet

customer needs. Thus, the Boehm and Thomas (2013) perspective was selected as the basis for the current research in order to reflect that PSS is defined as both product and service that coexist jointly in one system.

2. Although as many PSS publications as possible were reviewed some could not be studied as not all publications are written in English as some of it is written in German, Swedish, Danish and Finnish. Publications in other than English might give different contexts and innovations in PSS that are useful for paradigm development of PSS.

3. As PSS is an interdisciplinary field, many academics and practitioners have conceptualised and generated methods and models of PSS according to their work areas. Most of the research of PSS is applying single and confidential case study approaches and collaborations with industry. The models developed in the literature refer to the state of the company for instance how it operates and how it creates value (Magretta, 2002). Therefore, it is difficult to identify the guidelines, tools, methods and model techniques that would be applicable to replicate and evaluate in practice.

4. The PSS literature does not discuss in depth the applicability of PSS methodologies to other fields and their limitations. Because of the diversity in methodologies which have not been validated for achieved results, theories or models and their greater applicability for the context of sustainability, the literature relating to methodologies has not been summarised.

5. In many cases PSS research provides approaches that can be applied solely in one case and the company involved can be considered as big scale (Cf. Rolls-Royce; Xerox International; Mobility (Switzerland); Electrolux (Sweden); Eastern Energy (UK); Castrol Inc. (USA) and Parkersell (UK)). PSS affects firms differently based on company size (Lindahl, et al., 2006). An evaluation is needed to ensure more practical relevance and to better understand the PSS paradigm in all company sizes.

6. The literature published on PSS reveals that there is no specific research done from a manufacturing operations perspective that relates specifically to inventory control. However, there is a study that used inventory information for contract and fleet management in PSS that relates to the business management field. For example, Datta and Roy (2011) focus on inventory ordering patterns which is one of the factors related to delivery of performance-based service.

Table 2.5 presents the main issues selected from papers indicating the current gaps in research output applied to this research and affiliated areas. This research finds itself positioned within two main bodies of knowledge: PSS and inventory control. The positioning of the research is shown in Figure 2.4.

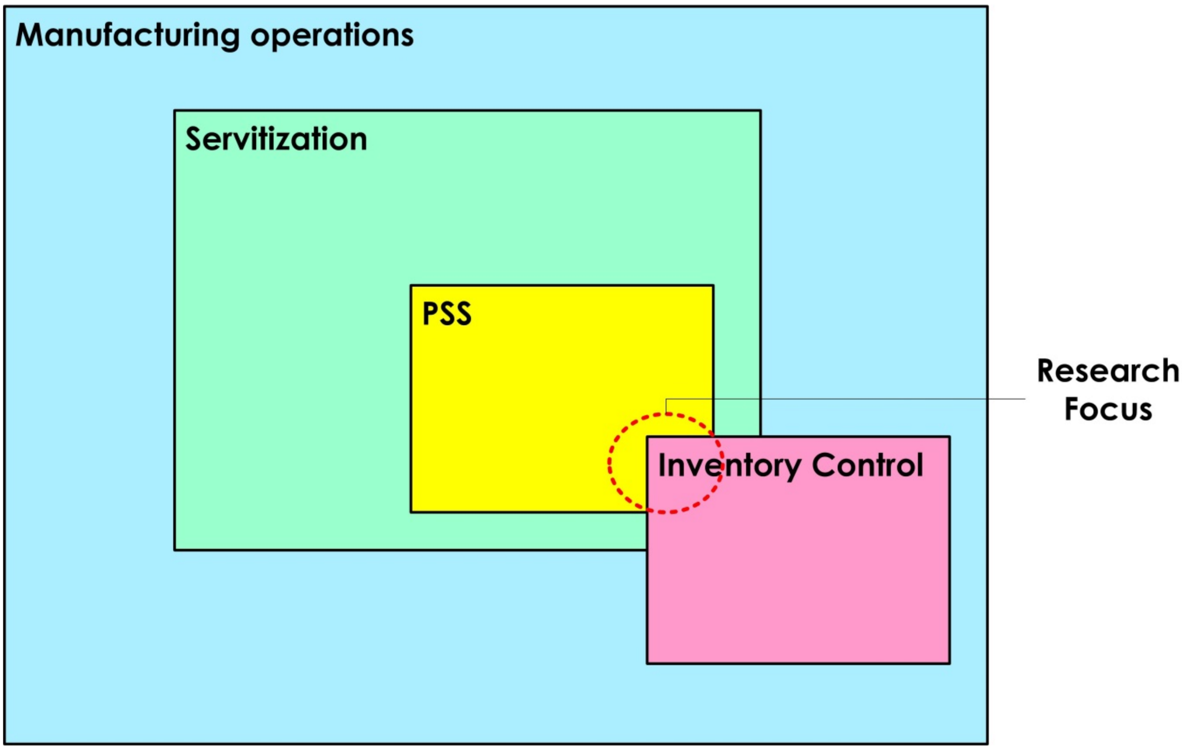

Figure 2.4 Positioning of the research

Author	Signification	Issues	Solution Method	Findings
Vandermerwe and Rada (1988)	First 'discovery' of the servitization of manufacturing	Driving corporations to servitization	Case study	Servitization as a competitive tool
Marklund (2011)	Recursive procedure for determining the expected inventory holding	Inventory replacement	Mathematical model	Cost model saving
Tukker (2004)	Describe what a PSS is and the types of PSS (sustainability field)	Value elements in PSS	Value characteristics analysis	8 types of PSS (sustainability field)
Ahamed et al. (2013)	Explain how pure manufacturing company has shifted to servitization in a manufacturing perspective	Transition from pure manufacturing to servitization	Case study	Conceptual model of firm process transition from pure manufacturing to servitization
Boehm and Thomas (2013)	Coverage of PSS literature	State-of-art of PSS	Meta-analysis of literature	Insights of PSS concept
Baines and Lightfoot (2013)	Explanation theory and practice of servitized manufacturers	Operation to deliver advanced services	Case study	Platform theory for servitized manufacturers
Proposed methodology	Explanation theory and practice in PSS manufacturing operations perspectives	PSS Inventory Control	Case study	Generic model of PSS Inventory Control using IDEFØ; resulting PSSIC Framework

Table 2.5 Characteristics of selected papers in the research

2.6 Chapter summary

This chapter provides an overview of published literature relevant to PSS Inventory Control from a manufacturing operations perspective. It outlined two main perspectives: PSS and Inventory Control. It began by reviewing the literature associated with developing of the manufacturing evaluation. An attempt was made to link servitization and the terms related to the servitization together with the application of PSS. The literature provides an in depth view for PSS Inventory Control development such as definition, classification and uncertainty elements. The literature review has helped to identify the research gaps and positioning of this. The research gaps that been identified in this research were definitions of PSS; material of the literature review used other than English might useful for understanding PSS; PSS research mostly conducted through case studies; difficulty to identify the guidelines, tools, methods and model techniques; the size of the company involved in the study are big scale; and no specific research done in PSS that relates specifically to inventory control. This research will be addressing the system characteristics of PSS across a representative range of manufacturing operations contexts as outlined within objective 1.

The next chapter will deal with the development of a research programme aimed at developing the new PSS Inventory Control methodology.

3. Development of a methodology

This chapter explains the choices the researcher made in selecting appropriate research theories for the research strategy, research design, research methodology and ethical issues for this thesis. The aim of this chapter is to provide a detailed description of the crafting of the research; how the research is conducted and rationale for the decisions taken.

3.1 Introduction

Research is "an activity that involves finding out, in a more or less systematic way, things you did not know" (Walliman, 2011, p.7). Research can be viewed and understood in different ways; conducted to add knowledge; or contribute new knowledge to a particular research field (Birley and Moreland, 1998). Research is not a neat procedure of a researcher's interaction that directly influences the course of action in the research project (Okley, 1994; Maines et al., 1980). There are many reasons why a researcher may select a piece of research to be conducted; those reasons are classified by Robson (2011) into the three categories of exploratory, descriptive and explanatory.

In contemplating the research questions, the researcher has to consider the research purpose. As the current research questions are both descriptive and explanatory, this research is focussed on the descriptive and explanatory types of research. An exploratory study is particularly useful for researchers to clarify their understanding of a problem; it focuses on "what is happening; to seek new insights; to ask questions and to assess phenomena in a new light" (Robson, 2011, p. 59). The objective of descriptive research is "to portray an accurate profile of persons, events or situations" (Robson, 2011, p. 59). On the other hand, explanatory research establishes studies of causal relationships between variables (Saunders et al., 2009).

The current research will explore and deepen understanding of inventory control in product-service systems (PSS). The aim of the research is to create a strategic approach or methodology to identify, analyse, and optimise the PSS Inventory Control. This research is set in the context of PSS operating companies in Malaysia and the United Kingdom and has four specific objectives, outlined later. Currently there is a lack of PSS methodologies in manufacturing operations contexts to assist practitioners and academics in determining PSS Inventory Control requirements. Most of the existing PSS methodologies are focussed towards environmental impact such as sustainability in PSS design. Although the current PSS methodologies fail to address the question of PSS Inventory Control, the existing theories from manufacturing, management and inventory planning and control have provided a basic platform for developing this PSS Inventory Control methodology.

3.2 Research philosophical standpoint

The adoption of a philosophy in research provides important assumptions about the way in which the researcher views the world. Research must be based on a philosophy of knowledge; before a researcher creates a new knowledge, there is a need to define what knowledge is (Lee and Lings, 2008). Kuhn (1962) popularised the term paradigm by providing a model for examining problems and finding solutions. It has been suggested a research paradigm is a perspective that is based on a set of shared assumptions, values, concepts and practices, which also can be summarised as a function of how a researcher thinks about the development of knowledge (Johnson and Christensen, 2010). Lincoln and Guba (1985) refer to a paradigm as a set of beliefs to guide research efforts on how one thinks about the world. Other studies have considered a paradigm to be a transformation of visionary abstraction and beliefs through necessary action to achieve research goals (c.f. Creswell, 2013). It has been demonstrated that the terms research paradigm

(Lincoln and Guba, 2000); research philosophy (Saunders et. al, 2009); and research worldview (Creswell, 2013) refer to the same subject.
Research philosophy assumptions are typically the first ideas in developing the research because research philosophies identify “what fits where” in determining the research design (Easterby-Smith et al., 2002). Morgan (1979) suggests that the term paradigm can be used at three different levels:

- Philosophical level: For reflecting the basic beliefs about the world.
- Social level: For providing the guidelines about how the researcher should conduct their research.
- Technical level: For selecting the ideal methods or techniques to be adopted in the research.

The selection of a research paradigm or philosophy to be adopted in research contains essential assumptions about the way in which the researcher views the world. Collis and Hussey (2003) point out that a research paradigm has two clusters; a *positivistic* paradigm and a *phenomenological* paradigm. Saunders et al. (2009) view the research paradigms as *positivism, realism, interpretivism* and *pragmatism*. Johnson and Clark (2006) suggest that research is not about how much the research should be philosophically informed, but it is how well the researcher reflects upon the choice of research paradigm and defends the selection in relation to the alternative paradigms that can be adopted. The choice of the research paradigm depends on the research field and the stance of the researcher in relation to the subject studied.

This research focuses on the *positivistic* and *phenomenological* paradigms. The *positivistic* paradigm implies that two independent researchers using the same quantitative research approach with standard research methods can obtain the same conclusion in a phenomenon study (Bryman, 2001). The *phenomenological* paradigm stresses human behaviour by focusing on the state of the human rather than the social phenomenon measurement of the human (Collis and Hussey, 2003). Table 3.1 illustrates the elements of the *positivistic* paradigm versus *phenomenological* paradigm by Collis and Hussey (2003). The terms of *positivistic* paradigm and *phenomenological* paradigm have alternative definitions depending on different approaches taken (Collis and Hussey, 2003) as shown in Table 3.2. The term *phenomenological* paradigm has been used as *interpretivist* in this research to avoid confusion with the methodology known as *phenomenology*.

***Positivistic* paradigm**	***Phenomenological* paradigm**
Tends to produce quantitative data	Tends to produce qualitative data
Uses large samples	Uses small samples
Concerned with hypothesis testing	Concerned with generating theories
Data is highly specific and precise	Data is rich and subjective
The location is artificial	The location is natural
Reliability is high	Reliability is low
Validity is low	Validity is high
Generalises from sample to population	Generalises from one setting to another

Table 3.1 Elements in positivistic and phenomenological paradigms (Collis and Hussey, 2003)

***Positivistic* paradigm**	***Phenomenological* paradigm**
Quantitative	Qualitative
Objectivist	Subjectivist
Scientific	Humanistic
Experimentalist	Interpretivist
Traditionalist	

Table 3.2 Common terms in the research paradigms

Researchers base their work on certain philosophical perspectives, which may be based on one or more paradigms, depending on the research problem or the kind of work they are doing. Researchers might also make a paradigm selection based on the dominant paradigm in their research discipline. In addition, the selection of the research paradigm can depend on the research methodology and method chosen. When describing the research approach, a researcher is faced with 4 questions; the *ontological* (the nature of reality); the *epistemological* (what counts as knowledge and how knowledge claims are justified); the *axiological* (the role of values in research); and the *methodological* (the process of research), (Guba and Lincoln, 1994).

In philosophy, *ontology* is a basic assumption about the fundamental nature of existence along with its relations and attributes (what is out there to know?). "An ontology is an explicit specification of a conceptualization" (Gruber, 1993, p.1). This raises questions of the assumptions researchers have about the underlying structures that affect individuals and groups, such as what are the fundamental parts of the world and how they are related. There are two extreme positions on *ontology*; *objectivism* (or *positivism*) and *subjectivism* (also known as *constructionism* or *interpretivism*). *Objectivism* is "an ontological position that asserts that social phenomenon and their meanings have an existence that is independent of social actors" (Bryman and Bell, 2007, p.22). *Subjectivism,* on the contrary, can be defined as an "*ontological* position which asserts that social phenomenon and their meanings are continually being accomplished by social actors" (Bryman and Bell, 2007, p.23). The term "social actors" in this context is referring to an individual who conforms to the social order. *Objectivism* is more allied to the use of quantitative methods, while *subjectivism* is more allied to qualitative method. The qualitative and quantitative methods will be covered in more detail in the next section.

Epistemology is the study of reality that aims to ground the knowledge claims to within where a researcher works, as close as possible to the participants being studied in conducting a qualitative research (Creswell, 2013). The knowledge is constructed through the subjective evidence of participant views (what and how can we can know about it?). The *axiology* or value theory is a study that covers the philosophy of values; the values derived from their research value covering critical analysis and debates on another aspects' research context (Hiles, 2008). *Methodology* is defined as a set of procedures for collecting and analysing data; this is normally conducted using inductive logic and emerging research design. O'Leary (2004, p.85) describes methodology as "the framework which is associated with a particular set of paradigmatic assumptions that we will use to conduct our research".

A researcher is faced with the ontological question; the epistemological question; and the methodological question when describing the research paradigm; these three questions are interconnected (Guba and Lincoln, 1994). This research is focussed mainly on *subjectivism* to answer the ontology question; the researcher is interested to discover general phenomenon and relationships about how the inventory of products and services tend to behave; the transfer and application of the knowledge gained may result in subjectively constructed findings. Remenyi et al. (1998, p.35) point out the necessity to study "the details of the situation to understand the reality or perhaps a reality working behind them." For PSS Inventory Control the current researcher takes the epistemological position of an interpretivist viewpoint, which is predicted on the previous selection of the ontological and epistemological paradigms. The two main choices, qualitative methods and quantitative methods, will be discussed later in this chapter.

3.3 Research strategy

A research strategy outlines the general approach that the investigation must take at a level of sophistication appropriate to deal with the complex nature of social research. In addition, the research strategy must also be flexible enough to deal with uncertainties that may occur in the process of social interaction. The rationale of the research strategy is to cut down the unforeseen contingencies in the research because research is designed in the course of its execution (Becker, 1965). A research investigation involves: a particular way of thinking appropriate skills and activities (Walsh, 2001).

The research approach may take one of two possible forms *deductive research* or *inductive research*. Researchers selecting deductive research move from the general theories to specific phenomenon; they are interested in knowing which theory works best and under what conditions when there are many relevant theories of the same phenomenon. Inductive research moves from particular situations to make or infer broad general ideas or theories. Inductive research is more appropriate when there are few prior theories of the phenomenon. Deductive research is also known as testing a theory; inductive research is known as building a theory (Saunders et al., 2009). Researchers have the flexibility to use both research approaches during various stages of the same research (Neuman, 1997).

Currently there is no theory to support the role of inventory control in PSS, thus it would be exceptionally difficult to apply a theory testing approach by utilizing quantitative systems. Therefore, this research will be developed by applying a qualitative, inductive approach in order to build theory. Table 3.3 shows an overview of the research development strategy for this PhD research.

Positioning the Research	Identify a broad area of study (research field)	Inventory Control and Product-Service System (PSS)
	Select the research topic	Inventory Control for PSS
Research Philosophy	Decide the approach	Insights from constructivism - interpretivist
Research Strategy	Formulate the plan-select appropriate research method/s	Case research
	Collect the data	Sources of evidence: Interview, documentation, direct observation
	Analyse and interpret the data	Within-case and cross-case analysis
	Present the findings	Framework for Inventory Control support for PSS

Table 3.3 An overview of the research process (adapted from Bryman, 1988)

Qualitative research provides detail, procedure, and affectability to context; typically seen as involving case studies, observation and interview. The selection of a qualitative methodology aims to examine and reflect theoretical explanations from participant understanding. Quantitative research is preferable for collection and analysis of numerical data such as 'how many' or 'how much'; typified as involving data collection through experiments and surveys. Quantitative research aims to test theoretical expectations with exact measures of variables. Results from utilizing quantitative and qualitative research strategies vary relying on the researcher's perceived connection between theory and research. For instance, the qualitative takes an inductive approach in which theory is produced from exploration; quantitative research strategies take a deductive approach in which research is utilized to test theory. Bryman (1988) argues that the researcher can mix and match between qualitative research and quantitative research. However, ambiguity may arise where terminology is used differently by different researchers.

3.4 Research methodology

The purpose of this section is to explain the overall process of the research including the multiple methods used to achieve the research objectives. Most researchers emphasise the distinction between research methodology and research methods. In this thesis, the research methodology refers to the overall approach in the research process, while, method is the way of collecting and analysing the research data. Crotty (1998) provides justification of the differences between research methodology and research methods:

- Methodology:

"The strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes" (Crotty, 1998, p.3).

- Method:

"The techniques or procedures used to gather and analyse data related to some research questions or hypothesises" (Crotty, 1998, p.3).

Allan and Randy (2005) suggest that the researcher should meet the following two criteria when conducting a research methodology:

- The methodology should be the most appropriate to achieve the objectives of the research.
- The methodology should be possible to replicate in other researches of the same nature.

Ferris (2009) described research methods as a practical consequence of the views of knowledge embedded in the worldview and proposes criteria for the taxonomy of research methods as:

- positivist hypothesis testing, which refers to the approach to research as one which proposes a hypothesis that purports to explain some observable phenomenon
- action research, which refers to an interpretivist paradigm research method concerned with a practitioner learning how to improve their practice
- grounded theory, which refers to a research methodology that seeks to develop a theory of the field under investigation from the observable phenomena, with emphasis on the development of knowledge as the goal
- design, which refers to an engineering research method in which the researcher addresses a problem that is important and novel through the activity of designing a solution.

3.4.1 Research design

Research design is the overall structure of the research development plan used to answer the research questions. The way the research questions are outlined would result in descriptive; descriptive and explanatory; or explanatory answers. The research designs that can be used for research in this field are experimental research; action research; survey research; or case study research (Bryman, 1988). The choice of research design will be guided by the research questions and objectives; the extent of existing knowledge; the amount of time and different resources accessible; and also the philosophical underpinnings. Therefore, survey research, case study research and experiment research have been selected for this research as they embrace aspects that cover almost all the available research orientations to locate the inventory control and PSS on the same platform.

Experiment is a type of exploration in natural sciences to test cause–effect relationships; it addresses much in sociology research, especially psychology. The reason for an experiment is to examine causal connections; whether an adjustment in one independent variable produces a change in another dependent variable (Hakim, 2000). Experiments have a tendency to be utilized as a part of exploratory and explanatory research to answer "how" and "why" questions. Experiments can be divided into two different elements; lab experiments and field experiments (Sekaran, 2003). The difference between the two elements is the settings in which the experiments happen and in the way variables are changed to conditions (Graziano and Raulin, 2007). Normally, an experiment is conducted far from the exact location of the phenomenon, such as in a laboratory, to restrict as many insignificant elements as possible in the experimental setting.

Action research can be defined as the process of research and a consultant approach to developing understanding and improving a phenomenon that is under investigation in order to develop knowledge. Action research can be characterized as a participatory, law-based procedure concerned with creating practical knowledge in the pursuit of worthwhile human purposes, grounded in a participatory perspective (Reason and Bradbury, 2006). Action research is not only generally aimed at understanding social plans, but rather ought to additionally effect desired change as a way to producing knowledge and enabling stakeholders (Bradbury-Huang, 2010).

Surveys are a collection of related questions on a specific topic and enable the researcher to gather numeric data on trends, attitudes or opinions of a population. The survey research is generally connected with the deductive methodology. It is mainly used to answer who, what, where, how much and what number types of inquiries. Surveys studying a sample of a population, in which the relationship between one or more dependent variables, and one or more independent variables, is examined. Surveys are popular as they permit the gathering of a lot of information from a sizeable populace in an exceedingly economical way. Exploratory survey research happens during the early phases of research on a phenomenon, when the objective is to increase preliminary understanding of a research context; it provides the basis for more in-depth research or something else (Forza, 2002).

Case studies are a strategy of enquiry when the boundaries between the phenomena and context are not clearly in exploring a programme, event, activity, process or one or more individuals in-depth (Cresswell, 2013 and Yin, 2014). Case studies provide in-depth analyses of specific phenomenon and can be used in quantitative and qualitative sets of data (Robson, 2011). Case studies strengthen the understanding of a phenomenon through theory construction. They start with a set of research questions, then go through the collection of data and, lastly, elaborate the answer for the research questions.

3.4.2 Methods of data collections

Yin (2014) categorised a number of potential methods by the form of the research question, i.e. whether the researcher has control over the events under consideration, and whether the focus of the research is on phenomena as in Table 3.4. Research methods such as experiment, case study and history are suitable for answering the research questions of the circumstances of "Why" and "How". A survey is appropriate in answering the research questions of "Who", "What", "Where" and "How". Archival analysis is ideal for dealing with the circumstances when there is no access to a condition.

Strategy	Form of research question	Researcher has control over events under consideration?	Contemporary context?
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

Table 3.4 Data collection research method characteristics (Yin, 2014)

Mixed methods strategies are popular in this field and have been defined as "the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g. use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroborations" (Johnson et al., 2007, p.123). In another study, Cresswell (2013) highlights there are three strategies for mixed methods:

- Sequential: The researcher seeks to expand or elaborate on the findings of one method with another

- Concurrent: The researcher converges or merges qualitative and quantitative data

- Transformative: The researcher uses a theoretical lens as an overarching perspective within a design that contains both qualitative and quantitative data.

In the context of this research the data collection methods are focussed on surveys and case studies which will briefly be described in the next sub-sections. In this research, three main methods of data collections are used:

- Interviews
- Observations
- Documents

Interview is “an inter-view where knowledge is constructed in the inter-action between the interviewer and the interviewee” (Kvale, 2007). Interviews can be used in both quantitative data collection and qualitative data collection. However, Tashakkori and Teddlie (1998) point out that selection of data collection for interviews relies on the nature of the questions used during the interviews; qualitative data collection is mostly used in the interview. Interviews can be the sole method employed in data collection or they can be used as part of other methods in the investigation of selected issues. The interviews can be of a formal type to a less formal type; the selection relies on the research aims and the problem to be tackled. Normally, interviews are conducted face-to-face, but telephone interviews and online webcam interviews are also common.

Gillham (2000) states that interviews are relevant in the following conditions:

- Small quantity of interviewees involved.
- The interviewee is an important and accessible person that is able to provide the information needed.

- The questions that need to be addressed are fundamentally open and require clarifications.
- When confidential information cannot be disclosed in questionnaires.

There are three types of research interviews; structured, semi-structured, and unstructured. Standard and predetermined lists of questions are asked in a standard interview. Meanwhile, in semi-structured interviews additional, expanded, individually-tailored questions may be added to a standard set of questions to provide flexibility in terms of the order of the topics discussed. Lastly, unstructured interviews are used in the initial stage of research for problem identification or exploration of the subject.

Observation is a data collection technique that is used for understanding complex issues and asking relevant questions to get clarification on certain issues (Sekaran, 2003). The researcher may observe the subject in their natural work environment and record the behaviour through a specified research purpose and systematic plan to generate data.

Documentation is a technique of data collection used for researching the natural behaviour including narratives; life histories; public and private documents, such as official and unofficial company documents; journals; and letters (Lee, 1999). Documentation analysis not only analyses the verbal text but also the quantitative data of archival records (Forster, 1994).

3.4.2.1 Execution of the survey

Morrison (1993, p.38-40) provides several characteristics of a survey:

- gathers data on a one-shot basis and hence is economical and efficient;
- represents a wide target population;
- generates numerical data;
- provides descriptive, inferential and explanatory information;
- manipulates key factors and variables to derive frequencies;
- gathers standardized information;
- ascertains correlations;
- presents material which is uncluttered by specific contextual factors;
- captures data from multiple choice, closed questions, test scores or observation schedules;
- supports or refutes hypotheses about the target population;
- generates accurate instruments through their piloting and revision;
- makes generalizations about, and observes patterns of response in, the targets of focus;
- gathers data which can be processed statistically;
- relies on large scale data gathering from a wide population in order to enable generalizations to be made about given factors or variables.

The design of a survey goes beyond the topics of interest and the quality of a survey should be evaluated on how well: it delivers a valid measure of the research questions; obtains the respondents' cooperation; and brings out accurate information (Robson, 2011). Rosier (1997, p. 154-62) argues that a clarification of the following points is needed in planning a survey:

- the research questions to which answers need to be provided;
- the conceptual framework of the survey, specifying in precise terms the concepts that will be used and explored;
- operationalizing the research questions;
- the instruments to be used for data collection;
- sampling strategies and subgroups within the sample;
- pre-piloting the survey;
- piloting the survey;
- data collection practicalities and conduct;
- data preparation;
- data analysis;
- reporting the findings

Robson (2011) suggests the survey questions should use simple language, comprise short questions, avoid misleading questions, avoid negative questions and standardise the questions to all respondents, and avoid prior alternatives between other respondents. The researcher should avoid lengthy questions because these often force respondents to reread the entire question or leave the questions unanswered. The order of questions in a survey is important because it can lead to interpretation context effects from the prior questions to subsequent questions (Schober, 1999). Also, it can affect how questions are set, what beliefs shape responses, and potential comparative judgments that may have been made (Tourangeau, 1999).

The researcher chose to provide a survey to the industry as a means of identifying how inventory control works in PSS; this was also used to identify the PSS companies for the case studies. The participants of the survey are industrial workers with a high degree of knowledge and industrial experience and were allowed to complete the survey at their own convenience, so that they could provide detailed answers. There were two phases of survey conducted with demographic questions and open-ended survey questions – see Chapter 4 for further description.

3.4.2.2 Developing the case studies

A case study is an extensive inquiry of a single phenomenon of interest that answers questions like "what", "how" and "why", and it does not provide answers for questions like "who" and "how many" (Yin, 2014). The reason for these types of questions in the case studies is typically to provide comprehensive understanding of phenomenon links in a natural setting and not the frequency of incidents or events (Yin, 2014). Eisenhardt (1989, p. 534) refers to a case study as "a research study which focuses on understanding the dynamics present within a single setting". Similarly, Yin (1984, p.23), has defined the case study as: "an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used". The case study is frequently used in many social science disciplines research (Verschuren, 2003). However, research into organizational and management research is increasingly being conducted through the use of case studies (Buchanan and Bryman, 2009).

Scapens (1990) pointed out that case studies are not only used as exploratory research, where there are few theories of knowledge, but also as illustrative case studies, where the research tries to pictorialize new and maybe unique practices adopted by particular companies; experimental case studies where the research evaluates the implementations of new procedures and techniques in a company; and descriptive case studies where the objective of the case study is restricted to describing the company's current practice. In addition, Otley and Berry (1994) add another type of case study, i.e., one arising by chance; the occurrence gives the researcher access and opportunity to evaluate the phenomenon. In this project, an exploratory type of case study was selected.

In examining a phenomenon, the researchers can choose to use single case study or multiple-case studies (Yin, 2014). Single case study design has several limitations regarding the generalisability of the findings and its analytical power (Verschuren, 2003); and are also subject to risks such as misjudging single events (Voss, 2002). On the other hand, the use of multiple-case studies has a better chance of making an analytical generalisation and will produce a strong effect when justifying the research findings (Yin, 2014). A statistical generalisation is not needed in case study because case studies are a sample out of a population (Bryman, 1988). Bryman and Bell (2007), pointed out that the selection of the case or cases is derived from the following factors:

- Literal replication: where the case is expected to deliver the same results that were found in previous case or cases.
- Theoretical replication: where the case is expected to deliver different findings to previous cases due to the availability of specific reasons.

Collis and Hussey (2003) identify the following stages in developing a case study:

- Selecting cases: The case is selected which encompasses the phenomenon that the researcher is interested in and the case can be single or multiple. The researchers are suggested to focus on the theoretical generalisation which means the theory applied in the case study can be generalised to another and distinct cases will provide opportunities to modify any theory.
- Preliminary investigations: The aim of this stage is to provide the researchers with familiarisation of the case context. The researchers are

suggested to reflect on their research paradigm and consider the purpose of their attributes to their research.

- Data stage: The researchers will need to determine how, where and when to collect data. The evidence or data obtained can be qualitative, quantitative or both.
- The analysis stage: Analysis of a case can be divided into two i.e. within case analysis or cross-case analysis. The two analysis techniques provide different levels and patterns of findings. Normally, the researchers who perform the within case analysis have deeper material information of cases that enable them to generate separate descriptions of the phenomenon to identify patterns. Researchers who perform the cross-case analysis may be able to identify the similarities and differences of the cases to identify standard patterns.
- The report stage: There is no standard format in reporting cases' however determining the appropriate structure to link all the material in cases is essential.

This research followed these stages as guidelines in developing the case studies. There were four case study companies in this research. The case study construction was done at different times for each company; starting with Company B, C, A and lastly D – see Chapter 5 for further descriptions.

3.4.3 Methods of data analysis

The choice of data analysis method depends on the type of data collected and, whether it is qualitative data or quantitative data; this research collected qualitative data. It was difficult to select methods of analysis in this research because the data collected provides the basis for how it will be analysed and inventory control in PSS does not appear to have any theoretical framework. The selection of analysis methods for this research was guided by the framework development analysis method diagram as shown in Figure 3.1. The initial stage of data analysis was to analyse the case studies. This involves several stages from open coding (basic level) to axial coding and selective coding, which is more complex. Codes are the main elements and work to separate, compile or organise qualitative data (Collis and Hussey, 2003). Then, from the uncertainty elements as in Section 2.3.4, an uncertainty matrix was developed to identify the confluence and linkages between uncertainty elements and PSS Inventory Control. Integration Definition for Function Modelling (IDEFØ) is a static graphical model which is used to understand what generic elements participate in the process and the functions that are performed in the PSS Inventory Control. The validation of IDEFØ was conducted in the 4 case study companies to examine and ensure the correct representation of activities and elements and certify the applicability of the generic model.

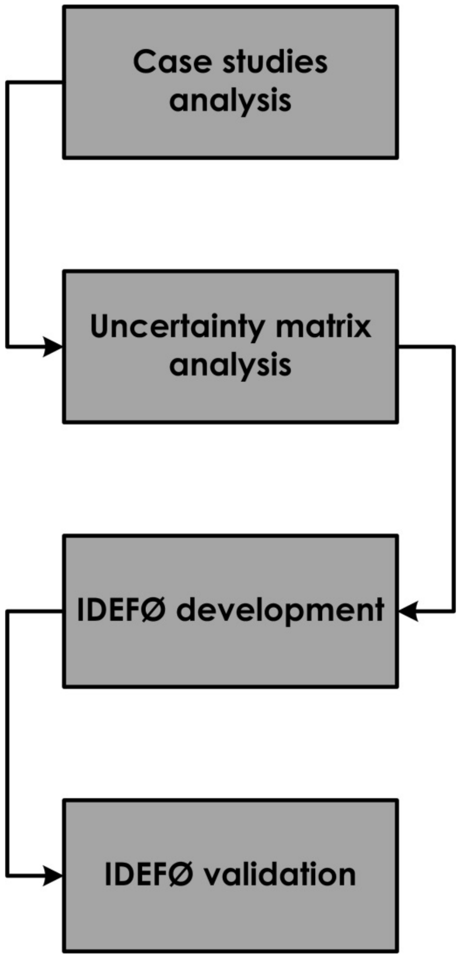

Figure 3.1 Framework development analysis method diagram

The data in qualitative research is not all meaningful. After data has been collected, a process of reduction and transformation of the data is needed to identify which data is meaningful. The main purpose of data analysis is to find answers to the research questions. Analysing qualitative data is challenging because there is "no clear and accepted set of conventions for analysis corresponding to those observed with quantitative data" (Robson, 2011, p.77). Other main challenges in qualitative data are data reduction, structuring data, anticipation of data reduction and de-textualising data (Collis and Hussey, 2003). Unfortunately, the few studies that do describe the methods adopted in PSS to analyse qualitative data are insufficient to provide a comprehensive guide.

There are many methods and techniques which can be used to analyse qualitative data. In general, data analysis of qualitative data can be divided into quantifying methods or non-quantifying methods. Quantifying methods can be classified into: informal methods; content analysis and repertory grid techniques. Informal methods are analysis techniques to quantify data informally in examining data, "such as repetitive or patterned behaviours" (Lindlof, 1995, p.216). Content analysis is a technique that converts text to numerical variables for quantitative data analysis using coding units (Collis and Hussey, 2003). The repertory grid technique "allows the interviewer to get a mental map of how the interviewee views the world, and to write this map with the minimum of observer bias" (Stewart and Stewart, 1981, p.5).

Alternatively, non-quantifying methods can be divided into: general analytical procedures; cognitive mapping; data displays; grounded theory; and quasi-judicial method. General analytical procedure deals with the required rigour and systematic processes of qualitative data and can be used with any methodology (Miles and Huberman, 1994). Cognitive mapping is used to structure, analyse and make sense of written or verbal problems such as development of strategy in action research (Kelly, 1955). Data displays are qualitative data analysis displays using visual format such as networks, matrices, charts and graphs (Miles and Huberman, 1994). Grounded theory uses a coding analysis technique to examine data where there is no preconceived theoretical framework (Collis and Hussey, 2003). The quasi-judicial method analyses data by interpreting empirical evidence (Bromley, 1986).

3.4.3.1 Case study analysis

In this research the case study analysis was performed together with the data collection during the construction of the case studies. A coding system is used to generate key factors from the descriptive details which are applicable to all case study companies together with the supplementation by illustration; focussed on looking for the PSS overall patterns and similarities. Illustration provides a clear graphical overview to support the descriptive elements in the analysis; for instance, the operation flow in the company can be precisely and clearly described in graphical rather than textual form. The coding was done by hand rather than using qualitative data analysis software such as Nvivo, thus the use of short coding labels. The major attention in this coding task was to clearly specify the whole operation flow and its elements, and their connections with each other. The coding processes used in this research were categorization and clustering. Categorization is a process of organising and categorising the data collected into the set of themes; clustering was derived from the categorization process but the aim was to provide the similarity and dissimilarity of the case studies. Typical concerns in analysis of the case studies were the volume of the information obtained from the four companies; the companies all represent different types of manufacturing. Statistical analysis cannot be applied as large amounts of qualitative information are involved.

3.4.3.2 Uncertainty matrix analysis

An uncertainty matrix is a qualitative type of matrix that was customised to fit the aim and was based on the analysis of the case studies. The aim of the uncertainty matrix is to identify the uncertainty elements of PSS from the manufacturing operations perspective by comparing the uncertainty elements of PSS in Hepperle et al. (2010) work with the data collected in survey by using the frequencies of occurrence analysis technique. Here the distinction is to identify the type of uncertainties of PSS in the manufacturing operations perspective only; the matrix shows relationships of uncertainty factors, factors identified in the case study analysis and the case study companies. Even though the PSS platforms for both contexts were different, the uncertainty elements generated in the PSS design is useful and feasible from a manufacturing operations perspective. This uncertainty matrix analysis also provided the uncertainty elements for each of the case study companies; the different types of manufacturing are associated with different types and levels of uncertainty. Uncertainty quantification generated in this matrix is used to add extra details to the development of the generic model which is elucidated in the following section.

3.4.3.3 IDEFØ development and validation

There is a lack of methodologies available to help understand PSS from a manufacturing operations perspective and this is crucial in this research. Qu et al. (2016) documented that modelling techniques such as IDEFØ are used as a tool to develop a model: Morelli (2006) used it in Solution Oriented Partnerships; and Maull et al. (2013) used it in product service supply chains. A static generic model of PSS from a manufacturing operations perspective can be developed by using a process modelling language such as Integration Definition for Function Modelling IDEFØ or Unified Modelling Language (UML) to understand and represent the elements and activities that make up a process. IDEFØ was selected as it is the most capable, practical and inexpensive for developing this generic model based on the researcher's preference and experience.

UML consists of a system of activities and actors to specify, visualise and modify the structure of a system such as component diagram, class diagram, sequence diagram and activity diagram (Foldoc, 2016). The advantages of UML are that it is widely used; provides clear visualisations and communications; and effective complexity management tool. However, it is very difficult to learn and adopt; poor formatting standard; and uses sophisticated software programs to support its application (Bell, 2004). IDEFØ is a process modelling language method designed to model complex processes and performs analysis at all level of a process. IDEFØ is a functional modelling language to represent the processes/activities and relationships within the modelled domain. IDEFØ is one of the families in the IDEF; there are more than 10 different modelling languages in IDEF. IDEFØ is comprised of a system of boxes; arrow diagrams; the textual descriptions and glossaries that describe each diagram. The benefits of using IDEFØ are that it provides flexibility and a comprehensive format of representation of a process that can decompose that information to any level of detail using a relatively inexpensive commercial software program (Mutic et al., 2010).

The PSS generic model from a manufacturing operations perspective is developed not only to provide a representation of the processes involved but also to provide accurate and relevant models of the real-world operation. This generic model must go through a rigorous validation to ensure credibility that the model usefully addresses the right functions, consistent with practical processes and matches the real-world setting.

3.4.4 Adopted research approach

Figure 3.2 summarises the methodologies selected in this research; the methodologies chosen match the stages of this research and the philosophical standpoint. Meanwhile, Table 3.5 presents the research stages and reflects the research objectives, research questions and adopted research methods for each of the phases.

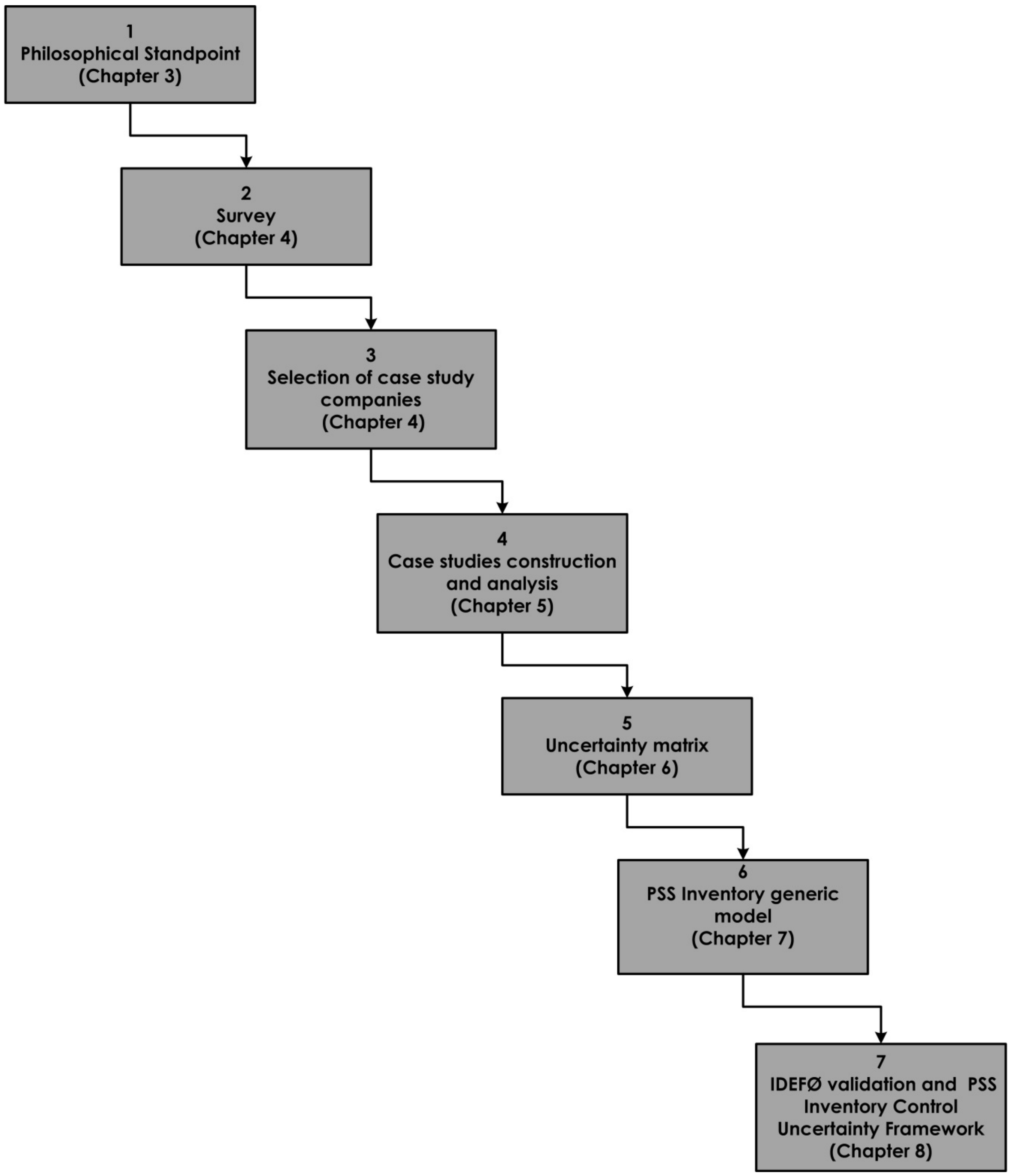

Figure 3.2 Research Methodology used to study PSS Inventory Control

Research stage	Research Objectives	Research Questions	Adopted research methods
1	To identify, categorise and evaluate the system characteristics of PSS across a representative range of manufacturing operations contexts.	1) What are the main debates related to PSS in manufacturing operations perspective?	Literature review
2	To determine the requirements for and related characteristics of inventory control in PSS and how these vary depending on the degree of focus on the service aspects of PSS.	2) What are the salient features of inventory control required for effective operation in manufacturing operations perspectives?	Survey and interview
3	To identify the key uncertainty elements relating to PSS Inventory Control.	3) What are the main elements of uncertainty in PSS Inventory Control?	Matrix development
	To create a generic system model incorporating all the key characteristics and flows in PSS from a manufacturing operations perspective.	4) How can the key characteristics in PSS Inventory Control be modelled for practitioners?	IDEFØ
		5) How can a company manage the interface between product and service to successful inventory control?	Literature review

Table 3.5 Summary of adopted research approach

3.5 Ethical considerations

Ethical issues have been considered at every stage of this research process. Bowen (2005) suggests some ethical considerations that are appropriate for consideration within the specific context of this research, as follows:

"A brief description of the study and its procedures; full identification of the researcher's identity; an assurance that participation is voluntary and that the respondent has the right to withdraw at any time without penalty; an assurance of confidentiality; and benefits and risks associated with participation in the study."

