CRANFIELD UNIVERSITY

ATHANASIA DOULTSINOU

SERVICE KNOWLEDGE CAPTURE AND RE-USE TO SUPPORT PRODUCT DESIGN

SCHOOL OF APPLIED SCIENCES

PhD THESIS
Academic Year: 2006- 2009

Supervisor: Professor Rajkumar Roy
May 2010

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This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

ABSTRACT

A significant change is taking place in manufacturing company strategies around the globe. With new monitoring and service methods, new opportunities of product use and service provision emerge. The manufacturing companies once focused on mere product manufacture, now have started to provide 'systemic solutions', i.e. products combined with service packages, which are often referred to as Product-Service Systems (PSS). Currently, there is not a well-established feedback mechanism between service and design. The aim of this research is to develop a methodology to capture, represent, and re-use service knowledge to support product design.

For the accomplishment of this aim an extensive literature review of the related themes to the research area took place. It was found that the feedback from service to design is fundamental for the enhancement of product performance; however, the existing literature in this area is not adequate. The industrial investigation led to the realisation that there is not an established mechanism in place to show how service knowledge (SK) can be used by designers. An in-depth investigation took place with the collaboration of, in total, four UK manufacturing companies. The author studied both the conceptual and detailed design, focusing on the design requirements (DR) and the design/service features (DF/SF) respectively.

The first step was the capture of SK and its representation using Protégé software. Following this, at the conceptual design stage, SK can be re-used through the DR-SK tool. The two main purposes of the tool are the knowledge retrieval by designers, and the identification of gaps in SK. At the detailed design stage, designers can access SK through the DF-SK tool, and the developed knowledge templates. The SKaD framework was created, as a result of the amalgamation among the SKaD methodology, the knowledge templates, and the tools developed to link SK and DR, SF, and DF.

Conclusively, the framework was applied on case studies within the pump manufacturing and aerospace industries, and its purpose (to aid designers accessing and re-using SK) was validated by experts within the collaborating organisations. As a result of this research's findings, the service personnel can capture SK in a structured manner, which can then be re-used by product designers at both the conceptual and detailed design stage.

Keywords: service knowledge re-use, knowledge management, design for service

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I should also acknowledge the support of all the people that have participated in my case studies, without which the service knowledge re-use framework would not have been developed. Special reference is necessary for Mr Andy Mann at Edwards Ltd, and Mr Colin Cadas at R-R Plc for their incredible collaboration, and effort made to engage the required resources for my research.

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Finally, I cannot but dedicate this thesis to my parents, and grandparents, Anastasia and Alexandros, for their constant care, and faith in me. Σας αγαπάω και σας ευχαριστώ!

Νάνσυ Δουλτσίνου

'You will never do anything in this world without courage. It is the greatest quality of the mind next to honour'.

Aristotle, 384BC- 322BC

LIST OF PUBLICATIONS

Doultsinou, A., Roy, R., Baxter, D. I. and Gao, J. X. (2009), Developing a Service Knowledge Reuse Framework for Engineering Design, *Journal of Engineering Design* 20(4), 389-411.

Doultsinou, A., Baxter, D., Roy, R., Gao, J. and Mann, A. (2009), *Service and manufacturing knowledge in product-service systems: a case study*, Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS 2) Conference, 1-2 April 2009, Cranfield University, UK.

Doultsinou, A., Roy, R., Baxter, D., and Gao, J., (2008), *Key Service Issues in Two UK Manufacturing Companies from a PSS Perspective*, Proceedings of the Cranfield Multi-strand Conference, 6-7 May 2008, Cranfield, UK, 287-292.

Doultsinou, N., Roy, R., Baxter, D. and Gao, J., (2007) *Identification of service knowledge types for technical Product-Service Systems*, Proceedings of 4th International Conference on Digital Enterprise Technology, 19-21 September 2007, Bath , UK.

Baxter, D., Roy, R., Doultsinou, A., Gao, J. and Kalta, M., (2009) A knowledge management framework to support product-service systems design, *International Journal of Computer Integrated Manufacturing,* 22 (12), 1073 – 1088.

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BM	Breakdown Maintenance
BOM	Bill Of Materials
BPR	Business Process Reengineering
CAD	Computer-Aided Design
CM	Corrective Maintenance
CMMS	Computerised Maintenance Management Systems
CNC	Computer Numerical Control
DCI	Decontamination- Clean- Inspection
DF	Design Feature
DFM	Design For Manufacture
DFMA	Design For Manufacture and Assembly
DR	Design Requirement
ECAR	Electronic Corrective Active Request
ECM	Effectiveness Centered Maintenance
EIS	Entry into Service
FBH	Front Bearing Housing
H&S	Health & Safety
HP	Hewlett-Packard
HR	Human Resources
ICT	Information and Communication Technologies
IMRC	Innovative Manufacturing Research Centre
IMS	Intelligent Maintenance Systems
IT	Information Technology