Denscombe (2010) outlines the following ethics for data protection:

- Collect and process data in a fair and lawful manner;
- Use data only for the purposes originally specified;
- Collect only the data that are actually needed;
- Take care to ensure the data are accurate;
- Keep data no longer than is necessary;
- Keep the data secure;
- Not distribute the data;
- Restrict access to data;
- Keep data anonymous.

The name of the companies and participants were anonymised and an informed consent statement was used at the beginning of each interview. In addition, participants' data are handled and stored confidentially throughout the research project on a secure drive. A case study report will be provided to the participating companies.

3.6 Chapter summary

This chapter has presented all the relevant methodological selections and their rationales. First, an overview of the research fundamental was provided before the research philosophical standpoint taken was discussed. This research is cohesive and interrelated with the ontological questions, the epistemological questions and methodological questions. Consistent with the critical philosophical standpoint taken, the research strategy adopted was discussed. The research development plan, which is also a research design was structured in this thesis to guide the research objectives and research question undertaken in this research. To meet the research objectives and answer the research questions, the research methodology was separated into three main sections: methods of data collections; methods of data analysis; and adopted research approach. Finally, the ethical considerations were taken into account and discussed.

The following chapter presents the survey findings from the second stage of the research. It explores the manufacturing operations perspective of PSS and identifies the inventory control practices for products and services in the United Kingdom and Malaysia industries.

4. Survey

The purpose of this chapter is to provide an overview of the activities involved in conducting a survey to identify companies operating PSS in different manufacturing operations *contexts and how inventory control works in those companies.*

4.1 Introduction

A survey was conducted as one of the research tools used in the second phase of this research – refer to Figure 1.3. This survey can be classified into 5 stages as shown in Figure 4.1. The survey aimed to build an understanding of inventory control in PSS and was used to identify PSS companies for case studies. It was envisaged that exploring PSS using a qualitative survey method guided by semi-structured interviews would help to understand and model the dynamic complex structures of PSS companies. To identify this target population, potential PSS companies in the United Kingdom and Malaysia were identified through the researcher's department industrial contacts and web searching. The survey was conducted through e-mails and phone; and the respondent feedback was recorded so that it could be studied to enable the studies to be designed and developed. In this survey the collected data were only a fraction of the units of the population and all data are qualitative.

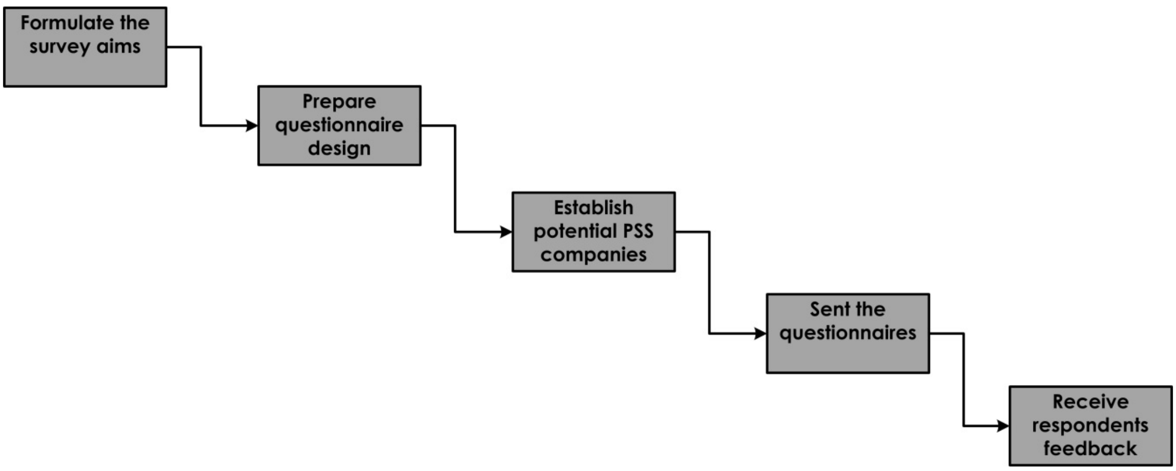

Figure 4.1 Stages in survey development

4.2 Survey aims

The survey was conducted to gather data on two topics; firstly, to describe the nature of PSS companies and secondly to identify the inventory control practices for products and services in those companies. This research identifies the convergence points and boundaries of a PSS company as a manufacturing company that produces a product and also provides a service with their own products.

Research objective	To determine the requirements for and related characteristics of inventory control in PSS and how these vary depending on the degree of focus on the service aspects of PSS.
Research question	What are the salient features of inventory control required for effective operation in manufacturing operations perspectives?

Table 4.1 Relationships between research objective and question in phase 2

This survey gathered data with the intention of achieving the survey aim through formulating specific information requirements relating to the subject. This survey examined several qualitative characteristics and no numerical or quantitative data was collected. This survey relied on a small-scale sample which enabled comparisons to be made among the respondents.

4.3 Developing the survey

There are three types of questions which can be asked through surveys; demographic questions; close-ended survey questions; and open-ended survey questions. The demographic questions are used to identify the characteristics of a population selected in the survey such as types of industry, profit level and gender. Closed-ended questions provide response choices in the survey when explicit response categories are offered. The open-ended survey questions do not limit the responses and therefore knowledge and/or opinions can be gathered to establish wider understanding of the subject. The survey used in this research was based on demographic questions and open-ended survey questions; closed-ended questions were not used in this survey. The purpose of the demographic questions was to identify factual business practices. The open-ended survey questions were aimed at establishing understanding of processes and operations in PSS and inventory control.

The context created by the questionnaire has a major impact on how individual questions are interpreted and answered. The aspects evaluated in this questionnaire are listed below:

- Type of company:
- Orientation of the company
- Complexity of the PSS
- Dynamic in the inventory control
- Subject knowledge
- Advantages of the PSS
- Decision making effectiveness in the inventory control
- Potential improvement in the inventory control

There were two phases of survey conducted; a set of five questions of demographics were created in the first phase of survey as in Table 4.2. The second phase of survey used the open-ended survey questions and answers were collected using a structured interview method as presented in Table 4.3.

Questions	Aspect evaluated
1) What is the industry sector/type of business your organizations are operating in?	Type of company
2) What are the existing products provided by your company?	Orientation of the company
3) Do you provide any services with your products- if so what are they?	Orientation of the company
4) Do you use the same resources and processes for the provision of products and services? If not, what are the differences?	Complexity of the PSS
5) How do your operating units obtain inventory information? How is this affected by the provision of service elements?	Dynamic in the inventory control

Table 4.2 First phase set of questions

Questions	Aspect evaluated
1) Are you aware of the concepts of servitization and product service system?	Subject knowledge
2) Do you think the product-service mix offering you are currently offering is a competitive business strategy?	Advantages of the PSS
3) When services are incorporated in the products offering, have you found that the organizational structures, principles and processes need to be changed? (yes or no) If yes…What and how?	Complexity of the PSS
4) What has been the biggest challenge thus far in managing inventory control of your products and services?	Dynamic in the inventory control
5) How useful do you think your inventory control is for decision making purposes?	Decision making effectiveness in the inventory control
6) How do you feel your inventory control could be improved?	Potential improvement in the inventory control
7) In your opinion, are there any issues that were overlooked that I should have covered?	Possible improvement in the survey/research

Table 4.3 Second phase set of questions

4.4 Survey approach

In this research, a mixed method was used, initially conducting the survey through e-mail (Phase 1) and making the follow-up survey by telephone (Phase 2). The e-mail survey was sent as messages to respondents' e-mail addresses. Respondents then provided their answers in the message and sent them back to the researcher. Respondents were also asked if they were willing to then take part in the 2nd phase of the survey. The survey over the phone in the second phase was selected so that the researcher could present the more sensitive questions to a respondent. All the questions have the same structure; respondents are able to give different answers to different questions because of the mode in which they are asked, rather than because they actually have to choose from a selection of answers.

4.5 Participants in the survey

The participants in this survey are manufacturing companies from the United Kingdom and Malaysia that have products and are also providing services. It was essential to classify companies by the type of PSS they offer in this research because there are different types of PSS companies in the manufacturing context as identified in the literature review section 2.3.2. Each of these elements has inventory functions which represent cost to a company.166 manufacturing companies were contacted to carry out the pilot study as presented in Table 4.4 after the details of each company were received from the researcher's school and internet searching. The survey was targeted at specific individuals within the target population who have some experience of being involved in developing PSSs within their organisation such as Manager and Senior Engineer.

Phase	No. of companies	Country
1	55	United Kingdom
	81	United Kingdom
	30	Malaysia
2	4	United Kingdom
	2	Malaysia

Table 4.4 Number of participants

Phase 1 can be categorised in 3 stages; in the first stage 55 manufacturing companies from the United Kingdom were identified and contacted. This was followed by a second stage in which 81 UK companies; and third stage was 30 companies from Malaysia, were contacted. During the first stage the 55 companies did not reply to the initial e-mail so the researcher sent a further e-mail to the 55 companies plus another new 26 companies from the United Kingdom. During the second stage the response rate was still very low so the researcher e-mailed 30 companies from Malaysia asking them to participate in the survey. In the phase 2, 4 companies from the United Kingdom and 2 companies from Malaysia agreed to participate in the next phase of the survey over the phone.

Table 4.5 summarises the number of responses received from the survey in the phase 1. In stage 1 the total number of e-mails sent was 55 and no replies were received. In stage 2, the total number of e-mails send were 81; 4 positive replies, 16 negative replies and 61 companies not reply at all. A positive reply means that the companies provided answers to all survey questions given and a negative reply means that the companies replied but did not want to join the survey. In stage 3, 30 e-mails were sent but only 2 companies gave positive replies, 1 negative reply was received and 27 did not reply.

Phase 1	Stage 1	Stage 2	Stage 3
Total e-mails	55	81	30
+ reply	0	4	2
- reply	0	16	1
No reply	0	61	27

Table 4.5 Participants response

4.6 Survey findings

There are several key findings that can be extracted from this survey:

- Finding 1:

PSS can be applied to a variety of industries such as oil and gas, automotive, energy, telecom and aerospace. Therefore, PSS can be operated in various types of products and services in those companies.

- Finding 2:

Most companies provide the services for their products either as part of their product offerings or as separate offers. There is also a possibility that a company does not provide a service with their products offering however they may provide the services for their own maintenance and inspection of equipment.

- Finding 3:

All the companies assign different resources and processes for their provision of products and services either using the same software or different software.

- Finding 4:

The software that the companies used in their operation has the capability to generate the inventory information through the integration of two different software systems; product and service.

- Finding 5:

All the respondents were familiar with the concepts of servitization and product service-system. They also agreed that a product-service mix offering is a competitive business strategy.

- Finding 6:

The respondents highlighted some inventory challenges that they are facing such as integration time between product inventory system and service inventory system; knowledge management; correct inventory information; accurate physical component; intangible assets; and personnel to be responsible to maintain the system.

- Finding 7:

The respondents suggested that the hierarchy and accuracy of good inventory data is dependent on the data capture technique. In addition, they also need more data and knowledge to improve their inventory system. Decision making is a cross functional task and depending on what type of information is required; some of the decisions are very effective and fast using their current inventory system.

- Finding 8:

All the data obtained from this survey was extracted into eight main themes and this is illustrated in Figure 4.2. Later, these themes were used to categorise the data in the case development (Chapter 5).

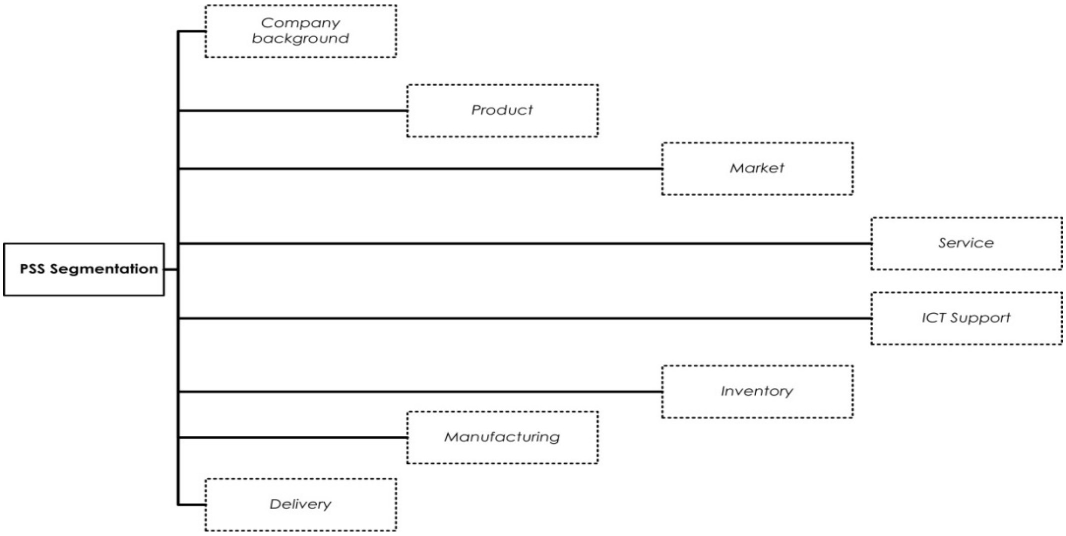

Figure 4.2 PSS segmentation

4.7 Chapter summary

This chapter has provided details into the how information was gathered about PSS in different manufacturing operations contexts; and inventory control management in the company's product and service in the UK and Malaysia. This chapter has explained the fundamentals of how surveys were applied such as how to plan the survey. The first stage of the survey sought to investigate industrial practice of PSS in manufacturing operations context and companies' willingness to participate in the 2nd phase of the survey through e-mails. The second stage of the survey sought to investigate in more detail PSS knowledge of PSS Inventory Control and decision making effectiveness. Analysis of the survey data has generated several key findings but further research was needed before a generic model for PSS and inventory control could be developed. The methodology for testing and evaluation of optimum system parameters also needed to be proposed.

The following chapter presents the case studies conducted in the United Kingdom and Malaysia. It provides unique scenarios of PSS manufacturers in real situations, enabling readers to understand this research more clearly.

5. Development of Case Studies

In this chapter, four cases study are explored individually to present descriptions of a range of different PSS cases in manufacturing operations *contexts. In addition, each case is explored in the context of PSS inventory control systems. The aim is to identify the similarities and differences of each case and consider these in detail, before the generic model of PSS Inventory Control is defined.*

5.1 Case study aim

The aim of the case studies is to identify similarities between operation and inventory control for the products and services in PSS companies; and also to determine the differences resulting from the structure of the PSS in each company, manufacturing practices, organisational structure, the relevant ICT support and other factors. The data obtained from these case studies are primarily qualitative. The case studies do not use statistical methods and the cases are not intended as a statistically significant sample. The selected companies come from the United Kingdom and Malaysia and are manufacturing companies that offer a product and also provide a service of some kind for their own products.

5.2 Case study approach

The case study approach used in this research is a combination of several data collection methods including pilot interviews and transcription. The transcription is made available for text analysis in the following chapter on data analysis. There are four one to one interviews that were conducted between March 2015 and May 2015. Each interview conducted took 1 hour to 2.5 hours. In general, all interviews followed the same process:

1. All the interviews conducted in the United Kingdom were set up at the participant's company. The interviews with the participants of the companies from Malaysia were conducted by phone.

2. All the participants received a set of questions to be asked through an e-mail prior to the interview date. The set of questions was as follows:

- Company's operation (main elements in operation system)
- Do all products include a service element and are they just the same? What% ?
- How does your company manage the interface between product and service to control inventory?
- How is the service development structured at the moment? (main processes/inputs/outputs)
- How long does the service contract last?
- What is the split between inventory related to product manufacture and inventory for service?
- What is in the inventory records (to identify the status between what is stored on the computer file and what physically exists in reality?) -How is inventory managed in each case? (product/service)
- Which parts of inventory control are working well? Are there parts with problems?
- What determines that service is required? Is it planned after a known period or is it due to failure or customer complaint or contract based manufacturer?
- What kind of knowledge and competence does the access accounting package require?
- What would you like to get out from this research? Is there anything we can do alongside for you? ***It is two-way process.

3. Interviews were carried out with all the participants. Additional questions were added to the set of questions that had been sent to them for clarification and understanding of the case subject. Interviews were conducted using a standard pattern to obtain data (this will be elaborated from section 5.4 to 5.7).

4. At the end of interview end the interviewee was given an opportunity to provide additional views that were important but which not had been addressed by the interviewer.

5.3 Participants in the case study

The participants of the case study as presented in Table 5.1:

Company	Location	Core business
A	Malaysia	Automotive, electrical and electronics industry
B	United Kingdom	Electric vehicles
C	United Kingdom	Engine technology
D	Malaysia	Petroleum

Table 5.1 List of the participants

5.4 Case study one: Company A

5.4.1 Background

Company A is a Malaysian Original Equipment Manufacturer (OEM) in the automotive, electrical and electronics industry. It was established in 1992 and currently has four factories in the industrial hub of Malaysia providing industrial product design and development, mould fabrication, injection moulding, painting and assembly. It fabricates 150 types of part and has 30 main customers, not only in Malaysia but also in Europe, South America and across Asia. Company A does not provide any services or maintenance for its products to the customer however it does provide integrated product design and development services from the initial idea to the finished products. Figure 5.1 summarises the available products and services.

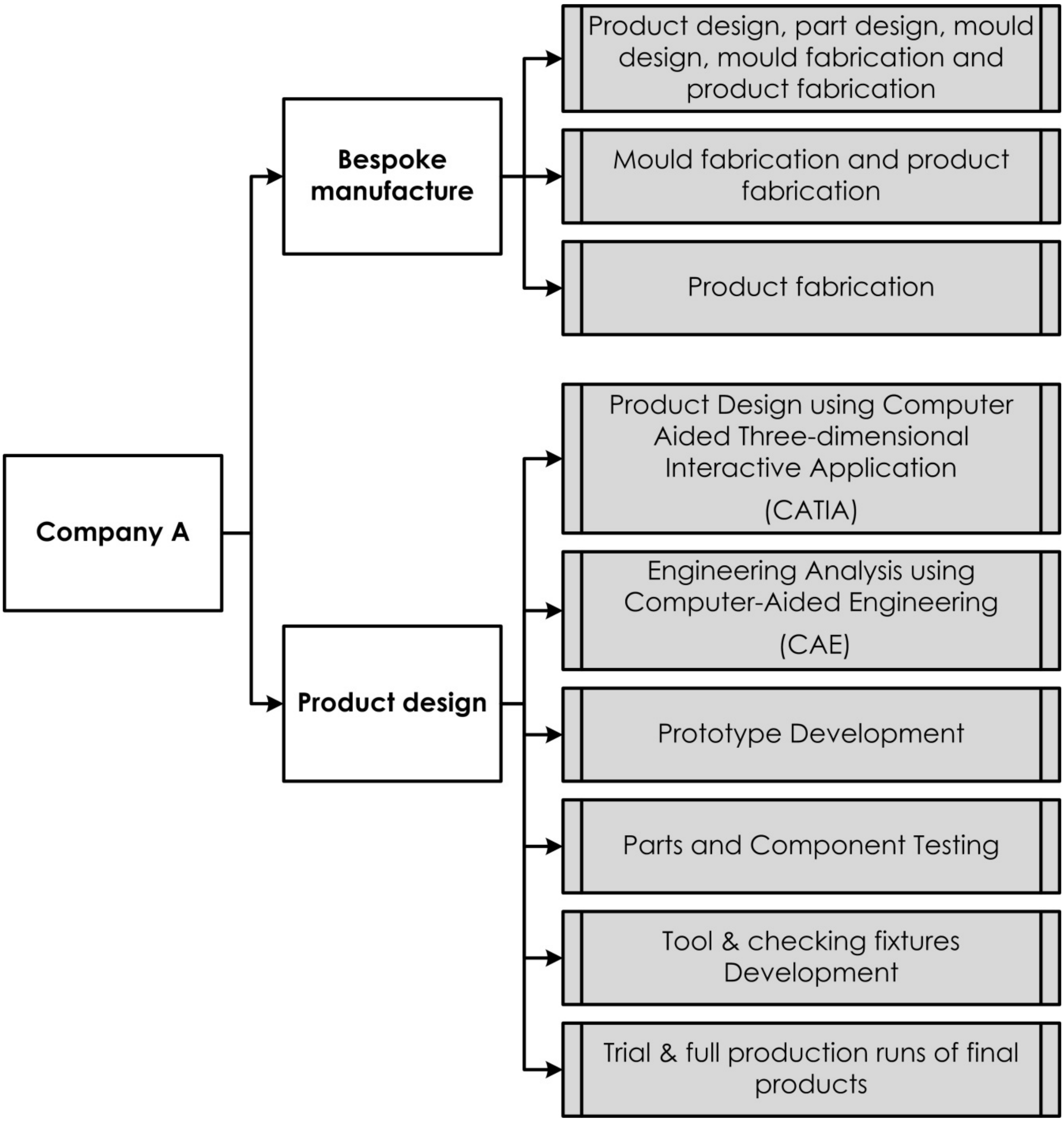

Figure 5.1 Company A's products and services

Company A's core business can be divided into two main markets:

Primary market: Bespoke manufacture from the product design, part design, mould design to product fabrication.

Secondary market: Research and Development platform for product design and proof of concept.

Company A's core business is summarised in Figure 5.2.

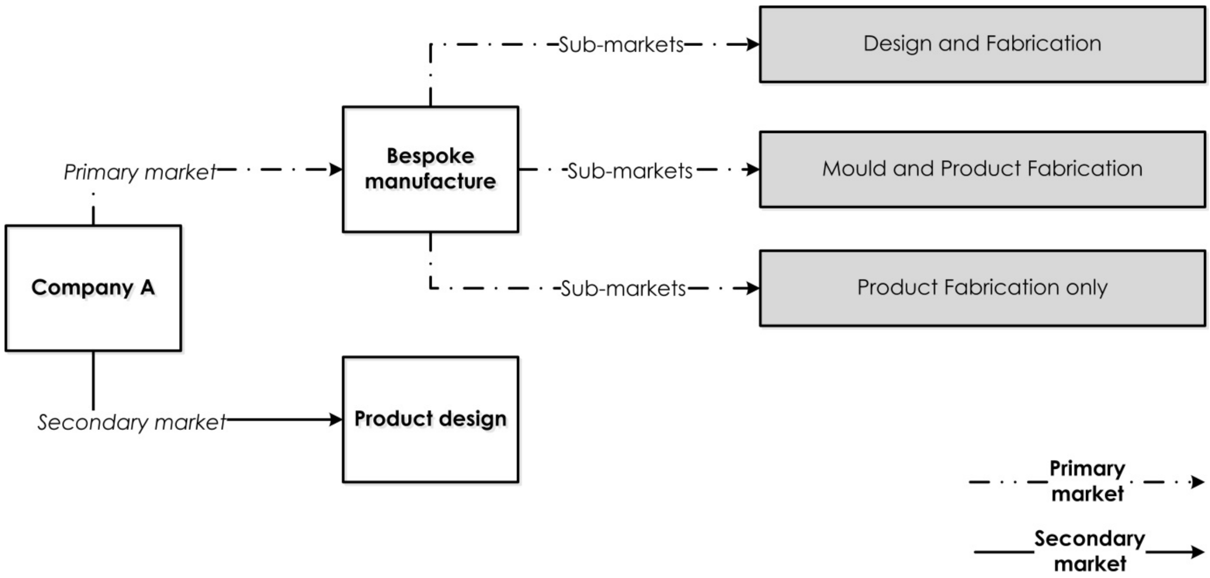

Figure 5.2 Company A's core business elements

Company A has 2 business markets however the types of products for both markets are the same. These are Automobile Central Locking, Automobile Security Systems, Automobile Security Alarms, Automobile Paddle Locks, Steering Locks, Gear Locks, Automobile Audio Systems, Steering Wheels, Automobile Lights, Automotive Horn Products, Automobile Air Conditioners, Automobile Cleaning & Polishing Materials, Key Duplication, Spacer Tubes, V-Belts- Automotive, Three Wheeler Parts & Spares, Commercial Vehicle Parts & Spares, Two Wheeler Parts & Spares, and Tyre Changing Equipment.

The primary market for Company A is bespoke manufacture and this can be divided into three main sub-markets which are:

- Design and fabrication including product design, part design, mould design, mould fabrication and product fabrication
- Mould fabrication and product fabrication
- Product fabrication

In the first sub-market, the customer provides the products' ideation or requirements then the Company A will propose the product design. After the customer has approved the product design concept, Company A will carry out the detailed design by creating the part design. Next, it will make the mould design and fabricate the mould according to the specification. Lastly, fabrication of the product will be performed. Meanwhile, in the second sub-market the customer provides all the detailed designs for the product and parts to mould. Company A only fabricates the mould and product. In the last sub-market, Company A only fabricates the product, and the customer prepares everything to fabricate the product except the material for the injection and fabrication machines.

The secondary market for company A provides the technical platform for research and development into products, supporting product design and proof of concept. Each technical platform has the technical personnel who are experts in the field and relevant machines involved to assist the customer. The customers are not allowed to operate the machines themselves except for using computer based Product Design tools for Computer Aided Three- dimensional Interactive Applications (CATIA) and Engineering Analysis using Computer-Aided Engineering (CAE). Company A also provides intensive training on using CATIA and CAE.

5.4.2 ICT support system

Company A manages a high volume of transactional environment data in customized spreadsheets using Microsoft Excel. Each section has various standard arrays of bespoke information and related function in Microsoft Excel because different departments in Company A (e.g. purchasing department and design department) have different ways of looking at and interpreting data. The ICT support system in Company A involves a variety of information transfers on an internal and external basis and it does not have the effective tools to respond to problem areas and analyse the entire system from one central location. Traditional operational databases are constructed to store large amounts of data over a long period. It is normalized in order to avoid redundancy and update anomalies, resulting in good quality data for efficient storage. When information needs to be integrated from different sections in Company A, the personnel who request the information not only need to search and understand the information by reading it. They also often need to ask the person in charge of the document to explain it. Then the personnel who request the information need to change the format of the spreadsheets according to their section's own format to include any necessary additional information. If the personnel who requested the information needs to integrate information from more than 1 section, it becomes even more complex and the time needed for integrating the different information elements increases.

The demand patterns for parts in production and those in distribution are radically different. Different concepts and formula are used for each type of inventory and therefore, the integration of different systems must ensure the materials and information flows smoothly between and within Company A's separate sections. For instance, in decision making for purchasing; inventory for raw materials used in production are based on the master production schedule (MPS) while finished goods are based on past usage patterns. Furthermore, the Microsoft Excel spreadsheets are prone to unintentional calculation errors especially when used in a shared environment with complex formulae.

5.4.3 Manufacture

Company A offers its customers various types of bespoke manufacture and product design. In general, every part in a product requires a different type of moulding. Product dimensions and other details from product drawings are needed to fabricate a mould. The production is based on customer orders, the production volumes vary from 8000 to 10000 units monthly, and the order lead-time is about 2 weeks. In this research, the V car model was selected because Company A produces the highest number of parts for this model that is 119 parts. The production line is divided into four main sections, which are Injection Moulding, Material Storage, Sub Assembly Area and Finished Goods. The injection moulding section has 27 machines with each machine operated by one operator to produce parts from both thermoplastic and thermosetting plastic materials. In one period, every machine will inject different types of product. Material storage or the main store is the section that stores all the child parts and raw materials to produce partial assemblies or complete products i.e. this section holds the entire inventory for the production. It uses pallet racking storage systems with labelling. The main raw material for this production is Polypropylene (PP). There are two sub assembly areas and each sub assembly area is divided into 5 compartments. Every compartment runs different processes and parts in one period. Each compartment operates one sub assembly function, therefore all the parts do not necessarily have to go through each of the sub assembly areas and a part might need to revisit a compartment as part of its process route to become a finished product. Finished products are products that are ready for sales and are stored according to the types of part in a poly-box before being packed ready for delivery.

A part in the production line goes through a sequence of process procedures to become finished products before they can be delivered to customers. The set of workstations that one part goes through includes a sequence of processes which will demand different setups so incurring changeover times. A part might need to revisit a workstation as part of its process route or possibly for rework due to any defects identified during inspection. Each of the process procedures operate either in the factory or/and is outsourced to a supplier. The outsourcing processes involved include painting, hardening and injection of small parts.

Currently the storage warehouse operates under a dedicated storage system in which shared storage areas are assigned to a particular product thus providing storage when needed. There are three main phases to describe the warehouse process as follows:

- Placement: A process to take the arriving products, determine where each product should be stored and physically bring the product to its designated storage location.
- Storage: A passive space where items reside in storage locations until needed.
- Retrieval: A process in which the finished products are transferred from the storage location to the warehouse.

Empty spaces within a shared storage warehouse are not assigned to any particular product. If needed, these empty storage spaces may be assigned to a particular product and will accept newly arriving items for the matching products. When the last item in storage is removed, the product stocks that previously existed are erased and the storage area may be reassigned to any other products as needed in the future. The main purpose of a warehouse is to buffer the disparity between supply and demand.

There are two modes of delivery, the first one is flexible logistics that can cope with demand fluctuations by making the delivery using Company A's lorry or van. Meanwhile, the second mode is Milk-Run logistics which has only been applied by one national automotive company. Flexible logistics is a mixed mass production system based on the Total Production System (TPS) and Just-In-Time (JIT) transportation which is concerned not just on speed but also on transportation quality. Milk-Run is a generic name for a logistics procurement method in which manufacturers utilize the same vehicle to fetch parts from multiple suppliers in other words the transportation of the product is not from Company A directly to the customer. If there is a problem on the product delivered to the customers, checks will be made to determine what or who has caused the faults. A replacement product will be made if the fault has resulted from its normal operation however if the fault has been caused by the customer there will be no replacement given.

Figure 5.3 illustrates the flow of manufacture in Company A.

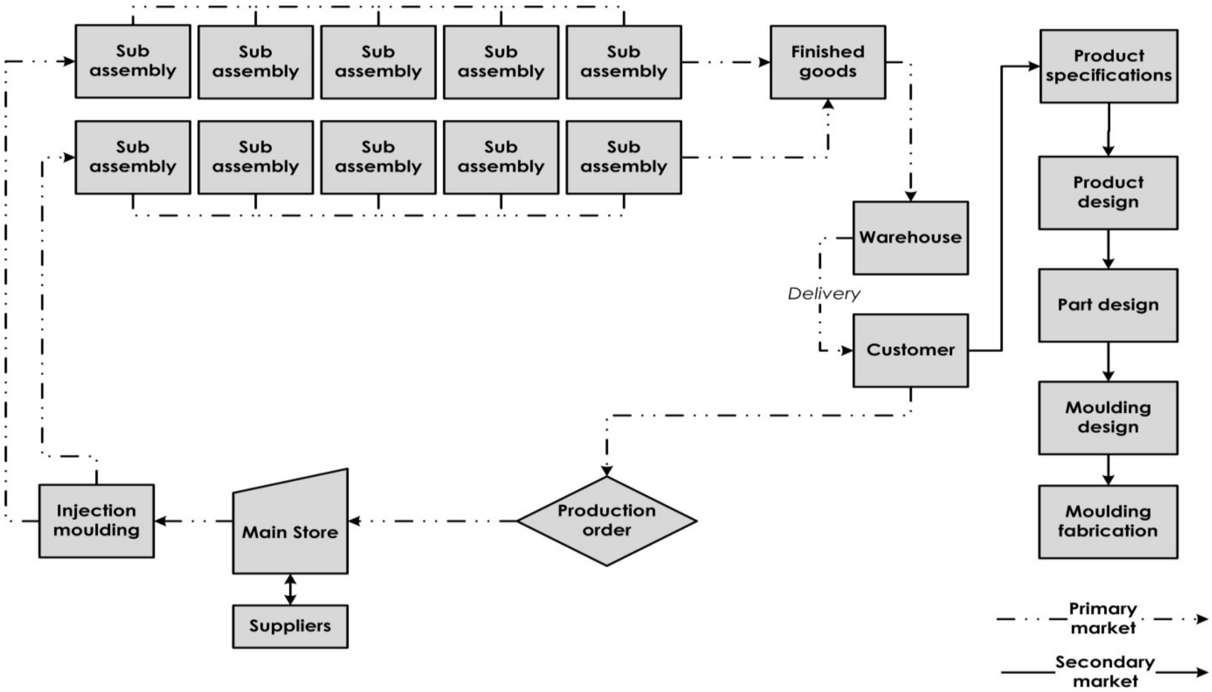

Figure 5.3 Company A's operation

5.4.4 Services provided

Company A does not provide the after-sales service for it products. Company A provides an integrated product design and development service from the initial idea to the finished goods by supporting its customers in:

- Product design using CATIA
- Engineering analysis (CAE)
- Prototype development
- Parts and component testing
- Tool and checking fixtures development
- Trial and full production runs of final products.

Normally, customers in R&D use this service to transform their product ideation to finished goods. Customers commonly will prepare the technical drawing or product samples. Company A also provides technical consultation and training for instance on how to use CAE.

5.4.5 Inventory

The production of a product often requires interaction with multiple materials, processes and parts in order to control cash flow and avoid high stock costs, Company A prefers to maintain its stock as low as possible because customer demand is uncertain. The technicians update the status of inventory manually. About 60 percent of materials come from a local supplier with a lead-time of 1 week. Safety stock quantities are permitted in the main store to avoid stock-out. This is especially common for high use small parts (i.e. screws, bolts and nuts) and child parts (i.e. gasket oil filter, trim clip and garnish pad) which are kept close to the assembly line.

The data collected on the production line are material inter-arrival time, downtime and cycle time. The inter-arrival time is defined as the time interval for a batch of parts to be delivered to a store. Ideally, parts are expected to be delivered continuously and on time, in order to avoid potential stock outs. Downtime is based on line stoppages caused by line breakdowns, some parts related issues, and control problems. This is obtained from daily production records. Cycle time is based on actual observation and a time study conducted by the author and a line supervisor. The potential parameters that cause high stock in each section are listed in Table 5.2:

Section	Potential Dependent Variables
Production line	▪ Machine capacity ▪ Machine downtime ▪ Machine utilization rate ▪ High reject rate ▪ Forecasting / Production Schedule ▪ Delivery lead time ▪ Order Quantity ▪ Batch ordering ▪ Number of workers ▪ Cycle time

	▪ Packaging
Warehouse	▪ Number of stockpiles ▪ Number and frequency of delivery ▪ Materials and parts inflows ▪ Safety stock ▪ Demand variability ▪ Goods visibility ▪ Lead time ▪ Demand volatility ▪ Replenishment orders

Table 5.2 Potential parameters of high inventory

5.4.6 Summary of issues and challenges

Inventory levels are indicators of process capability and production efficiency. Company A is having problems keeping their inventory level low due to the complexity in their production line, forecasting, ordering sequence, outsourcing and mode of delivery. Company A has always faced the challenge of increasing fluctuation in demands, customer expectations, market conditions and opportunities and number of suppliers in the turbulent and volatile environment. Production stocks in Company A are more complex and their behaviour is dynamic because of the interactions of multiple materials processes and parts. For instance, it has five main customers if one of these customers makes an urgent order change, the whole system will be affected.

The factory practices a manual tracking and reconciliation system to manage their stock of raw material, work in progress; supplies used in operations and finished products. However, the information flow among all the departments and all significant vendors is not smooth. If there is any disturbance of process procedures, the operation may cause discontinuity of the main system. The transformation process from one function to another function in the factory involves stock control issues and the whole system is exposed to uncertainties. Every section in Company A has multiple versions of spreadsheets, can be overwhelmed by the personnel from the production and planning sections irrelevant information and lots of time can be wasted. Multiple versions of spreadsheets can lead to confusion and time wasting when distributing and retrieving key information. For example, if the production and planning sections want to plan to produce a product; they need data from the purchasing, design and management functioning. Without accurate, ongoing and correct information in real time, Company A is not equipped to foresee the potential issues or quickly respond to them when they arise. They have complex data on a large manual database, and errors might occur when values are missing or in a wrong format. Meanwhile, a supplier who is sharing data and jointly developing factory forecasts maintains the factory inventory by reducing the stock-outs and optimizing supply items as and when required.

In an organization, decisions are made at different levels on a regular basis. These decisions must also be made as quickly as possible in order to maintain competitiveness and make the correct decisions, a solid base in terms of data, information and knowledge must be available. The task of collecting, sorting and analysing data is very time consuming if only performed manually. Eventually, there will be an enormous amount of data and to store and retrieve what is required will become increasingly difficult. Problems within the system typically stem from the complex relationship inherent in the system. Normalization, however, is not so efficient for reporting. Extraction of data from several different folders or sections can become very time consuming. However, access and manipulation of large volumes of data is scalable when using Microsoft Excel.

5.5 Case study two: Company B

5.5.1 Background

Company B is based in the United Kingdom and was founded in 1960. It is a SME company with approximately 50 employees. It has been selling, renting, and manufacturing electric, petrol and diesel vehicles since 1975. The company's principal business activities are design, manufacture and distribution of industrial electrical vehicles. It manufactures about 300 vehicles a year and 99% of these are bespoke manufacture. The company has a wide range of products including tow tractors, load carriers, powered/pedestrian controlled range, personnel carriers and golf buggies. It also offers second hand equipment, service packages, spare parts and driver training. In addition, the company offers vehicles specifically for rent for event hire and short-term hire and there are all covered by full maintenance and on-site service packages. Figure 5.4 shows the full range of products and services offered by Company B. It provides vehicles in the following marketplaces, waste movement and recycling, hospitals, airport and rail, transportation and leisure, golf courses and events.

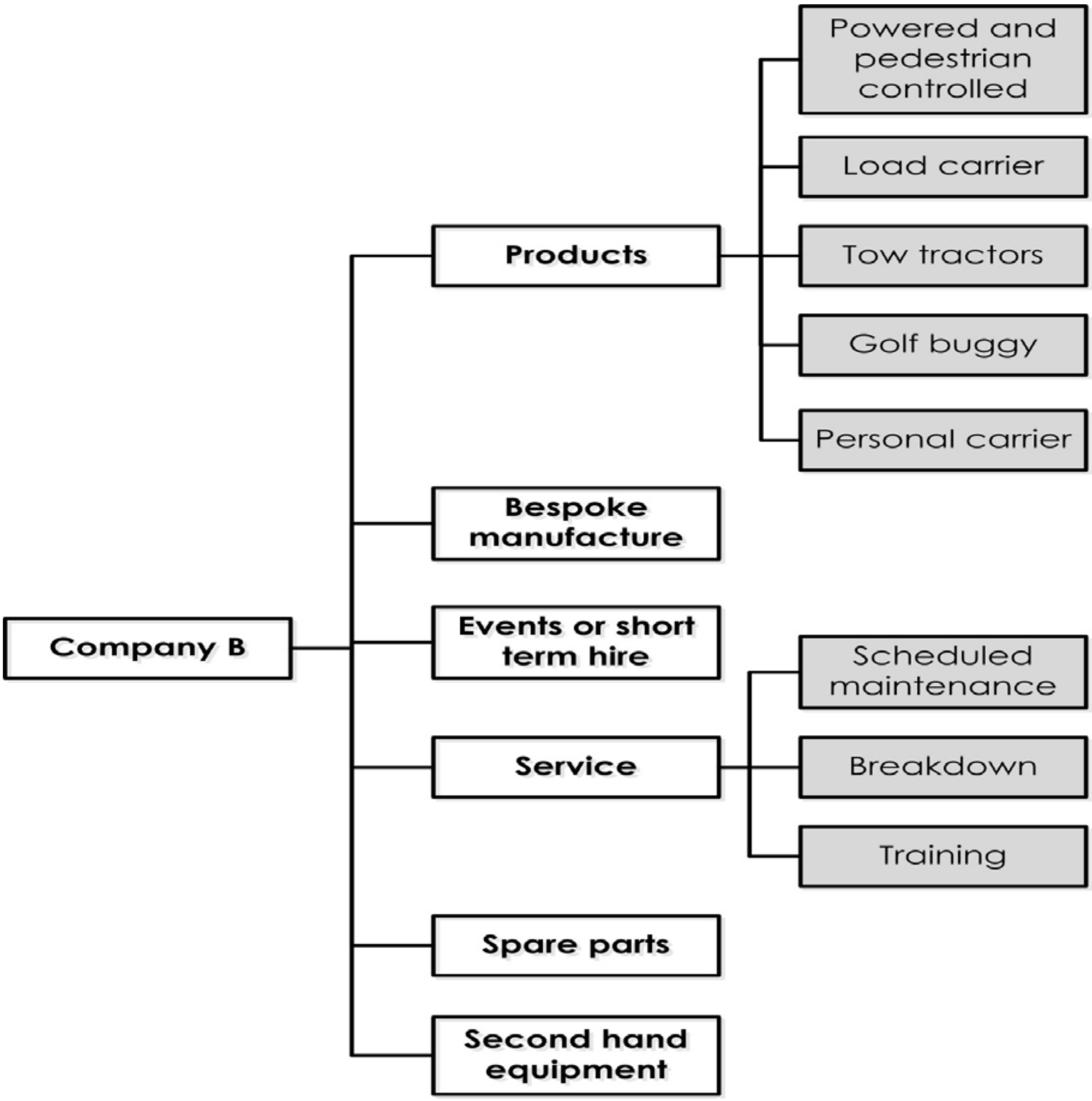

Figure 5.4 Company B's products and services

Company B's core business can be divided into three main markets:

Primary market: Selling the vehicle with a service package including an option of driver training.