IVHM	Intelligent Vehicle Health Monitoring
KM	Knowledge Management
KMS	Knowledge Management Systems
KPI	Key Performance Indicator
LCC	Life-Cycle Cost
LED	Light-emitting Diode
Ltd	Limited
MBA	Master of Business Administration
MO	Maintenance Outsourcing
MP	Maintenance Prevention
MS	Microsoft
NPD	New Product Development
OEM	Original Equipment Manufacturer
PDR	Personal Development Review
Plc	Public Limited Company
PLM	Product Lifecycle Management
PM	Preventive Maintenance
PreM	Predictive Maintenance
PrM	Productive Maintenance
PSS	Product-Service Systems
QC	Quality Circle
QFD	Quality Function Deployment
R&D	Research and Development
RBM	Risk-based Maintenance
RCA	Root Cause Analysis

RCM	Reliability Centered Maintenance
RP	Research Protocol
R-R	Rolls-Royce
SE	Service Engineering
SERVQUAL	Service Quality
SF	Service Feature
SK	Service Knowledge
SKaD	Service Knowledge and Design
SMM	Strategic Maintenance Management
TDS	Tool Drawing System
TPM	Total Productive Maintenance
t-PSS	technical PSS
TQM	Total Quality Management
UK	United Kingdom
US	United States
VAT	Value-Added Tax

1 Introduction

1.1 Introduction

A major shift is taking place in company strategies across western manufacturing organisations. Such strategies, previously focused on product manufacture, are beginning to offer product-service systems (PSS), i.e. systematic solutions by integrating products and services. The idea is to combine the tangible product with the intangible service elements and create a system that is improved for delivering the desired outcome (Doultsinou et al, 2009). A formal definition by Baines et al. (2007) describes PSS as an integrated product and service offering that delivers value in use.

The definition of manufacturing and service is not clear cut. Often, 65-75% of the employees in a traditional manufacturing enterprise perform 'service sector' roles. These roles range from production-related activities such as research, logistics, planning and maintenance, to product and process design. General support services are also required, such as accounting, finance, law, and personnel (Mont, 2002). Due to the broadness of the field of 'service', it is necessary to define what this research aims to address. Also, improving service delivery, identifying and developing the relationships between service and other core elements of the organisations, including manufacturing and design, will lead to a better organisational performance (Doultsinou et al., 2009).

The research offers an understanding about Service Knowledge (SK), and the impact of the use of SK in design. Knowledge can be defined as personalised information processed in the individuals' minds associated with facts, interpretations and judgements (Alavi & Leidner, 2001). A SK definition was developed by the author; SK is the amalgamation of processed information, and experiences of service personnel, gained through the execution of their tasks. Within the context of this research, the IBM definition of service will be adopted, which describes service as an activity or a series of activities provided as a solution to customer's problems (IBM website, 2006); nevertheless, the focus of this research is on technical services (e.g. maintenance).

PSS is shifting through life responsibilities from the customer to the OEM. It is now necessary to consider SK at the design stage to reduce service related issues later. The focal area of this research is technical services. In this area it has been identified that there is a lack of research in methods to support service requirements in product design, and also in service design. Literature shows that communication links need to be established between product design and service provision groups. This is because information related to past failures and malfunctions can be used by designers in order to avoid similar mistakes in a future product generation (Jones and Hayes, 1997; Petkova, 2003; Jagtap et al., 2007b). Petkova (2003) highlighted also the lack of literature in the area of field feedback.

The main groups benefiting from this research are the designers and the service personnel of manufacturing organisations. Mutual understanding between the two groups is essential, as designers need to understand the difficulties that the service engineers face while capturing the in-service information. On the other hand, service engineers ought to be aware of the designers' requirements in terms of the information that needs to be captured.

1.2 Research Context and Aim

This research focuses on the service knowledge capture of complex mechanical products. A typical mechanical product would involve structural units, mechanical assemblies, and mechanisms. The scope of this study, with regards to the methodology development, concentrates mainly on two industries: the pump manufacturing and aerospace. However, some elements of the research, such as the service features' identification and the Service Knowledge (SK) capture and representation are intended to be applicable in more areas.

The context of this research is about the provision of technical services, and more specifically, those services which directly enhance the operation phase of the product life cycle (e.g. decrease the number of failures that occur). Figure 1.1 shows the main stages of product lifecycle. Similar product lifecycle stages were also mentioned by Jovane et al. (1993). These are: need, design/ development, production, distribution, usage, and disposal/ recycling.

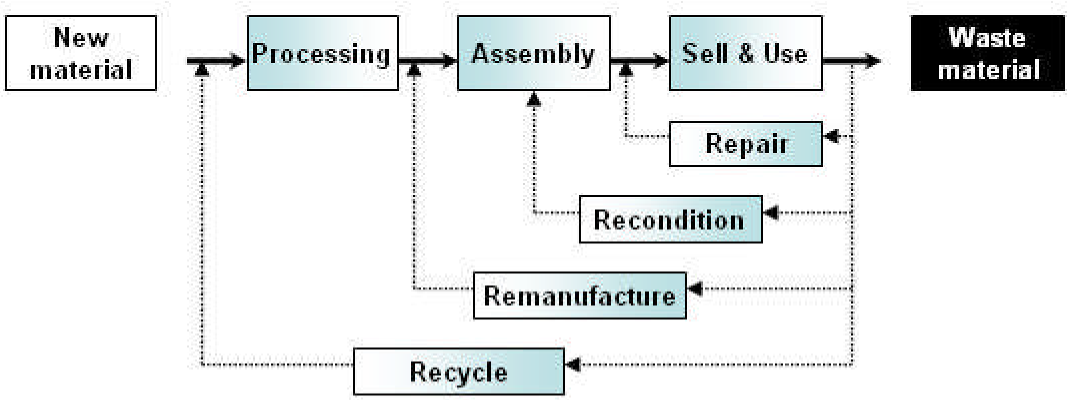

Figure 1.1: Product lifecycle (Source: King et al., 2006)

Supporting product design through improved access to service knowledge will support the fulfilment of customer needs via the provision of improved products and services. Therefore, within this context SK is defined as in-service information related to failures and breakdowns of existing products; this information and experience gained from past projects should be utilised by product designers to avoid future mistakes. Effectively, the decrease of in-service product failures will result in the cutback of maintenance costs.