Secondary market: Renting the vehicles for event hire or short-term hire.

Tertiary market: Remanufacturing older vehicles for the second hand vehicle rental market.

Company B's core business is summarised in Figure 5.5.

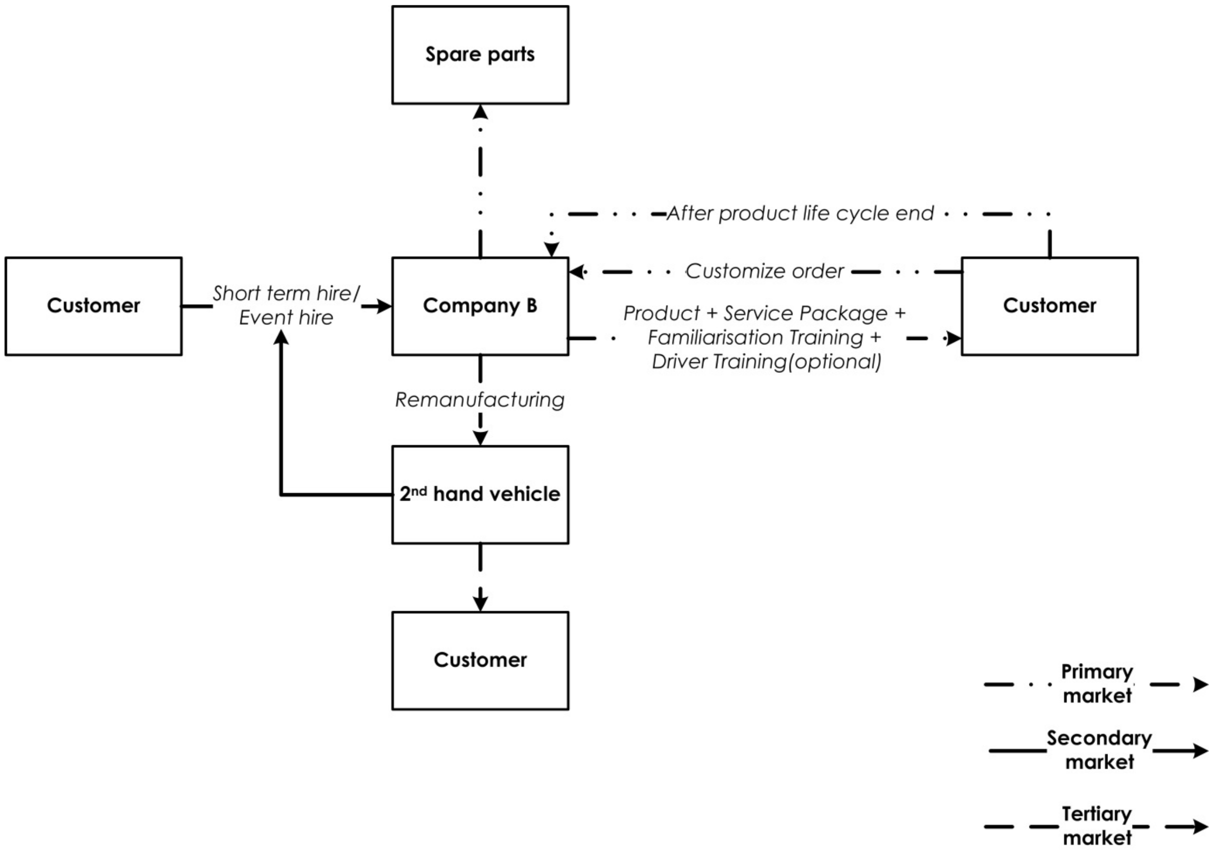

Figure 5.5 Company B's core business elements

In the primary market, the customers have an option to select from the showcase of standard products or a bespoke product can be designed and manufactured to suit the customer's requirement. A service package is included with the product however; the package depends on the type of product. It provides working days service mobility and a team of engineers ready to get the vehicles repaired within 24 hours of the call in the case of breakdown. In addition, the company will provide familiarisation training to ensure the customer understands how to operate the vehicle safely. The service package includes maintenance 4 times a year for a period of four or five years. Industrial vehicles probably have an average life cycle of 7 years whereas golf vehicles will be 4 years. Although some products are still bought outright, the Company B have identified an increasing trend in its primary market. The customers wish to buy under a form of leasing agreement for up to 7 years and are not interested in the buying the product at the end of the lease when the warranty and service agreements come to an end. As a result, such vehicles will then commonly be transferred to Company B's tertiary market.

The secondary market of Company B's business is for events or short term hire. Currently it has more than 400 vehicles specifically for the events market such as The British Grand Prix and Chelsea Flower Show. The short-term hire is for the industry usage such as load carriers, tow tractors and utility vehicles. The vehicle hire agreements are available from one week to 5 years and are all covered by maintenance and on-site service packages. The company has flexibility and can usually offer vehicles for last minute event hire, even at extremely limited notice. The vehicle will arrive fully serviced, clean, fully charged or fuelled and ready to work on arrival.

The tertiary and final market targeted is for second-hand vehicles in Europe and this requires remanufacturing processes. Remanufacturing is a process of restructuring the value and function of the product so that it can be used again. When the vehicles that were initially sold to the primary market reach the end of their life cycle, an increasing number of vehicles are returned to Company B although some customers choose to manage the vehicle themselves. The vehicles returned to Company B will go through a number of phases in the remanufacturing process. The remanufactured vehicles are supported by a six months' warranty.

5.5.2 ICT support system

Company B has two main ICT support systems that support the Before-Sales Department and After-Sales Care. The focus of the Before-Sales Department is to sell the products to the customer whilst the After-Sales Care focuses on supporting customers who have purchased a product or service. The ICT support systems in Before-Sales Department and After-Sales Care are integrated to some extent as they allow documents to be shared and provide real-time activity notifications. Therefore, the ICT support can make good use of the same resources and information in both the Before-Sales Department and After-Sales Care even though the two computing systems are separate and have different system interfaces.

5.5.2.1 The Before-Sales Department operations

The ICT support system of the Before-Sales Department operation is a tool that is used to help Company B reach business targets and financial goals not only in its primary market but also supports its secondary and tertiary markets. The system integrates internal and external resources, information and processes of its customer, production and transportation units. The integration process between the Before-Sales Department and other operational functions are summarised in Figure 5.6.

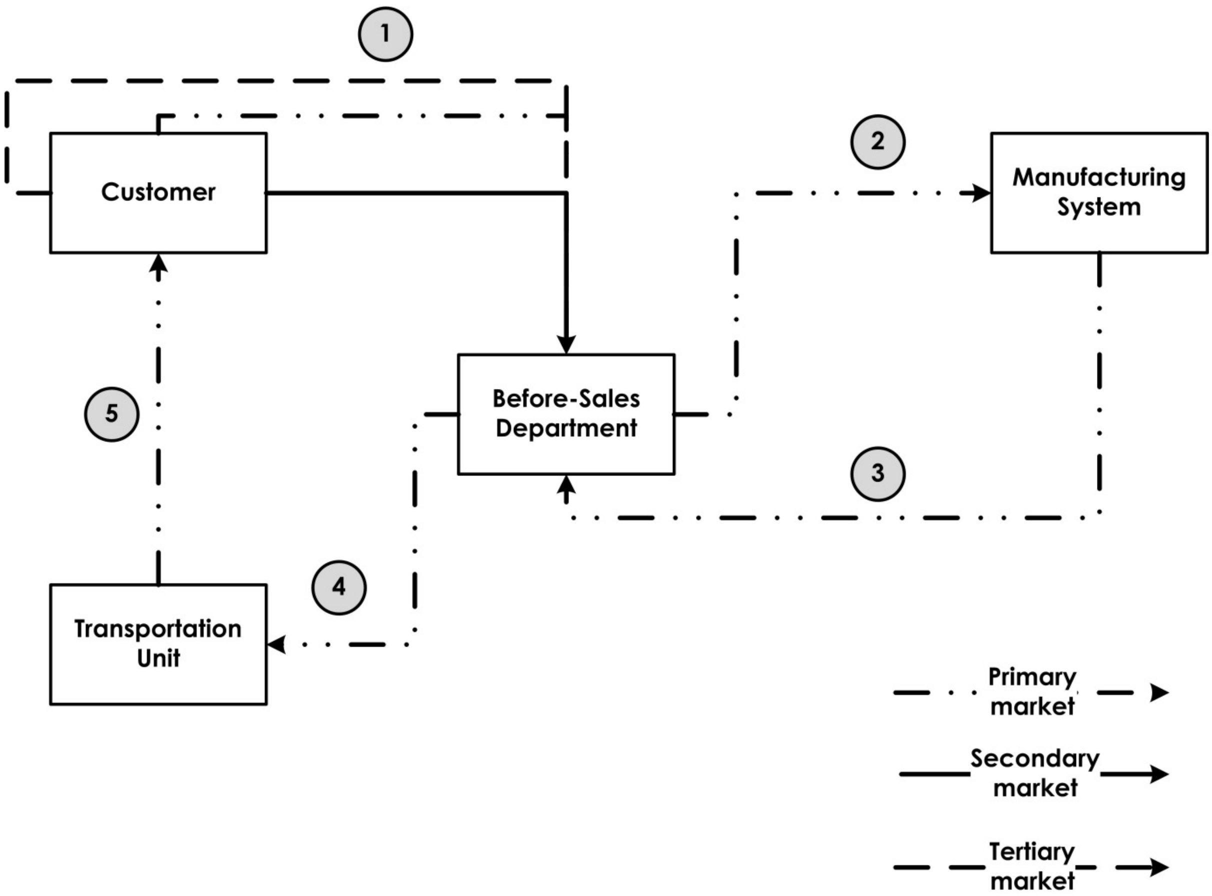

Figure 5.6 Before-Sales Department integration elements

Table 5.3 provides a description of the main processes and information flows from the receipt of the customer order (flow 1) to the delivery of the product to the customer (flow 5).

Flow	Description of the main processes and information flows
1	Customer requests a quotation for their desired product including the technical details of the product, price of the product, contract terms and length, and payment terms to the Company B. The customer can select from the existing product range available or request a bespoke design their own electric vehicle. A discussion between the Before-Sales Department and customer may be held to detail all the specifications involved with the product purchased. The customers can also obtain a quote for an electric vehicle for an event hire and short-term hire. There are also second-hand electric vehicles available to the customers (tertiary market).
2	The Before-Sales Department will issue relevant documentation including all the specifications that have been agreed with the customer. When a customer places an order, the order will be given a code. Then, the Before-Sales Department will extract and validate all the relevant information and input defaults of the product into the system. The system will then directly email all relevant people about the new order that has been placed. Next, the system will generate technical requirements for the manufacturing system to build the order.
3	The manufacture department receives information of what needs to be built and when it needs to be built by in order to deliver to the customer on time from the Before-Sales Department. The manufacturing system has five main sections: design, build, paint, finished goods and quality inspection. Every vehicle will go through every section to become a complete product. Once the process of fabrication has completed, the product will be tested and inspected to ensure the vehicle meets the specification and safety requirements. Once the manufactured product is ready, the manufacturing system forwards the notifications to the Before-Sales Department. The Before-Sales Department will update the system and an invoice will be generated and sent to the customer.
4	The Before-Sales Department will request the transportation unit to deliver the product to the customer. The transportation unit will then generate scheduling not only to deliver the product but also service products for other customers whose services are due within the next month in the delivery area. This planning for servicing simultaneously with the delivery of new product is possible due to sharing of information between the Before-Sales Department and After-Sales Care.
5	The Before-Sales Department will update the delivery date scheduled to the customer. The transportation unit will handle the delivery to the

	customer on the date given.

Table 5.3 Operation process in Before-Sales Department

5.5.2.2 The After-Sales Care operations

After-Sales Care is a planned or as required support system for service and maintenance of the product purchased by the customer including additional user training to operate the product. The elements of the process, After-Sales Care, are presented in Figure 5.7. The After-Sales Care not only, covers the services for the primary market but also for the secondary market. For instance, planned service maintenance leads to optimisation of vehicle performance that in turn can reduce the vehicle breakdown rates. The support given to every customer is dependent on the individual contract detailed and signed when the customer purchased the product with the Before-Sales Department such as duration of service, maintenance policy and warranty. Table 5.4 compares the function of every element and operation in After-Sales Care support system.

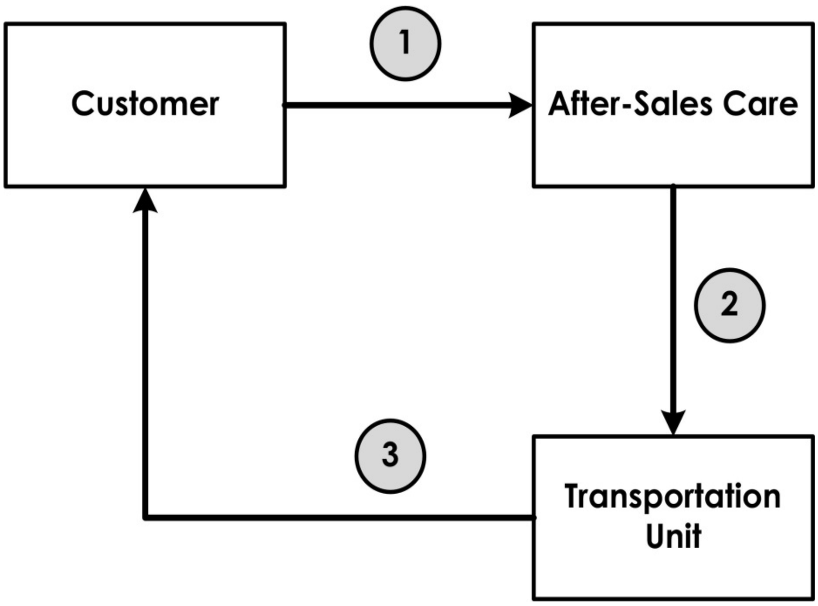

Figure 5.7 After-Sales Care integration process

Flow	Description of the elements
1	The customers call Company B to receive help because the vehicle is not working. After-Sales Care will identify potential causes and equipment involved in the breakdown according to the scenarios explained by the customer.
2	After-Sales Care will update the system and generate the components needed to remedy the breakdown. It also will identify other customers near the breakdown customer location to visit for the service and maintenance. During the period of contract, Company B will visit the site at no cost in order to repair or replace any component and remedy any fault of the vehicle.
3	The transportation unit will prepare all the components and tools to respond to the customer breakdown and other planned scheduling service and maintenance in the area. Repair work authorised by Company B will be carried out during working days and within 24 hours after receiving the customer's call.

Table 5.4 After-Sales Care support system

5.5.3 Manufacture

Company B provides two forms of manufacture, the production of new vehicles and remanufacture of old vehicles at the end of their lives.

5.5.3.1 New vehicle production

Manufacture of a vehicle by Company B involves several sections to produce finished goods as illustrated in Figure 5.8. Company B's manufacturing system has five main sections: design, build, paint, finished product and quality inspection. The company will build an order to meet customer requirements. About 99 percent of vehicles ordered are bespoke by customers with differences such as the colour and width of the vehicle. Every vehicle comprises about 100 components. The lead-time from a customer order will be 4 to 6 weeks for standard vehicles and up to 8-10 weeks for bigger vehicles. Meanwhile, the time taken to build a vehicle will be 1 to 2 weeks on average.

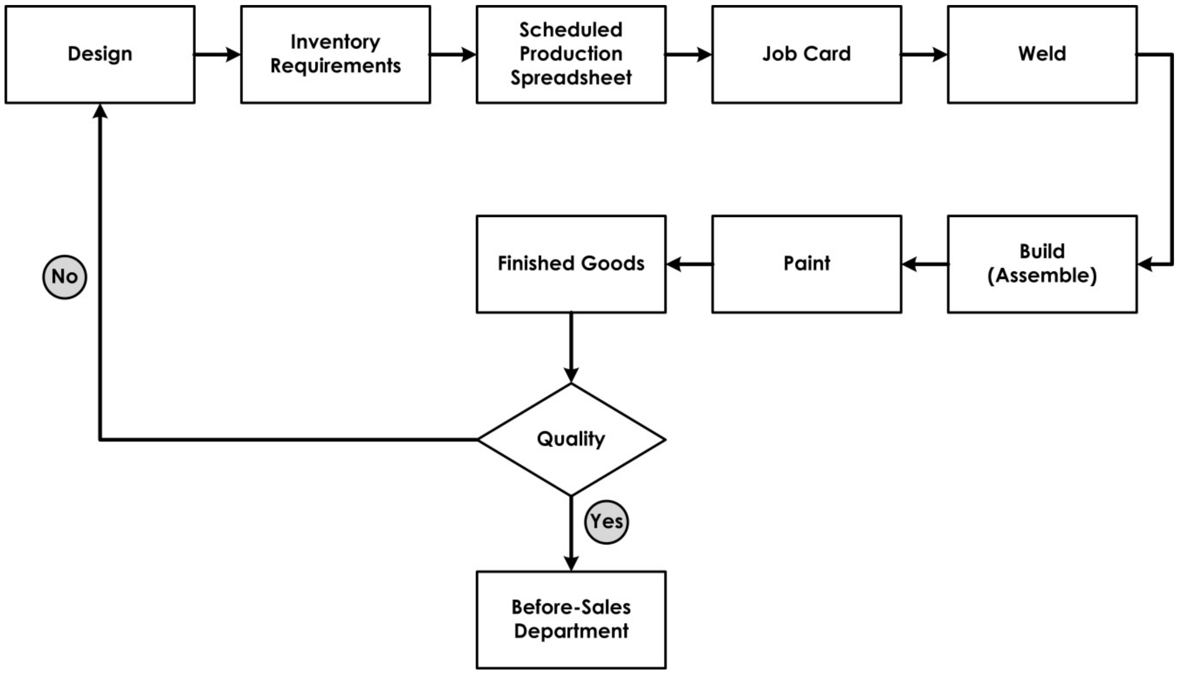

Figure 5.8 Production flow

The design team will create the bespoke design or update a design of the vehicle with all the requirements and specifications as given by the Before-Sales Department. There are many aspects to consider in designing the electric vehicle such as the outside and inside shape of the vehicle, colour, material used and interior layout. The design team not only need to create a design that will function effectively according to the customer requirements but also meet the stringent health and safety regulations, maintaining performance and braking requirements. After approval of the technical design, the team will generate the bill of the material (BOM) which is needed to fabricate the vehicle. A BOM is a detailed list of materials, parts and the quantities needed to manufacture a product including the child parts such as screws and nuts. Then, the inventory requirements are established from the list of parts in the BOM. The inventory system will identify the stock availability and level, and determine which parts need to be ordered.

Scheduled production spreadsheets will be used to allocate the time needed for each labour section. A scheduled production spreadsheet is used to distribute the task planning to not only provide information on when to produce and how long it will take to produce but also information on quantity of the product, equipment requirements and operator requirements. Next, a job card for every task in the production process flow to fabricate the vehicle will be published. The job card provides the procedures for completing a job and production methods from one process to another process in the production line for instance the parts used and time taken to perform the work.

The labour in Company B's manufacturing system is divided into welding, build and paint. Welding is a process to join parts together at specific point. After parts go through the welding process, the welded parts and other components will all be passed along the production line to be assembled. Lastly, the assembled parts will then move to paint. Before painting, the assembled parts need to be cleaned to remove dirt and oil. A traffic lights system is used in production to flag the status of the product and problems in the production line; a red signal indicates the production line cannot go ahead, orange means the production can go ahead however, the production cannot finish and a green signal suggests positive production line. If there is an error in the production line for instance a red light flashing, the assembly line will be stopped and the parts will not be sent to the next process until the problem is fixed. Once the process fabrication is completed quality inspection will be run to ensure the vehicle meets the specification and safety requirements.

The finished goods inspection will be conducted to ensure the vehicle standards and functions are met. Should there be any error or malfunction of vehicle the quality section will refer back to the design team, otherwise the production will close the job and inform the Before-Sales Department team that the vehicle is ready to be delivered to the customer. The check sheet of the inspection will go to the Before-Sales Department.

5.5.3.2 Remanufacturing

Company B collects its vehicle back at the end of the vehicle's life (or end of lease) if it is still working and the customer does not want to keep it anymore; it will then be fully serviced and repaired or parts replaced to restore it to an "as new" condition. It will then sell it to the European market or keep it for event hire or short-term hire. This is a process in manufacturing that is called remanufacturing. Remanufacturing is a process that reassembles and refurbishes a product that has been used. This will enable the product to perform at its original level of functionality and be resold into Company B's tertiary market. On arrival of the vehicle, an initial inspection is made to identify the quality and usability of the vehicle, parts that need to be repaired and/or replaced, cosmetic value of the vehicle and parts to be cleaned. Normally, the majority of the parts are found to be working. The diagnosis information from the inspection is then used to create the scheduled production spreadsheets for the remanufacturing process. The remanufacturing process goes through the same cycle as Company B's manufacturing process. At the end of the cycle, the remanufactured products will be performance tested to ensure the quality and safety of the vehicle meets the specifications. In general, the remanufacturing process of the electric vehicle can be divided into several stages, which are:

1) inspecting and diagnosing the condition of the vehicle system
2) disassembly of the electric vehicle
3) cleaning of all components
4) sorting and inspecting of all components
5) reconditioning of components or replenishment by new components
6) product reassembly
7) quality check of the vehicle

The electric vehicle consists of mechanical and electronic components. Mostly the mechanical components are made-up from metals and rubbers. In contrast, the electronic components are made-up of a plastic or metal casing housing with delicate and complex circuits. The heart of the electric vehicle is the black box that is the electronic control unit of the vehicle. Therefore, the process and tool of inspection and diagnosis of the components are different. For instance, the mechanical components after having been used for a certain period will get worn or crack. So during the inspection the mechanical components will only be used in the remanufacturing process if they are in top-notch condition. Meanwhile, the electronic components need to be safe, reliable and continue to work properly without any intervention in order to be used in remanufacturing.

5.5.4 Services provided

The performance of a vehicle is dependent on the usage by the customer and the working environment. Company B provides three types of service; scheduled maintenance, breakdown and training as shown in Figure 5.9. It has mobile service engineers who are fully trained; seven external engineers for the industrial vehicle; and a dedicated engineer for the golf vehicle. Service mobility means that installation, maintenance and repair are done at the customer's premises. According to its record, 90% of calls are attended within 24 hours of receiving a call however; in 2014, the figure fell to 87%.

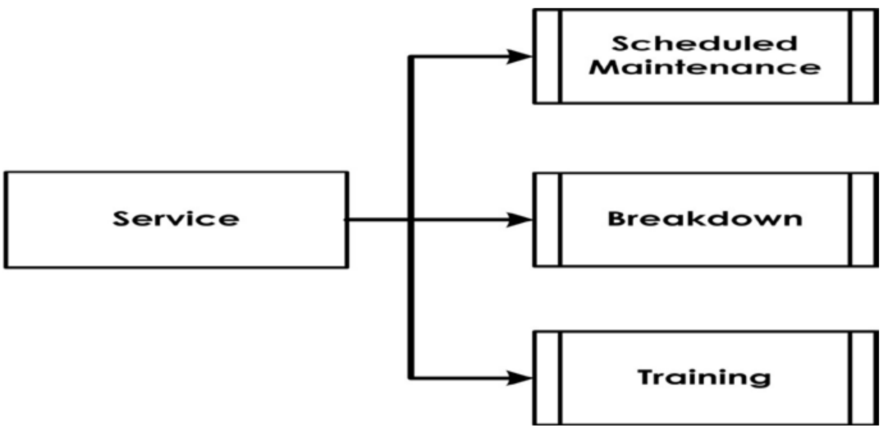

Figure 5.9 Services offered by Company B

For every vehicle purchased by a customer a service package is included. The service package included with the vehicle is dependent on the type of vehicle purchased and additional requirements needed by the customer. For the standard service, Company B provides a scheduled maintenance 4 times a year for a period of 4 to 5 years, which covers all aspects of a vehicle's running requirements. Notifications are given to the customer for every scheduled service. Company B will perform the service maintenance once every quarter of the year; it is not necessary for the vehicle to be serviced exactly on a certain date. Actual service dates are agreed with the customers within a month of the service due date.

Vehicle breakdown is an uncertainty condition that can occur anytime and affect the operation of the customer's business. Company B provides 24 hour rapid response services during working days to keep the vehicle running. However, this does not include weekends so for instance, if Company B receives a report of a breakdown on Friday night it will do the repair of the vehicle on Monday. When it receives a call from the customer about the breakdown, it will diagnose the possible causes and the components needed to repair the breakdown. Normally, when the customer calls, they cannot specify the main causes or components affected by the breakdown; they just provide some indication of the breakdown to Company B. Through the expertise and experience of Company B's service engineers, the faults are approximately diagnosed and they will load the components in the service truck that might be needed to repair the vehicle.

Company B offers comprehensive vehicle training for all of its electric vehicles or related products such as operator training and engineer training. It will tailor the training for the specific type of vehicle to be used with emphasis upon health and safety matters. The training programme conducted is based on Health and Safety Executive (HSE) guidelines. When a vehicle is delivered to a customer, it will provide familiarisation training on how to operate the vehicle safely, but further training is often also needed. HSE suggest that all operators of powered plant equipment and vehicle are to be trained on a regular basis. The regularity varies according to the type of vehicle and working environment where it is used.

5.5.5 Inventory

Company B holds inventory of many components and the inventory is sorted by the type of components not by the quantity components needed for a vehicle. It commonly has about £800k internal inventory. Every vehicle has about 100 components. It sells approximately 300 units of electric vehicles a year. Inventory in its system is not only used for production but most also be used for the service, spare parts and remanufacture. It does not keep any expensive and high technology components in its inventory such motors and these are bought in as requested for individual products. Normal stock items will be purchased when the number of components in inventory reaches the minimum level or when components that it does not store in the system are needed. It normally sets the maximum and minimum inventory levels depending of the type, price and supplier warranty of the components to make sure the life package inventory meets its aim. As Company B provides service and maintenance mobility, it needs to keep some inventory of vehicle components and tools in its trucks. Most inventories are kept in a central store. However, some items are kept permanently in trucks to provide service and maintenance on customer sites.

The storage of inventory in Company B keeps all the components for the fabrication, service, spare parts and remanufacture of the vehicles. The Before-Sales Department controls the inventory for both sales and remanufactured vehicles. The After-Sales Care controls the inventory of service and spare parts although there are some exceptions that are dealt with on a case-by-case basis. The inventory-processing interface for both departments is different however; the source and information provided about inventory for both systems are the same. Parts of the system are automated using a stock control software package, while the remaining inventory is processed manually using Microsoft Excel. The integration process between the Before-Sales Department and After-Sales Care is also through an automated process. Certain components such as bolts and nuts use a bar code system to control the inventory. Moving stock from the raw material store to other production sections is run manually. Figure 5.10 provides the overview of its inventory system.

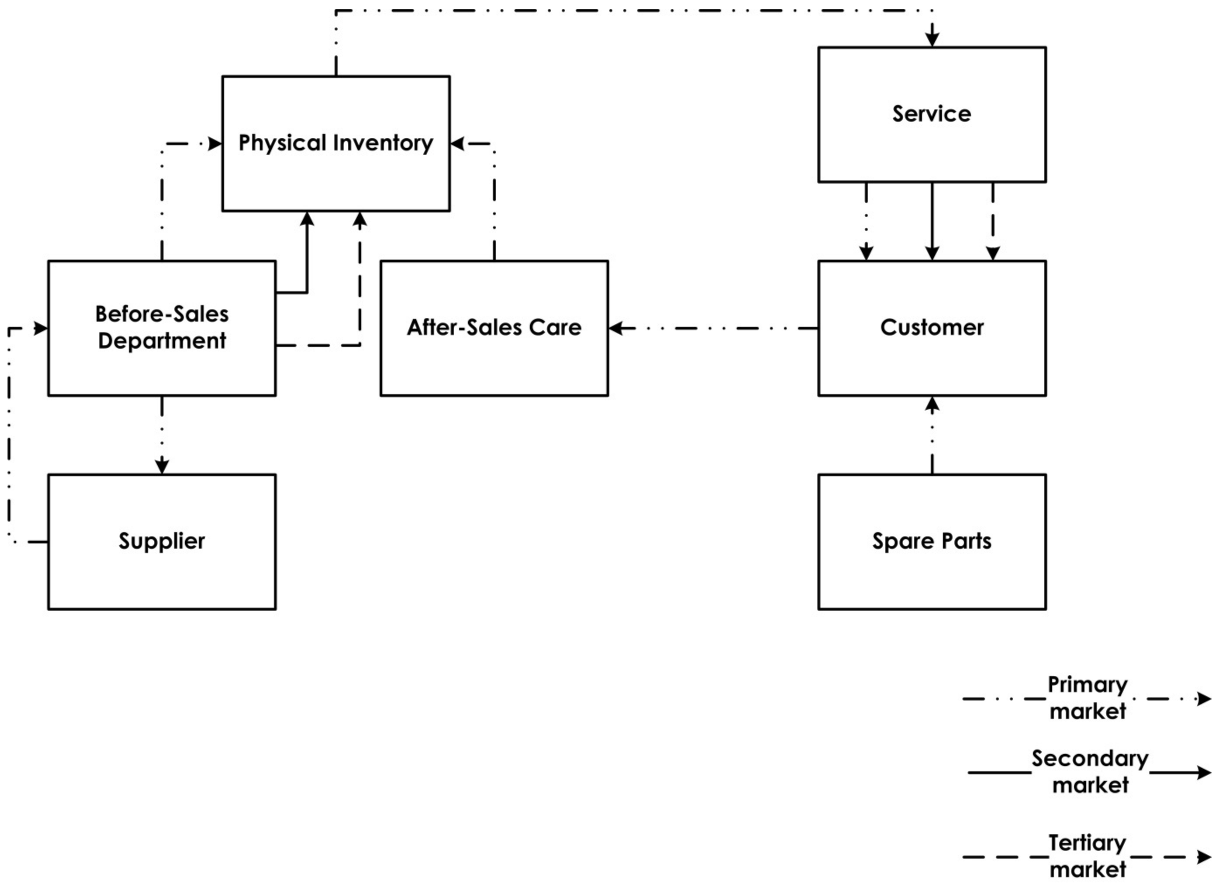

Figure 5.10 Inventory system of Company B

5.5.6 Summary of issues and challenges

There is increasing concern that some of Company B operations are being disadvantaged:

- The integration support tools in half automated and half manual between Before-Sales Department and After-Sales Care have high potential issues on time integration and accuracy of information.

- Every component of inventory has physical cost associated with it. The vehicle consists of different types of components such as black-box and electronic components with rapid changes in versions of technology, which are expensive. Therefore, it is challenging to maintain an optimal level of inventory at the same time as keeping the cost of inventory to the minimum and avoiding obsolescence.

- Storage of obsolete spare inventory is difficult and expensive and such items are disposed of where possible through EBay for example.

- The uncertainty in service mobility. Service mobility normally will be performed at the customer's premises. Normally Company B's trucks will store certain components and tools that are likely to be needed to perform service or maintenance. The costs of storing extra inventory items on truck are high but if the trucks do not have the relevant components the travel cost and service time are increased which also causes extra costs. Thus, duplication of inventory is necessary but expensive.

5.6 Case study three - Company C

5.6.1 Background

Company C is located in United Kingdom and was founded in 2012. It is a SME company with 15-20 employees. The main product of the company is a Wankel type rotary engine. It offers four Wankel type configurations of rotary engines and bespoke engine configurations based around their patented rotary engine technology. Its core business activities are design and development of innovative products and solutions for the automotive and aerospace sectors. Its primary goal is to produce power solutions that are simple, low cost and yet can deliver real 'game changing' capabilities for end users. The major market for the products and solutions are for the companies requiring high-power, low weight and compact power solutions for hybrid electric vehicles in the defence and civilian markets. It also offers product support and technical support to the customers with the products purchased. In addition, the company offer genuine spare parts selection used in its engines. Figure 5.11 illustrates the full range of Company C's product and service.

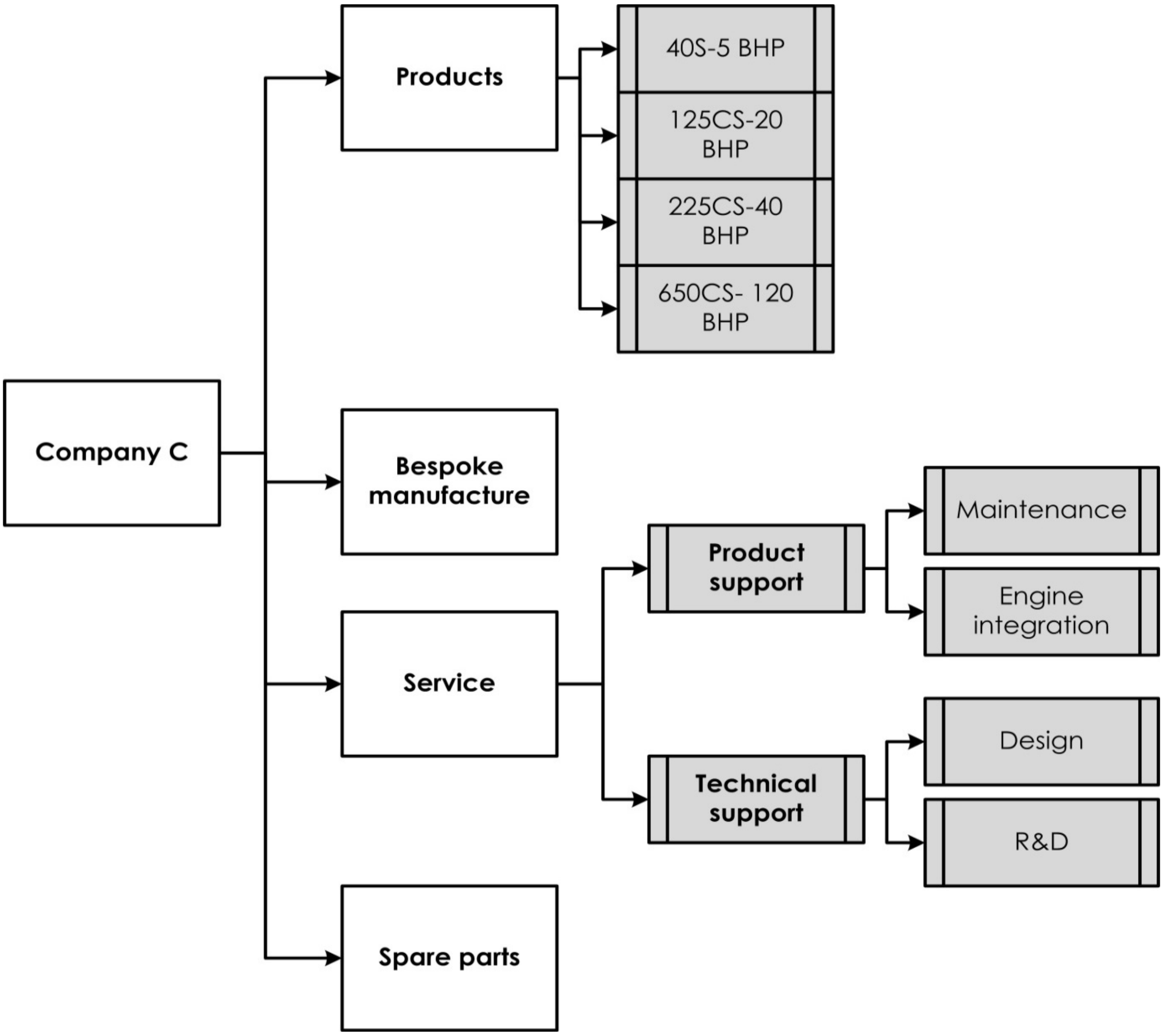

Figure 5.11 Company C's product and service selection

Company C's core business can be divided into three main markets:

Primary market:	Selling standard engines with an optional service package
Secondary market:	Designing and manufacturing a bespoke engine
Tertiary market:	Providing a kit to service (spare parts)

Figure 5.12 provides an overview of Company C's core business.

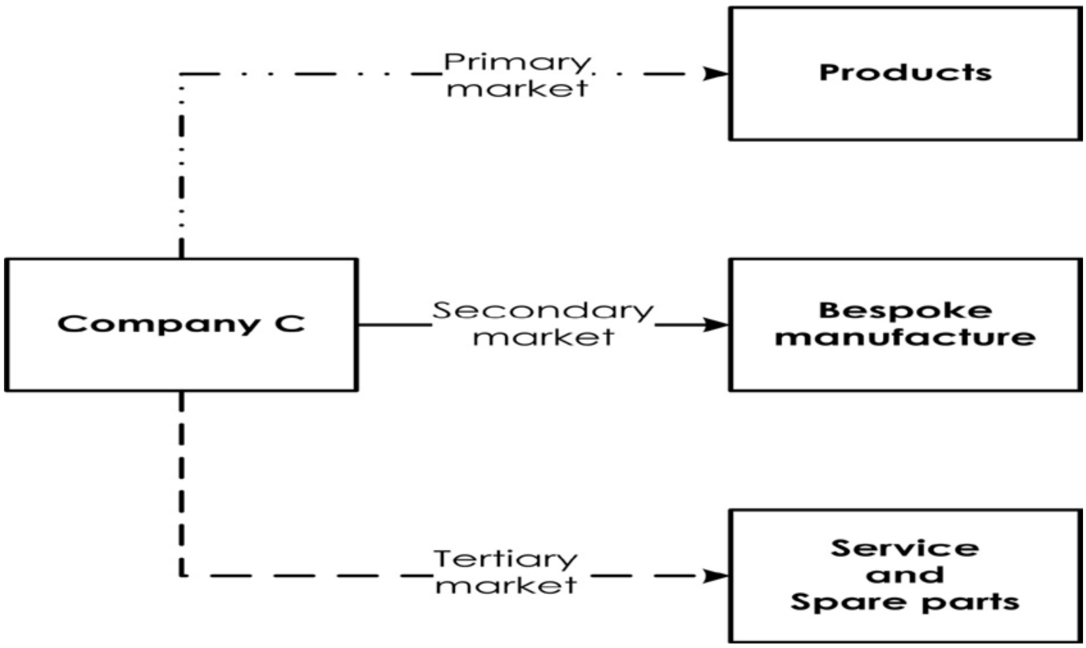

Figure 5.12 Company C's core business elements

In the primary market, the customers have an option to select from the four types of engines configuration for instance, 125CS-20BHP. The 125CS-20BHP engine indicates that the engine displacement is 125, CS is an abbreviation for Carburetted/California Emissions Controlled, and 20BHP is the power output of the engine (BHP is Brake House Power). A service package that includes the warranty is an optional extra offered to the customer. The customer can customise their own service elements needed. There is no service mobility offered to the customer and all services are performed at the Company C's premises.

The secondary market of Company C is a bespoke engine which can be designed and manufactured to suit the customer's requirements. In this market, the customer establishes their engine requirements and configurations. The dedicated design team in Company C will then develop the design and, depending on the complexity of the engine requirements and configurations, the research and development (R&D) will be required.

The tertiary and final market is supplying comprehensive genuine spare parts throughout the engine life cycle. The spare parts that it provides are called a "kit to service." All of the spare parts have passed through experienced quality inspection in order to make sure that they comply with the required configuration.

5.6.2 ICT support system

The Company C ICT support systems are Product Data Management (PDM) and Enterprise Resource Planning (ERP). In general, its ICT support is able to capture, monitor and manage information; for instance, work order, bill of materials and inventory tracking. In addition, the ICT support system determines how the planning and control system works for ordering, manufacturing, receiving and delivering products. However, PDM and ERP have been developed as separated systems, and have different functions in the operation and are used by different departments. The design team of the company uses PDM to manage the product data and related process information. Meanwhile, ERP is used to manage the operational functions of the company such as planning, human resources, inventory management, supply chain, financial and customer information. PDM and ERP can be integrated to coordinate different functions in the operation such as engineering, manufacturing and purchasing. When the requirements of the product are established, it will integrate the information from the PDM to ERP, for instance job priorities and materials allocation. The ICT support care has a relatively standard pattern for how it works and flexibility in allying to work in slightly different ways between the customers.

5.6.2.1 Product Data Management (PDM)

Product Data Management (PDM) is an engineering support system for managing the entire life cycle of the product to ensure effective engineering data management, and configuration for the process enablement and product history of the engines. PDM works as a master repository for the engines in Company C by coordinating and controlling the access of documented versions of both products designs and task management tools. PDM controls the input and output of the product data to multiple personnel in the company, generates and manipulates the product structure into a bill of material (BOM) for assembly process. A product design process involves complex tasks to accommodate both different engineering disciplines from functional and non-functional factors. The design team in Company C interconnect the functional and non-functional factors in managing and tracking their engine design configuration from new creation to any updates of the design related to the engines. The detail of product structure and information that is being stored and managed will include data such as engine model, drawings, BOM, task lists, documents and materials. PDM assists the integration with ERP and data exchange among all personnel in the company who interact with the products, such as designers, project managers and operations engineers.

5.6.2.2 Enterprise Resource Planning (ERP)

Enterprise Resource Planning (ERP) consolidates all the departments in Company C into a single system that services each department's specific needs. Company C used commercial ERP to provide the real time operational data of their product and service to support decision-making. The ERP system provides the operational data from the integration of various processes starting from the customer order request to final product to delivery. The software is classified into the following modules that operate different types of functions on the data:

- Sales
- Purchase
- Inventory
- Production planning
- Finance and accounts
- Contracts

- Logistics

For instance, in the sales modules function there are the following elements; order entry and tracing, invoicing, lead tracking, customer information, quote processing and pricing. Meanwhile, the production-planning module consists of elements for optimising manufacturing capacity, material and components resources.

5.6.3 Design and manufacture

Company C's engines range from two to twenty kilograms, all integrating the self-pressurized-air rotor cooling system (SPARCS). Its engines are very compact, lightweight, powerful, low variation and efficient. Its main products are developed on a technology based on the Wankel type rotary engine, which was an invention from Germany back in the 1950s.

Generally, the operation in Company C can be divided into three areas which are design, build and test, and delivery. The operational processes relate to both the primary market and secondary markets of Company C. In the primary market, the customers purchase the engine from the four types of existing engine configurations that are available in the Company C, whereas in the secondary market the engine can be bespoke and manufactured according to the customer's requirements and configurations. Design processes and R&D in manufacture of the engine are involved only for the secondary market. However, the processes involved in the build and test, and delivery for both markets are the same. The operation flow of Company C is presented in Figure 5.13.

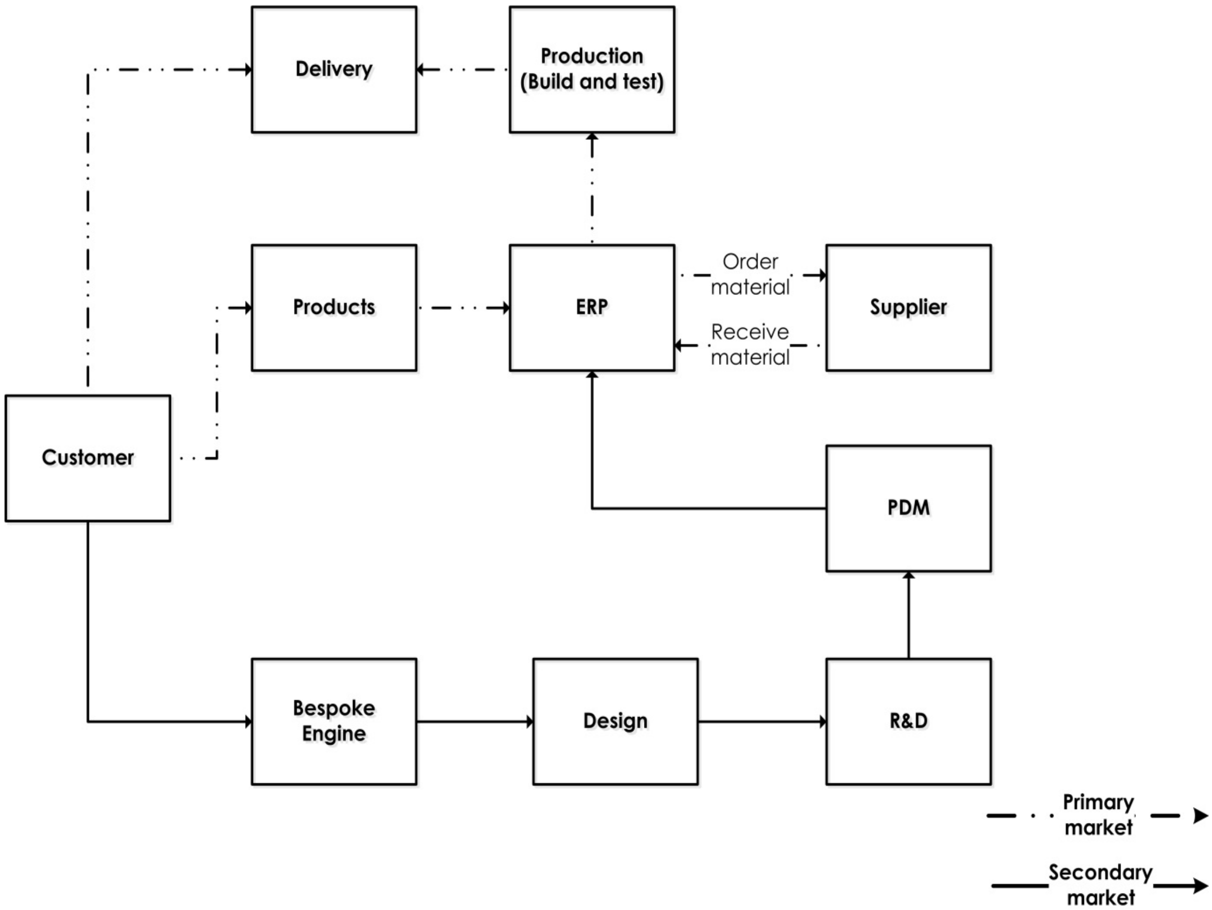

Figure 5.13 Company C's operation overview

Table 5.5 provides a description of the main processes and information flows from the main operation in the Company C.

Operation	Descriptions
Design	▪ Design of the engine is served as a contract. The customer establishes their engine requirements and configurations. The design team will manage and track the requested engine design as a project with related engineering data such as models, drawings and other associated documents in PDM. ▪ Company C stores data on the development of all of their products so when designing they refer to this information to help them in refinement of ideas to processes. ▪ Designing an engine needs very technical knowledge and skills in engine core technologies to ensure the engine works effectively and safely. Depending on the complexity of the integrated engine's configuration, a

	research and development (R&D) team will be required. ▪ Once the design of the engine has been approved, the next stage will be the production. If the customer rejects the design they need to provide the feedback to Company C.
Build and test	▪ Normally, the customer requests a quotation through an email. Then, Company C identifies the customer requirements and creates the quotation. The quotation is stored in the ERP system so when the purchase orders (PO) comes in, they can load the PO on the system and pull through the quotation information from the sales order. ▪ Customers raise the PO in their own format. If there are any modifications at this stage, Company C obviously has the option in their sales order module to make those modifications. For instance, if the customer wants to modify the summary items on the quotation. ▪ The sales order will be loaded on the system. The sales order is attached to a part number which is the same number as in the quotation. The sales order will be activated; the part number is then broken down to produce the associated material requirements. All associated information and material needed to assemble the product are listed after the PO is approved and finalized. ▪ Assembly information, bill of material (BOM) and lead-time information will then be updated in the system. ▪ Company C does not fabricate any of the components in the engines. An engine consists of a multitude of components with various different materials from different suppliers. The production team will then update the required parts for the order and begin the component parts procurement. Company C manually decides the parts that need to be ordered. Some of the components will need to be ordered from suppliers. They will then communicate with the suppliers and select the source of optimal pricing and availability. ▪ If the parts ordered are from regular suppliers, PO will be automatically raised for the suppliers. However, for suppliers that Company C does not normally work with, they will raise an invitation to tender (ITT). They schedule the integration of jobs and sub-jobs to complete the order by applying a Master Production

	Schedule (MPS) system. Once they receive the material from the supplier, the system updates a stock record so the system knows the quantity of material available. All the material received will go through a quality inspection; materials must have correct dimension. If the material passes the quality inspection, the material is going to become stock and will be available to use for the production. If not the materials obviously will be rejected. The requirement will be created back in material requirements planning (MRP), which becomes lost material and needs to have a replacement. When all the materials needed are available, a work order will be created. The work order is then attached to the PO and MRP will be updated so that the ordered engine can be built. Then all the materials to build an engine is allocated by issue of the material based on the works order. ▪ They can integrate the engines to the vehicles by themselves or purchase a service provided by the company. ▪ Once all the components are available to build the engine the production team will create the works order. They will then assemble all the parts and when the engine is completed, testing is conducted to ensure the engine performance is in the running order. ▪ After the engine is built, tested and completed, the works order will be shut down and a stock record for finished engines are created. The engine is then ready for shipment. In sales order modules they have a dispatch area which creates delivery notes and these are attached to the engine for stock and delivery paper work. The product is ready to pay for. The contract module creates a stage payments system associated with the sales order.
Delivery	▪ Company C does not offer any delivery of their products to the customer. Therefore, the customer is responsible for all the costs associated with the shipping and handling of the engine from the Company C to their premises. ▪ The customer can use their vehicle or the third party logistics company for transportation mode. ▪ The customer will arrange the transportation mode to collect the engine from the Company C.

	▪ If there are problems with the product, Company C will perform a test to identify whether the fault is from their manufacturing or the operational issues caused by the customer.

Table 5.5 Company C operation in details

5.6.4 Services provided

Company C supplies a kit to service which is a genuine spare part. The spare parts are essential in ensuring proper operation of the engine. The need for a kit to service can be ascertained during the inspection or any time by monitoring.

All the engines are rated in hours per year. Typical standard engines will last about 1000 hours depending on the environment and usage, for instance where the engines has been used and how hard they being used. Therefore, 1000 hours for a customer may last 3 years and for another customer, it can last just 4 months. The customers can customise their own service elements according to their needs to support their engine. The price of the service package varies depending on the customer requirements. They offer two types of service, which are product support and technical support. Product support covers the maintenance and integration of the engine in the customer's vehicle. The maintenance needed by the customer is established when the customer makes an order for the product such as disassembly, cleaning and inspection of engine parts.

The customer can integrate the engines by using the experts from the Company C or they can do these themselves. Technical support serves to ensure that Company C is capable to meet their customer's operational requirements and constraints. The customer can have a specific configuration of the engine to deliver exact performance criteria to meet their operational requirements achieved through design and R&D performed by Company C. It has been demonstrated that the more sophisticated customers normally service their own engines. Meanwhile, the less sophisticated ones usually return the engine for service by Company C. Normally, the commercial customers are more concerned with the warranty. Company C does not offer any service mobility to their customers.

The service elements and spare parts in Company C are summarised in Figure 5.14.

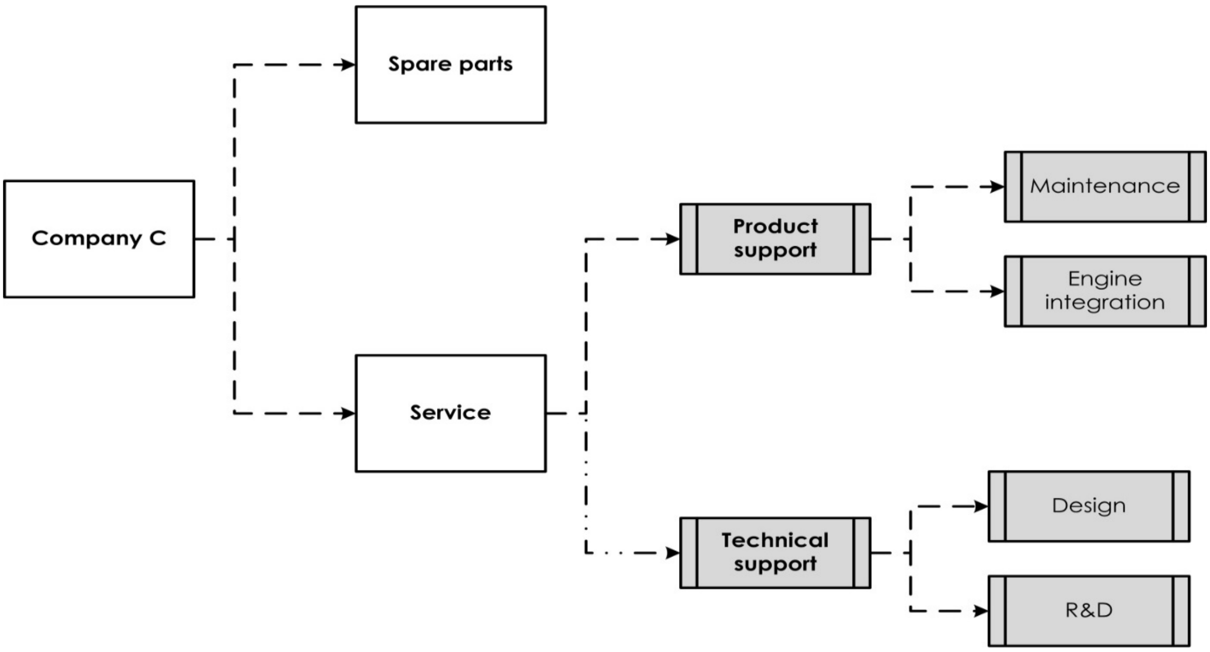

Figure 5.14 Company C's spare part and service elements

5.6.5 Inventory

Company C always ensures that their inventory level is at the minimum quantity. It has two types of inventory, engines and components. The inventory of kit to service that has been offered is classified under components inventory. 99 percent of the material supplies the company obtains are from the UK; material stocks have different module target quantities, reorder points and records levels. The company facilitate the processes of maintaining the appropriate inventory levels through the inventory module in their ERP. It has the same inventory module interface and storage for the production, spare parts and services elements. The inventory modules are able to identify the inventory requirements, monitor item usages, reconcile inventory balances and report inventory status.

5.6.6 Summary of issues and challenges

Company C appears not to have any issues in their inventory systems. However, if the system can work faster and easier in tracking the inventory it would be more advantageous. It customer requirements are not of the standard configuration from their product list and this will relate to engine function, weight and reliability improvement. The demand and developments for these engines continues to push Company C to go beyond its knowledge and skills in its engine configuration.

5.7 Case study four - Company D

5.7.1 Background

Company D is an upstream oil and gas company which is based in Malaysia and was incorporated in 2007. Their core business activity is exploration, development and production of natural gas resources in Malaysia. An upstream company provides facilities and processes for the oil and gas industry that enable the production and stabilisation of production from the wellhead manifolds in the form of crude oil, condensates or gas. Therefore, their products are crude oil, condensates and gas. Company D conduct their business and share their platforms with their shareholders and they only have one customer which is also one of their shareholders. They do not provide any services to their customer or shareholders. However, they perform most of their equipment maintenance service and inspection by themselves. Figure 5.15 shows the products and services offered by Company D.

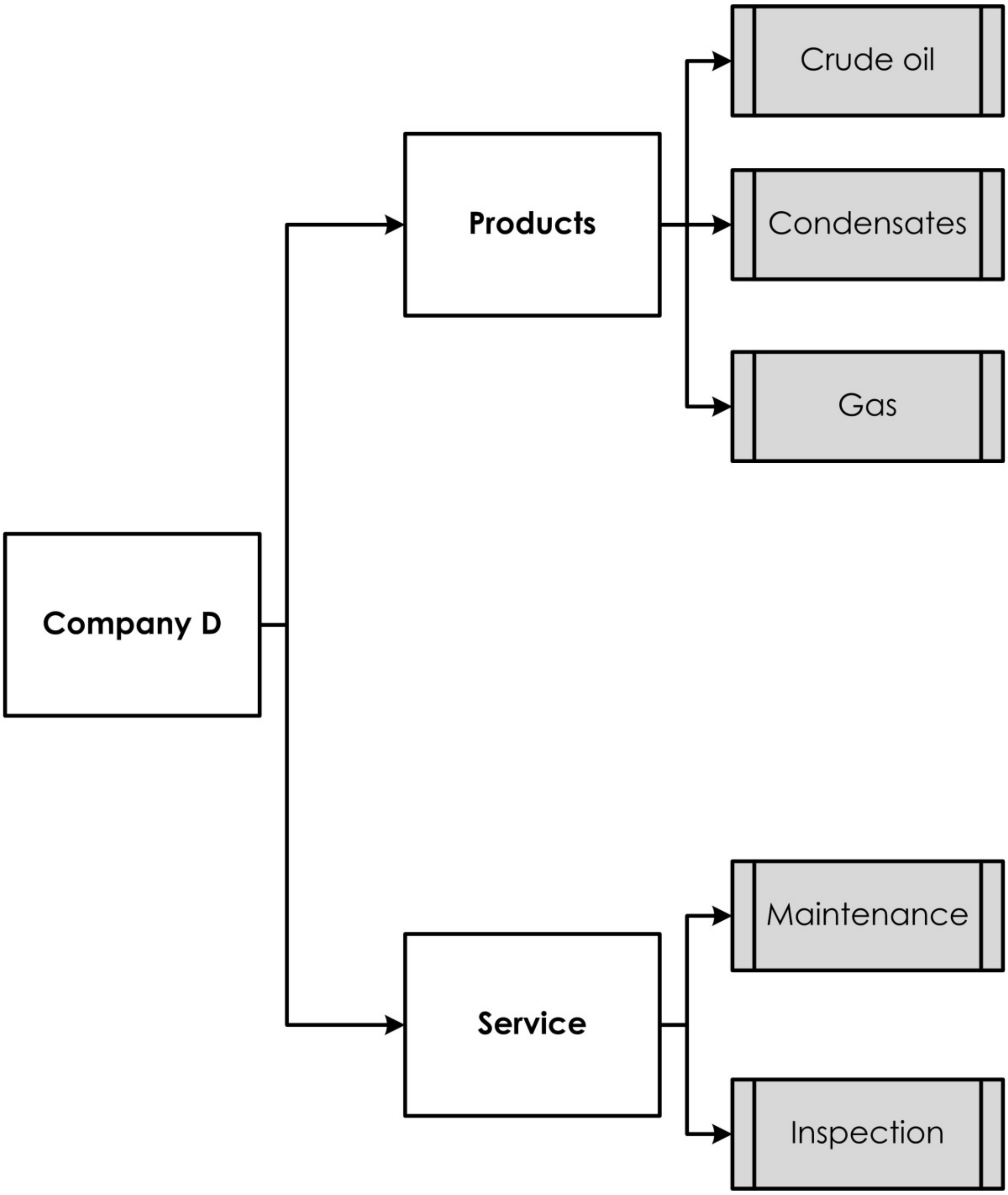

Figure 5.15 Company D's products and services

Company D's core business can be classified into two main markets:

Primary market: Exploration, development and production of crude oil, condensates and gas.

Secondary market: Maintenance and inspection of their instrumentation.

Figure 5.16 provides an overview of Company D's business operation.

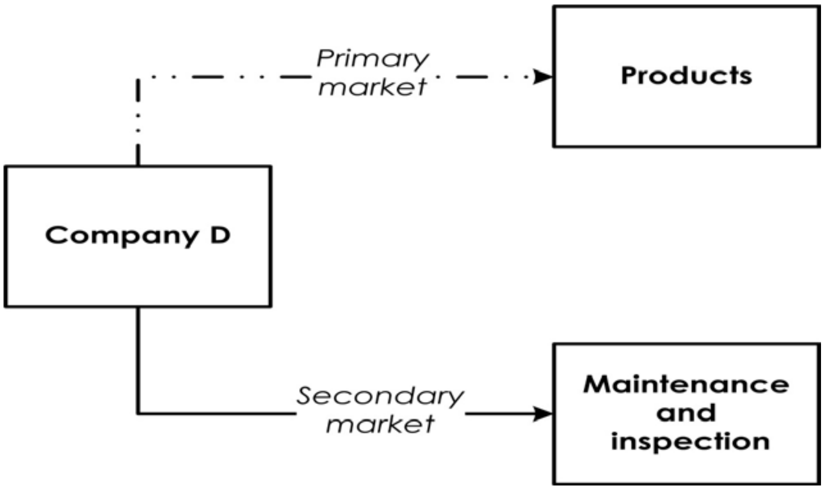

Figure 5.16 Company D's core business elements

Company D's primary business is providing facilities for exploration, development and production of oil and natural gas. The exploration and development activities involve identifying the location of hydrocarbon using sophisticated geological equipment. Meanwhile, the production activity focuses on stabilisation of crude oils and gas using their production facilities such as:

- Onshore well
- Offshore, fixed, multi platforms
- Offshore, fixed, self-contained platforms
- Offshore, self-contained, concrete gravity platforms
- Offshore, floating, single-point mooring
- Storage/Shuttle tanker
- Offshore, floating, tension leg platforms
- Subsea manifolds

It shares some of it facilities, such as platforms to perform certain activities in exploration and development, with its shareholders. However, it also has its own facilities, such as pipelines to transport product from the platform to the plant. Its shareholders have different proportions of shares in the company. Its only customer is also the biggest shareholder for their company.

The secondary market of Company D's business is for the maintenance and inspection of their instrumentation. This requires a combination of technical and managerial actions to ensure the safety, reliability and integrity of their operations and facilities. They have a preventive maintenance system which means planned maintenance, planned inspection and planned repair systems are used in this secondary market. Their preventive maintenance system has not only increased the safety, reliability and integrity of their instrumentation but has also reduced the unplanned breakdowns of the instrumentation.

5.7.2 ICT support system

As the upstream oil and gas platform involves many processes with different ICT support systems, this case study will discuss only ICT support systems involved in the production to delivery of products in Company D. Company D uses a Distributed Control System (DCS) and SAP (Systems, Applications and Products in Data Processing) in their production and delivery of products. The DCS and SAP are two separate systems and not only have different functions in Company D's ICT support systems, but also require different interface and technical knowledge to operate the systems. However, in general these ICT support systems aim to maintain the asset management, work management and performance management in Company D. For their production, Company D depends on real time instrumentation data that is sent into the DCS from offshore. While, for maintenance items or spares, they use the SAP system to catalogue all the spares and manage all the work orders and supply chain work processes.

5.7.2.1 *The Distributed Control System (DCS)*

The Distributed Control System is a combination of hardware and software that is used to control production activities and resources, as well as to monitor and report on work execution for the production processes. The DCS in Company D uses a custom-designed processor as a process controller. In addition, a server and application processor is included for computational, data collection and reporting capability. Company D have many input/output devices (I/O) and employ a very large DCS system. The (I/O) devices are used as signals to transmit the flow measurements to the controller. The elements of a DCS are connected to sensors and actuators of the physical instrumentations for instance the pumps and valves. The DCS elements are:

- Network
- Connectivity
- Visualisation
- Platform
- Application tools
- Digital busses
- Controller and I/O
- Security

A control room operator with a considerable technical knowledge and skill is required to deploy the DCS system and manage the inventory by using the control panel. This system is boosted by supplier support that includes training and maintenance supports.

5.7.2.2 *The Systems, Applications and Products in Data Processing (SAP)*

The Systems, Applications and Products in Data Processing (SAP) is Enterprise Resource Planning (ERP) software that is used for operations performance management for the upstream. The main function of SAP for Company D is to provide correct and accurate information in capturing, storing, managing, presenting and making operational decisions and for production planning and also to enable appropriate reporting. In addition, the SAP has the capability to reduce the overhead of maintaining multiple products and providing the required information. SAP is not only used for production planning but also the planning for the maintenance, specific changes in the network and production impact. The SAP has the following elements to help in prompt decision-making:

- Field data capture
- Production planning
- Analytic and reporting
- Maintenance
- Production allocation
- Accounting
- What if planning scenarios

The interface of the SAP in Company D is not very complicated as they only have 1 customer and 3 products. This system is augmented by supplier support that includes the training and maintenance support.

5.7.3 Manufacture

The upstream can be sub-divided into searching, evaluating and identifying the potential oil sites, drilling exploratory wells and operating the wells to extract the crude oils. The shareholders of the Company D focus on the exploration and drilling activities. Meanwhile, Company D core focus is on the recovering and producing the crude oil and natural gas from underground fields and includes the offshore and onshore activities. Company D have their own pipelines, associated pumping, compression facilities, and supporting instrumentations necessary to perform their production activities. The pipelines are connected to high-pressure compressors to distribute gas flow, water flow and oil flow in three different phases of separation. They use the same pipeline to transport their 3 different products. They normally ensure that their products meet their specifications before delivery to their customer, by lab tests that are performed offshore.

5.7.4 Services provided

The services provided by Company D mainly relate to the maintenance equipment in their plant. They do not provide any external services to their customer. They perform most of the instrumentations maintenance and inspection however, for the sophisticated and complex instrumentation the maintenance and inspection are performed by the suppliers. The maintenance of the instrumentations specifications are based on the Original Equipment Manufacturer (OEM) guidelines, international standard and code, and experiences of the workers and the shareholders. The multiple factors that cause the product not to meet the specifications are:

- Crude composition changes from the well depending on the unknown time
- Operating parameters changes due to the equipment health status
- Planned maintenance
- Planned inspection
- Corrective maintenance
- Personnel error when controlling production
- Personnel error when executing maintenance
- Production specification

5.7.5 Inventory

The inventory in Company D can be divided into three main areas; hydrocarbon volume to be exported, chemical inventory and spare parts. The hydrocarbon volume to be exported relies on metering and is connected to the DCS which can obtain the data online. Meanwhile chemical inventory as show by the tank level indicator is obtained by using the real instrumentation data and is connected to the DCS and again the data can be obtained online. Alternatively, the spare parts inventory is maintained by using SAP system. In the production, an offshore technician will revalidate the inventory of the product onsite based on the onsite gauge and the manual calculation will be carried out if required. They have a warehouse personnel and offshore crew to countercheck the stock in service. Besides that, they also depend on a 3rd party supplier to monitor the spares (outsource maintenance and inspection process). For instance, the product inventory is based on the instrumentation of gas metering, level indicator, flow meter and multi-face meter.

5.7.6 Summary of issues and challenges

Company D is increasingly improving their efficiency in logistics, planning, scheduling, communications, especially with their shareholders, contractors and suppliers, data management and risk analysis. Company D does have few issues in their inventory systems:

- In production, they may have to address facing instrumentation sensor faults to enable themselves to monitor the inventory efficiently and correctly.
- In services, they have issues relating to the identification of the suitable spares for the maintenance tasks.
- If the systems are not in place, manual work has to be carried out. This will cause loss of efficiency and time responses will reduce significantly. In addition, the accuracy of the data also will be impacted.

5.8 Chapter summary

This chapter has provided useful insights into the actual data collection and the preliminary analysis, as well as the contextual and associated information relating to PSS inventory control system. In this chapter each case study was presented as an individual entity. Having the necessary data from each case allowed the analysis processes chosen to be employed to achieve research results. Importantly, it has also provided contextual background information which enables more detailed discussion in the subsequent analysis chapters.

Chapter 6 is focused on the data analysis to examine the uncertainty factors from each of the case companies.

6. Data Analysis

This chapter identifies the uncertainty elements in PSS inventory from the case studies. The research data were categorised and clustered to understand the state of the art from the case study companies. Findings are presented as a matrix of the overall company operations in relation to a generic model development.

6.1 Introduction

The selection criteria for the case studies were:

- The company is a product manufacturer
- The company offered services with their products.

Representatives of four companies were interviewed in this case study research:

- Company A: Malaysian Original Equipment Manufacturer (OEM) in the automotive, electrical and electronics industry.
- Company B: A manufacturer of industrial electrical vehicles in the UK.
- Company C: A company that designs and develops Wankel type rotary engines in the UK.
- Company D: An upstream oil and gas company which is based in Malaysia. Its business activity is exploration, development and production of natural gas resources in Malaysia.

All the interviewees are managers who are experts, not only in managerial aspects of the company but also in every stage of the products and services offered. The interviews were conducted in two phases. In the first phase, the interviews were conducted by phone. During this phase, the interviews were carried out to obtain an overview of the company and also to help the interviewer to develop a set of interview questions for the next phase. All the information gathered in this phase was written down. The data obtained were organised and a set of interview questions for the second phase was developed. The second phase used semi structured interviews and these were conducted at the company premises. The questions were sent to the interviewees two weeks prior to the interviews.

6.2 First stage: categorization

The data collected in the interviews were organised and categorised into the following themes:

- Company background
- Product
- Market
- Service
- ICT support Inventory
- Manufacturing
- Delivery

The data was coded as in Appendix A. While some of the second stage data may be a repeat of data collected previously in first stage, these were also used in the categorisation process to ensure completeness.

6.3 Second stage: clustering

The second stage was to cluster the data to provide comparative case studies. The data was clustered into main categories as in the first stage and the same coding numbers were used to provide references to the information in the first stage – see Appendix B. The summary of the analysis in this stage is provided in Table 6.1:

Category	Findings
Company background	Similarity ▪ All of the case study companies have a complex organizational structure with the involvement of multi-disciplinary teams from different departments. ▪ All of the case study companies produce more than 1 product and service. ▪ All the products of the case study companies

	come with the service. ▪ Companies A, B and C have design facilities in their manufacturing system ▪ The product and service in Companies B and C can produce bespoke items to meet customer requirements. ▪ The product in Company A is always bespoke to meet customer requirements. Dissimilarity ▪ All of the case study companies differ in the ways in which they organize their products and services.
Product	Similarity ▪ All of the case study companies have a variety of types of product. ▪ Companies A, B and C offer bespoke products. ▪ All of the case study companies having a system to manage their products. Dissimilarity ▪ Company A does not have any standard product; all of their products offering are bespoke products. ▪ Company A fabricates their own product and the moulds to produce their product. ▪ Company D only has a standard product and does not offer a bespoke product. ▪ Companies B and C do not fabricate any parts of their product. They perform other manufacturing processes such as assembly to make complete products.
Market	Similarity ▪ All of the case study companies have at least two business markets; primary market and secondary market. Dissimilarity ▪ Company B has 3 complex types of market (remanufacturing in tertiary market).
Service	Similarity ▪ Companies B, C and D produce their services in cooperation with customers. ▪ All of the case study companies provide demonstration or training to the customers on how to use the products. ▪ Product design is considered to be a service in Companies A, B and C.

	▪ Service elements/packages needed by customers can be customised in Companies A, B and C. ▪ Companies B and C provide service package which include periodic maintenance. ▪ All of the case study companies have an ICT support system to manage their services. Dissimilarity ▪ Company A does not provide any services or maintenance for its products. ▪ Company B provides service schedules to its customers. ▪ Company B provides service mobility in their service package. ▪ Company C can provide service mobility (but normally service is carried out in house). ▪ Company D does not provide service for their product but they provide service for their own instrumentations.
ICT support	Similarity ▪ All of the case study companies have ICT support for their administration and operational functions ▪ All of the case study companies have more than 1 type of ICT support however every support has the capability to integrate with different functions. ▪ Companies B, C and D have different ICT support tools for their products and services. ▪ Companies B and C have customised their own ICT support. Dissimilarity ▪ The ICT support for Company A's products are not linked to their other factories in other locations.
Inventory	Similarity ▪ All of the case study companies aim to minimize/optimize their inventories. ▪ All of the case study companies have potential areas in their operations which can lead to accumulation of excess inventories. ▪ All of the case study companies use ICT support to manage their inventory. ▪ All of the case study companies have storage areas to keep their inventory. Dissimilarity

	▪ Company B keeps some of its service inventory in vans that are used for service mobility.
Manufacturing	Similarity ▪ The production in all of the case study companies is based on customer orders. ▪ All of the case study companies employ technical experts in fields that are relevant to their equipment/machines and software used. Dissimilarity ▪ Company B operations involve remanufacturing.
Delivery	Similarity ▪ Companies A, B and D provide delivery of their products to the customers using their own transportation. Dissimilarity ▪ Company C uses standard couriers for the delivery of their products.

Table 6.1 Second stage summary of the analysis

6.4 Third stage: comparison of summaries

PSS embraces the product and service continuum as one system (Ismail et. al., 2015). It is important to consider factors related to inventory in many decision-making contexts for production or operational planning. Inventory is therefore at the heart of any business. The matrix in Table 6.2 compares the key uncertainty factors identified in Section 2.3.4 with key factors identified in the case study analysis in Section 4.5; this matrix has been developed which aimed to identify the elements of uncertainty in PSS inventory. The body of the matrix was filled with the relevant company names identified during case study analysis by using the frequencies of occurrence analysis technique. For instance, for market uncertainty, Company A had 5 occurrences of the key factors derived from the case studies (product, market, service, inventory and manufacturing).

		Key factors identified in case study analysis – see section 4.6							
		Company background	**Product**	**Market**	**Service**	**ICT support**	**Inventory**	**Manufacturing**	**Delivery**
Key uncertainty factors – see section 2.3.4	**Market uncertainty**		A, B and C	A, B and C	A, B and C		A, B, C and D	A, B, C and D	
	Company uncertainty	A, B, C and D							
	Environment uncertainty						A, B, C and D	A, B, C and D	
	Reliability uncertainty				B and C	A, B and D	A, B and C	B and C	
	Product function uncertainty		A, B, C and D			A, B and D	A, B and C	A, B, C and D	A, B, C and D
	Uncertainty of innovative service				B and C	B	B and C		
	PSS integration uncertainty		B and C	A, B, C and D		A, B and C	B and C		
	Supplier coordination uncertainty					A, B, C and D	A, B, C and D	A, B, C and D	
	Communication uncertainty	A, B and C			B and C	A, B and D	A, B and C		
	Uncertainty with remanufacturing		B		B	B	B	B	

Table 6.2 Case studies comparison matrix in Companies A, B, C and D

From the case studies the main elements of uncertainty for all the case companies are market uncertainty in inventory management; product function uncertainty and supplier coordination uncertainty. Table 6.3 extracts from the Table 6.2 the highest-rated uncertainty factors for each company. Table 6.3 shows that the highest-rated uncertainty factor for majority of the companies is market analysis and the lowest-rated is uncertainty with remanufacturing.

Company	A	B	C	D
Highest uncertainty factor	▪ Market uncertainty ▪ Product function uncertainty	▪ Market uncertainty ▪ Product function uncertainty	▪ Market uncertainty	▪ Product function uncertainty
Lowest uncertainty factor	▪ Uncertainty of innovative service ▪ Uncertainty with remanufacturing	▪ Company uncertainty	▪ Company uncertainty	▪ Uncertainty of innovative service

Table 6.3 Summary of highest and lowest uncertainty factors for each company

6.5 Chapter summary

This chapter has provided an assessment of the uncertainty factors in PSS inventory which were identified and then evaluated through the literature review and combined with the findings from the analysis of the case studies in a matrix form – see Table 6.2 and 6.3. Based upon the findings from this matrix the following conclusions have been drawn which can be used as a research platform for future work:

- This chapter provides an answer to the research question "What are the main elements of uncertainty in PSS inventory?"
- Uncertainties were identified for the PSS Inventory Framework and these will be discussed in Chapter 8.
- The identified uncertainty factors have more impact on the uncertainty of the product than on the service; the impact of the uncertainty factors in service is limited. It is possible that this is because the manufacturing companies originally only produce products and outsources the services to other companies. However, outsourcing the services comes at a high cost and complex service execution. More work could be conducted to integrate uncertainty elements in service.

The next chapter presents the generic model of PSS Inventory Control in a manufacturing operations context using the static process modelling language method, called IDEFØ. The IDEFØ method can be used to model information flow; the IDEFØ approach illustrates the inputs, outputs, mechanics and constraints of a system.

7. Development of PSS Inventory Control Model

This chapter focuses on the development of a generic model of PSS Inventory Control in a manufacturing operations *context. The proposed model was developed using the static process modelling language method, called IDEFØ. IDEFØ provides a comprehensive graphical format of representation which can be decomposed to any required level of detail. IDEFØ was used to model PSS Inventory Control functions (i.e. the activities that the organisation performs) to manage and control inventory.*

7.1 Introduction

In the 1970s, the U.S Air Force founded Integrated Computer Aided Manufacturing (ICAM) to increase manufacturing productivity; a series of modelling languages known as Integration Definition (IDEF) was developed in 1990 for better analysis and communication with the people in manufacturing industry. The IDEF family provides different languages that enable different types of modelling; Integration Definition for Function Modelling (IDEFØ) is a process modelling language method and part of this family – see section 3.4.3 for further explanation. IDEFØ was used in the current research to specify system requirements and generate a functional view of the PSS Inventory Control elements (generic model) and to give clear illustrations of all levels of the inventory processes identified in the case studies.

The modelling of the entire PSS Inventory Control functions (i.e. what activities are performed in the case study companies) is difficult because it involves high complexity. IDEFØ has been used as it is a modelling language method that can facilitate the modelling of complex processes and therefore enable the PSS Inventory Control activities to be modelled as a complex system, i.e. the definition, analysis and documentation of the PSS Inventory Control as a whole, providing a flexible level of detail across the decomposed layers.

IDEFØ is comprised of three types of information: graphical diagrams, text and glossary. The structure of IDEFØ is hierarchical in which each activity is a node in a tree; each node is labelled indicating the parent and child – see next section for further descriptions. The IDEFØ model that has been developed is currently at a relatively high level for each node but could be decomposed for further detail. However, the aim of this process modelling was to develop a generic model of PSS Inventory Control and this has been achieved by the IDEFØ model that has been created and documented in the following sections.

7.2 Development of IDEFØ

7.2.1 Structure of IDEFØ

IDEFØ is a modelling method; consisting of a graphical language and modelling process which compromise a context diagram, parent/child diagram and node tree. The graphical language and modelling process capture the systems function, functional connections, data and objects. A context diagram is the top most diagram in an IDEFØ model (labelled as the A-0 diagram); the parent/child diagrams are an IDEFØ decomposition hierarchy using parent/child relationships; the node tree represents a full IDEFØ decomposition in a single diagram. Decomposition divides the scenarios/ problems into several smaller sub-scenarios / sub-problems, which are again, divided into sub-scenarios/ sub-problems until a trivial solution can be identified. It is crucial to understand the contextual rules in constructing the IDEFØ model.

The IDEFØ model is structured to gradually present more and more details as each level is decomposed. One of the most important features of IDEFØ is that it starts by presenting the whole process as a single unit which is called the A-0 diagram. Then the model is decomposed to an A0 diagram; the IDEFØ system limits the number of decomposed activities at each level to a minimum of three and a maximum of six. Each decomposed activity (node) is labelled with a code according to the label of the parent activity. This permits the detail to be exposed progressively but limits the complexity of each node. Figure 7.1 shows an example of decomposition in IDEFØ; the A-0 node is decomposed into 6 nodes (A0, A1, A2, A3, A4, A5 and A6); then the A2 nodes are decomposed into another 4 nodes (A21, A22, A23 and A24).

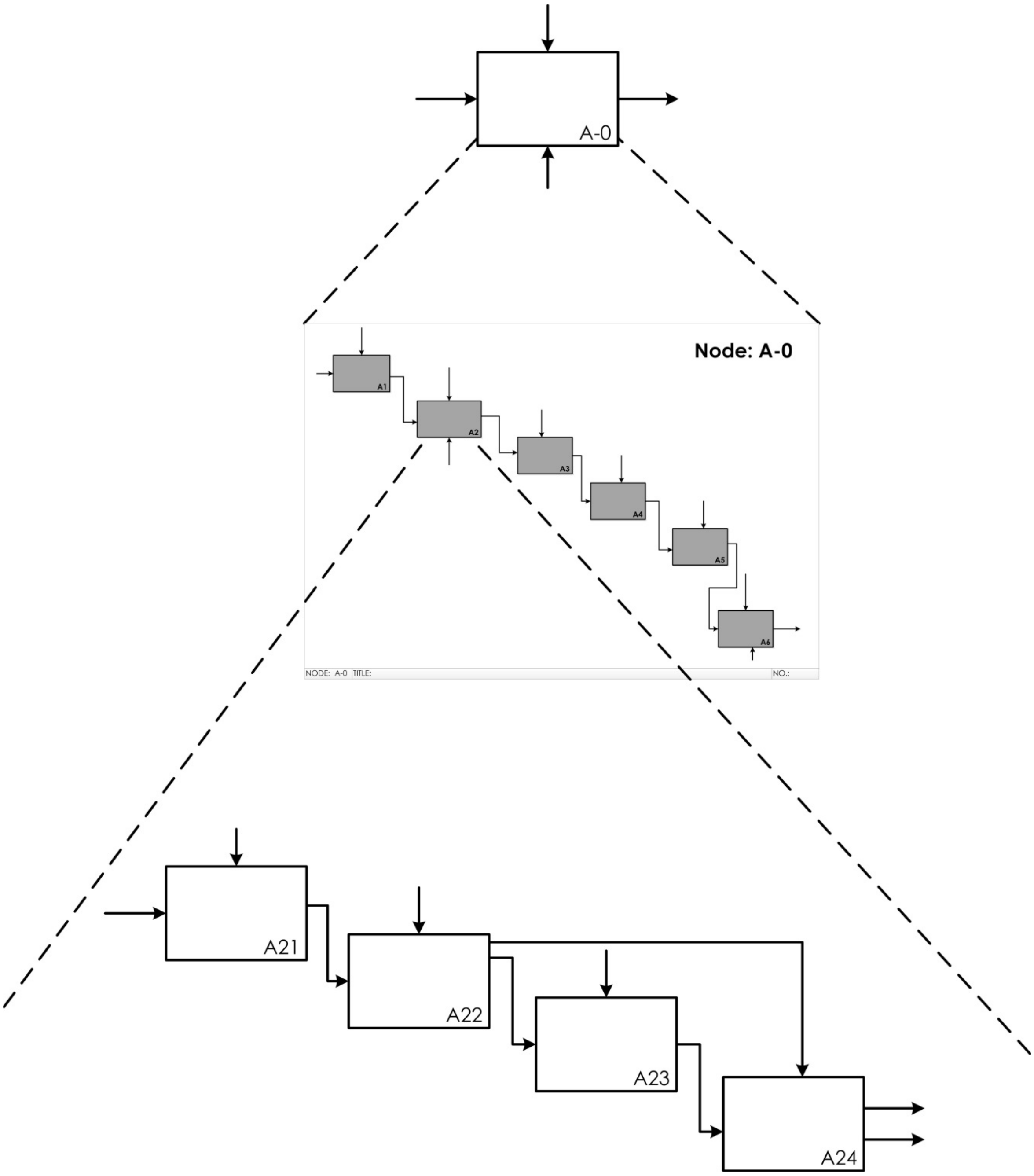

Figure 7.1 Example of IDEFØ decomposition

Each labelled box contains a verb or verb phrase in the centre to summarise the main activity or event which takes place during that particular process. Each box is uniquely labelled at the lower right corner for reference. Arrows are used to convey data or objects from source. There are four types of arrow, the Input Arrow, Output Arrow, Control Arrow and Mechanism Arrow. Straight arrows connect directly to the box with a label that will affect or be affected by the activity on top of it; the bent-note arc arrow has the same function as the straight arrow, the forked arrow is used when one arrow is decomposed into two elements; and the joined arrow is applied when two separate arrows are composed into one. Figure 7.2 shows the IDEFØ set of syntax symbols.