This research aims to develop a methodology to capture, represent, and re-use service knowledge to support product design.

1.3 The 'U-KNOW' Project

This research was carried out in the context of a 3-year research project, which aimed to develop a methodology to capture, represent, and re-use design, manufacturing and service knowledge to support new product development (NPD). According to Krishnan and Ulrich (2001) the NPD process can be split into five key sequential activities:

1. Concept development: The product specifications, the product fundamental physical configuration, and additional offerings, such as life cycle services need to be defined at this stage. A product concept is generally realised through decisions related to the physical form and appearance of the product. These decisions constitute an activity generally called industrial design. The latter along with mechanical design and other design subareas are part of ***concept design*** (Keinonen and Takala, 2006). Conceptual design can be defined as this part of the design process which begins with a problem statement in the form of a set of requirements (adapted from Serrano D., 1987).
2. Supply chain design: This stage includes the selection of the suppliers, along with decisions regarding the production and distribution system design issues, the components that should be specifically designed, the configuration of the physical supply chain, the process type for product assembly, and the development and supply of the process equipment and the product itself.
3. Product design: Product design is used in its narrow sense, referring only to the ***detailed design stage***. The design parameters need to be specified, and the relationships in the assembly and the detailed design of the components (along with selection of materials and process) have to be determined.
4. Performance test and verification: The design is prototyped in order to be verified for fit, function, and manufacture while detailed design decisions are made.

5. Production ramp-up and product launch: Examples of decisions taken at this stage are: the progression of product introduction to diverse markets, and the level to which test marketing should be carried out.

The 3-year project was entitled 'Unification of Design, Manufacturing Capability, and Service Knowledge in Collaborative Product Development', and forms a key part of the Cranfield Manufacturing Department's research portfolio in IMRC Enablers. Specifically, it compliments research projects, such as 'knowledge representation and re-use for predictive design and manufacturing evaluation' (IMRC 24), 'distributed and collaborative product development and manufacturing knowledge management' (IMRC 11), 'feature based knowledge management framework to support collaborative product development and service' (Rolls-Royce) and 'building a knowledge management strategy for product development and manufacturing' (Vaillant Hepworth Group). The two main industrial sponsors of the 'U-KNOW' project were Rolls-Royce Plc and Edwards Ltd.[1]

Figure 1.2 graphically depicts the areas of investigation within the context of the 'U-KNOW' project. These are: design, manufacturing, and service. Two full-time researchers worked on this project; the first one dealt with the design and manufacturing areas, and the author, who was the second researcher, managed the service part of the project.

[1] The source of all the aforementioned information is the research proposal document of the 'U-KNOW' project.

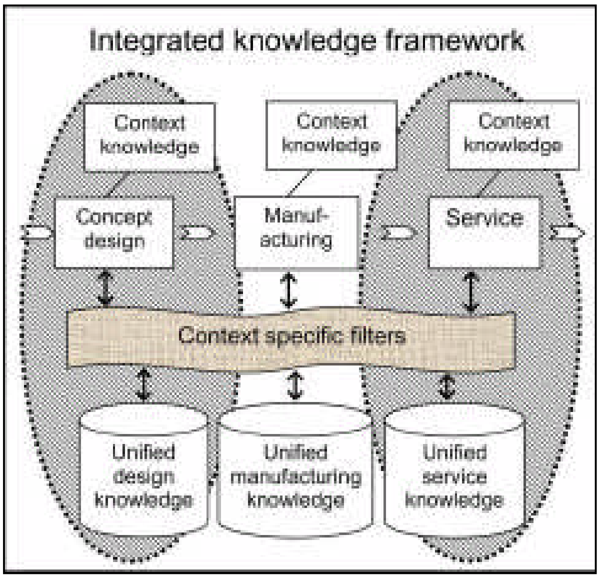

Figure 1.2: 'U-KNOW' research context (Source: Doultsinou et al., 2009)

More specifically, the first core element for the 'U-KNOW' project was a process-based design model: defining design in relation to specific tasks, and connecting previous knowledge with those tasks. The second was manufacturing capability knowledge: supporting feature-based design and manufacture through the representation of machining features, best practices in machining and inspection, and machining capability. The third element was service knowledge: making sure that design takes into consideration the service requirements (Baxter et al., 2009). Since the main project purpose was the knowledge unification, the author had to mainly explore the third core element in conjunction with findings encompassed in the first one.

1.4 The Collaborators

All the way through the research the author collaborated with several organisations in order to enrich her understanding of the field. The author was in contact with experienced individuals within the industrial environment and had the opportunity to exchange valuable ideas and get helpful advice on the theme studied.