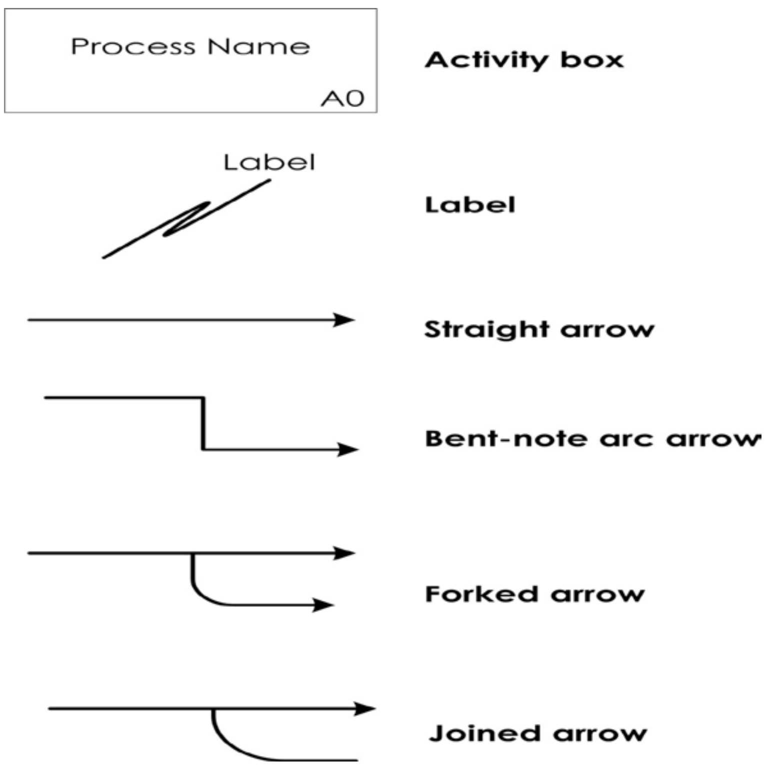

Figure 7.2 IDEFØ syntax symbols

IDEFØ interfaces are categorised into four elements:

- Input is something that will be processed by the activity to produce the output;
- Output is something that results from the process;
- Control can be a condition, a situation or some information that controls the activity; and
- Mechanism is a means by which human resource or tool can be applied.

Figure 7.3 shows a basic IDEFØ model, including syntax descriptions. Reading the structure in IDEFØ is done top down by considering each diagram as a context bounded by its parent box. The specific details about a model are found at the node index through the levels of the required diagrams.

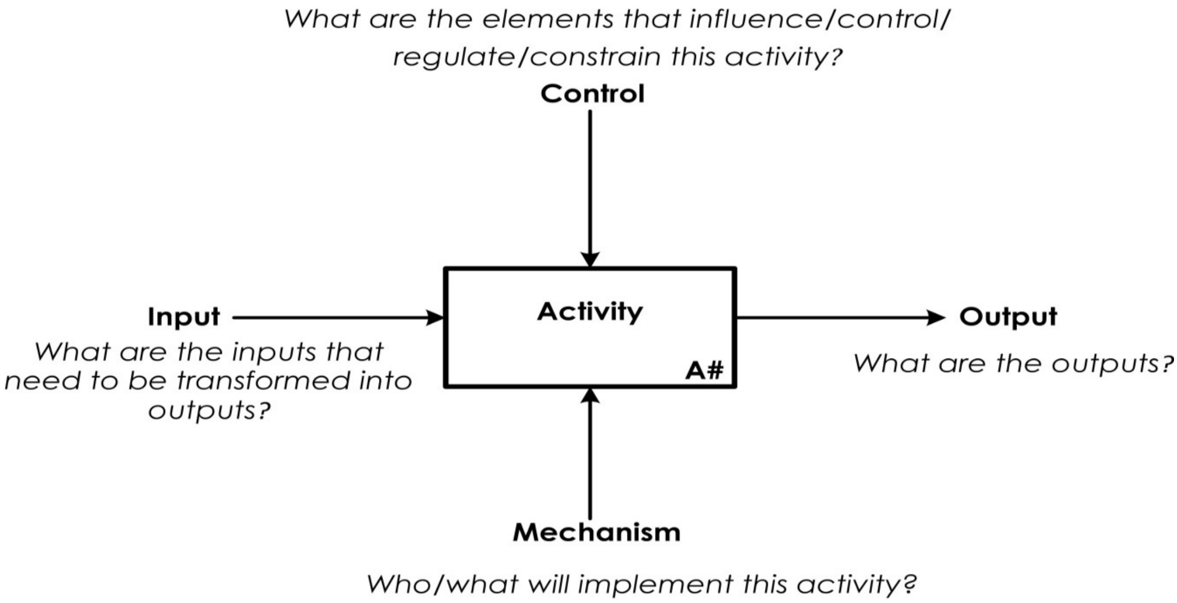

Figure 7.3 IDEFØ modelling language

The software package Microsoft Visio 2010 was used to develop the IDEFØ model using its pre-installed symbols. There are three main elements in developing IDEFØ using Microsoft Visio 2010: context diagram (e.g. A-0 model); parent/child diagram and node trees. All elements in developing the model can be dragged from the IDEFØ Diagram Shapes in Microsoft Visio 2010 and the development process is as follows:

i. Insert a node name for title and number for the diagram in the Title block; by dragging a Title block shape onto the drawing page from IDEFØ Diagram Shapes. Then set the title block border offset.

ii. To insert activity boxes, drag from the IDEFØ Diagram Shapes. In the Shape Data dialog box the user needs to provide a name for the process with its details: Process ID (A-0); Process name; and Node number.

iii. To insert an external interface arrow, use the 1-legged connector shapes and drag their endpoints to connection points on activity boxes or an IDEFØ connector to create function of arrows that join. Text can be inserted on the connector by selecting the connector and then typing. Text can also be inserted in the model by using the Text block function.

iv. In one title block the maximum number of activity boxes (parents) is six. Continue the above steps to complete the development of the IDEFØ model.

7.2.2 IDEFØ model descriptions

7.2.2.1 A-0 diagram of Product Service System Inventory

An IDEFØ model starts by presenting the whole process as a single unit; the highest level within the overall process is the A-0 (A minus zero) diagram as shown in Figure 7.4. As A-0 represents the process as a whole, the function name of the process is general. This diagram has been used to show the overall inputs, outputs, mechanisms and constraints to provide general information about the PSS inventory. The inputs are customer order and raw material. The input goes through the mechanism and constraint elements to become outputs; order confirmation/invoice, physical product, service to customers and production waste. The constraints of this model are customer requirements, safety standards, plan/budget and inventory data. Meanwhile, the mechanism elements are infrastructure, in-service assets, equipment and human resource.

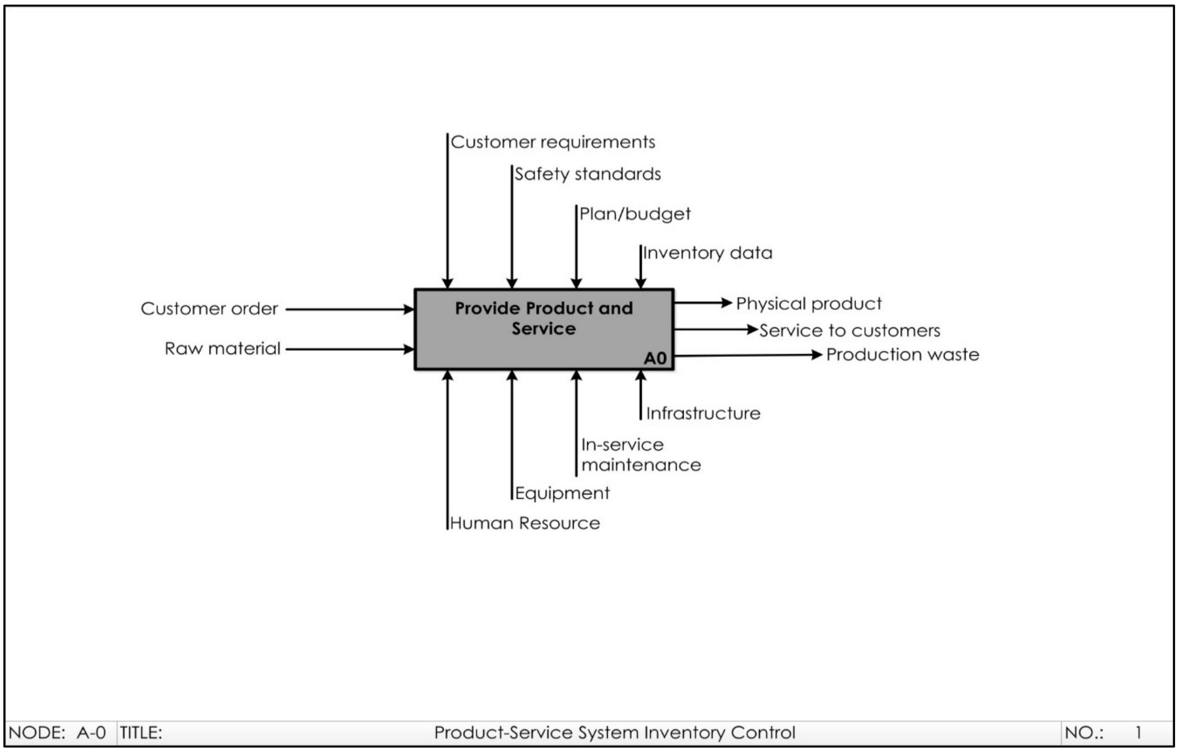

Figure 7.4 A-0 diagram of Product Service System Inventory

7.2.2.2 A0 diagram of Product Service System Inventory

The A0 diagram as in Figure 7.5 shows the decomposed elements from the A-0 which represents the context of the model and is called a context diagram. A0 contains the major sub-levels of the model with each process having its own specific designation; 6 key sub-processes are involved in PSS Inventory Control. All the inputs and outputs required for each key activity and inter-relationship between these activities are illustrated in the diagram. The A0 is the node number of the parent box and the child diagrams for the whole model are detailed by boxes with identifying node numbers:

A1: Market and sell; product and service

A2: Design configuration

A3: Prepare resources

A4: Produce product

A5: Ship order

A6: Provide customer support

Each node has a unique, descriptive name that distinguishes it from another node with which it may associate. The nodes then will be decomposed into more details for specific process activities. For example, for the ‘A1: Market and sell; product and service customer calls/emails are the input. The output to this activity are design ideas/preliminary design, service requirements and approved specification or accepted tender, which become the input activity for A2; support enquires become an input for A6. At this stage, however, the information provided is not sufficient to understand the details of how the activities to be carried out as part of A1 will be done. The sub-activities of A1 will be described and broken down into sufficient details to allow the activity to be understood in the A1 diagram.

In developing the A0 diagram and then decomposing the elements further, there are constraints on the elements which must be considered for instance in A1 (Market and sell; product and service) the constraints elements are policies and company procedures. All the constraints in developing this IDEFØ involve policy, procedures, safety guidelines, planning, technical standards, drawing standards and documentation. The constraints elements provide value to the company for compliance, operational needs, managing risks and continuous improvements. They ensure that all employees and customers understand what is expected of them and what they can expect from the company. For instance, the constraints elements are very important so that every member of staff in the company clearly understands individual and team responsibilities and doing their job in the required way without using a trial and error approach so that the operation can be effective and minimise any product error or accident.

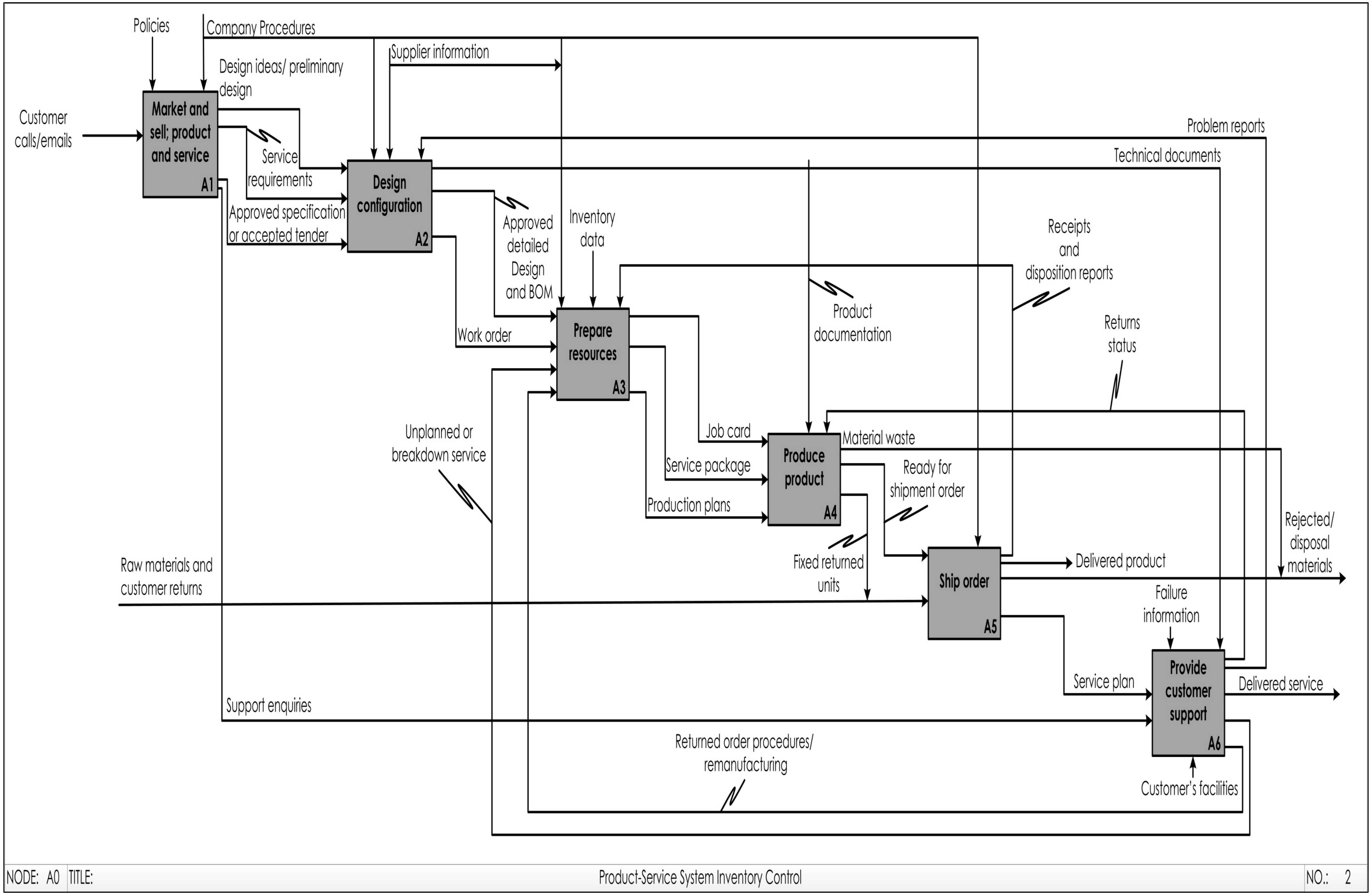

Figure 7.5 A0 diagram of Product Service System Inventory

7.2.2.3 Market and sell; product and service

In this section each of the sub-activities in A1 are described as in Figure 7.6. This sub-activity includes all the activities required to identify the customer requirements and prepare the customer order documentation. These activities are led by the customer. The key input is the customer interest; the key outputs are service documentation and accept/reject/postpone order notifications. The key constraint is company policies. The sub-activities contain all the tasks associated with the activity of negotiate with the customer, define product requirements, define service support requirements and verify availability.

7.2.2.4 Design configuration

A2 as illustrated in Figure 7.7 contains all the sub-activities and tasks associated with developing the product design and service plans through a design configuration. Once the customer has accepted the product and service specification, an overall design will be prepared by the designer which is the key mechanism of the activity together with the design support tool. The design team then will develop the detailed design and generate a BOM which provides essential information to prepare planning for the manufacture as well for planning in the service provision. The key constraints in developing the detailed design are legal and technical standards, documentation of changes, and drawing standards.

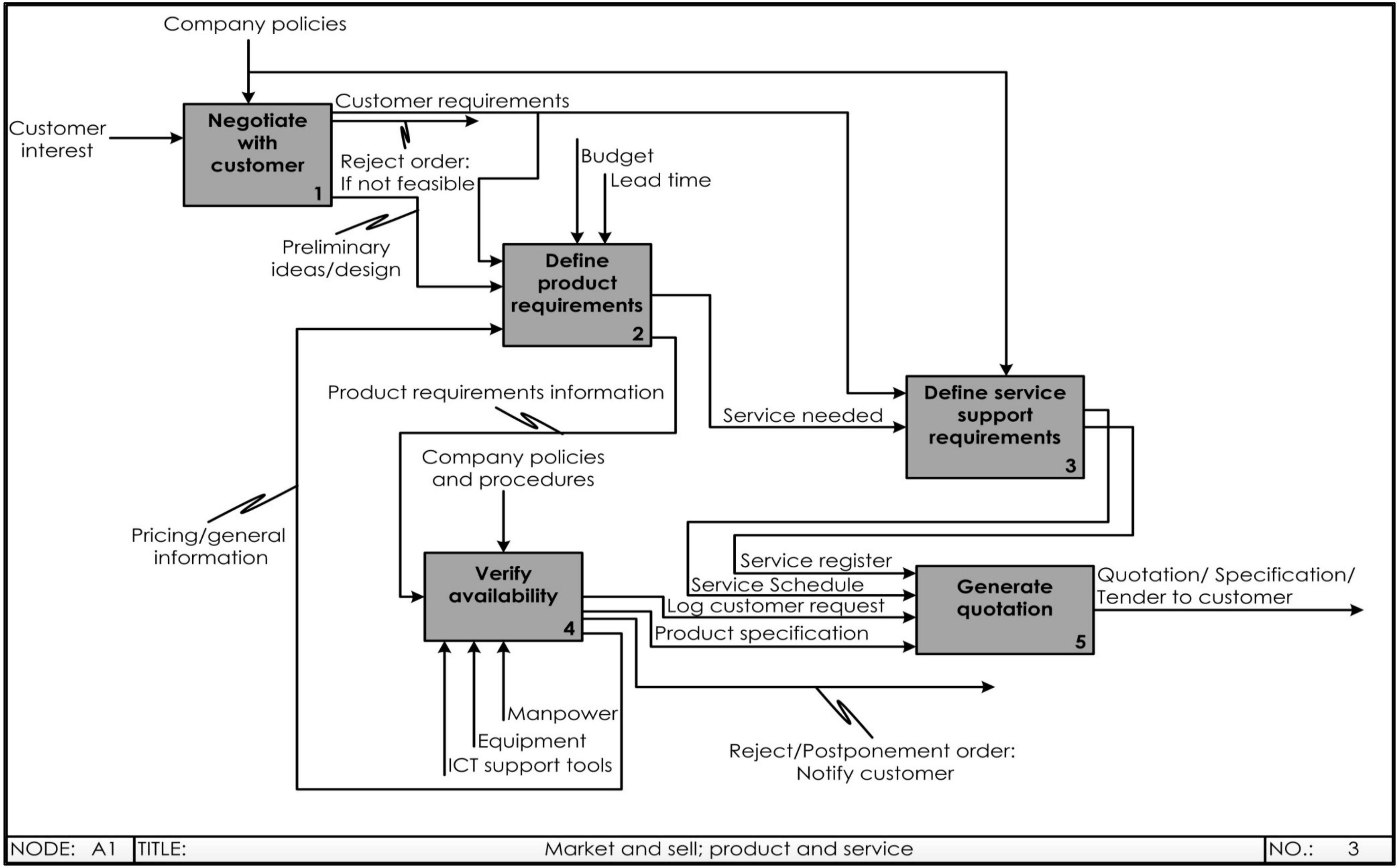

Figure 7.6 A1 diagram of market and sell; product and service

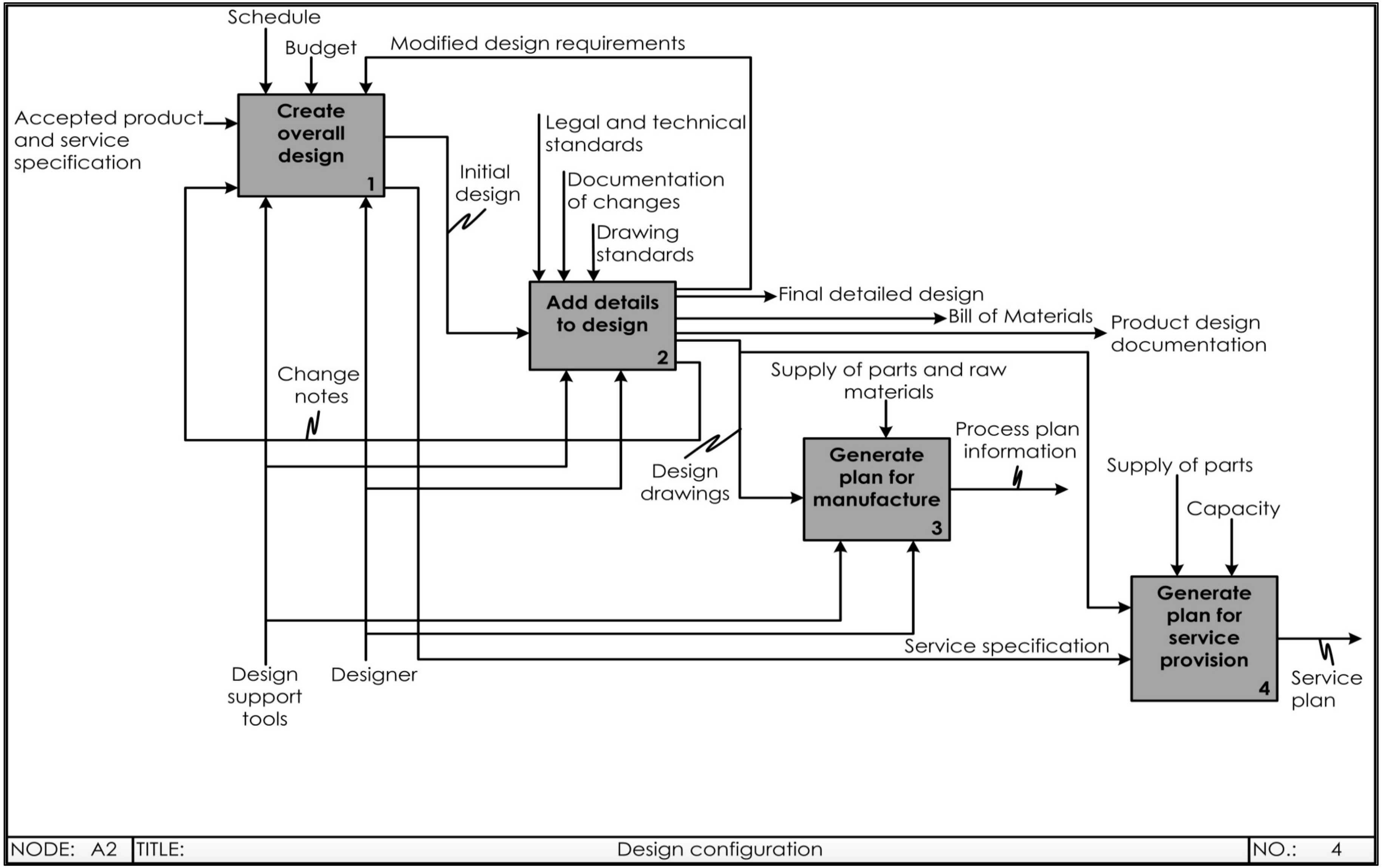

Figure 7.7 A2 diagram of design configuration

7.2.2.5 Prepare resources

All the initial activities associated with the identification of resources needed, which include all the key areas within the asset such as machine and inventory specification and availability are the key activities in A3 which is shown in Figure 7.8. The key input in this diagram is the work order which has been generated in A2 and the key mechanisms are ICT supports tools and employees. At this stage, the activities involved are not only in house but may also involve the suppliers. For instance, the parts which are not available in the company's store must be ordered from the suppliers. Substantial documentation is involved in these sub-activities and the key output is the work order for the shop floor manufacture of the products.

7.2.2.6 Generate product

In this section each of the sub-activities in A4 is described as in Figure 7.9. A4 contains all the tasks associated with the activity not only to produce the product but also to repair faulty products. The key inputs are production plans, material from the supplier, product documentation and materials requisition. The key constraint in this diagram is the production schedule and the key mechanisms are human resource and equipment. It is important that manufacture and assemble parts activities comply with safety regulations. Products are inspected before delivery to the next stage; any defects will go through reworking or repairing processes.

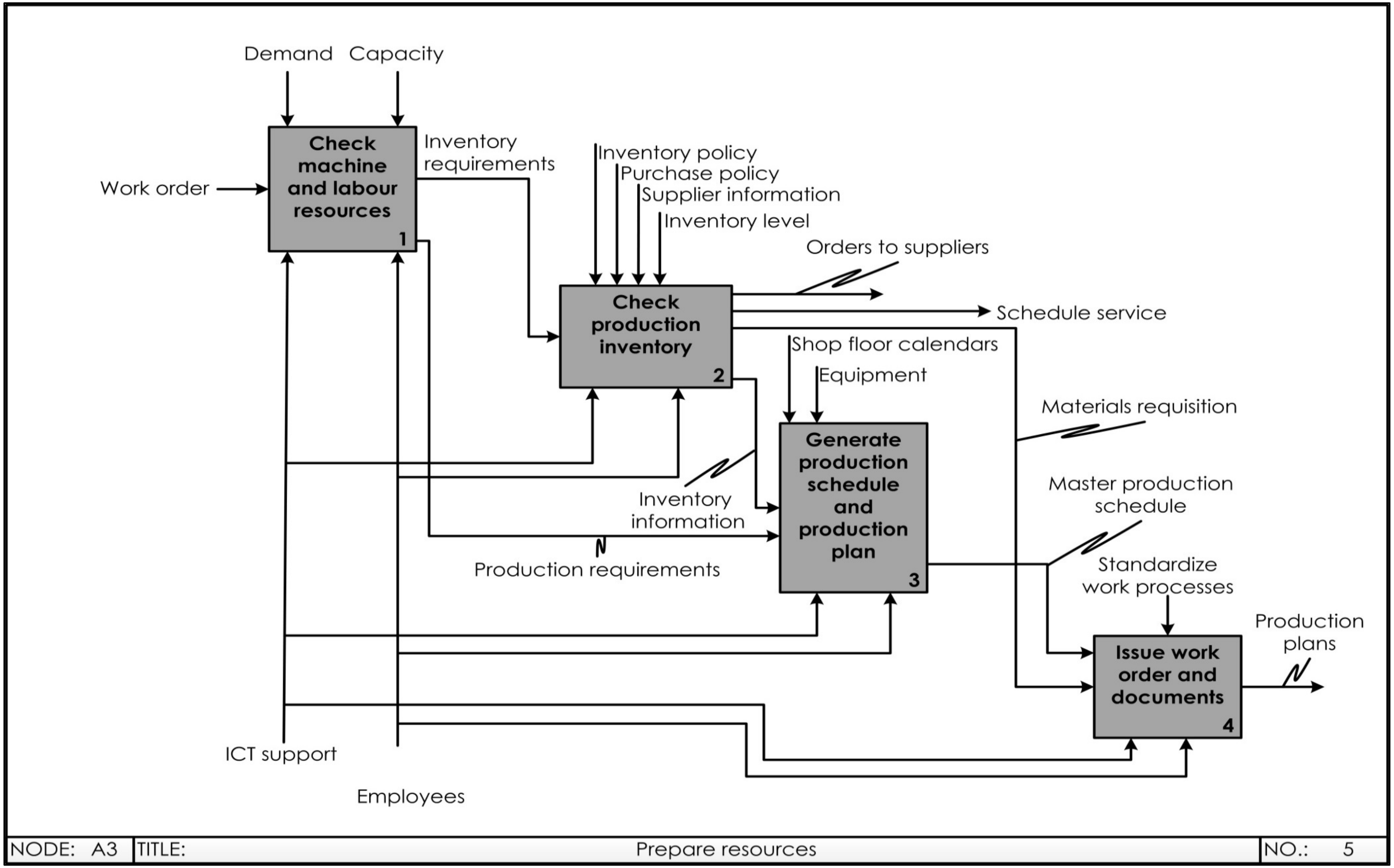

Figure 7.8 A3 diagram of prepare resources

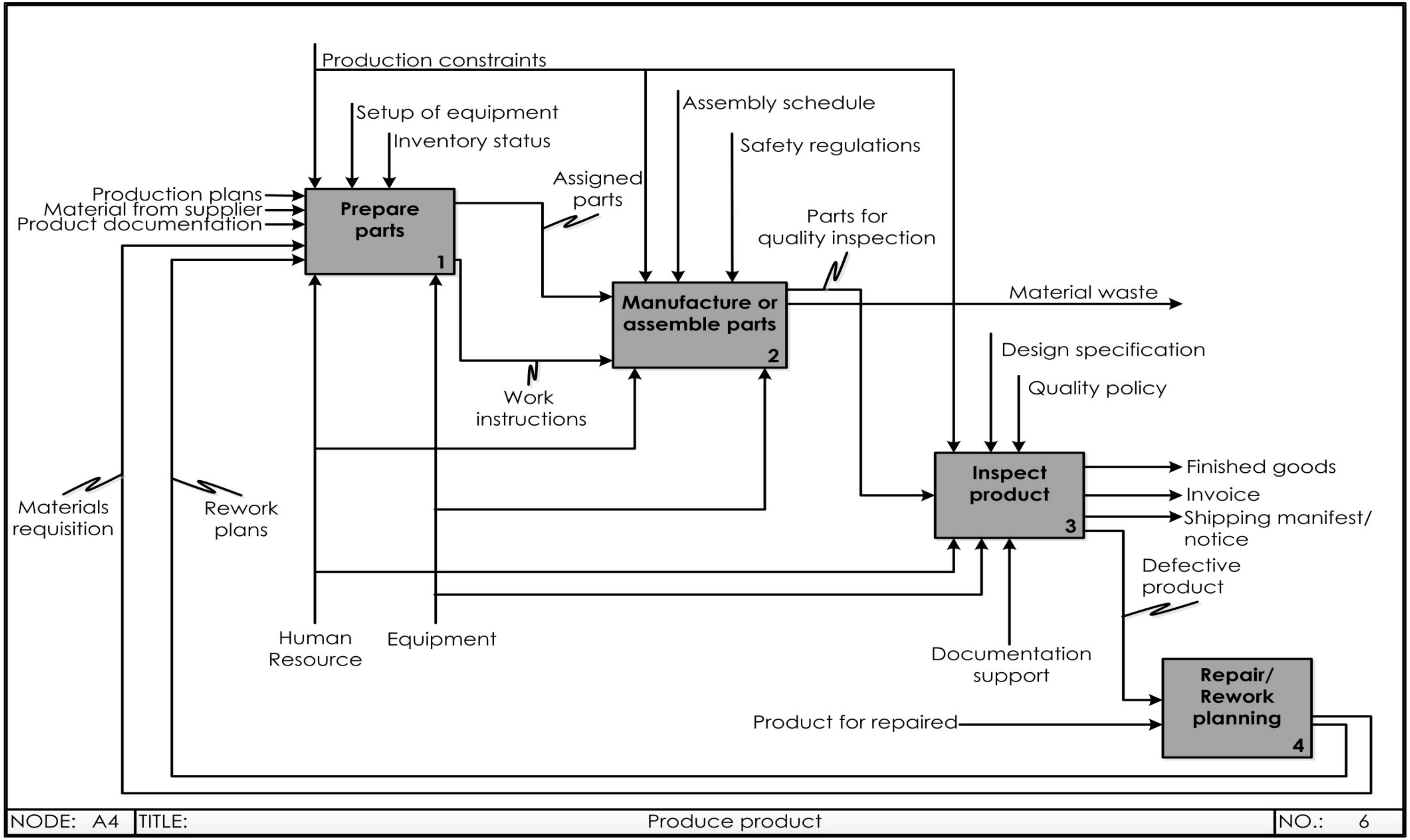

Figure 7.9 A4 diagram of generate product

7.2.2.7 Ship order

The sub-activities of A5 are shown in Figure 7.10 and include all the tasks associated with the delivery of products and services. The sub-activities in A5 involve interactions of the company, customers and shipping carrier. The key constraint is the policy and the key mechanism is ICT support tools. The key inputs are purchase order (PO) ready notification and service order; and the key outputs are the sign-off documentation and undeliverable or rejected product. The product or service can only be confirmed as received by the customer after the customer signs off the documentation as received. Any undeliverable or rejected product by the customers will be returned to the company using a traceable method.

7.2.2.8 Provide customer support

Figure 7.11 shows the A6 diagram which contains all the tasks associated with the activity of providing customer support. The key inputs are the condition report and product or resource; the key outputs are maintenance cost, current condition documents and asset history. The key mechanisms are tools and spares. There are two types of services, unplanned or breakdown service and scheduled service, which have different constraints but the same mechanism. The company aims to provide rapid response to unplanned or breakdown service whilst scheduled service is performed according to the maintenance log.

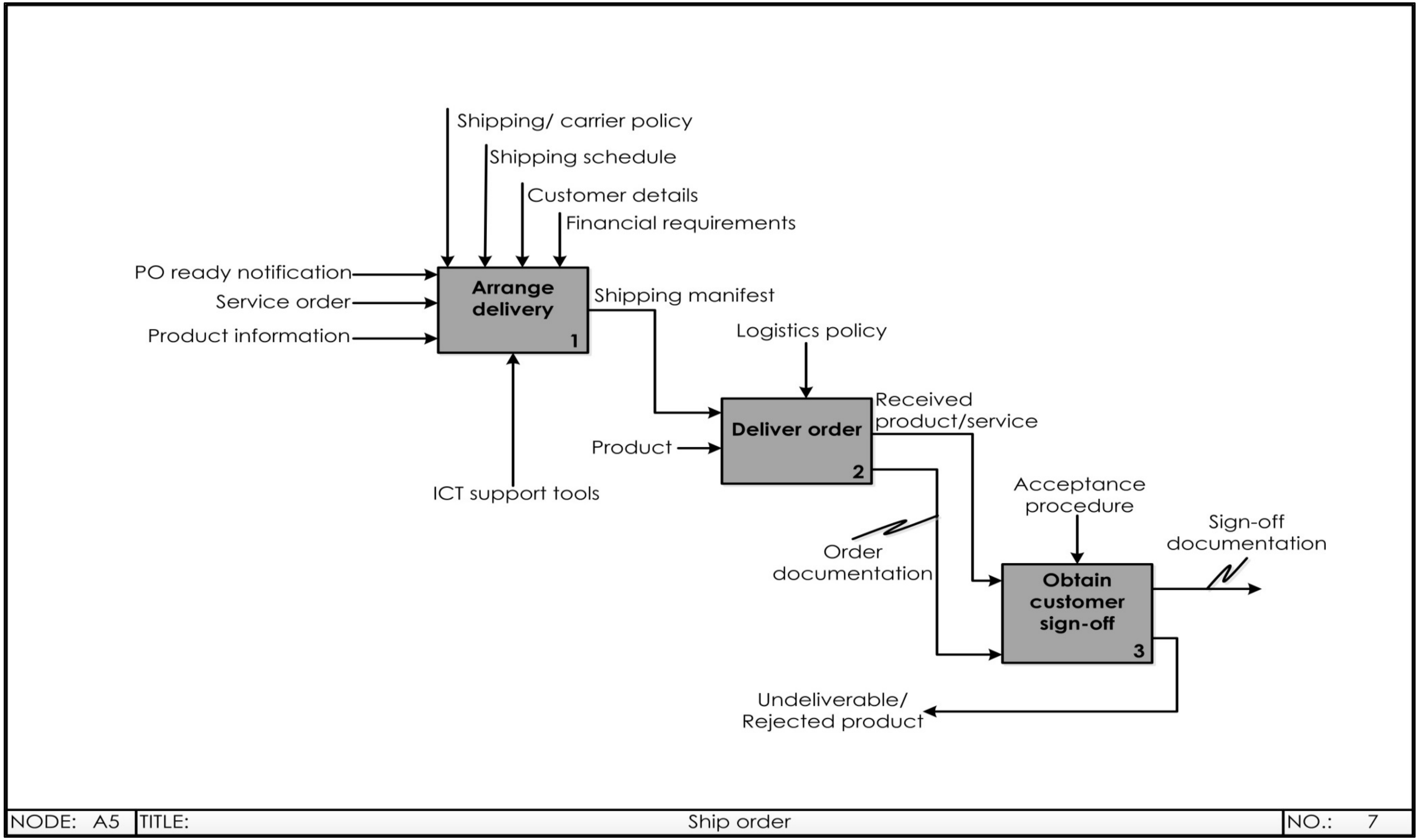

Figure 7.10 A5 diagram of ship order

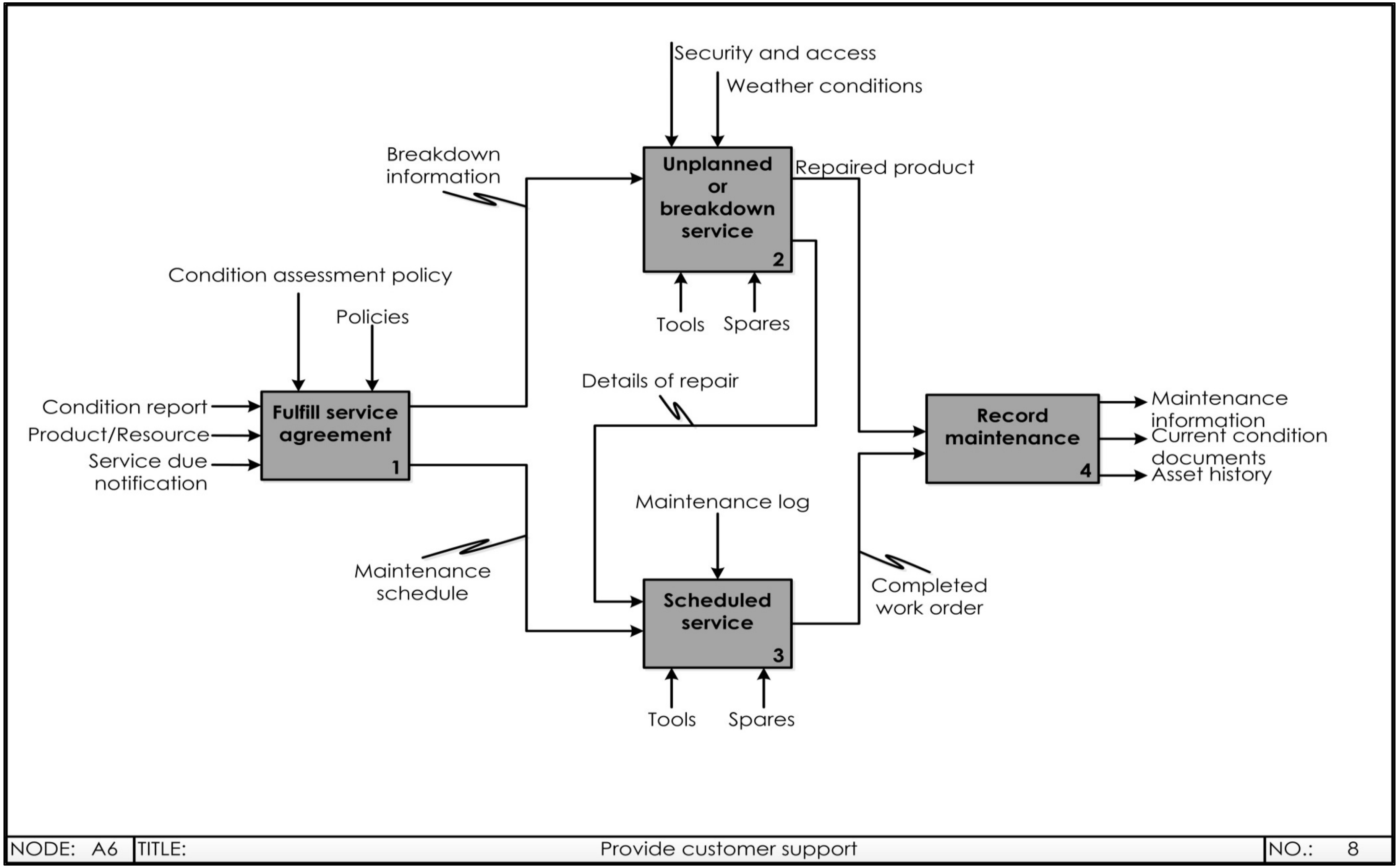

Figure 7.11 A6 diagram of provide customer support

7.3 Chapter summary

This chapter has detailed the implementation of a generic model process using a modelling language method; IDEFØ. The IDEFØ diagrams provide a visual representation of PSS Inventory Control which uses simple language in English and is intuitive to follow. IDEFØ has the capability to decompose to the lowest level of the tasks; displaying the controls and mechanisms that form part of the tasks. Brief descriptions are provided in Section of 7.2.2.2 the PSS Inventory Control elements in this generic model. The generic model that has been created could be adopted for all types of PSS Inventory Control companies in manufacturing operations contexts. The novelty of this generic model lies within its ability to generate PSS Inventory Control elements for each department or type of company in manufacturing.

The next chapter presents the results and discussion related to the presented material throughout this thesis and these include the validation of the generic model for each of the case study companies, new methodology for development of PSS Inventory Control in manufacturing perspectives and limitations of the research.

8. Results and Discussion

This chapter is used to elucidate and discuss the key findings related to the presented material throughout this thesis. It consists of the key findings of the project and the discussion for each of the key findings of which there are 4:

- *The methodology for development of PSS Inventory Control in manufacturing* operations *perspectives (derived from Chapter 2).*
- *The characteristics of PSS Inventory Control in manufacturing* operations *perspectives from the industrial context (derived from Chapter 4 and 5)*
- *The key uncertainty elements in PSS Inventory Control (derived from Chapter 6)*
- *PSS Inventory Control practical application (derived from Chapter 7)*

8.1 Summary of the research key findings

The research reported within this thesis was conducted in three stages – see Figure 1.3. The key findings in this research are illustrated in Figure 8.1.