The collaboration with two of them led to carrying out two of the main case studies of this research. These were used in the methodology and framework development, and their validation. An additional organisation contributed to the validation of the SK types along with the expansion of the Service Feature (SF) list. The last collaborator assisted in the preliminary validation of the SK capture exercise, the identification of service issues within the manufacturing sector, and provided the researcher with an initial understanding of PSS offerings.

Edwards Limited

Edwards are the main sponsor of this research. The organisation holds a leading position in the global supply of integrated solutions for the manufacture of semiconductors, flat panel displays, light-emitting diodes (LEDs) and solar cells, and in vacuum technology for industrial, pharmaceutical, chemical, scientific, process, glass coating and food packaging industries as well as a wide range of Research and Development (R&D) applications. They are an international sales and service organisation having around 3000 employees. Their range of products spans from small wet/dry pumps to exhaust management systems and semiconductor pumps (Edwards Limited website, 2010). The researcher focused on the small dry pumps and the semiconductor pumps. The whole range of Edwards' products is illustrated in Figure 1.3. Additionally, Edwards offer on demand product services, support contracts and applications and operations support. Each of these service provisions is presented in a more detailed manner in Figure 1.4, Figure 1.5 and Figure 1.6 respectively.

Figure 1.3: Edwards' product range (Source: Edwards Ltd website, 2010)

Figure 1.4 illustrates the on demand product services. Edwards have a global network of service centres, through which they provide a broad range of product repair and maintenance options. Edwards' offices, agents, distributors or representatives can be found around the globe.

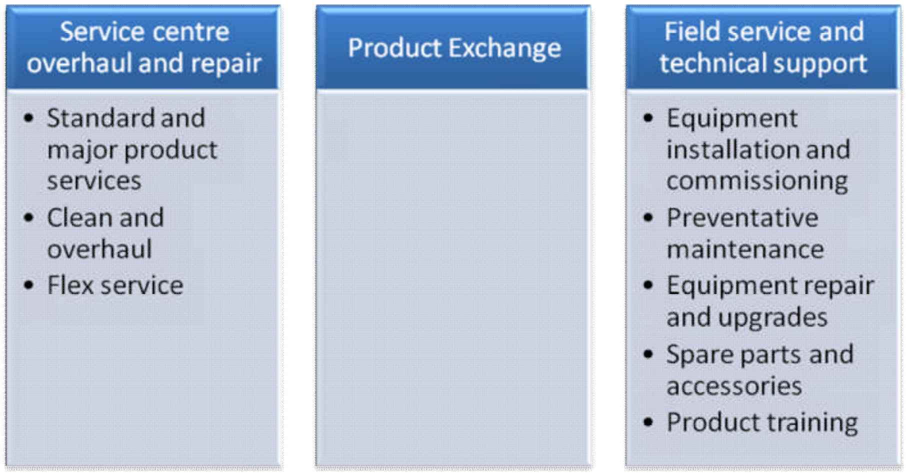

Figure 1.4: Edwards' on demand product services (Source: Edwards Ltd website, 2010)

Regarding the *overhaul and repair* services, Edwards offer standard and major product services, which is a fixed price full remanufacturing service with a 6-month warranty. They also provide clean and overhaul as a fixed price preventative maintenance service supported by a 90-day parts' and labour warranty. Finally, they have a flex service, where the customer can control the service costs. As far as *product exchange* is concerned, Edwards hold a wide-ranging inventory of service exchange products, remanufactured to as-new performance specifications in their service centres. With regards to *field service and technical support*, the organisation offers equipment installation and commissioning, preventative maintenance, equipment repair and upgrades, spare parts and accessories, and training courses (Edwards Ltd website, 2010).

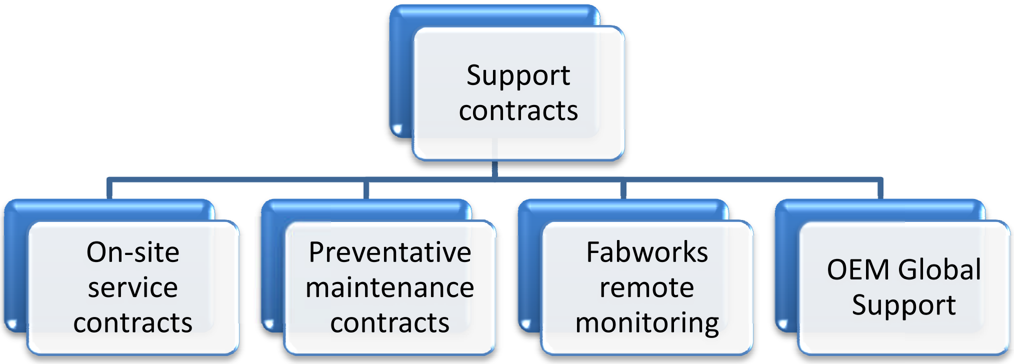

Figure 1.5: Edwards' support contracts (Source: Edwards Ltd website, 2010)

Figure 1.5 shows the types of support contracts. These are (Edwards Ltd website, 2010):

- *On-site service contracts*: Edwards' technicians can be based at any company's site, and provide the installation and commissioning of equipment, equipment monitoring, preventative maintenance and upgrades, logistics management to re-organise the supply chain, emergency hotline and service support available outside of normal working hours.
- *Preventative maintenance contracts*: They are fixed-fee maintenance agreements with an option to include all spares, consumables and repairs. Also, operator training and regularly scheduled visits can be arranged.
- *Fabworks remote monitoring*: a comprehensive condition monitoring and analysis system for vacuum and exhaust management equipment.
- *OEM Global Support:* Edwards recognise the need for consistency in service provision around the globe. The company's global service agreements range from local phone and field support to a permanent on-site presence integrated into the customer's team.

Edwards also offer applications' and operations' support (Figure 1.6).

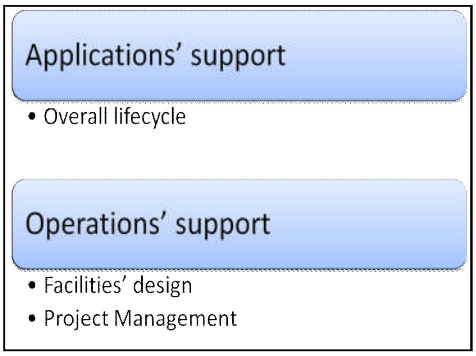

Figure 1.6: Edwards' applications' and operations' support (Source: Edwards Ltd website, 2010)

Rolls-Royce Plc

Rolls-Royce (R-R) Plc is a global business provider of integrated power systems to be used on land, at sea and in the air. They operate in four sectors: civil and defence aerospace, marine and energy. R-R's strategy is based on mainly five elements (Rolls-Royce website, 2010):

1. Concentrate on four global markets (mentioned above)
2. Invest in infrastructure, technology and capability
3. Build up a competitive range of products and services
4. Increase market share and installed product base
5. Add value to their customers with the provision of product-related services.

Services are a core element of the R-R business.

Figure 1.7 shows the revenues from services; they account for 50% of the total sales and they have experienced a growth of 10% over the past ten years.

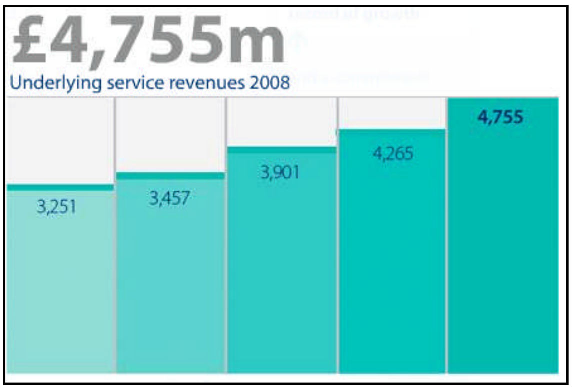

Figure 1.7: Revenue from services (Source: R-R website, 2010)

As it can be found in R-R annual reports and accounts (R-R website, 2010), 57% of the civil aerospace fleet is now under TotalCare support; more than 8,000 engines and auxiliary power units are supported by in-service monitoring. Global repair services have been created, and the capability of global operation centres has been expanded, including satellite sites with two major customers. All these facts show clearly the importance of services for a traditional manufacturing organisation. The revenue stemming from services, along with their illustration as a percentage within the group revenue are shown in Table 1.1.

Key performance indicators	2008	2007	2006	2005	2004
Underlying services revenue £m	4,755	4,265	3,901	3,457	3,251
Underlying services as percentage of Group revenue	52	55	53	54	55

Table 1.1: Service revenue and percentages, 2004-2008 (Source: R-R website, 2010, Annual reports and accounts)

The R-R group's services include: field services, the sale of spare parts, equipment overhaul services, parts' repair, data management, equipment leasing, and inventory management services. These services are usually sold as a package within the TotalCare provision.

The researcher focused on a product from the civil aerospace range. The products of this range are: large aircraft engines, small aircraft engines, and helicopter engines. The studied product belongs to the large aircraft engine family, which is presented in Figure 1.8.

Figure 1.8: R-R Large aircraft engines (Source: R-R website, 2010)

Hardinge Machine Tools Limited

Hardinge provide a broad variety of highly reliable turning, milling, grinding and workholding solutions. Their product lines vary from precision, manual lathes to super-precision, multi-tasking CNC lathes, grinding machines, and they are the largest manufacturer of precision collets, chucks and workholding systems globally. In addition to the products that Hardinge manufacture, they provide a wide choice of services that range beyond the traditional pre-sale or warranty support. These services are performed on a paid basis in the way that matches the customer requirements;

either 'pay as you go' or purchase 'service contracts' that cover a specific period of time (Hardinge UK website, 2010). The author, within the boundaries of this research, did not focus on any particular product of Hardinge; emphasis was given on the service provision, issues faced with the customers, how these were dealt with, and the aspects that make a 'good service' and the provided value to the customer.

BAE Systems

BAE Systems are the second largest global defence organisation based on 2008 revenues with approximately 105,000 employees worldwide. Their range of products and services accounts for air, land and naval forces, as well as advanced electronics, security, information technology solutions and customer support services. The organisation is active in seven markets: Australia, India, Saudi Arabia, South Africa, Sweden, UK and the US, comprising four operating groups (BAE Systems website, Company Structure, 2010):

- Electronics, Intelligence and Support
- Land and Armaments
- Programmes and Support
- International

The author had a very limited amount of interaction and involvement with BAE Systems; as a result, there was not enough available time to familiarise herself with the array of products and services provided. However, she had the opportunity to gain an initial understanding of the importance of service provision for the company and the care taken of the customer needs and requirements.