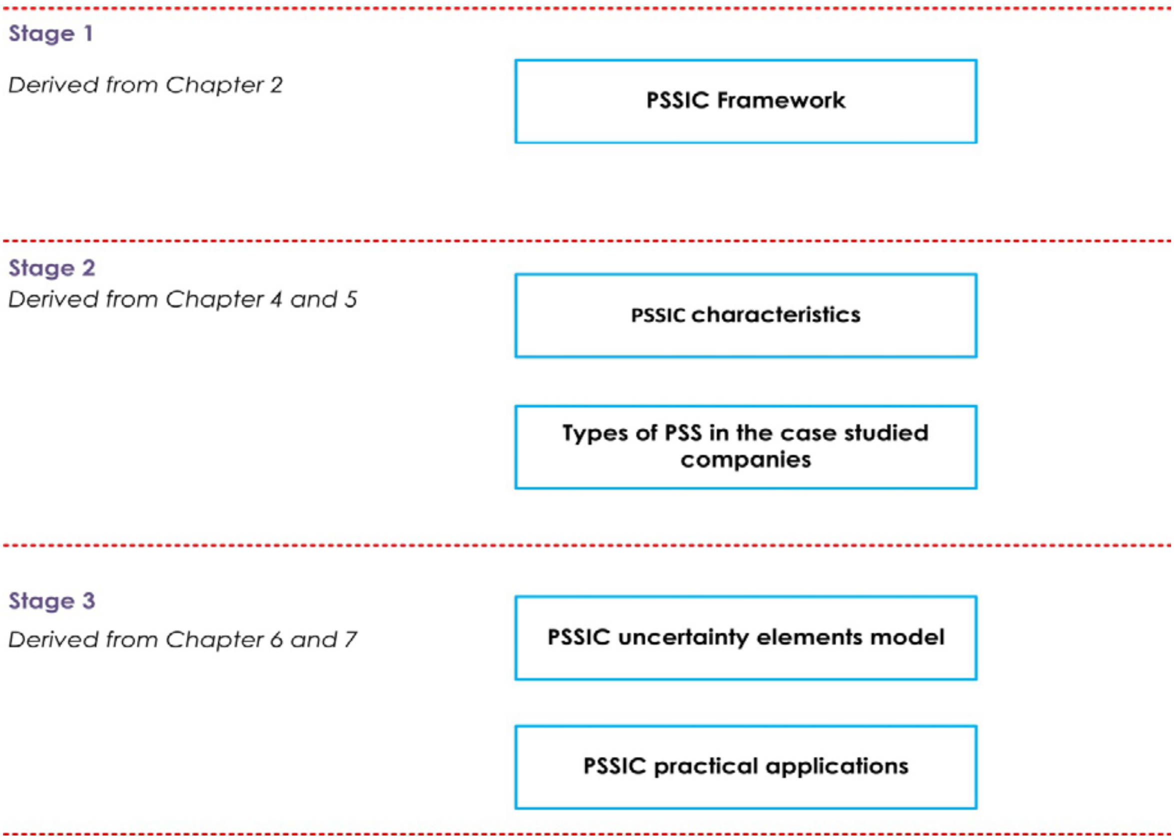

Figure 8.1 Summary of the research key findings

The key finding in this research is labelled as PSSIC which is an acronym for PSS Inventory Control. During stage 1, the PSS model by Tukker (2004) was synthesised from the literature; the model made three main categories of PSS: product-oriented services, use-oriented services and result-oriented services. In the PSSIC framework (Figure 8.2), the current researcher has modified Tukker's model to include the two main categories of PSS: product and service; and product with service, and has further included subcategories such as PSS uncertainty elements. In stage 2, rich pictures of the current industry situation on PSS inventory was investigated through a survey; the outcome in this task was the development of PSSIC characteristics. Then four case studies from four different types of manufacturing were developed. Stage three sought to evaluate the uncertainty elements identified by Hepperle et al. (2010) with the current PSS Inventory Control scenario; the PSSIC uncertainty elements model was the output of this task. Next, the PPSIC practical applications were developed to present the validation of the generic model using IDEFØ.

8.2 The methodology for development of PSS Inventory Control in manufacturing perspectives

In the current research, Tukker's (2004) model has been adapted for use in PSS Inventory Control from manufacturing operations perspectives – see Section 2.3.2. The adapted model is called as PSSIC Framework, illustrated in Figure 8.2. The PSSIC Framework is intended for use by traditional manufacturers who want to transform their companies into PSS businesses or by PSS companies who that want to improve their inventory control. Both types of company must have 3 elements in their operation: product, service and process; product conditions list (cf. Sakao, 2009); and PSS characteristics (cf. Minguez et al., 2012). In other words, the PSSIC framework is not applicable to pure product or pure service companies; however, they can offer a product without a service or a service without a product to their customer. The PSS uncertainty elements are also included in this framework; further discussion will be given in section 8.4. In

Tukker's (2004) model, types of PSS are categorised into product-oriented service, use-oriented service, and result oriented service; in this new PSSIC framework PSS is simplified into two types: product and service; and product with service. In 'product and service' element, the service is an option for the customers (e.g. Company A); meanwhile 'product with service' element, the product comes with the service package (e.g. Company B). Tukker (2004) divided the product and service offerings into different types of PSS; in this framework a product and service offering is set as one category but new elements have been added (e.g. remanufacturing) that can be used in different types of PSS. In this framework the product and service offering is set as one category to make it easier for the manufacturer to deploy the PSSIC framework in their business and operational strategy.

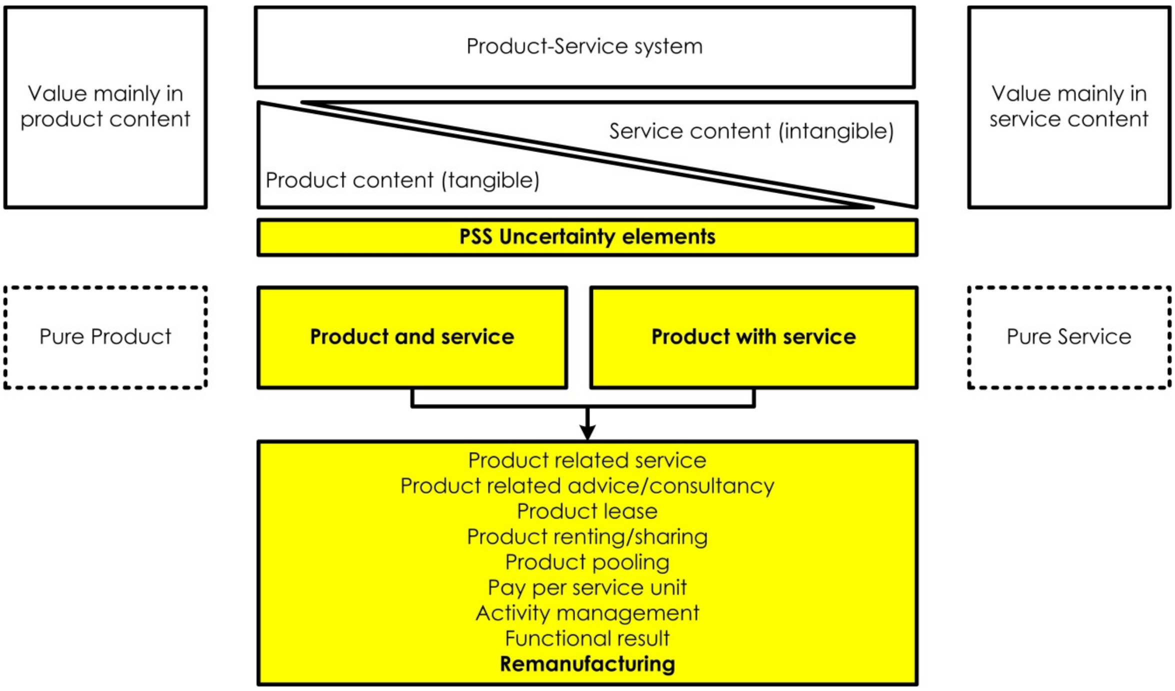

Figure 8.2 PSSIC Framework

The PSSIC Framework gave the current researcher an understanding of how PSS could be delivered within the manufacturing perspective. The knowledge gained from this stage provided the researcher with a solid platform to investigate and develop case studies in the 2nd stage of the research.

8.3 PSS Inventory Control characteristics in manufacturing perspectives (industrial context)

The PSS Inventory Control characteristics from manufacturing operations perspectives and the industrial context were developed through surveys by identifying how inventory control works in PSS. There were two phases of survey conducted with demographic questions and open-ended survey questions for a more in depth account of the surveys, see Chapter 4. The surveys were conducted in the United Kingdom and Malaysia through e-mails and phone. 7 main findings were generated:

- Finding 1: Different types of PSS can be applied in manufacturing operations contexts.
- Finding 2: Types of services provided by manufacturers for their operation and/or customers were identified.
- Finding 3: The ICT support that has been used for products and services has been identified and discussed.
- Finding 4: The capabilities of software that is used by the manufacturers to generate inventory information has been identified and discussed.
- Finding 5: The manufacturers involved in this survey were familiar with the concepts of servitization and PSS.
- Finding 6: Several inventory challenges in managing products and services have been identified.
- Finding 7: A data capture technique is essential to provide efficient hierarchy and accuracy of good inventory including decision making.
- Finding 8: All the data in this survey were qualitative type of data which were categorised into: company background; product; market; service; ICT support; inventory; manufacturing; and delivery.

The findings have provided useful insight into the design 2 operations of PSS in manufacturing operations contexts; and inventory control management in the company's. The categorization of this data resulting from the pattern of data that been obtained in this survey which also provided the characteristic elements of

PSS Inventory Control in manufacturing operations perspectives. The characteristic elements of PSS Inventory Control were identified using the development of the case studies; the data obtained from these case studies were qualitative and do not use statistical methods (Chapter 5). The selected manufacturing companies come from the United Kingdom and Malaysia that offer a product and also provide a service of some kind for their own products.

Table 8.1 provides a summary of the companies according to the types of PSS from manufacturing operations perspectives (c.f. Ismail et al., 2015). Company A, C and D are 'product and service' type of PSS where they offer services as an option for their customers. Meanwhile, Company B is 'product with service' type of PSS; their product comes with the service package. Different types of core business in manufacturing to be categorised in PSSIC Framework can be extracted from this summary table. For instance, Company A PSSIC Framework is illustrated in Figure 8.3:

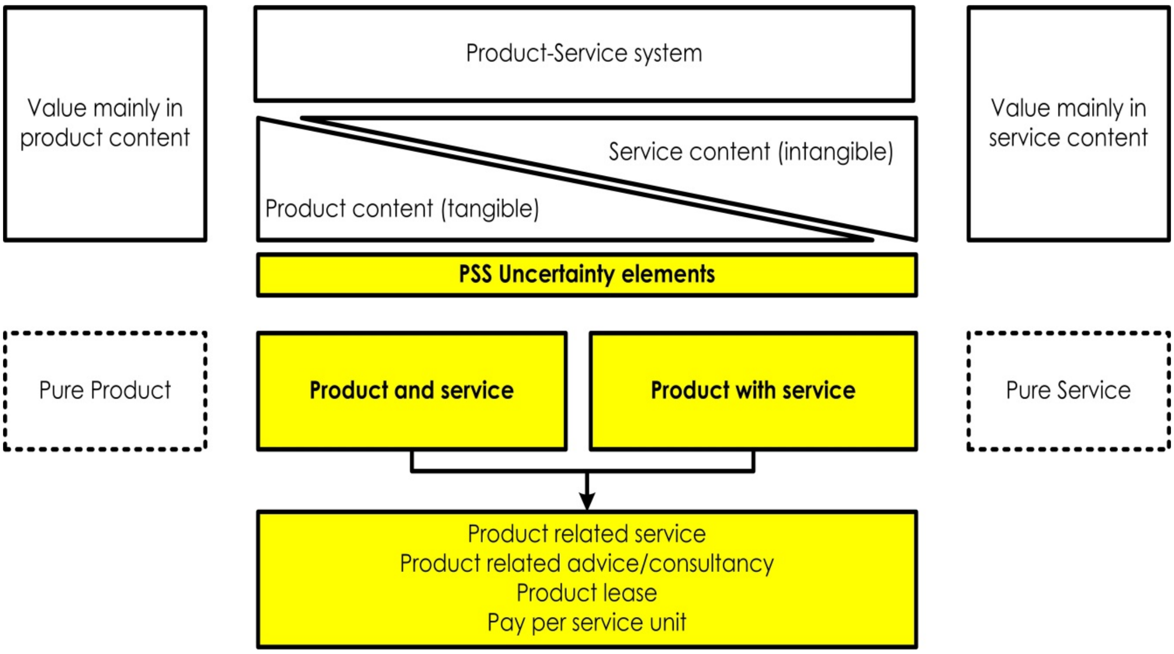

Figure 8.3 PSSIC Framework for Company A

Case Study			Product-Service System (PSS) Element			
Co.	**Location**	**Core Business**	**Product**	**Product and Service**	**Product with Service**	**Service**
A	Malaysia	Automotive, electrical and electronics industry	—	**Product:** ▪ Automotive, electrical & electronics industry spare parts e.g. Automobile central locking; security systems and alarms; paddle, steering **Services:** ▪ Does not provide the after-sales service for it products. ▪ Integrated product design and development services from the initial idea to the finished products	—	—
B	UK	Electric vehicles	—	—	**Products:** ▪ Industrial electrical vehicles, e.g. tow tractors, powered / pedestrian controlled range personnel carriers **Services:** ▪ Scheduled maintenance ▪ Events hire and short term hire ▪ Service packages ▪ Spare parts ▪ Driver training ▪ Second hand equipment	—
C	UK	Engine technology	—	**Products:** ▪ Wankel type rotary engine for the automotive and aerospace sectors. e.g. 40S-5 BHP, 125CS-20 BHP **Services:** ▪ Maintenance ▪ Engine Integration ▪ Spare parts ▪ Technical supports	—	—
D	Malaysia	Petroleum	—	**Products:** ▪ Crude oil, Condensates, Gas **Services:** ▪ Equipment maintenance and inspection (internal service)	—	—

Table 8.1 Types of PSS in the case studied companies

8.4 The key uncertainty elements in PSS Inventory Control

In Chapter 6 a matrix was developed to assess the uncertainty factors in PSS inventory; identification and evaluation from the literature review was combined with the findings from the analysis of the case studies using the frequencies of occurrence analysis technique. Based on the matrix findings, uncertainty factors have more impact on the uncertainty of product rather than service; uncertainty factors in service is limited – see Table 6.2 and 6.3. There are 10 uncertainty elements from planning to design and development of PSS generated by Hepperle et al. (2010) and these were used as the basic platform to identify the key uncertainty elements in this research.

Figure 8.4 illustrates the uncertainty elements model of PSS Inventory Control in sequence from the highest uncertainty elements (market uncertainty) to the lowest uncertainty elements (uncertainty with remanufacturing). The uncertainty elements were derived from the development of an uncertainty matrix comparing the findings of uncertainty elements from Hepperle et al. (2010) with the findings from the case studies as developed in Table 6.2. The uncertainty elements model that been developed not only illustrate the ranking from the highest to the lowest but also show the interrelation of the uncertainty elements in PSS Inventory Control. All the case study companies are exposed to all of the uncertainty elements except remanufacturing uncertainty which only applied for Company B.

The highest uncertainty elements in planning of PSS Inventory Control are market uncertainty. Meanwhile, the highest uncertainty elements in design and development of PSS Inventory Control are product function uncertainty. The customer needs of PSS in product and service are different; for instance, a customer of Company C may just want to buy the product (before sales activity) and will order the spare parts and will perform the maintenance by themselves (after sales activity). In another example, a customer for Company B may need the product for short period of time with services for the product such as in-house maintenance if the product breakdown. This scenario is an example in planning of PSS Inventory Control for market analysis to minimize the market uncertainty. Companies A, B and C offer their customers bespoke products; this process will expose these companies to high product function uncertainty as the standard product functions or structure will need to be redesigned to meet the customer requirements.

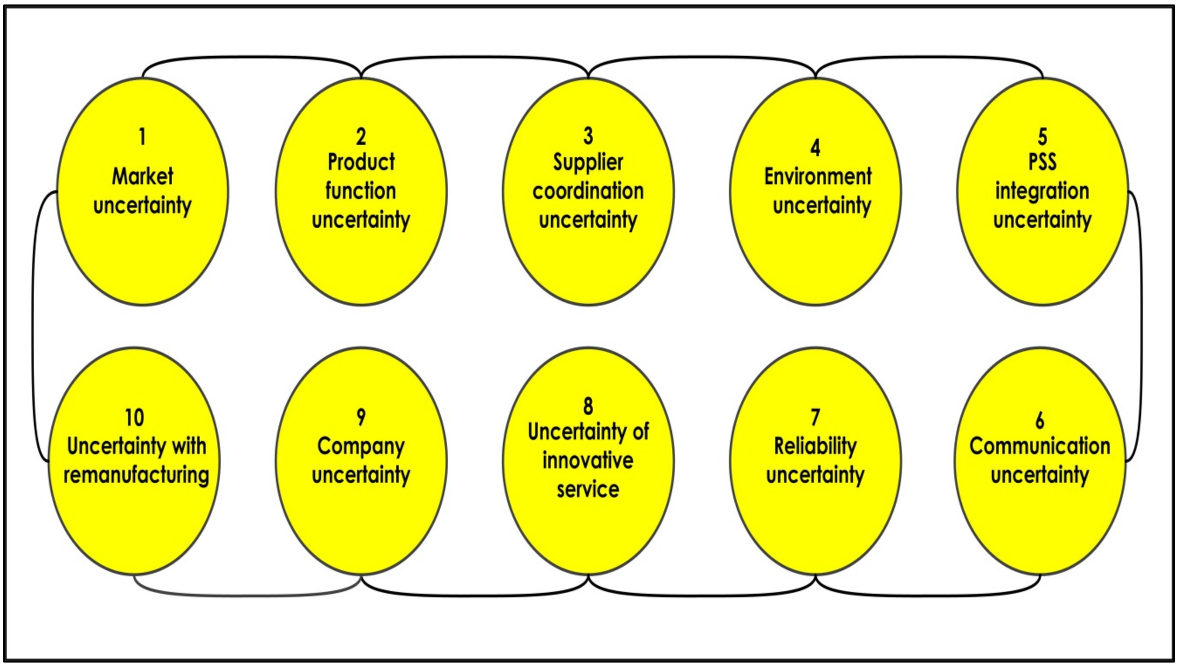

Figure 8.4 PSSIC uncertainty elements model

8.5 PSS Inventory Control practical application

The PSS Inventory Control practical applications were conducted through the validation of the generic model that was developed using IDEFØ – see Chapter 7. IDEFØ is a process modelling language that represents the flow of PSS Inventory Control activities and describes the relationships between them through the flow in both a hierarchical and parallel use of information. The validation was done to ensure that the generic model is useful and that it approximately represents the PSS Inventory Control requirements in each of the case study companies. The case study companies are from different types of manufacturing contexts which means that each of them has different types of characteristics in the PSS Inventory Control. Company A: Automotive, electrical and electronics industry; Company B: Electric vehicles; Company C: Engine technology; and Company D: Petroleum. The A0 level of IDEFØ was only used in this validation; as the purpose was to validate whether the generic model represents what activities the case study companies perform.

In Figure 8.5 to Figure 8.8, each of the generic models for each of the case studies company syntax arrows were coloured with blue solid lines and red dotted lines. The blue syntax arrows represent the elements and structure of PSS Inventory Control in the company; the red lines indicate the elements and structure of PSS Inventory Control that are not applicable or not normally used in the company. In Company A, red syntax arrows show that there was no After-Sales Care involved however it provides service for the customer between node A1 (Market and sell; product and service) and A2 (Design configuration). The validation achieved all solid blue syntax arrows for Company B; the only company in this study that has remanufacturing elements in it's operation. Company C does not provide any services (After-Sales Care) on a regular basis to their customer at customer's facilities or at it factory but it does offer spare parts to its customers; in the validation the researcher used red syntax arrows to show this area. Company D is another unique example of PSS companies as it only performs it services for its operation not for the customer.

This validation found that:

- Overall, the generic model matches well with each of the case study companies.
- As the case study companies represent the 4 different types of manufacturing, the generic model can be used as a reference for practitioners or researchers, and a platform for them to generate appropriate requirements for their own PSS Inventory Control.

- IDEFØ in this generic model has not only been used as a static process modelling language method to represent the process including the dependencies of certain tasks, but has also been used to generate requirements of PSS Inventory Control. For example, during the activity in the A3 “Prepare resources”, the activity is affected by the output of activity in A2 “Design configuration” together with constraint elements for A3. The output of the A3 then affects the following three activities (A4, A5 and A6), and all of these relationship can be accurately represented in IDEFØ.

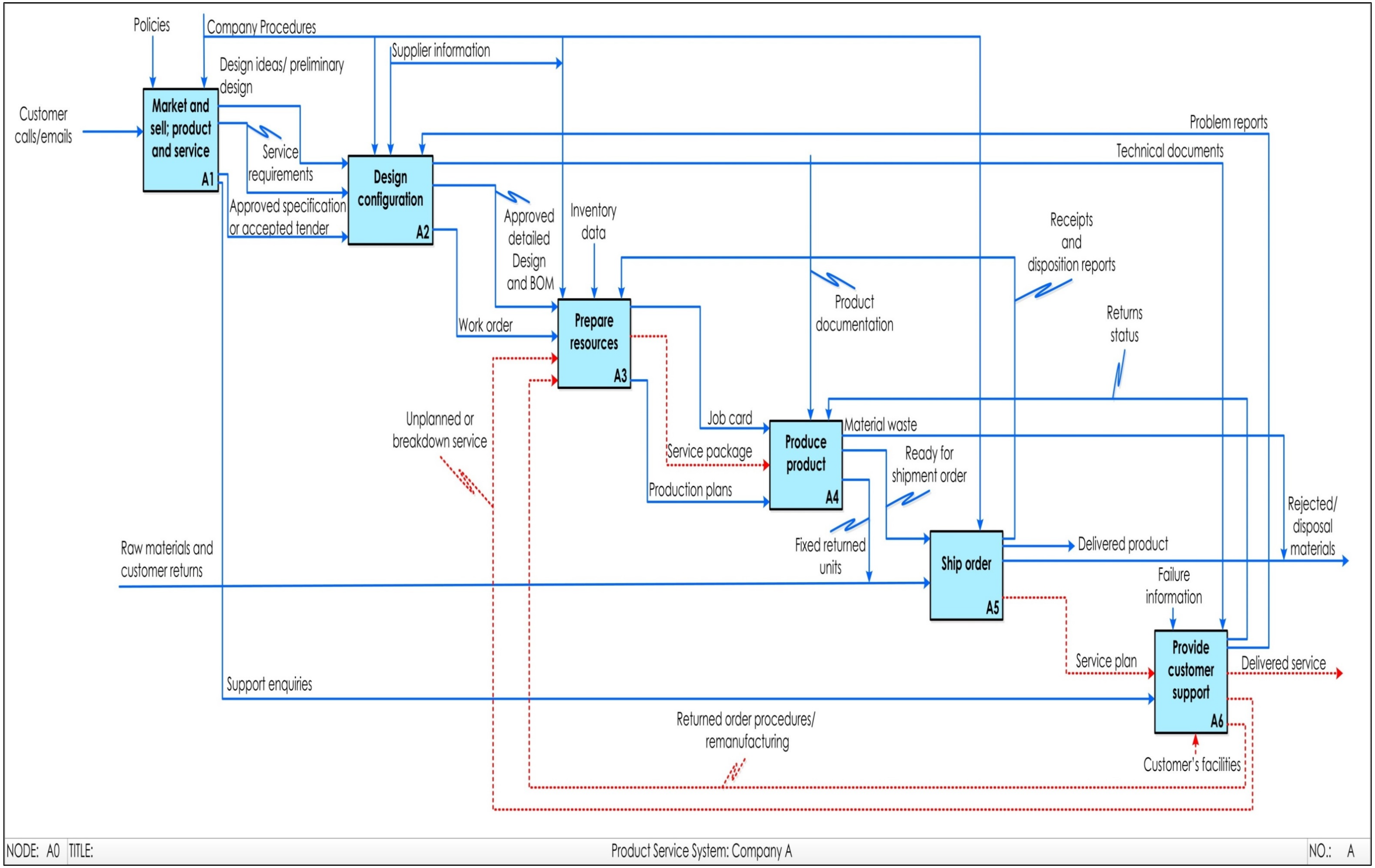

Figure 8.5 Validation of the generic model in Company A

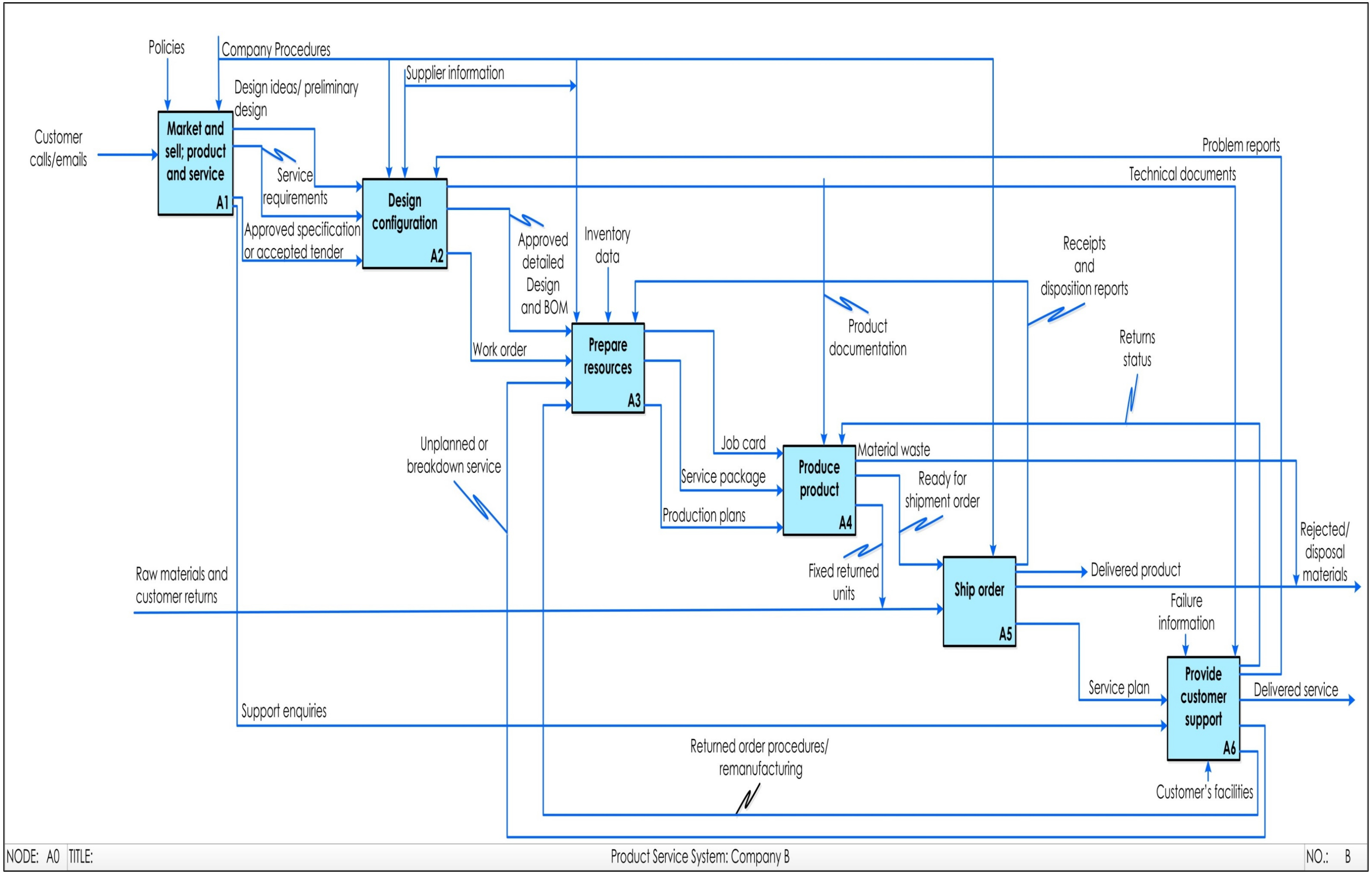

Figure 8.6 Validation of the generic model in Company B

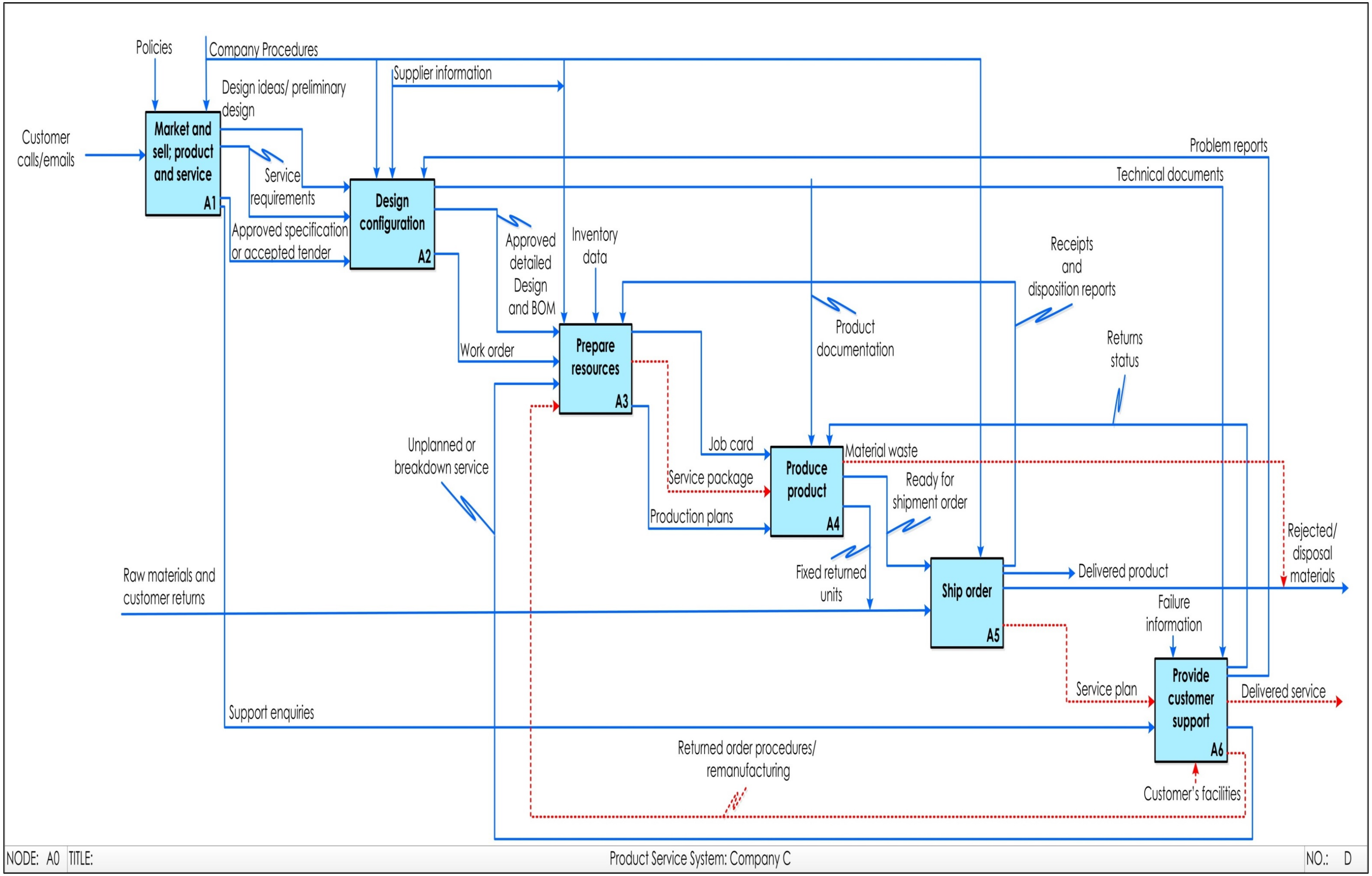

Figure 8.7 Validation of the generic model in Company C

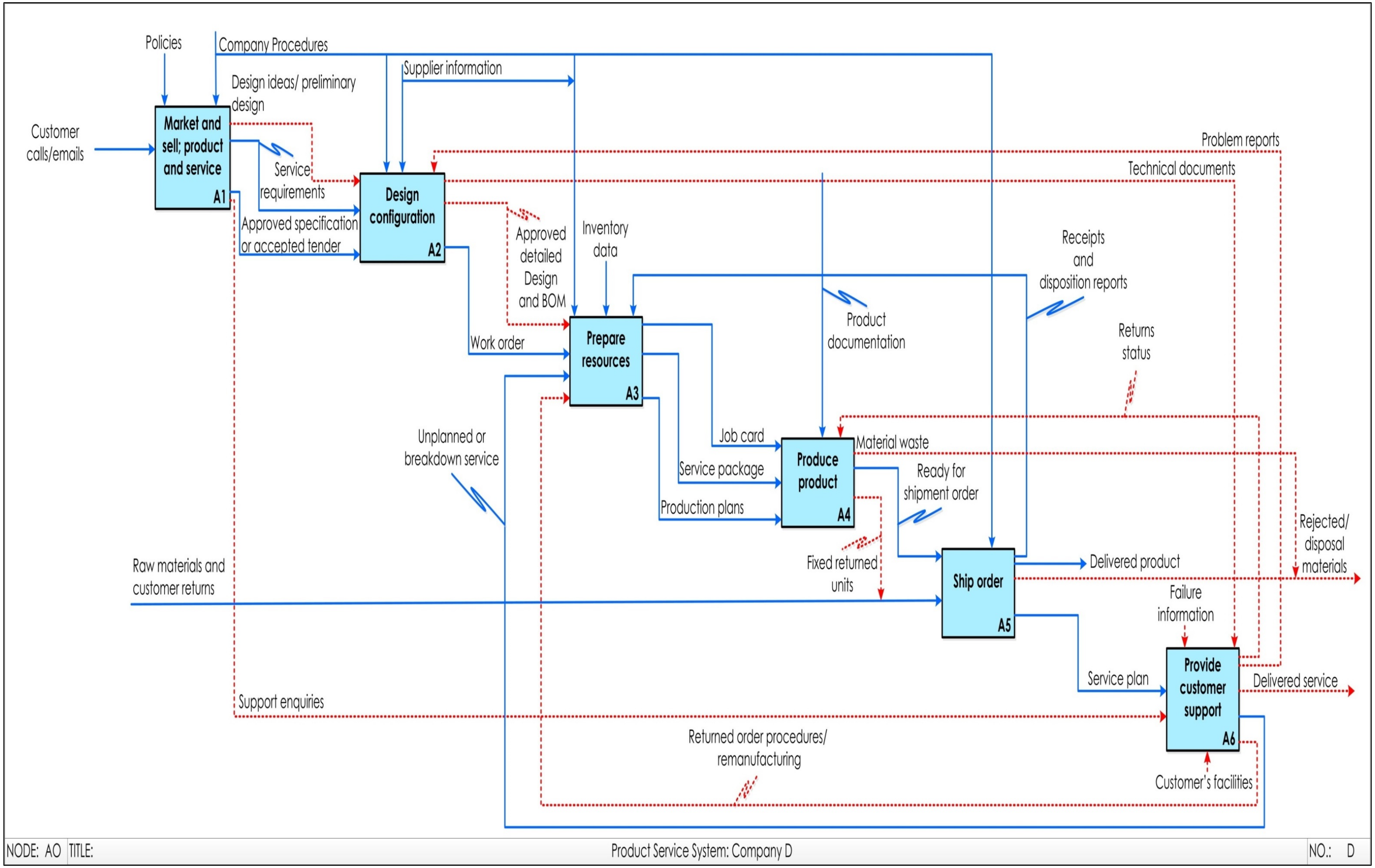

Figure 8.8 Validation of the generic model in Company D

8.6 Chapter summary

This chapter has discussed the key findings of the research: methodology for development of PSS Inventory Control in manufacturing operations perspectives; characteristics of PSS Inventory Control in manufacturing operations perspectives (industrial context); uncertainty elements in PSS Inventory Control; and practical application of the PSS Inventory Control.

The next chapter will present how research objectives were met; answer of the research questions; make contributions to knowledge; and recommend future research in the field before drawing the general conclusions.

9. Conclusion

This chapter concludes the work carried out in this research; presents answer for the research questions and how the research objectives were achieved. The chapter also describes the research contributions to academia and industry concerning PSS Inventory Control in manufacturing operations perspectives. *Finally, possibilities for improving this research and directions for future research are documented.*

9.1 Answering the research questions

This research sets out to answer five research questions; the answers produced by this research are depicted in Table 9.1 with respect to each research question:

Research questions	Research questions answers
1) What are the main debates related to PSS in manufacturing operations perspective?	▪ Clarifying terminology of PSS paradigm ▪ Not all publications are written in English ▪ No standard and applicable conceptual, methods or models of PSS in manufacturing operations perspective ▪ Adoptability of PSS methodologies in different field ▪ Understanding the PSS paradigm in all company sizes
2) What are the salient features of inventory control required for effective operation in manufacturing operations perspectives?	▪ Accurate quantities ▪ Storage locations ▪ Pricing and identification ▪ Tracking and tracing inventory flows ▪ Capacity in managing inventory ▪ Minimise/eliminate damage inventory ▪ Inventory identification
3) What are the main elements of uncertainty in PSS Inventory Control?	▪ Market uncertainty ▪ Company uncertainty ▪ Environment uncertainty ▪ Reliability uncertainty ▪ Product function uncertainty ▪ Uncertainty of innovative service ▪ PSS integration uncertainty

	▪ Supplier coordination uncertainty ▪ Communication uncertainty ▪ Uncertainty with remanufacturing
4) How can the key characteristics in PSS Inventory Control be modelled for practitioners?	Using IDEFØ
5) How can a company manage the interface between product and service to successful inventory control?	Applying PSSIC Framework

Table 9.1 Research objectives achievements

9.2 Achieving research objectives

Four objectives were outlined to achieve the research aim; a summary of how each objective was achieved is documented in Table 9.2:

Research Objectives	Achieving research objectives
Objective 1: To identify, categorise and evaluate the system characteristics of PSS across a representative range of manufacturing operations contexts.	This objective was met through after conducting an extensive review of the literature published in the areas of manufacturing paradigm, servitization and PSS.
Objective 2: To determine the requirements for and related characteristics of inventory control in PSS and how these vary depending on the degree of focus on the service aspects of PSS.	This objective was met through with two approaches: conducting an extensive review of the literature published in the areas PSS and Inventory Control; and conducting survey in manufacturing companies.
Objective 3: To identify the key uncertainty elements relating to PSS Inventory Control.	The objective was met by a comparative in-depth from Hepperle et al. (2010) research with the data collected by the current researcher using a matrix method.
Objective 4: To create a generic system model incorporating all the key characteristics and flows in PSS from a manufacturing operations perspective.	The objective was met by developing the generic model using IDEFØ. The objective was met by adapting Tukker (2004) eight types of product–service system sustainability model

Table 9.2 Research objectives achievements

9.3 Scope and limitations

Many researchers have studied PSS or inventory control in manufacturing but not the consequences to be addressed in inventory control due to the PSS manufacturing operations perspective even though a large percentage of real-world manufacturers face this problem. Clearly, PSS in manufacturing operations perspectives has a broad coverage. This research will be limited to examine of how the discussion on PSS Inventory Control operates as a system. The main focus of this research is to study the interactions between PSS and inventory control system in manufacturing operations perspectives. This research mainly focuses upon product-centric manufacturers that transform their company to PSS manufacturing or PSS manufacturing companies that want to enhance their business strategy in inventory control.

The research has attempted to go beyond the purely theoretical level by providing credible results for implementation. The dominant interests within this research included uncertainty, service, product and PSS in manufacturing perspective. Other activities within the PSS that do not have any connection and integration between product and service and inventory has been omitted in order to provide an initial focus for the methodology. The method of this research was adapted from current multiple criteria in PSS from sustainability perspective and inventory control in manufacturing perspective. The research methodology was tested on real data collection from a factory in order to obtain typical results. Industrial tools selection was targeted towards linking PSS and inventory control in implemented the research works. Regardless of the stated limitations in the scope, the methodology should be of value in some areas of manufacturing.

There are limitations associated with this research. Firstly, the research has focussed solely on manufacturing operations by applying a case study method and therefore the possibilities to generalise further from the case studies to other manufacturing contexts such as manufacturing strategy, manufacturing design, manufacturing management and manufacturing productivity are limited.

However, the aim of this research is not to achieve generalisation over the broad spectrum of PSS Inventory Control in other fields; but, rather, to use the case studies to validate of the research from the manufacturing operations perspectives only. Secondly, the research utilises small and medium sized manufacturing in the United Kingdom and Malaysia; thus, generalisation of the findings to other sizes of manufacturing in the United Kingdom and Malaysia or other countries may or not yield similar findings. Finally, the researchers should be cautious when using the current research findings as the context of this research is manufacturing perspectives; the findings may no longer be accurate when totally diverged from the context for instance sustainability perspectives. The constructions from different perspectives may have different definitions and perceptions in different environments.

9.4 Research contributions

This research has done by conducting surveys; constructing four case studies from companies in the United Kingdom and Malaysia; identifying uncertainty elements in PSS Inventory Control; developing and validating of the generic model using IDEFØ. It has been successful in studying Product-Service System (PSS) in manufacturing operations perspectives and inventory control elements in the PSS operations. This research builds on the work of PSS in manufacturing operations however, from sustainability perspectives such as work from Baines and Lightfoot (2013), Ahamed et al. (2013), Boehm and Thomas (2013), and Tukker (2004); and also through case development from the industry in the United Kingdom and Malaysia. The research by Baines and Lightfoot (2013), Ahamed et al. (2013), Boehm and Thomas (2013), and Tukker (2004) were selected even though the works focused on PSS from sustainability as they still provide useful insights into this research context. There were very limited instructive case studies in manufacturing operations, however, the previously mentioned papers show how service as an added value in manufacturing operations works in products domains; and how manufacturers' competencies can be exploited to transform from traditional manufacturers to PSS manufacturers. Researchers will benefit from this study researching into PSS Inventory Control and the findings of this research will contribute to the advancements in PSS and inventory control from manufacturing perspectives framework. The work presented in this thesis contributes to both theoretical and industrial practice by:

- Clarifying the elements in PSS Inventory Control from manufacturing operations perspectives. PSS is an interdisciplinary field and the definitions generated in the publication have a lack of focus on the manufacturing perspective. Understanding a PSS as a system is particularly important for supporting meaningful research. This research examines PSS from a manufacturing operations perspective by taking the epistemological position of an interpretivist viewpoint, specifically, the research focuses on the PSS Inventory Control. The literature published on PSS reveals: methods and models of PSS generated according to work areas such as sustainability and design; and no specific research done from a manufacturing operations perspective that relates specifically to inventory control.