1.5 Thesis Structure and Summary

This Section presents the structure of this thesis in order to familiarise the reader with the content of this work and the succession of activities leading to the achievement of the research aim.

Chapter 1 gave an overview of the research context and the motivation of this study. Moreover, it described the 'U-KNOW' overall project and its objectives along with the collaborating industrial organisations of this study. The main aim of this research was also presented; this is to develop a methodology to capture, represent and re-use service knowledge to support product design. Finally, the thesis structure is part of this Chapter.

Chapter 2 is concerned with the exploration and critical analysis of the literature relevant to this research, while also the research gaps were identified. Another purpose for studying the literature was to define the objectives, which would in turn fulfil the overall research aim.

Chapter 3 presents the aim and objectives of this study, based on the literature review findings. Subsequently, the research methodology is presented; this was developed after a thorough analysis of the available approaches and strategies. The nature of the objectives and the available resources to the author were the factors impinging on the selection of an approach and strategy for this research.

Chapter 4 is linked with SK capture and representation. The SK types were firstly identified through case studies conducted with the collaborating organisations, then represented with the use of ontology, and finally validated with the organisations that took part in this study. Also, the AS-IS process followed when a product failure occurs was captured, showing lack of interaction between designers and service personnel.

Chapter 5 examines the service involvement at the conceptual design stage. The author, based on the literature and the industrial findings, developed a design requirements list; afterwards, a mapping between design requirements and SK types is created, and a SK audit tool was built in order to assist the New Product Development (NPD) personnel in the identification of SK gaps with regards to the design requirements. A validation exercise took place in collaboration with two of the industrial sponsors.

Chapter 6 is related to the service involvement at the detailed design stage. A SF list was created, stemming from the literature and the industrial case studies. Then, a Design Feature (DF) list is presented, along with mappings between SF and resources, DF and SK types, and SF and SK types. These links enable the detailed designers to utilise the SK that is relevant to their tasks. Two case studies were used to validate these findings.

Chapter 7 presents the SK and design (SKaD) methodology and framework. The methodology was created based on observations and findings from Chapters 4, 5 and 6, and the framework was implemented in an Access database.

Chapter 8 is about the validation of the overall methodology, describing also the products used for the case studies.

Finally, Chapter 9 discusses the research findings with regards to their applicability and generalisability. The main research contributions are stated, along with the limitations, the future research directions and the overall conclusions demonstrating how the objectives and the aim have been attained.

2 Literature Review

2.1 Introduction

In Chapter 1, the author introduced the research area and presented the aim of this study. As a logical progression, this Chapter highlights the literature associated with the context and research areas related to this study; the objective being to bring to light any research gaps in the existing pool of knowledge, and accordingly provide a better understanding of the investigated areas.

Figure 2.1 depicts the focus of the literature review. The literature presented in this Chapter is principally divided into three key discipline areas: knowledge, service, and design. More specifically, in the area of knowledge the author focused on its capture, representation, and re-use. In addition to this, various types of services were found in the literature; the emphasis on this research is given to services that support the product, such as maintenance and repair. Since the main aim of this study is to support product design with knowledge of service, the area of 'design' was also explored; in particular, the 'product design', 'design for service', and 'design for manufacture' themes.

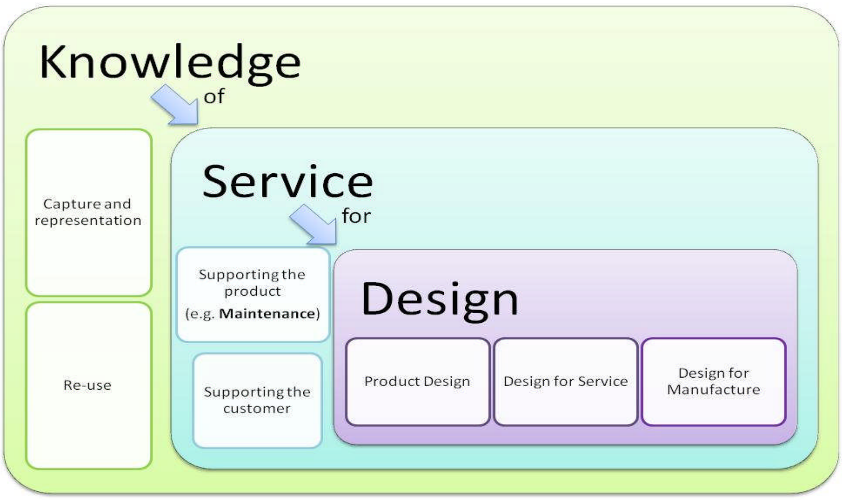

Figure 2.1: Literature review areas

2.2 Knowledge

The first part of the literature review makes an introduction to the concept of knowledge, and more specifically presents definitions, types, elicitation, and re-use of knowledge. Moreover, it describes Knowledge Management (KM) notion, as well as its strategies and activities.

The study of knowledge was established by Plato. Aristotle developed a systematic terminology for knowledge representation. Additionally, he created Logic as an accurate method for reasoning about knowledge, and Syllogism, which is a three-part pattern to represent Logical Deduction (Kabilan, 2007).

2.2.1 Knowledge definition

Knowledge can be defined as a justified true belief (Nonaka, 1994). Also, it can be defined as 'the full utilisation of information and data, coupled with the potential of people's skills, competences ideas, intuitions, commitments, and innovations' (Sobodu, 2002). Some authors, mostly in IT literature, propose that the definition of knowledge should take place after the distinction among data, information, and knowledge. Thus, Alavi and Leidner (2001) stated that knowledge is personalised information, as managed by individuals, and associated with facts, interpretations, and judgements.

Davenport and Prusak (1998) defined knowledge as 'a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organisations, it often becomes embedded not only in documents or repositories but also in organisational routines, processes, practices, and norms'. According to Han and Park (2009) it is important that knowledge should be attached to the conducted tasks and employees should capture knowledge as part of their normal work in order to attain a better performance.

The author believes that the definition provided by Alavi and Leidner (2001) is simple and easily understood; however, it encapsulates the essence of the meaning of knowledge. Hence, it is going to be the definition used in the context of this research. Elements of other knowledge definitions are also taken into account. The fact that knowledge can be found in organisational practices and processes, apart from documents or repositories (Davenport and Prusak, 1998), and that employees capture knowledge in the course of their work and achieve better performance (Han and Park, 2009) are the two factors considered by the author when defining knowledge.

2.2.2 Knowledge Pyramid

As described in the previous Section, knowledge is the outcome of personalised processed data and information according to specific experiences. The hierarchy of data, information, knowledge, and wisdom concepts is most commonly referred to as 'knowledge pyramid' or 'knowledge hierarchy' and can be seen in Figure 2.2.

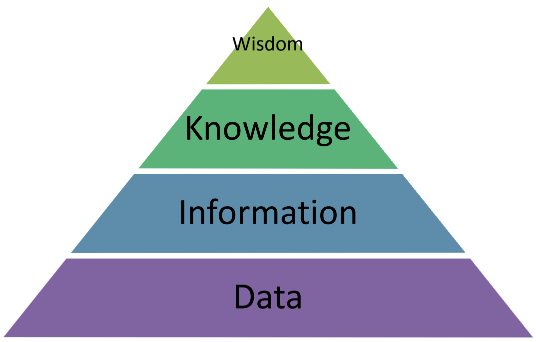

Figure 2.2: Knowledge Pyramid (Source: Hey, 2004)

The hierarchy has the shape of a pyramid, because according to Hey (2004) big amounts of data are refined and a smaller amount of information is created; this, in turn, is distilled further to create knowledge.

Data: it has different definitions depending on the specific domain. Saint-Onge (1996) said that data is discrete and consists of scattered elements. Ackoff (1989) believed that data is not important, because it is unstructured and does not have any meaning by itself. Wilson (2002) mentioned that data is simply facts.

Information: it is data with meaning. It can be defined as a message and the person who receives it can decide whether it informs him/her or not. According to Wilson (2002) data becomes information when embedded in a relevant context.

Knowledge: it is subjective, personal and shaped by an individual's perceptions and experiences (Hey, 2004).

Wisdom: it is an extrapolative process, through which individuals differentiate between right and wrong, good and bad. According to Ackoff (1989) wisdom is linked to the future, since it integrates design and vision, whereas the other pyramid levels are connected to the past, since they are related to known things.

Davenport and Prusak (1998) suggested five methods to transform data into information. These are the following:

- Contextualised: when the data is gathered and its purpose is known.
- Categorised : when the main elements of the data are known.
- Calculated : when the data is analysed mathematically or statistically.
- Corrected : when the data is cleared from errors.
- Condensed : when the data is summarised in a brief manner.

Moreover, there is conversion of information into knowledge. Nonaka (1996) stated that 'information is the flow, and knowledge is the stock' meaning that the gathering of information is essential for obtaining and creating knowledge. However, this process can explain only the creation of explicit knowledge, since tacit knowledge has firstly to be internalised.

Davenport and Prusak (1998) proposed four methods of transforming information into knowledge. These are:

- Comparison: How can information about this situation be compared with other situations that have been experienced?
- Consequences: Which are the insinuations of information in actions taken and decisions made?
- Connections: How is this piece of knowledge related to others?
- Conversation: What are others thinking regarding this information?

2.2.3 Knowledge types

Based on the literature studied, there are two types of knowledge: tacit and explicit.

Tacit: It is the knowledge that stems typically from experience. It is also quite unstructured and hard to communicate (Nonaka, 1994; Sobodu, 2002).

Garcia-Perez and Mitra (2007) expanded further on tacit knowledge, describing three types:

1. Individuals' education, abilities, know-how.
2. Individuals' ideas found in publications or patents.
3. Individuals' consciousness of others' knowledge within and out of organisational boundaries.

*Explicit***:** It is knowledge that can be transmitted in formal, systematic and well-structured language (Nonaka, 1994; Sobodu, 2002).

It should be noted that this research mostly attempts to capture tacit knowledge and make it explicit by externalizing through a knowledge capture and re-use methodology.

Table 2.1 summarises the main comparison points for tacit and explicit knowledge.