- Developing four case studies that demonstrate that PSS Inventory Control can be applied in different types of manufacturing sectors such as automotive, spare parts and oil and gas industry. Prior to this research there had been no through review of the case studies development in PSS Inventory Control from manufacturing operations perspectives; most of the case studies are confidential case study approaches and collaborations with industry. The case studies were developed in Chapter 5 which was then used to study the PSS Inventory Control uncertainty elements found within Chapter 6 and generic model of PSS Inventory Control in Chapter 7. The implications of this case study companies contribution should allow researchers or practitioners a clearer perceptive in transformation or improvement of their business strategy and operation.

- Identifying potential uncertainty elements in PSS Inventory Control and the importance of considering these when planning inventory control methods; all the case study companies are exposed to all of the uncertainty elements except remanufacturing uncertainty which only applied for company that offers remanufacturing in their business. A detailed discussion of uncertainty in PSS Inventory Control was presented in Chapter 6. The main elements of uncertainty for all the case companies are market uncertainty; product function uncertainty and supplier coordination uncertainty. Therefore, other researchers or practitioners should give high attention to the main elements of uncertainty as key factors to minimize or eliminate the uncertainty risk in their operation.

- Developing a generic model of PSS Inventory Control using IDEFØ and a PSSIC Framework. The generic model PSS Inventory Control using IDEFØ was developed in Chapter 7 and the validation of the generic model were conducted in Chapter 8. This generic model provides different types of PSS characteristics to be implemented into manufacturing companies from generate design ideas to unplanned services or maintenance. IDEFØ provided the generic model that can accurately describe the various situations and operations of PSS. PSSIC Framework gives perspectives of integration between product and service from manufacturing operations perspectives and aimed to be used by traditional manufacturers who want to transform their companies into PSS businesses or by PSS companies who that want to improve their inventory control; the company must have 3 elements in their operation: product, service and process. Highlighting the elements that are needed to be performed in the company strategy will enable manufacturers to gain greater understanding in the transformation or improvement process.

9.5 Future work

Potential valuable future work in this research area includes:

- Gathering quantitative data for additional applications for inventory control; inventory control in PSS not only about understanding the integration of products and services but also the quantity needed and cost involves in the operation. For instance, formulating financial model incorporating PSS inventory cost that will give a direct estimate for company profit.

- More work is needed to identify the uncertainty elements in service area in PSS to integrate uncertainty element in service. The research conducted by Hepperle et al. (2010) identified uncertainty elements in PSS which focused on planning phase; and design and development. However, the identified uncertainty elements have limited impact on service.

- Testing the compatibility of the generic model to a wider range, complex applications and different sizes of company; further research should be conducted to determine whether the generic model is contingent on other factors. Also, extending the generic model PSS Inventory Control using IDEFØ with dynamic model such as IDEF3.

10. References

Ahamed, Z., Inohara, T. and Kamoshida, A., 2013. The Servitization of Manufacturing: An Empirical Case Study of IBM Corporation. *International Journal of Business Administration*, 4(2), pp.18–27.

Åhlström, P. and Nordin, F., 2006. Problems of establishing service supply relationships: Evidence from a high-tech manufacturing company. *Journal of Purchasing and Supply Management*, 12(2), pp.75–89.

Allan, A. G. and Randy, L.J., 2005. *Writing the winning thesis or dissertation: A step-by-step guide*, California: Corwin Press Inc.

Almeida, L.F., Miguel, P.A.C. and Silva, M.T.D., 2008, May. A literature review of servitization: a preliminary analysis. In Proceedings of the POMS 19th annual conference (pp. 9-12).

Alonso-Rasgado, T., Thompson, G. and Elfström, B.-O., 2004. The design of functional (total care) products. *Journal of Engineering Design*, 15(6), pp.515–540.

Anosike , A.I. and Zhang , D.Z., 2006. Dynamic reconfiguration and simulation of manufacturing systems using agents. *Journal of Manufacturing Technology Management*, 17(4), pp.435–447.

Anderson, J.C. and James A. Narus., 1995. Capturing the Value of Supplementary Services. *Harvard Business Review 73 (January-February)*, pp.75–83.

Anderson, E.W., Fornell, C. and Rust, R.T., 1997. Customer satisfaction, productivity, and profitability: Differences between goods and services. *Marketing Science*, 16(2), pp.129–145.

Anderson, N.R. and West, M.A., 1998. Measuring climate for work group innovation: development and validation of the team climate inventory. *Organizational Behavior*, 19(3), pp.235–258.

Anderson, J.C., Narus, J.A. and Van Rossum, W., 2006. Customer value propositions in business markets. *Harvard Business Review*, 84(3), pp.91–99.

Antonacopoulou, E.P. and Konstantinou, E., 2008. The New Service Model: a review, a critique and a way forward. *Service Industries Journal*, 28(6), pp.845–860.

Armistead, C. and Clark, G., 1994. The “coping” capacity management strategy in services and the influence on quality performance. International Journal of Service Industry Management, 5(2), pp.5-22.

Avșar, Z.M. and Henk Zijm, W., 2014. Approximate queueing models for capacitated multi-stage inventory systems under base-stock control. *European Journal of Operational Research*, 236(1), pp.135–146.

Azarenko, A., Roy, R., Shehab, E. and Tiwari, A., 2009. Technical product-service systems: some implications for the machine tool industry. Journal of Manufacturing Technology Management, 20(5), pp.700-722.

Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A. and Alcock, J.R., 2007. State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 221(10), pp.1543-1552.

Baines, T., Lightfoot, H., Peppard, J., Johnson, M., Tiwari, A., Shehab, E. and Swink, M., 2009a. Towards an operations strategy for product-centric servitization. International Journal of Operations & Production Management, 29(5), pp.494-519.

Baines, T.S., Lightfoot, H.W., Benedettini, O. and Kay, J.M., 2009b. The servitization of manufacturing: A review of literature and reflection on future challenges. Journal of Manufacturing Technology Management, 20(5), pp.547-567.

Baines, T.S. and Lightfoot, H., 2013. Made to serve; Understanding what it takes for a manufacturer to compete through servitization and Product-Service Systems. Hoboken: Wiley.

Becker, G.S., 1962. Irrational behavior and economic theory. *Political Economy*, 70(1), p. 1–13.

Becker, H.S., 1965. *Sociological Work*, Chicago: Aldine.

Behrendt, S., Jasch, C., Kortman, J., Hrauda, G., Pfitzner, R. and Velte, D., 2003. Eco-service development-reinventing supply and demand in the European Union (Vol. 14, No. 3, pp. 424-425). Emerald Group Publishing Limited.

Bell, A.E., 2004. Death by UML fever. Queue, 2(1), p.72.

Berling, P. and Marklund, J., 2013. A model for heuristic coordination of real life distribution inventory systems with lumpy demand. *European Journal of Operational Research*, 230(3), pp.515–526.

Besch, K., 2005. Product-service systems for office furniture: Barriers and opportunities on the European market. *Journal of Cleaner Production*, 13(10-11), pp.1083–1094.

Birley, G. and Moreland, N., 1998. A Practical Guide to Academic Research, London: Kogan Page Ltd.

Bitner, M.J. and Brown, S.W., 2008. The service imperative. *Business Horizons*, 51(1), pp.39–46.

Blackstone, J.H.J. and Cox, J.F., 2005. *APICS: The association for operations management.* 11th ed., APICS Dictionary.

Boehm, M. and Thomas, O., 2013. Looking beyond the rim of one's teacup: A multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. *Journal of Cleaner Production*, 51, pp.245–250.

Bowen, G. a, 2005. Preparing a qualitative research-based dissertation: Lessons learned. *The Qualitative Report*, 10(2), pp.208–222.

Buchanan, D.A. and Bryman, A., 2009. *The SAGE Handbook of Organizational Research Methods*, London: SAGE.

Bradbury-Huang, H., 2010. What is good action research?: Why the resurgent interest? *Action Research*, 8(1), pp.93–109.

Brady, T., Davies, A. and Gann, D.M., 2005. Creating value by delivering integrated solutions. *International Journal of Project Management*, 23(5 SPEC. ISS.), pp.360–365.

Brandstotter, M., Haberl, M., Knoth, R., Kopacek, B. and Kopacek, P., 2003, December. IT on demand-towards an environmental conscious service system for Vienna (AT). In Environmentally Conscious Design and Inverse Manufacturing, 2003. EcoDesign'03. 2003 3rd International Symposium on (pp. 799-802). IEEE.

Brax , Saara, 2005. A manufacturer becoming service provider – challenges and a paradox. *Managing Service Quality*, 15(2), pp.142–155.

Brezet, J.C., Bijma, A.S., Ehrenfeld, J. and Silvester, S., 2001. The design of eco-efficient services. Delft University of Technology, Design for Sustainability Program, Delft, pp.599-616.

Bromley, D.B., 1986. The Case-study Method in Psychology and Related Disciplines , Chichester: Wiley.

Bryman, A. (1988). Quantity and quality in social research. London: Unwin Hyman.

Bryman, A., 2001. *Social Research Methods*, Oxford: Oxford University Press.

Bryman, A. and Bell, E., 2007. *Business Research Methods* 2 ed., Oxford: Oxford University Press.

Chase, R.B., 1981. The Customer Contact Approach to Services: Theoretical Bases and Practical Extensions. *Operations Research*, 29(4), pp.698–706.

Cheng, C.-Y., Barton, D. and Prabhu, V., 2010. The servicisation of the cutting tool supply chain. *International Journal of Production Research*, 48(1), pp.1–19.

Cohen, M.A., Agrawal, N. and Agrawal, V., 2006. Winning in the aftermarket. Harvard business review, 84(5), p.129.

Collis, J. and Hussey, R., 2003. *Business Research: A Practical Guide for Undergraduate and* 2nd edn., Basingstoke: Palgrave Macmillan.

Creswell, J., 2013. *Research design.Qualitative, quantitative and mixed methods approaches* 3rd ed., CA: Thousand Oaks.

Crotty, M., 1998. *The Foundation of Social Research: Meaning and Perspectives in the Research Process.*, London: SAGE.

Crul, M., Diehl, J.C. and Ryan, C., 2009. Design for sustainability-A step-by-step approach. UNEP, Paris.

Datta, P.P. and Roy, R., 2011. Operations strategy for the effective delivery of integrated industrial product-service offerings: Two exploratory defence industry case studies. *International Journal of Operations & Production Management*, 31(5), pp.579–603.

Davies, A., 2004. Moving base into high-value integrated solutions: A value stream approach. *Industrial and Corporate Change*, 13(5), pp.727–756.

Davies, A., Brady, T. and Hobday, M., 2006. Charting a path towards integrated solutions. *Sloan Management Review, Spring*, pp.8–49.

Denscombe, M., 2010. *The good research guide: For small-scale social research projects* 4th ed., Maidenhead, England: McGraw-Hill/Open University Press.

Desmet, S., van Dierdonck, R. and van Looy, B. (2003), "Servitization: or why services management is relevant for manufacturing environments", in van Looy, B., Gemmel, P. and van Dierdonck, R. (Eds), Services Management: An Integrated Approach, Harlow: Pearson Education Limited.

De Toni, A., Nassimbeni, G. and S. Tonchia., 1994. Service dimensions in the buyer supplier relationship: A case study. Physical Distribution & Logistics Management, 24(8), p. 4–14.

Easterby-Smith, M.P. V, Thorpe, R. and Lowe, A., 2002. Management Research: An Introduction M. Easterby-Smith & R. Thorpe, eds. *London Sage publication*, 2nd, p.194.

Eisenhardt, K.M., 1989. Building theories from case-study research. *Academy of Management Review*, 14(4), pp.532–550.

Evans, T., 2007. Environmental impact study of food waste disposers. available online][accessed 26th April 2015] available on World Wide Web via http://www.insinkerator.com/environmental/global.shtml.

Ferris, T.L., 2009. On Methods of Research for Systems Engineering (Doctoral dissertation, Loughborough Uni).

Fuchs, V.R., 1965. The growing importance of the service industries. *Business*, 38(4), pp.344–373.

FOLDOC. "Knowledge-Based System (KBS)," FOLDOC-Free [Online] http://foldoc.org/knowledge-based%20system. [Accessed: July. 1, 2016]

Ford, H. and S. Crowther., 1992. *My Life and Work: Doubleday* 1992, Page & Company.

Forster, N., 1994. *The analysis of company documentation. In C. Cassell & G. Symon*, London: Sage Publications.

Forza, C., 2002. Survey research in operations management: a process-based perspective. *International Journal of Operations & Production Management*, 22(2), pp.152–194.

Gaiardelli, P., Resta, B., Martinez, V., Pinto, R. and Albores, P., 2014. A classification model for product-service offerings. Journal of Cleaner Production, 66, pp.507-519.

Galbraith, J.R., 2002. Organizing to deliver solutions. *Organizational Dynamics*, 31(2), pp.194–207.

Gebauer, H. and Kowalkowski, C., 2012. Customer-focused and service-focused orientation in organizational structures. *Journal of Business & Industrial Marketing*, 27(7), pp.527–537.

Gillham, B., 2000. *The Research Interview*, London and New York: Continuum.

Goedkoop, M., Van Halen, C.J., Te Riele, H. and Rommens, P.J., 1999. Product service systems, ecological and economic basics. Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ), 36(1), pp.1-122.

Goffin, K. and New, C., 2001. Customer support and new product development - An exploratory study. *International Journal of Operations & Production Management*, 21(3), pp.275–301.

Graziano, A. M., and Raulin, M.L., 2007. *Instructor's manual to accompany "Research Methods: A process of inquiry"* 6th ed., Boston: Allyn & Bacon.

Gruber. Thomas R., 1993. *A Translation Approach to Portable Ontology Specifications.Knowledge Acquisition*, Stanford, California.

Gruneberg, S., Hughes, W. and Ancell, D., 2007. Risk under performance based contracting in the UK construction sector. *Construction Management and Economics*, 25(7), pp.691–699.

Guba, E.G. & Lincoln, Y.S., 1994. Competing Paradigms in Qualitative Research Denzin & Y. S. & N. K. Lincoln, eds. *Handbook of qualitative research*, pp.pp. 105–117.

Gunasekaran, A., 1999. Agile manufacturing: a framework for research and development. *International Journal of Production Economics*, 62(1), pp.87–105.

Hakim, C., 2000. *Research Design: Successful Designs for Social and Economic Research* 2nd edn., London: Routledge.

Halme, M., Anttonen, M., Kuisma, M., Kontoniemi, N. and Heino, E., 2007. Business models for material efficiency services: Conceptualization and application. Ecological Economics, 63(1), pp.126-137.

Henkel , Carsten B, Oliver B Bendig, Tobias Caspari, and N.H., 2004. *Industrial Services Strategies: The quest for faster growth and higher margins*, Consultancy Report, Monitor Group.

Hepperle, C., Orawski, R., Nolte, B, D., Mortl, M., Lindermann, U., 2010. An Integrated Lifecycle Model of Product Service Systems, CIRP IPS2 conference 2010.

Hiles, D., 2008. “Axiology.” In LM Given (ed.), ed. *The SAGE encyclopedia of qualitative research methods*. Thousand Oaks, CA, : SAGE Publications, pp. 53–7.

Hill, T.P., 1977. On Goods and Services. *Review of Income and Wealth*, 23(4), pp.315–338.

Hockerts, K. and Weaver, N., 2002. Are service systems worth our interest. Assessing the eco-efficiency of sustainable service systems, working document INSEAD. Fontainebleau, France, 3.

Investopedia. “Inventory Management,” investopedia.com. [Online]. Available:http://www.investopedia.com/terms/i/inventory-management.asp#axzz2HbbwWeph [Accessed: Aug. 1, 2016]

Ismail, S.Z.B., Morton, S.C., Harding, J.A. and Michaelides, R., 2015, March. Product-Service System in inventory control: A new paradigm? In Industrial Engineering and Operations Management (IEOM), 2015 International Conference on (pp. 1-6). IEEE.

James, P., Slob, A. and Nijkuis, L., 2001. *Environmental and Social Well Being in the New Economy: Sustainable Services – An Innovation Handbook*, Bradford: University of Bradford.

Johnson, P, and Clark, M., 2006. *Research Methods in Business and Management : Volume 1: Recent Methodological Debates in Business and Management Research*, London: Sage.

Johnson, R.B., Onwuegbuzie, A.J. and Turner, L.A., 2007. Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research*, 1(2), pp.112–133.

Johnson, R. B., and Christensen, L.B., 2010. *Educational research: Quantitative, qualitative, and mixed approaches* 4th ed., Thousand Oaks: CA: Sage.

Johnstone, S., Dainty, A. and Wilkinson, A., 2008. In search of “product-service”: evidence from aerospace, construction, and engineering. *The Service Industries Journal*, 28(6), pp.861–875.

Kim, S.-H., Cohen, M.A. and Netessine, S., 2007. Performance Contracting in After-Sales Service Supply Chains. *Management Science*, 53(12), pp.1843–1858.

Kitson, H.D., 1922. The Growth of the" Service Idea" in Selling. The Journal of Political Economy, pp.417-419.

Kelly, G., 1955. The psychology of personal constructs: A theory of personality, New York: Norton.

Kriston, A., Szabó, T. and Inzelt, G., 2010. The marriage of car sharing and hydrogen economy: A possible solution to the main problems of urban living. *International Journal of Hydrogen Energy*, 35(23), pp.12697–12708.

Kuhn, T.S., 1962. *The Structure of Scientific Revolutions*, London: The University of Chicago Press.

Kumar, N., 2004. *Marketing as strategy: understanding the CEO’s agenda for driving growth and innovation*, Boston: Harvard Business School Press.

Kumar Rajesh and Kumar Uday, 2004. A conceptual framework for the development of a service delivery strategy for industrial systems and products. *Journal of Business & Industrial Marketing*, 19(5), pp.310–319.

Kvale Steinar, 2007. *Doing Interviews* , Thousand Oaks: SAGE Publications.

Lee, N. and Lings, I., 2008. *Doing Business Research: A Guide to Theory and Practice* Sage., London.

Lee, T.W., 1999. *Using Qualitative Methods in Organizational Research* 1st ed., Thousand Oaks: CA: SAGE Publications.

Levitt, T., 1969. *The Marketing Mode: Pathways to Corporate Growth.*, New York: McGraw-Hill.

Levitt, T., 1972. Production-line approach to service. *Harvard Business Review*, 50(5), pp.41–52.

Lewis, M., Portioli Staudacher, A. and Slack, N., 2004. Beyond products and services: opportunities and threats in servitization. In *The IMS International Forum 2004*. pp. 162–70.

Lightfoot, H., Baines, T. & Smart, P., 2013. The servitization of manufacturing: A systematic literature review of interdependent trends. *International Journal of Operations and Production Management*, 33(11), pp.1408–1434.

Lincoln, Y.S. & Guba, E.G., 1985. *Naturalistic Inquiry*, Beverley Hills: Sage.

Lincoln, Yvonna S. and Guba, E.G., 2000. *Paradigmatic controversies, contradictions, and emerging confluences. In Norman K. Denzin & Yvonna S. Lincoln (Eds.), The handbook of qualitative research* 2nd edn., London: SAGE.

Lindahl, M. and Ölundh, G., 2001, June. The meaning of functional sales, Life Cycle Engineering: Challenges and Opportunities. In Proceedings of 8th International Seminar on Life Cycle Engineering, Varna, Bulgaria.

Lindahl, M., Sundin, E., Shimomura, Y. and Sakao, T., 2006. An outline of an interactive design model for service engineering of functional sales offers. In DS 36: Proceedings DESIGN 2006, the 9th International Design Conference, Dubrovnik, Croatia.

Lindberg, N. and Nordin, F., 2008. From products to services and back again: Towards a new service procurement logic. *Industrial Marketing Management*, 37(3), pp.292–300.

Lindlof, T. (Tom) R., 1995. Qualitative Communication Research Methods, Thousand Oaks: SAGE.

Lodefalk, M., 2010. *Servicification of Manufacturing-Evidence from Swedish Firm and Enterprise Group Level Data.*

Lovelock, C. and Gummesson, E., 2004. Whither services marketing? *Journal of Service Research*, 7(1), pp.20–41.

Lusch, R.F. and Vargo, S.L., 2006. Service-dominant logic: reactions, reflections and refinements. Marketing theory, 6(3), pp.281-288.

Magretta, J., 2002. Why business models matter. *Harvard Business Review*, 80(5), pp.86–87.

Maines, D.R., Shaffir, W. and Turowetz, A., 1980. Leaving the field in ethnographic research: Reflections on the entrance-exit hypothesis. Fieldwork experience: Qualitative approaches to social research, pp.261-80.

Manzini, E. and Vezzoli, C., 2003. A strategic design approach to develop sustainable product service systems: Examples taken from the "environmentally friendly innovation" Italian prize. *Journal of Cleaner Production*, 11(8 SPEC.), pp.851–857.

Manzini, E., Collins, L. and Evans, S. eds., 2004. Solution oriented partnership: how to design industrialised sustainable solutions. Cranfield University.

Marklund, J., 2011. Inventory control in divergent supply chains with time-based dispatching and shipment consolidation. *Naval Research Logistics*, 58(1), pp.59–71.

Marklund, J. and Rosling, K., 2012. Lower Bounds and Heuristics for Supply Chain Stock Allocation. *Operations Research*, 60(1), pp.92–105.

Mathieu , Valérie, 2001. Service strategies within the manufacturing sector: benefits, costs and partnership. *International Journal of Service Industry Management*, 12(5), pp.451–475.

Maull, R., Smart, A. and Liang, L., 2013. A process model of product service supply chains. Production Planning & Control, , pp. 1-16.

McLoughlin, C., 2015. When Does Service Delivery Improve the Legitimacy of a Fragile or Conflict-Affected State?. Governance, 28(3), pp.341-356.

Meier D., H.. K., 2007. Operation fields and solution approaches for the automation of service processes of industrial product-service-systems. *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses*, pp.159–163; 480.

Meier, H., Roy, R. & Seliger, G., 2010. Industrial Product-Service systems-IPS2. *CIRP Annals - Manufacturing Technology*, 59(2), pp.607–627.

Meier, H., Völker, O. and Funke, B., 2011. Industrial Product-Service Systems (IPS2) : Paradigm shift by mutually determined products and services. *International Journal of Advanced Manufacturing Technology*, 52(9-12), pp.1175–1191.

Meijkamp, R., 2000. Changing Consumer Behaviour through Eco-efficient Services. An Empirical Study of Car Sharing in The Netherlands. *Doctoral Thesis, Delft University of Technology* .

Miles, MB. and Huberman, A., 1994. *Qualitative Data Analysis* 2nd ed., Thousand Oaks, CA: Sage Publications.

Miller, D. and Hartwick, J., 2002. The problem of solutions: balancing clients and capabilities. *Business Horizons, March / April*, pp.3–12.

Minguez, J., Baureis, D. and Neumann, D., 2012. A reference architecture for agile product-service systems. CIRP Journal of Manufacturing Science and Technology, 5(4), pp.319-327.

Moeller, S., 2010. Characteristics of services – a new approach uncovers their value. *Journal of Services Marketing*, 24(5), pp.359–368.

Mont, O.K., 2002. Clarifying the concept of product-service system. *Journal of Cleaner Production*, 10(3), pp.237–245.

Mont, O., 2004. Institutionalisation of sustainable consumption patterns based on shared use. *Ecological Economics*, 50(1-2), pp.135–153.

Mont, O. and Tukker, A., 2006. Product-Service Systems: reviewing achievements and refining the research agenda. *Journal of Cleaner Production*, 14(17), pp.1451–1454.

Morelli, N., 2003. Product-service systems, a perspective shift for designers: A case study - The design of a telecentre. *Design Studies*, 24(1), pp.73–99.

Morelli, N. (2006). Developing new product service systems (PSS): methodologies and operational tools. Journal of Cleaner Production, 14(17), 1495–1501.

Morgan, G., 1979. Response to Mintzberg. *Administrative Science Quarterly*, 24(1), pp.137–139.

Morrison, K.R.B., 1993. *Planning and Accomplishing School-Centred Evaluation*, Dereham, UK: Peter Francis.

Müller, P., Schulz, F. and Stark, R., 2012, October. Guideline to elicit requirements on industrial product-service systems. In Proceedings of the 2nd CIRP IPS2 Conference 2010; 14-15 April; Linköping; Sweden (No. 077, pp. 109-116). Linköping University Electronic Press.

Müller, P. and Stark, R., 2010. A generic PSS development process model based on theory and an empirical study. In DS 60: Proceedings of DESIGN 2010, the 11th International Design Conference, Dubrovnik, Croatia.

Mutic, S., Brame, R.S., Oddiraju, S., Michalski, J.M. and Wu, B., 2010. System mapping of complex healthcare processes using IDEF0: a radiotherapy example. International Journal of Collaborative Enterprise, 1(3-4), pp.316-331.

Nagarur , N.N., Hu , T. and Baid , N.K., 1994. A Computer-based Inventory Management System for Spare Parts. *Industrial Management & Data Systems*, 94(9), pp.22–28.

Narasimhan, R., Swink, M. and Kim, S.W., 2006. Disentangling leanness and agility: An empirical investigation. *Journal of Operations Management*, 24(5), pp.440–457.

Neely, A., 2009. Exploring the financial consequences of the servitization of manufacturing. *Operations Management Research*, 1(2), pp.103–118.

Neuman,William, N., 1997. *Social research methods: qualitative&quantitative approaches*, Boston: Allyn&Bacon.

Ng, I.C.L., Maull, R. and Yip, N., 2009. Outcome-based contracts as a driver for systems thinking and service-dominant logic in service science: Evidence from the defence industry. *European Management Journal*, 27(6), pp.377–387.

Nilsson, S. and Lindahl, M., 2016. A Literature Review to Understand the Requirements Specification's Role when Developing Integrated Product Service Offerings. Procedia {CIRP}, 47, p.150-155

O'Leary, Z.I.N.A., 2004. *The Essential Guide to Doing Research*, London: SAGE Publications Ltd.

Ohno, T., 1988. *Toyota Production System*.

Okley, J., 1994. Analysing Qualitative Data. In G. Bryman, A. and Burgess, R., ed. *Thinking through fieldwork*. London: Routledge, pp. 18–33 .

Oliva , R. and Kallenberg , R., 2003. Managing the transition from products to services. *International Journal of Service Industry Management*, 14(2), pp.160–172.

Otley, D. and Berry, A., 1994. Case study research in management accounting and control. *Management Accounting Research*, 5, pp.45–65.

Pong, C.K.M. and Mitchell, F., 2012. Inventory investment & control: How have UK companies been doing? *British Accounting Review*, 44(3), pp.173–188.

Qu, M., Yu, S., Chen, D., Chu, J. and Tian, B., 2016. State-of-the-art of design, evaluation, and operation methodologies in product service systems. Computers in Industry, 77, pp.1-14.

Reason, P., and Bradbury, H., 2006. *Handbook of Action Research: Concise paperback edition: 362*, London: Sage Publications.

Remenyi, D., Williams, B., Money, A., and Swartz, E., 1998. *Doing Research in Business and Management* 1st ed., London: Sage Publications.

Ren G, G.M., 2007. Servitization in manufacturing companies. *paper presented at 16th Frontiers in Service Conference*, San Francisco, CA.

Rese, M., Strotmann, W.-C. and Karger, M., 2009. Which industrial product service system fits best?: Evaluating flexible alternatives based on customers' preference drivers. *Journal of Manufacturing Technology Management*, 20(5), pp.640–653.

Robinson, T., Clarke-Hill, C.M. and Clarkson, R., 2002. Differentiation through Service: A Perspective from the Commodity Chemicals Sector. *The Service Industries Journal*, 22(3), pp.149–166.

Robson, C., 2011. *Real World Research* 3rd ed., Chichester: John Wiley and Sons.

Rosier, M.J., 1997. Survey research methods. In J. P. Keeves, ed. *Educational Research, Methodology and Measurement: An International Handbook*. Oxford: Elsevier Science, pp. 427–438.

Roy, R. and Cheruvu, K.S., 2009. A competitive framework for industrial product-service systems. International Journal of Internet Manufacturing and Services, 2(1), p.4

Sakao, T. (2009). A View of Service, Quality, and Value for Sustainability. 12th International QMOD Conference, Verona.

Sakao, T., Lindahl, M., Sundin, E., Öhrwall Rönnbäck, A. and Tang, O., 2008. Addressing Uncertainty as a Key for Successful Integrated Product and Service Offerings: Literature Review and Company Interview. In Swedish Production Symposium, 2008.

Saunders, M., Lewis, P. and Thornhill, A., 2009. *Research methods for business students* 5th ed., Harlow: Pearson Education.

Scapens, R.W., 1990. Researching management accounting practice: the role of case study methods. *British Accounting Review*, 22, pp.259–281.

Schmenner, R.W., 2009. Manufacturing, service, and their integration: some history and theory. *International Journal of Operations & Production Management*, 29(5), pp.431–443.

Schober, M.F., 1999. Making sense of questions: An interactional approach. In M. G. Sirken et al., eds. *Cognition and survey research*. New York: John Wiley & Sons, pp. 77–93.

Sekaran, U., 2003. *Research method for business: A skill building approach* 4th ed., John Wiley & Sons.

Shih, L.H. and Chou, T.Y., 2011. Customer concerns about uncertainty and willingness to pay in leasing solar power systems. International Journal of Environmental Science & Technology, 8(3), pp.523-532.

Shimomura, Y. and Tomiyama, T., 2005. Service modeling for service engineering. In *Knowledge and Skill Chains in Engineering and Manufacturing*. Springer, pp. 31–38.

Slack, N., 2005. Patterns of Servitization: Beyond Products and Service, Institute for Manufacturing. *Cambridge University*.

Spekman, R.E. and Carraway, R., 2006. Making the transition to collaborative buyer-seller relationships: An emerging framework. *Industrial Marketing Management*, 35(1), pp.10–19.

Sundin, E. and Bras, B., 2005. Making functional sales environmentally and economically beneficial through product remanufacturing. *Journal of Cleaner Production*, 13(9), pp.913–925.

Sundin, E., Öhrwall Rönnbäck, A. and Sakao, T., 2010. From component to system solution supplier: Strategic warranty management as a key to efficient integrated product/service engineering. *CIRP Journal of Manufacturing Science and Technology*, 2(3), pp.183–191.

Stewart, Valerie and Stewart, A., 1981. Business Applications of Repertory Grid, Maidenhead: McGraw-Hill.

Storbacka, K., 2011. A solution business model: Capabilities and management practices for integrated solutions. *Industrial Marketing Management*, 40(5), pp.699–711.

Storbacka, K., Polsa, P. and Sääksjärvi, M., 2011. Management Practices in Solution Sales—A Multilevel and Cross-Functional Framework. *Journal of Personal Selling and Sales Management*, 31(1), pp.35–54.

Takata, S., Kirnura, F., Van Houten, F.J.A.M., Westkamper, E., Shpitalni, M., Ceglarek, D. and Lee, J., 2004. Maintenance: changing role in life cycle management. CIRP Annals-Manufacturing Technology, 53(2), pp.643-655.

Tashakkori, A., and Teddlie, C., 1998. *Mixed methodology: combining qualitative and quantitative*, Thousand Oaks: CA: Sage.

Tellus Institute, 1999. Servicizing: The Quiet Transition to Extended Product Responsibility. . *Tellus Institute.*

The Foresight Programme in the UK Government Office & for Science, 2013. Future of manufacturing: a new era of opportunity and challenge for the UK - summary report.

Thoben, K.-D., Eschenbächer, J. and Jagdev, H., 2001. Extended products: evolving traditional product concepts. In *7th International Conference on Concurrent Enterprising*. pp. 429–439.

Tomiyama, T., 2001. Service engineering to intensify service contents in product life cycles. In Environmentally Conscious Design and Inverse Manufacturing, 2001. Proceedings EcoDesign 2001: Second International Symposium on (pp. 613-618). IEEE.

Tonelli, F., Taticchi, P. and Sue, E.S., 2009. A framework for assessment and implementation of product-service systems strategies: Learning from an action research in the health-care sector. *WSEAS Transactions on Business and Economics*, 6(7), pp.303–319.

Tourangeau, R., 1999. Context effects on answers to attitude questions. In M. G. Sirken et al., eds. *Cognition and survey research*. New York: John Wiley & Sons, pp. 111–122.

Tukker, A., 2004. Eight types of product-service system: Eight ways to sustainability? Experiences from suspronet. *Business Strategy and the Environment*, 13(4), pp.246–260.

Tukker, A. and Tischner, U., 2006. Product-services as a research field: past, present and future. Reflections from a decade of research. *Journal of Cleaner Production*, 14(17), pp.1552–1556.

Tuli, K.R., Kohli, A.K. and Bharadwaj, S.G., 2007. Rethinking Customer Solutions: From Product Bundles to Relational Processes. *Journal of Marketing*, 71(3), pp.1–17.

Ulaga, W. and Reinartz, W.J., 2011. Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully. *Journal of Marketing*, 75(6), pp.5–23.

Vandermerwe, S. and Rada, J., 1988. Servitization of business: Adding value by adding services. *European Management Journal*, 6(4), pp.314–324.

Vargo, S.L. and Lusch, R.F., 2004. The Four Service Marketing Myths: Remnants of a Goods-Based, Manufacturing Model. *Journal of Service Research*, 6(4), pp.324–335.

Verschuren, P., 2003. Case study as a research strategy: some ambiguities and opportunities. *International Journal of Social Research Methodology*, 6(2), pp.121–139.

Verstrepen, S., Deschoolmeester, D. and van den Berg, R.J., 1999. Servitization in the automotive sector: creating value and competitive advantage through service after sales. In Global production management (pp. 538-545). Springer US.

Voss, C., 2002. Case research in operations management. *International Journal of Operations & Production Management*, 22(2), pp.195–219.

Walliman, N., 2011. *Research methods: the basics* 1st ed., Abingdon, Oxon : Routledge.

Walsh, M., 2001. *Research Made Real: A Guide for Students*, Cheltenham: Nelson Thornes.

Wang, P.P., Ming, X.G., Li, D., Kong, F.B., Wang, L. and Wu, Z.Y., 2011. Modular development of product service systems. Concurrent engineering, 19(1), pp.85-96.

Ward, Y. and Graves, A., 2005. Through-life management: the provision of integrated customer solutions by aerospace manufacturers. Report available at: http://www. bath. ac. uk/management/research/pdf/20, pp.05-14.

White, A.L., Stoughton, M. and Feng, L., 1999. Servicizing: the quiet transition to extended product responsibility. Tellus Institute, Boston, 97.

Williams, A., 2007. Product service systems in the automobile industry: contribution to system innovation? *Journal of Cleaner Production*, 15(11-12), pp.1093–1103.

Williams, D., 1994. *Manufacturing Systems: An Introduction to the Technologies.*, London: Chapman & Hall.

Wise, R. and Baumgartner, P., 1999. Go Downstream: The New Profit Imperative in Manufacturing. *Harvard Business Review*, 77(5), pp.133–141.

Wong, M.T.N., 2004. Implementation of Innovative Product Service Systems in the Consumer Goods Industry. *University of Cambridge*.

Yin, R.K., 1984. *Case Study Research: Design and Methods*, Beverly Hill, London, New Delhi: SAGE Publications.

Yin, R.K., 2014. *Case study research: Design and methods* 5th ed., Thousand Oaks: CA: Sage.

Zaring, O., Bartolomeo, M., Eder, P., Hopkinson, P., Groenewegen, P., James, P., de Jong, P., Nijhuis, L., Scholl, G., Slob, A. and Örninge, M., 2001. Creating eco-efficient producer services. Gothenburg, Gothenburg Research Institute, 503.

Zeithaml, V. A, 1981. How consumer evaluation processes differ between goods and services Array, ed. *Marketing of Services*, 9(1), pp.186–190.

Appendix A

First stage of analysis

How to read the coding?
Code: **1A1**
1st code= Stage number
2nd code= Company's name
3rd code: Category number

Company A
Category:

1 Company background	2 Service	3 Market	4 Product	5 Manufacturing	6 ICT support
7 Inventory	8 Delivery				

1A1 Malaysian Original Equipment Manufacturer (OEM) in the automotive, electrical and electronics industry	1A1 Established in 1992	1A1 It has four factories in the industrial hub of Malaysia	1A1 It providing industrial product design and development, mould fabrication, injection moulding, painting and assembly	1A1 It fabricates 150 types of part
1A1 It has 30 main customers, not only in Malaysia but also in Europe, South America and across Asia	1A2 It does not provide any services or maintenance for its products to the customer	1A2 It does provide integrated product design and development services from the initial idea to the finished products	1A2 It provides the technical platform for research and the development into products, supporting product design and proof of concept	1A2 It provides intensive training using CATIA and CAE
1A2 It does not provide the after-sales service for it products	1A2 It provides an integrated product design and development service from the initial idea to the	1A2 Customers in R&D using this service to transform their product ideation to finished goods	1A2 provides technical consultation and training for instance on how to use CAE	1A3 primary market is bespoke manufacture and this can be divided into three main sub-markets

	finished goods by supporting its customers			
1A3 3 main sub-markets in primary market: ▪ Design and fabrication including product design, part design, mould design, mould design, mould fabrication and product fabrication ▪ Mould fabrication and product fabrication ▪ Product fabrication	1A3 secondary market provides the technical platform for research and the development into products, supporting product design and proof of concept	1A4 products' ideation or requirements	1A4 product design	1A4 product design concept
1A4 offers its customers various types of bespoke manufacture and product design	1A4 product dimensions and other details from product drawings	1A5 sub-markets 1 ▪ Company A will carry out the detailed design by creating the part design ▪ it will make the mould design and fabricate the mould according to the specification ▪ fabrication of the product will be performed	1A5 sub-markets 2 ▪ customer provides all the detailed designs for the product and parts to mould ▪ Company A only fabricates the mould and product	1A5 sub-markets 3 ▪ Company A only fabricates the product, and the customer prepares everything to fabricate the product except the material for the injections and fabrication machines
1A5	1A5	1A5	1A5	1A5

Each technical platform has the technical personnel who are experts in the field and relevant machines involved to assist the customer	The customer are not allowed to operate the machines themselves	a product requires a different type of moulding	production is based on customer orders	production line: Injection Moulding, Material Storage, Sub Assembly Area and Finished Goods
1A5 The injection moulding section has 27 machines with each machine operated by one operator to produce parts from both thermoplastic and thermosetting plastic materials	1A5 In one period, every machine will inject different types of product	1A5 Material storage or the main store is the section, which stores all the child parts and raw materials to produce partial assemblies or complete	1A5 It uses pallet racking storage systems with labelling	1A5 The main raw material for this production is Polypropylene (PP)
1A5 There are two sub assembly areas and each sub assembly area is divided into 5 compartments	1A5 Every compartment runs different processes and parts in one period	1A5 Each compartment operates one sub assembly function, therefore all the parts do not necessarily have to go through each of the sub assembly areas and a part might need to revisit a compartment as part of its process route to become a finished product	1A5 Finished products are products that are ready for sales and are stored according to the types of part in a poly-box before being packed ready for delivery	1A5 A part in the production line goes through a sequence of process procedures to become finished products before they can be delivered to customers
1A5 The set of workstations that one part goes through includes a sequence of processes which will demand different setups so incurring changeover	1A5 A part might need to revisit a workstation as part of its process route or possibly for rework due to any defects identified during	1A5 Each of the process procedures operate either in the factory or/and is outsourced to a supplier	1A5 the outsourcing processes involved include painting, hardening and injection of small parts	1A5 production of a product often requires interaction with multiple materials, processes and parts

times	inspection			
1A6 using computer based Product Design tools: ▪ Computer Aided Three-dimensional Interactive Applications (CATIA) ▪ Engineering Analysis using Computer-Aided Engineering (CAE)	1A6 provides intensive training using CATIA and CAE	1A6 manages a high volume of transactional environment data in customized spreadsheets using Microsoft Excel	1A6 Each section has various standard arrays of bespoke information and related function in Microsoft Excel because different departments in Company A have different ways of looking at and interpreting data	1A6 involves a variety of information transfers on an internal and external basis and it does not have the effective tools to respond to problem areas and analyse the entire system from one central location
1A6 Traditional operational databases are constructed to store large amounts of data over a long period	1A7 demand patterns for parts in production and those in distribution are radically different	1A7 Different concepts and formula are used for each type of inventory	1A7 Material storage holds the entire inventory for the production	1A7 Finished products are products that are ready for sales and are stored according to the types of part in a poly-box before being packed ready for delivery
1A7 storage warehouse operates under a dedicated storage system	1A7 in order to control cash flow and avoid high stock costs, Company A prefers to maintain its stock as low as possible because customer demand is uncertain	1A7 The technicians update the status of inventory manually	1A7 About 60 percent of materials come from a local supplier, PolyPacific Proprietary Limited with a lead-time of 1 week	1A7 Safety stock quantities are permitted in the main store to avoid stock-out
1A7 Inventory record accuracy	1A8 flexible logistics that can cope with demand fluctuations by making the delivery using	1A8 Milk-Run logistics which has only been applied by one national automotive company	1A8 Flexible logistics is a mixed mass production system based on the Total Production System	1A8 Just-In-Time (JIT) transportation which is concerned not just on speed but also on

	Company A's lorry or van		(TPS)	transportation quality
1A8 Milk-Run is a generic name for a logistics procurement method in which manufacturers utilize the same vehicle to fetch parts from multiple suppliers in other words the transportation of the product is not from Company A directly to the customer	1A8 A replacement product will be made if the fault has resulted from its normal operation however if the fault has been caused by the customer there will be no replacement given			

Company B

Category:

1 Company background	2 Product	3 Service	4 Market	5 ICT support	6 Manufacturing
7 Remanufacturing	8 Inventory	9 Delivery			

1B1 based in the United Kingdom	1B1 founded in 1960	1B1 a SME company with approximately 50 employees	1B1 selling, renting, and manufacturing electric, petrol and diesel vehicles since 1975	1B1 principal business activities are design, manufacture and distribution of industrial electrical vehicles
1B1 manufactures about 300 vehicles a year and 99% of these are bespoke manufacture	1B1 products including tow tractors, load carriers, powered/pedestrian controlled range, personnel carriers and golf buggies	1B1 offers second hand equipment, service packages, spare parts and driver training	1B1 offers vehicles specifically for rent for event hire and short-term hire	1B2 manufactures about 300 vehicles a year
1B2	1B2	1B2	1B2	1B2

products including tow tractors, load carriers, powered/pedestrian controlled range, personnel carriers and golf buggies	customers wish to buy under a form of leasing agreement for up to 7 years and are not interested in the buying the product at the end of the base when the warranty and service agreements come to an end.	has more than 400 vehicles specifically for the events market such as The British Grand Prix and Chelsea Flower Show	short-term hire is for the industry usage such as load carriers, tow tractors and utility vehicles	Every vehicle comprises about 100 components
1B2 performance of a vehicle is dependent on the usage of the customer and the working environment	1B2 Every vehicle has about 100 components	1B3 company offers vehicles specifically for rent for event hire and short-term hire and there are all covered by full maintenance and on-site service packages	1B3 service package is included with the product ; the package depends on the type of product and additional requirements needed from the customer	1B3 vehicle breakdown is an uncertainty condition that can occur anytime and affect the operation of the customer's business; provides working days service mobility
1B3 a team of engineers ready to get the vehicles repaired within 24 hours of the call in the case of breakdown	1B3 provide familiarisation training to ensure the customer understands how to operate the vehicle safely	1B3 service package includes maintenance 4 times a year for period of four or five years	1B3 Industrial vehicles probably have an average life cycle of 7 years whereas golf vehicles will be 4 years	1B3 vehicle hire agreements are available from one week to 5 years and are all covered by maintenance and on-site service packages
1B3 company has flexibility and can usually offer vehicles for last minute event hire, even at extremely limited notice	1B3 vehicle will arrive fully serviced, clean, fully charged or fuelled and ready to work on arrival	1B3 three types of service; scheduled maintenance, breakdown and training	1B3 mobile service engineers are fully trained; seven external engineers for the industrial vehicle; and a dedicated engineer for the golf vehicle	1B3 90% of calls are attended within 24 hours of receiving a call however; in 2014, the figure was 87%
1B3 Notifications are given to the customer for every	1B3 service maintenance will be performed once every	1B3 provide 24 hours rapid response during working	1B3 when the customer called, they cannot	1B3 comprehensive vehicle training for all of its

scheduled service	quarter of the year; it is not necessary for the vehicle to be serviced only on a certain date	days to keep the vehicle running	specify the main causes or components of the breakdown; they just provide some indication of the breakdown	electric vehicles or related products such as operator training and engineer training
1B3 training emphasis upon health and safety matters; based on Health and Safety Executive (HSE) guidelines	1B4 provides vehicles in the following marketplaces, waste movement and recycling, hospitals, airport and rail, transportation and leisure, golf courses and events	1B4 core business can be divided into three main markets	1B4 primary market, the customers have an option to select from the showcase of standard products or a bespoke product can be designed and manufactured to suit the customer's requirement; service package is included with the product; provide familiarisation training to ensure the customer understands how to operate the vehicle safely	1B4 secondary market is for events or short term hire; has more than 400 vehicles specifically for the events market; short-term hire is for the industry usage such as load carriers, tow tractors and utility vehicles
1B4 tertiary market targeted is for second-hand vehicles in Europe and this requires remanufacturing processes	1B4 support given to every customer is dependent on the individual contract detailed signed when the customer purchased the product with the Before-Sales Department	1B5 two main ICT support systems: Before-Sales Department and After-Sales Care	1B5 Before-Sales Department is to sell the products to the customer; support primary, secondary and tertiary, markets	1B5 After-Sales Care focuses on supporting customers who have purchased a product or service
1B5 ICT support systems in Before-Sales Department and After-Sales Care are integrated to some extent	1B5 ICT support can make good use of the same resources and information; two	1B5 Before-Sales Department; integrates internal and external resources, information and	1B5 After-Sales Care covers services for primary and secondary market	1B6 two forms of manufacture; production of new vehicle and remanufacture of old vehicles at the end of

as they allow documents to be shared and prove real-time activity notifications	computing systems are separate and have different system interface	processes of its customer, production and transportation units		their lives.
1B6 has five main sections: design, build, paint, finished product and quality inspection	1B6 build an order to meet customer requirements	1B6 99 percent of vehicle ordered is a bespoke from customers such as the colour and width of the vehicle	1B6 Every vehicle comprises about 100 components	1B6 lead-time from customer order will be 4 to 6 weeks for standard vehicles and up to 8-10 weeks for bigger vehicles
1B6 time taken to build a vehicle will be 1 to 2 weeks on average	1B6 design team will create the bespoke design or update a design of the vehicle with all the requirements and specifications as given by the Before-Sales Department	1B6 consideration aspects in designing the electric vehicle: outside and inside shape of the vehicle, colour, material used and interior layout	1B6 Design; function effectively according to the customer requirements, meet stringent health and safety, maintaining performance and braking requirements	1B6 Scheduled production spreadsheets will be used to allocate the time needed for each labour section
1B6 Scheduled production spreadsheet is used to distribute the task planning providing information: on when to produce, how long to produce, quantity of the product, equipment, requirements and operator requirements	1B6 job card provides the procedures for completing a job on production methods from one process to another process in production line	1B6 Once the process fabrication completed it will run quality inspection; any error or malfunction of vehicle the quality section will refer back to the design team	1B7 B collects its vehicle back at the end of the vehicle life if it is still working and the customer does not want to keep it anymore	1B7 sell it to the European market or for event hire or short-term hire; tertiary market
1B7 process of remanufacturing will go through the same cycle as manufacturing process	1B8 Every vehicle comprises about 100 components	1B8 99 percent of vehicle ordered is a bespoke from customers such as the colour and width of	1B8 inventory requirements are established from the list of parts in BOM; a detail list of materials,	1B8 Inventory system will then identify the stock availability and level, and determine which parts

		the vehicle	parts and the quantities needed to manufacture a product including the child parts such as screw and nuts	need to be ordered
1B8 Scheduled production spreadsheet is used to distribute the task planning providing information: on when to produce, how long to produce, quantity of the product, equipment, requirements and operator requirements	1B8 The process of remanufacturing will go through the same cycle as in manufacturing process	1B8 Vehicle breakdown; customer just provide some indication of the breakdown to Company B, they will load the components in the service truck that might be needed to repair the vehicle	1B8 hold inventory of several components; inventory is sort by the type of components not by the quantity components needed for a vehicle	1B8 has about £800k internal inventory
1B8 Inventory in its system not only been used for production but also for the service, spare parts and remanufacture; does not keep any expensive and high technology components in its inventory such a motor	1B8 the maximum and minimum inventory level depending of the type, price and supplier warranty of the components to make sure the life package inventory meet its aim	1B8 it need to keep some inventory of vehicle components and tools in its trucks (service)	1B8 Most inventories are kept in a central store	1B8 Before-Sales Department controls the inventory for both sales and remanufactured vehicles
1B8 After-Sales Care controls the inventory of service and spare parts although there are some exceptions that are deals with a case-by-case basis	1B8 inventory-processing interface for both departments is different however; source and information of inventory for both systems are the same	1B8 bolts and nuts use a bar code system to control the inventory	1B8 Moving stock from the raw material store to other production sections is run manually	1B9 Before-Sales Department: request the transportation unit to deliver the product to the customer

1B9 The transportation unit will plan to deliver the product and service products for other customers who’s service are due within the next month in the delivery area	1B9 Before-Sales Department will update delivery date scheduled to the customer			

Company C
Category:

1 Company background	2 Product	3 Market	4 Service	5 Contract	6 ICT support
7 Inventory	8 Manufacturing	9 Delivery			

1C1 we are still SME really	1C1 developing a technology based on one could torque rotary engine	1C1 design consultancy	1C1 assemble and test engine	1C1 test engine
1C1 Turnover not very high	1C1 We are new 3 years	1C1 we predominant in research R&D	1C1 When we set the business we decide to start our business the way we want going to be supposed where we were now.	1C1 when we start this business we would put the system in day one and that way as we growth the business we don't have to have the translation of data you know
1C1 We on IS but you can't get IS really unless you got the ISO	1C1 We are fortunately bring together basically pretty much on people of highly experienced so and a lot of them work together	1C2 rotary engine	1C2 it is a Germany invention back 1950s and it's got very high pad variation, very compact, etc.	1C2 weight about 2kg and produce 5,6 horse power

	before so again it was rather whole			
1C2 compact rotary engine, light weight, powerful, low vibration, small full products	1C2 unmanned aeronautical vehicle (UAV)	1C2 we design our product	1C2 assemble and test engine	1C2 we subcontract manufacturers but we do the test engine here
1C2 we develop a sort of a core product then every customer unfortunately as a rule of thumb customer tend to have a slightly configuration so you end up customize the engine according to the customer requirements	1C2 a configuration information for the products is develop in one system PDM- Product Data Management System	1C2 customers used the engines in very different ways	1C2 one engine can last very short period of time	1C2 Product is rated on hours used
1C2 standard product will last may be 10000 hours depending on the environment, load and 10000 hours for 1 customer could last 3 years, 10000 hours for other customer could last 4 months	1C2 Physical items	1C2 engines again can be little effected by environmental and usage; where the engines been used, and how hard they being used for the better word	1C2 It's environmentally more friendly to keep the engines replaces	1C2 it is quite easy recycle because they are all metals
1C2 we don't take back the engines	1C2 As we developed the engine we very careful we document the stages of development we document all the process through we got the thing	1C3 major market for the technology historically have been anywhere to customize engine so cars, motorbikes, etc.	1C3 modern rotary seem to advance a bit of the niche in aerospace industry specifically unmanned aeronautical vehicle (UAV)	1C3 we don't have large consistent customers we tend to have a variety of small customers

	called design journals			
1C3 One off type of customer to be batch, one off but then it will come back for another 2 years; so you never get the maturity of the customers that will laid that actually develop a you know the interface document	1C4 we also offer sort of after products support really as well as technical support to customer using our product	1C4 we also do the consultancy in R&D can be service as well	1C4 they can just buy service to solve the problems	1C4 All products comes with sort of a standard service; customers may request additional support over above that
1C4 Maintaining capability	1C4 Standard service requirement	1C4 we have 500 hours service	1C4 engine life is for 10000 hours but it's actually we called as 10000 hours service which basically pretty much 0 hour engine again to give like a new supply is like another engine form the better word in theory 0 hour engine again plus any car	1C4 There's a standard service which is 500 hours but it can be flexible depending on customer requirements
1C4 it's good to take 3 years you know which case you say to them you can probably service your own engine 4 to 500 hours because it is built to service for 3 years	1C4 We can do service mobility but we don't do so much	1C4 if it is sophisticated customers they tend do the service themselves so they just buy the kit to service the engine themselves	1C4 if it less sophisticated customers then we tend sent the engine back to us. But it doesn't mean we won't guarantee it just not something	1C4 spare kit
1C4 training	1C5 Template contract	1C5 we tend to develop the contract project on case by case basis	1C5 we develop the contract document random requirements really	1C5 Contract modules
1C5	1C5	1C5	1C5	1C5

if the customers ask to work on design for them so like we treat it like as the contract	the standard policies	Warranty; we it is sort of negotiate you know it is sort of a depending on the application, the customers what they want	commercial customers yeah they are more concerned with warranty so yeah we tend to working in the price depending how much warranty they want depends on the engine costs	training
1C6 ERP software which have MRP built into it	1C6 software package we use is called EFAX which is very well used in UK but it is not particularly international products but it covers the inventory packages you need	1C6 ERP software operates on the module basis	1C6 ERP; have a module for stock control, the module for the purchase, module for the manufacturing or assembly, etc. and service module	1C6 ERP; single package
1C6 we don't want to do the a lots of carry-able works in administrative work we want the system to do the heavy lifting for us	1C6 ERP; sales delivery modules	1C6 PDM- Product Data Management Systemwhich design engineer configuration control then it's automatically export into in ERP system EFAX	1C6 when we then put the requirement on the EFAX system for the engine or the spares or what ever it is the system will you know you need to order the materials because I have no stock of it or the material you have is committed therefore you need to order some more	1C6 ERP works very well. I mean as you go the system it could be fast
1C6 So EFAX is quite logical approach its mean to make a job done. It's pretty good but it could always be better you	1C6 We tend to try to use new products as standard as possible and the reasons we try using the standard as possible is because it	1C6 Some of the packages like PDM is basically a sort of a package anyway actually is like blank sheet you have to go to the	1C6 Our packages do not links to both of customers and suppliers at the both end. So we still have to do the manual entry at the front	1C6 We can automate documents sending from the system so it will automatically documented etc. but there's no

know	means you get the best support from the supplier	configuration is like a framework system. And then you built your own interface on top of it. That's a platform.	and then we start to send the manual document at the back end.	electronic integration in the end. The reason for that because we don't have large consistent customers we tend to have a variety of small customers.
1C6 the system has a sort of relatively standard pattern on how it's work and it has a flexibility which is ally to work in slightly different ways between customers	1C6 For the payment between the contract model will set the schedule and obviously we deliver the line item from the contract almost the same way to deliver physical item from sales order. Obviously there is no physical quid involved. It's just electronic trigger that sent it off.	1C6 We got MRP system we start at May we got the MRP on October. So it almost from the start.	1C6 when we start this business we would put the system in day one and that way as we growth the business we don't have to have the translation of data you know. So ERP system in day one not really been used but as we moved more and more it start to get used as we move forward. So huge growth for us I supposed is best way to describe.	1C6 So the same configuration system be PDM system a lot of system we bought and implemented it were very heavy for the size of our organisation we are. They still large I supposed. We know that we don't need to change you know we know they are capable with the business.
1C6 we spend about 120000 on system like ERP. So it's big cash. Subscription every year that is.	1C6 ERP don't have a stock then when the stock came in we do not to anything you know the system is there so we stock in and the system shows straight away show we receive the order	1C6 we built the engine data base you built the configuration with all the information, customer requirement, customer information, and you can pass the information as well.	1C7 inventory packages	1C7 So you have a module for stock control, the module for the purchase, module for the manufacturing or assembly, etc. and service module
1C7 set the priority to get so you can prioritize certain job and it allocate the	1C7 Purchase order (PO)	1C8 We then also assemble and test engine, we subcontract	1C8 module for the manufacturing or assembly, etc. and	1C8 configuration information for the products is develop in one system

material accordingly		manufacturers but we do the test engine here.	service module	PDM- Product Data Management System
1C8 set the priority to get so you can prioritize certain job and it allocate the material accordingly	1C8 a part number which job is identified in quotation	1C8 you can through the assembly information, BOM information, then also lead time information in store in the system	1C8 Obviously if the customer comes in and says you know you want something pretty quickly then potentially we have the opportunity to do that if we got the stock off component.	1C8 supply chain some of part component have you know three to four months lead times
1C8 Batch order	1C8 Batch manufacturers	1C8 We on IS but you can't get IS really unless you got the ISO	1C8 Is you have to produce 2 years of all records really to show you operated control system for 2 years	1C9 shipment
1C9 We have basically a dispatch area	1C9 Delivery notes	1C9 Creates delivery paper works	1C9 For service; there's no physical delivery should we say or the physical delivery if it is a you know USB stick of data.	1C9 we deliver the line item from the contract almost the same way to deliver physical item from sales order
1C9 Using standard courier	1C9 Depend to the customers decisions to have how they want to shipping; we don't want to take any responsible of lost			

Company D

Category:

1 Company background	2 Product	3 Service	4 Market	5 Manufacturing	6 Maintenance
7 ICT Support	8 Inventory	9 Delivery			

1D1 upstream oil and gas company	1D1 based in Malaysia	1D1 incorporated in 2007	1D1 core business activity is exploration, development and production of natural gas resources in Malaysia	1D1 provides facilities and processes for the oil and gas industry that enables the production and stabilisation of production from the wellhead manifolds in the form of crude oil, condensates or gas
1D1 conduct their business and share their platforms with their shareholders	1D1 they only have one customer which is also one of their shareholders	1D2 crude oil	1D2 condensates and gas	1D3 perform most of their equipment maintenance service and inspection by themselves
1D3 training and maintenance supports	1D3 services provided by Company D mainly relate to the maintenance equipment in their plant	1D3 do not provide any external services to their customer	1D3 perform most of the instrumentations maintenance and inspection	1D3 They have a warehouse personnel and offshore crew to countercheck the stock in service
1D4 Exploration, development and production of crude oil, condensates and gas	1D4 Maintenance and inspection of their instrumentation	1D5 production activity focuses on stabilisation of crude oils and gas using their production facilities	1D5 share some of it facilities	1D5 it also has its own facilities
1D5 requires a combination of technical and managerial actions to ensure the safety, reliability and integrity of their operations and facilities	1D5 upstream oil and gas platform involves many processes	1D5 uses a Distributed Control System (DCS) and SAP (Systems, Applications and Products in Data Processing) in their production and delivery of products	1D5 Production; depends on real time instrumentation data that is sent into the DCS from offshore	1D5 The DCS is a combination of hardware and software that is used to control production activities and resources

1D5 Company D have many input/output devices (I/O)	1D5 The elements of a DCS are connected to sensors and actuators of the physical instrumentations for instance the pumps and valves	1D5 The upstream can be sub-divided into searching, evaluating and identifying the potential oil sites, drilling exploratory wells and operating the wells to extract the crude oils	1D5 The pipelines are connected to high-pressure compressors to distribute gas flow, water flow and oil flow in three different phase of separation	1D5 They use the same pipeline to transport their 3 different products
1D5 They normally ensure that their products meet their specifications before delivery to their customer, by lab test that are performed offshore	1D5 In the production, offshore technician will revalidate on site based on the onsite gauge and the manual calculation will be carried out if required.	1D5 increasingly improving their efficiency in logistics, planning, scheduling, communications, especially with their shareholders, contractors and suppliers, data management and risk analysis.	1D6 They have a preventive maintenance system	1D6 planned maintenance, planned inspection and planned repair systems are used in this secondary market
1D6 preventive maintenance system has not only increased the safety, reliability and integrity of their instrumentation but has also reduced their unplanned breakdown of the instrumentation	1D6 maintenance items or spares, they use the SAP system to catalogue all the spares and manage all the work orders and supply chain work processes	1D6 maintenance supports	1D6 SAP has the capability to reduce the overhead of maintaining multiple products	1D6 SAP: also the planning for the maintenance
1D6 The services provided by Company D mainly relate to the maintenance equipment in their plant	1D6 They perform most of the instrumentations maintenance and inspection however, for the sophisticated and complex instrumentation the maintenance and	1D6 maintenance of the instrumentations specifications are based on the Original Equipment Manufacturer (OEM) guidelines, international standard and code, and	1D6 outsource maintenance and inspection process	1D7 ICT support system involved in the production to delivery of products

	inspection are performed by the suppliers	experiences of the workers and the shareholders		
1D7 uses a Distributed Control System (DCS) and SAP (Systems, Applications and Products in Data Processing) in their production and delivery of products	1D7 DCS and SAP are two separate systems and not only have different functions in Company D's ICT support systems, but also require different interface and technical knowledge to operate the systems	1D7 ICT support systems aim to maintain the asset management, work management and performance management	1D7 For their production, Company D depends on real time instrumentation data that is sent into the DCS from offshore	1D7 for maintenance items or spares, they use the SAP system to catalogue all the spares and manage all the work orders and supply chain work processes
1D7 The DCS is a combination of hardware and software that is used to control production activities and resources, as well as to monitor and report on work execution for the production processes	1D7 DCS uses a custom-designed processor as a process controller	1D7 employ a very large DCS system	1D7 A control room operator with a considerable technical knowledge and skill is required to deploy the DCS system and manage the inventory by using the control panel	1D7 system is boosted by supplier
1D7 SAP is Enterprise Resource Planning (ERP) software that is used for operations performance management for the upstream	1D7 function of SAP is to provide correct and accurate information in capturing, storing, managing, presenting and making operational decisions and for production planning and also to enable appropriate reporting	1D7 SAP has the capability to reduce the overhead of maintaining multiple products and providing the required information	1D7 SAP is not only used for production planning but also the planning for the maintenance, specific changes in the network and production impact	1D7 interface of the SAP is not very complicated as they only have 1 customer and 3 products
1D7 SAP is augmented by	1D7 using the real	1D8 manage the inventory by	1D8 SAP is Enterprise	1D8 The inventory can be

supplier support that includes the training and maintenance support	instrumentation data and is connected to DCS and again the data can be obtained through online	using the control panel	Resource Planning (ERP) software	divided into three main areas; hydrocarbon volume to be export, chemical inventory and spare parts
1D8 chemical inventory the tank level indicator which means using the real instrumentation data and is connected to DCS and again the data can be obtained through online	1D8 the spare parts inventory is using SAP system	1D8 warehouse personnel and offshore crew to countercheck the stock in service	1D8 3rd party supplier to monitor the spares	1D8 product inventory is based on the instrumentation of gas metering, level indicator, flow meter and multi-face meter
1D9 DCS and SAP are used in their production and delivery of products	1D9 products meet the specifications before delivery to customer, by lab test that are performed offshore			

Appendix B
Comparative Case Studies

	Case A	*Case B*	*Case C*	*Case D*
Company background				
Origin	2A1 Malaysian Original Equipment Manufacturer (OEM) in the automotive, electrical and electronics industry	2B1 based in the United Kingdom	2C1 we are still UK SME really	2D1 based in Malaysia
	2A1 It has four factories in the industrial hub of Malaysia	2B1 a SME company with approximately 50 employees		
Establishment date	2A1 Established in 1992	2B1 founded in 1960	2C1 We are new 3 years (2012)	2D1 incorporated in 2007
Business activity	2A1 industrial product design and development, mould fabrication, injection moulding, painting and assembly	2B1 selling, renting, and manufacturing electric, petrol and diesel vehicles since 1975	2C1 developing a technology based on one could torque rotary engine	2D1 exploration, development and production of natural gas resources in Malaysia
		2B1 principal business activities are design, manufacture and distribution of industrial electrical vehicles	2C1 design consultancy 2C1 assemble and test engine 2C1 test engine	2D1 provides facilities and processes for the oil and gas industry that enables the production and stabilisation of production from the wellhead manifolds in the form of crude oil, condensates or

				gas
	2A1 It fabricates 150 types of part	2B1 manufactures about 300 vehicles a year and 99% of these are bespoke manufacture 2B2 Every vehicle comprises about 100 components	2C2 customize the engine according to the customer requirements	
		2B1 offers second hand equipment, service packages, spare parts and driver training	2C1 we predominant in research R&D	2D1 conduct their business and share their platforms with their shareholders
	2A1 has 30 main customers, not only in Malaysia but also in Europe, South America and across Asia			2D1 only have one customer which is also one of their shareholders
Product	2A2-4 various types of bespoke manufacture and product design	2B2 products including tow tractors, load carriers, powered/pedestrian controlled range, personnel carriers and golf buggies	2C2 compact rotary engine, light weight, powerful, low vibration, small full products 2C2 it is a Germany invention back 1950s and it's got very high pad variation, very compact, etc. 2C2 weight about 2kg and	2D2 crude oil 2D2 condensates and gas

			produce 5,6 horse power	
	2A2-4 products' ideation or requirements 2A2-4 product design 2A2-4 product design concept 2A2-4 product dimensions and other details from product drawings	2B2 has more than 400 vehicles specifically for the events market such as The British Grand Prix and Chelsea Flower Show 2B2 short-term hire is for the industry usage such as load carriers, tow tractors and utility vehicles	2C2 we design our product 2C2 assemble and test engine 2C2 we subcontract manufacturers but we do the test engine here	
		2B2 performance of a vehicle is dependent on the usage of the customer and the working environment	2C2 one engine can last very short period of time 2C2 Product is rated on hours used 2C2 standard product will last may be 10000 hours depending on the environment, load and 10000 hours for 1 customer could last 3 years, 10000 hours for other customer could last 4 months 2C2	

			engines again can be little effected by environmental and usage; where the engines been used, and how hard they being used for the better word	
			2C2 It's environmentally more friendly to keep the engines replaces 2C2 it is quite easy recycle because they are all metals 2C2 it is quite easy recycle because they are all metals 2C2 we don't take back the engines 2C2 As we developed the engine we very careful we document the stages of development we document all the process through we got the thing called design journals	
Market	2A3	2B3-4	2C3	2D3-4

	primary market is bespoke manufacture and this can be divided into three main sub-markets 2A3 3 main sub-markets in primary market: ▪ Design and fabrication including product design, part design, mould design, mould fabrication and product fabrication ▪ Mould fabrication and product fabrication ▪ Product fabrication	primary market ▪ the customers have an option to select from the showcase of standard products or ▪ a bespoke product can be designed and manufactured to suit the customer's requirement; ▪ service package is included with the product; ▪ provide familiarisation training to ensure the customer understands how to operate the vehicle safely	we don't have large consistent customers we tend to have a variety of small customers 2C3 modern rotary seem to advance a bit of the niche in aerospace industry specifically unmanned aeronautical vehicle (UAV)	Exploration, development and production of crude oil, condensates and gas
	2A3 secondary market provides the technical platform for research and the development into products, supporting product design and proof of concept	2B3-4 secondary market: ▪ events or short term hire; ▪ has more than 400 vehicles specifically for the events market; ▪ short-term hire is	2C3 One off type of customer to be batch, one off but then it will come back for another 2 years; so you never get the maturity of the customers that will laid that actually develop a you know the interface document	2D3-4 Maintenance and inspection of their instrumentation

		for the industry usage		
		2B3-4 tertiary market: • targeted is for second-hand vehicles in Europe and this requires remanufacturing processes		
		2B3-4 provides vehicles in the following marketplaces, waste movement and recycling, hospitals, airport and rail, transportation and leisure, golf courses and events	2C3 major market for the technology historically have been anywhere to customize engine so cars, motorbikes, etc.	
Service	2A4-2 It does not provide any services or maintenance for its products to the customer	2B4-3 three types of service; scheduled maintenance, breakdown and training 2B4-3 service package is included with the	2C4 we also offer sort of after products support really as well as technical support to customer using our product 2C4 we also do the consultancy in R&D can be service as well	2D4-3 perform most of their equipment maintenance service and inspection by themselves 2D4-3 services provided by Company D mainly relate to the maintenance equipment in their plant

		product ; the package depends on the type of product and additional requirements needed from the customer 2B4-3 company offers vehicles specifically for rent for event hire and short-term hire and there are all covered by full maintenance and on-site service packages 2B4-3 provide familiarisation training to ensure the customer understands how to operate the vehicle safely	2C4 they can just buy service to solve the problems 2C4 We can do service mobility but we don't do so much 2C4-5 training	2D4-3 do not provide any external services to their customer
	2A4-2 It does provide integrated product design and development services from the initial idea to the finished products 2A4-2	2B4-3 vehicle breakdown is an uncertainty condition that can occur anytime and affect the operation of the customer's business; provides working days service	2C4 All products comes with sort of a standard service; customers may request additional support over above that 2C4 There's a standard service which is 500	2D4-3 training and maintenance supports 2D4-3 They have a warehouse personnel and offshore crew to countercheck the stock in service

	It provides the technical platform for research and the development into products, supporting product design and proof of concept 2A4-2 It provides intensive training using CATIA and CAE 2A4-2 Customers in R&D using this service to transform their product ideation to finished goods	mobility 2B4-3 a team of engineers ready to get the vehicles repaired within 24 hours of the call in the case of breakdown 2B4-3 mobile service engineers are fully trained; seven external engineers for the industrial vehicle; and a dedicated engineer for the golf vehicle 2B4-3 service package includes maintenance 4 times a year for period of four or five years 2B4-3 service maintenance will be performed once every quarter of the year; it is not	hours but it can be flexible depending on customer requirements 2C4 engine life is for 10000 hours but it's actually we called as 10000 hours service which basically pretty much 0 hour engine again to give like a new supply is like another engine form the better word in theory 0 hour engine again plus any car 2C4 it's good to take 3 years you know which case you say to them you can probably service your own engine 4 to 500 hours because it is built to service for 3 years 2C4 if it is sophisticated customers they tend do the service themselves so they just buy the kit to service the engine themselves 2C4 if it less sophisticated	

		necessary for the vehicle to be serviced only on a certain date 2B4-3 Industrial vehicles probably have an average life cycle of 7 years whereas golf vehicles will be 4 years 2B4-3 Notifications are given to the customer for every scheduled service 2B4-3 when the customer called, they cannot specify the main causes or components of the breakdown; they just provide some indication of the breakdown 2B4-3 90% of calls are attended within 24 hours of receiving a	customers then we tend sent the engine back to us. But it doesn't mean we won't guarantee it just not something	

		call however; in 2014, the figure was 87% 2B4-3 provide 24 hours rapid response during working days to keep the vehicle running		
	2A4-2 It does not provide the after-sales service for it products	2B4-3 company has flexibility and can usually offer vehicles for last minute event hire, even at extremely limited notice 2B4-3 vehicle hire agreements are available from one week to 5 years and are all covered by maintenance and on-site service packages 2B4-3 vehicle will arrive fully serviced, clean, fully charged or fuelled and ready to work on arrival	2C4 spare kit 2C4 Training 2C4-5 Template contract 2C4-5 we tend to develop the contract project on case by case basis 2C4-5 we develop the contract document random requirements really 2C4-5 if the customers ask to work on design for them so like we treat it like as the contract	

		2B4-3 comprehensive vehicle training for all of its electric vehicles or related products such as operator training and engineer training 2B4-3 training emphasis upon health and safety matters; based on Health and Safety Executive (HSE) guidelines	2C4-5 Warranty; we it is sort of negotiate you know it is sort of a depending on the application, the customers what they want 2C4-5 commercial customers yeah they are more concerned with warranty so yeah we tend to working in the price depending how much warranty they want depends on the engine costs	
ICT support	2A5-6 using computer based Product Design tools: ▪ Computer Aided Three-dimensional Interactive Applications (CATIA) ▪ Engineering Analysis using Computer-Aided Engineering (CAE) 2A5-6	2B5 two main ICT support systems: Before-Sales Department and After-Sales Care 2B5 Before-Sales Department is to sell the products to the customer; support primary, secondary and tertiary, markets	2C5-6 when we start this business we would put the system in day one and that way as we growth the business we don't have to have the translation of data you know. So ERP system in day one not really been used but as we moved more and more it start to get used as we move forward. So huge growth for us I supposed is best way to describe	2D5-7 ICT support system involved in the production to delivery of products 2D5-7 The DCS is a combination of hardware and software that is used to control production activities and resources, as well as to monitor and report on work execution for the production processes 2D5-7

	provides intensive training using CATIA and CAE 2A5-6 Traditional operational databases are constructed to store large amounts of data over a long period	2B5 After-Sales Care focuses on supporting customers who have purchased a product or service	2C5-6 software package we use is called EFAX which is very well used in UK but it is not particularly international products but it covers the inventory packages you need 2C5-6 ERP software operates on the module basis 2C5-6 ERP; have a module for stock control, the module for the purchase, module for the manufacturing or assembly, etc. and service module 2C5-6 we don't want to do the a lots of carry-able works in administrative work we want the system to do the heavy lifting for us 2C5-6 PDM- Product Data Management System which design engineer configuration control then it's automatically	SAP is Enterprise Resource Planning (ERP) software that is used for operations performance management for the upstream

			export into in ERP system EFAX 2C5-6 Some of the packages like PDM is basically a sort of a package anyway actually is like blank sheet you have to go to the configuration is like a framework system. And then you built your own interface on top of it. That's a platform.	
	2A5-6 manages a high volume of transactional environment data in customized spreadsheets using Microsoft Excel 2A5-6 Each section has various standard arrays of bespoke information and related function in Microsoft Excel because different departments in		2C5-6 Our packages do not links to both of customers and suppliers at the both end. So we still have to do the manual entry at the front and then we start to send the manual document at the back end. 2C5-6 We can automate documents sending from the system so it will automatically documented etc. but there's no electronic integration in the end. The reason for that because we don't have	2D5-7 DCS uses a custom-designed processor as a process controller 2D5-7 employ a very large DCS system 2D5-7 A control room operator with a considerable technical knowledge and skill is required to deploy the DCS system and manage the inventory by using the control panel 2D5-7 system is boosted by supplier

	Company A have different ways of looking at and interpreting data 2A5-6 involves a variety of information transfers on an internal and external basis and it does not have the effective tools to respond to problem areas and analyse the entire system from one central location		large consistent customers we tend to have a variety of small customers. 2C5-6 the system has a sort of relatively standard pattern on how it's work and it has a flexibility which is ally to work in slightly different ways between customers	2D5-7 using the real instrumentation data and is connected to DCS and again the data can be obtained through online
				2D5-7 function of SAP is to provide correct and accurate information in capturing, storing, managing, presenting and making operational decisions and for production planning and also to enable appropriate reporting 2D5-7 SAP has the capability to reduce the overhead of maintaining multiple products and providing

				the required information 2D5-7 interface of the SAP is not very complicated as they only have 1 customer and 3 products 2D5-7 SAP is augmented by supplier support that includes the training and maintenance support
Inventory	2A6-7 demand patterns for parts in production and those in distribution are radically different 2A6-7 Different concepts and formula are used for each type of inventory 2A6-7 Material storage holds the entire inventory for the production 2A6-7 Finished products that are ready for sales and	2B6-8 Every vehicle comprises about 100 components 2B6-8 99 percent of vehicle ordered is a bespoke from customers such as the colour and width of the vehicle 2B6-8 inventory requirements are established from the list of parts in BOM; a detail list of materials, parts and the	2C6-7 inventory packages 2C6-7 So you have a module for stock control, the module for the purchase, module for the manufacturing or assembly, etc. and service module 2C6-7 set the priority to get so you can prioritize certain job and it allocate the material accordingly	2D6-8 manage the inventory by using the control panel 2D6-8 the spare parts inventory is using SAP system 2D6-8 The inventory can be divided into three main areas; hydrocarbon volume to be export, chemical inventory and spare parts 2D6-8 chemical inventory the tank level indicator which means using the real instrumentation data and is connected to DCS and

	are stored according to the types of part in a poly-box before being packed ready for delivery 2A6-7 storage warehouse operates under a dedicated storage system	quantities needed to manufacture a product including the child parts such as screw and nuts 2B6-8 hold inventory of several components; inventory is sort by the type of components not by the quantity components needed for a vehicle 2B6-8 it need to keep some inventory of vehicle components and tools in its trucks (service)2B6-8 has about £800k internal inventory 2B6-8 Inventory in its system not only been used for production but also for the service, spare parts and remanufacture; does		again the data can be obtained through online 2D6-8 warehouse personnel and offshore crew to countercheck the stock in service 2D6-8 3rd party supplier to monitor the spares 2D6-8 product inventory is based on the instrumentation of gas metering, level indicator, flow meter and multi-face meter

		not keep any expensive and high technology components in its inventory such a motor 2B6-8 the maximum and minimum inventory level depending of the type, price and supplier warranty of the components to make sure the life package inventory meet its aim 2B6-8 Scheduled production spreadsheet is used to distribute the task planning providing information: on when to produce, how long to produce, quantity of the product, equipment, requirements and operator requirements 2B6-8 bolts and nuts use a		

		bar code system to control the inventory 2B6-8 Moving stock from the raw material store to other production sections is run manually 2B6-8 Most inventories are kept in a central store		
		2B6-8 Before-Sales Department controls the inventory for both sales and remanufactured vehicles 2B6-8 After-Sales Care controls the inventory of service and spare parts although there are some exceptions that are deals with a case-by-case basis 2B6-8		

		inventory-processing interface for both departments is different however; source and information of inventory for both systems are the same		
Manufacturing	2A7-5 production is based on customer orders 2A7-5 production line: Injection Moulding, Material Storage, Sub Assembly Area and Finished Goods 2A7-5 Each technical platform has the technical personnel who are experts in the field and relevant machines involved to assist the customer 2A7-5 a product requires a different type of moulding	2B7-6 two forms of manufacture; production of new vehicle and remanufacturing 2B7-6 has five main sections: design, build, paint, finished product and quality inspection 2B7-6 99 percent of vehicle ordered is a bespoke from customers such as the colour and width of the vehicle 2B7-6 Every vehicle comprises about 100 components	2C7-8 Batch manufacturers 2C7-8 Batch order 2C7-8 set the priority to get so you can prioritize certain job and it allocate the material accordingly 2C7-8 a part number which job is identified in quotation 2C7-8 We then also assemble and test engine, we subcontract manufacturers but we do the test engine here 2C7-8 you can through the assembly information, BOM information, then	2D7-5 production activity focuses on stabilisation of crude oils and gas using their production facilities 2D7-5 share some of it facilities 2D7-5 it also has its own facilities 2D7-5 requires a combination of technical and managerial actions to ensure the safety, reliability and integrity of their operations and facilities 2D7-5 upstream oil and gas platform involves many processes

	2A7-5 The customer are not allowed to operate the machines themselves 2A7-5 A part in the production line goes through a sequence of process procedures to become finished products before they can be delivered to customers 2A7-5 The set of workstations that one part goes through includes a sequence of processes which will demand different setups so incurring changeover times 2A7-5 A part might need to revisit a workstation as part of its process route or possibly for	2B7-6 lead-time from customer order will be 4 to 6 weeks for standard vehicles and up to 8-10 weeks for bigger vehicles 2B7-6 time taken to build a vehicle will be 1 to 2 weeks on average 2B7-6 Scheduled production spreadsheets will be used to allocate the time needed for each labour section	also lead time information in store in the system 2C7-8 module for the manufacturing or assembly, etc. and service module 2C7-8 configuration information for the products is develop in one system PDM- Product Data Management System	

	rework due to any defects identified during inspection 2A7-5 Each of the process procedures operate either in the factory or/and is outsourced to a supplier 2A7-5 the outsourcing processes involved include painting, hardening and injection of small parts			
	2A7-5 sub-markets 1 ▪ Company A will carry out the detailed design by creating the part design ▪ it will make the mould design and fabricate the mould according to the specification ▪ fabrication of the	2B7-6 design team will create the bespoke design or update a design of the vehicle with all the requirements and specifications as given by the Before-Sales Department 2B7-6 consideration aspects in designing the	2C7-8 Obviously if the customer comes in and says you know you want something pretty quickly then potentially we have the opportunity to do that if we got the stock off component 2C7-8 supply chain some of part component have you know three to four months lead times	2D7-5 uses a Distributed Control System (DCS) and SAP (Systems, Applications and Products in Data Processing) in their production and delivery of products 2D7-5 Production; depends on real time instrumentation data that is sent into the DCS from offshore

	product will be performed 2A7-5 sub-markets 2 ▪ customer provides all the detailed designs for the product and parts to mould ▪ Company A only fabricates the mould and product 2A7-5 sub-markets 3 ▪ Company A only fabricates the product, and the customer prepares everything to fabricate the product except the material for the injections and fabrication machines	electric vehicle: outside and inside shape of the vehicle, colour, material used and interior layout 2B7-6 Design; function effectively according to the customer requirements, meet stringent health and safety, maintaining performance and braking requirements 2B7-6 job card provides the procedures for completing a job on production methods from one process to another process in production line 2B7-6 Once the process fabrication completed it will run quality inspection; any error		2D7-5 The DCS is a combination of hardware and software that is used to control production activities and resources 2D7-5 Company D have many input/output devices (I/O) 2D7-5 They use the same pipeline to transport their 3 different products

		or malfunction of vehicle the quality section will refer back to the design team		
	2A7-5 The injection moulding section has 27 machines with each machine operated by one operator to produce parts from both thermoplastic and thermosetting plastic materials 2A7-5 In one period, every machine will inject different types of product 2A7-5 Material storage or the main store is the section, which stores all the child parts and raw materials to produce partial assemblies or complete 2A7-5		2C7-8 We on IS but you can't get IS really unless you got the ISO 2C7-8 Is you have to produce 2 years of all records really to show you operated control system for 2 years	2D7-5 The elements of a DCS are connected to sensors and actuators of the physical instrumentations for instance the pumps and valves 2D7-5 The upstream can be sub-divided into searching, evaluating and identifying the potential oil sites, drilling exploratory wells and operating the wells to extract the crude oils 2D7-5 The pipelines are connected to high-pressure compressors to distribute gas flow, water flow and oil flow in three different phase of separation 2D7-5 **They normally ensure that their products meet their specifications**

	It uses pallet racking storage systems with labelling 2A7-5 The main raw material for this production is Polypropylene (PP) 2A7-5 There are two sub assembly areas and each sub assembly area is divided into 5 compartments 2A7-5 Every compartment runs different processes and parts in one period 2A7-5 Each compartment operates one sub assembly function, therefore all the parts do not necessarily have to go through each of the sub assembly areas and a part might need			**before delivery to their customer, by lab test that are performed offshore** 2D7-5 In the production, offshore technician will revalidate on site based on the onsite gauge and the manual calculation will be carried out if required. 2D7-5 Increasingly improving their efficiency in logistics, planning, scheduling, communications, especially with their shareholders, contractors and suppliers, data management and risk analysis.

	to revisit a compartment as part of its process route to become a finished product 2A7-5 Finished products are products that are ready for sales and are stored according to the types of part in a poly-box before being packed ready for delivery			
		2B7 (remanufacturing) B collects its vehicle back at the end of the vehicle life if it is still working and the customer does not want to keep it anymore 2B7 (remanufacturing) sell it to the European market or for event hire or short-term hire; tertiary market		

		2B7 (remanufacturing) process of remanufacturing will go through the same cycle as manufacturing process		
Delivery	2A8 flexible logistics that can cope with demand fluctuations by making the delivery using Company A's lorry or van 2A8 Milk-Run logistics which has only been applied by one national automotive company	2B8-9 Before-Sales Department: request the transportation unit to deliver the product to the customer 2B8-9 The transportation unit will plan to deliver the product and service products for other customers who's service are due within the next month in the delivery area 2B8-9 Before-Sales Department will update delivery date scheduled to the customer	2C8-9 We have basically a dispatch area 2C8-9 Delivery notes 2C8-9 Creates delivery paper works 2C8-9 For service; there's no physical delivery should we say or the physical delivery if it is a you know USB stick of data 2C8-9 Using standard courier	2D8-9 DCS and SAP are used in their production and delivery of products 2D8-9 products meet the specifications before delivery to customer, by lab test that are performed offshore
	2A8		2C8-9	

	Flexible logistics is a mixed mass production system based on the Total Production System (TPS) 2A8 Just-In-Time (JIT) transportation which is concerned not just on speed but also on transportation quality 2A8 Milk-Run is a generic name for a logistics procurement method in which manufacturers utilize the same vehicle to fetch parts from multiple suppliers in other words the transportation of the product is not from Company A directly to the customer		we deliver the line item from the contract almost the same way to deliver physical item from sales order 2C8-9 Depend to the customers decisions to have how they want to shipping; we don't want to take any responsible of lost	
	2A8 A replacement product will be made if the fault has resulted from			

	its normal operation however if the fault has been caused by the customer there will be no replacement given			