Comparison point	Tacit knowledge	Explicit knowledge
Characteristics	1. Difficult to document and systemise 2. Difficult to change 3. Examples: secrets, experience, personal feelings	1. Can be documented and more easily systemised 2. Fixed information, applications vary 3. Examples: business manuals, operation guidance
Storage space	Human mind	Databases, computers, documents
Sharing method	The degree of difficulty depends on the ability of personal expression	Presented by video or audio media, or transferred via print, movies etc.
Nature	Technical (e.g. skills gradually developed by master craftsmen) or cognitive (e.g. implicit mental models and perceptions that are so deep-rooted that are taken for granted)	Technical (A level of academic knowledge gained through education or a structured study is needed)

Table 2.1: Knowledge comparison (Adapted from: Liang, 2002 and Smith, 2001)

Nonaka (1994) carried out an extensive research in the area of Organisation Knowledge Creation and found out that organisational knowledge creation is the outcome of a continuous dialogue between tacit and explicit knowledge. Beyond this, he identified four patterns of knowledge conversion, which are:

- From tacit knowledge to tacit knowledge
- From explicit knowledge to explicit knowledge
- From tacit knowledge to explicit knowledge
- From explicit knowledge to tacit knowledge

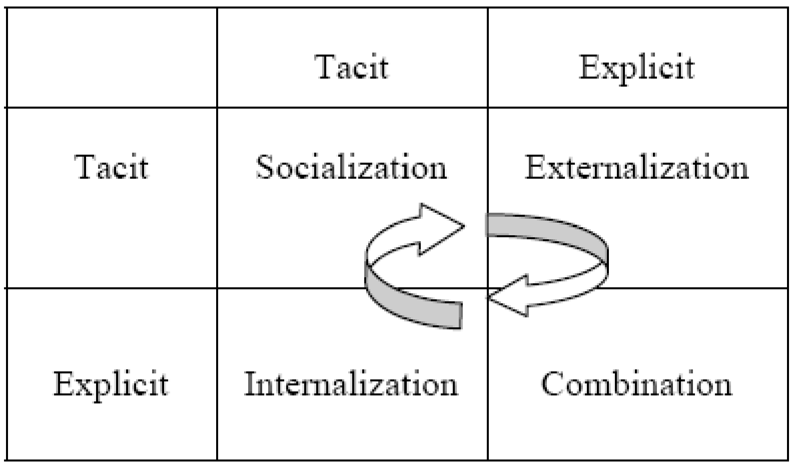

Figure 2.3: Knowledge conversion and the spiral of knowledge (Source: Nonaka and Takechi, 1995)

The *first* mode of knowledge conversion is referred to as socialisation and is the process of converting old to new tacit knowledge through interaction between individuals and sharing of their experiences. People learn new things by observing and mimicking other people's techniques; the use of language is not necessary.

The *second* mode is called combination and is the process of converting old to new explicit knowledge through the use of social processes, which allow the combination of different pieces of the individuals' explicit knowledge, e.g. conversations and meetings.

The *third* mode is referred to as externalisation and is the process of converting tacit knowledge to explicit knowledge. This can be achieved by the development of a creative dialogue, for instance by using storytelling and metaphors.

The *fourth* mode is called internalisation and is related to learning by doing. The explicit knowledge is shared within the company and absorbed by individuals. This conversion mode along with the third one illustrates the idea that explicit and tacit knowledge are complimentary and can develop over time through a mutual interaction process.

2.2.4 Knowledge Capture (elicitation) and Representation

Loss of knowledge commonly happens when employees spend part of their working hours attempting to obtain knowledge for the analysis and resolution of problems, while similar issues have occurred in the past, but the knowledge used in the provided solution was not captured. Therefore, knowledge capture aids the organisation and retention of knowledge for future use (Sobodu, 2002). It should be noted that the term ‘knowledge elicitation’ is also used in the literature when referring to knowledge capture.

Soltan (2006) mentioned that five techniques are used for knowledge elicitation: interview, card sorting, 20 questions, protocol, and laddered grid. In addition to this, Garcia-Perez and Mitra (2007) expanded this list by adding concept mapping, knowledge audits, cognitive modelling, data analysis, and work patterns analysis as knowledge elicitation techniques. Other techniques are dialogue, scenarios (where a particular situation is considered), task analysis. Brainstorming, diagrammatic representations, stimulus (e.g. poor quality pictures), teach-back (where operators teach the knowledge engineer a specific process or parts of it) are also complimentary methods. Card sorts and 20-question methods can also prove useful in the knowledge elicitation process (Browne et al., 2006). Hoffman et al. (1999) argued that the use of a combination of existing methods is one of the most important approaches to knowledge elicitation.

Schreiber et al. (2000) divided the knowledge elicitation methods into natural and contrived. A natural method is one that an expert might informally take up while expressing or showing expertise. Interviews or observation of actual problem solving are examples of natural methods. A contrived method is one that elicits expertise in ways the expert is not usually familiar with. Sorting is an example of a contrived elicitation method. In total, they discuss five techniques in their CommonKADS methodology book. These are: 1) interviewing, 2) protocol analysis, 3) laddering, 4) concept sorting, and 5) repertory grids. The first two methods can be classified as natural; the last three are more contrived.

Interviewing is the most commonly used method in knowledge elicitation. Interview form can vary from totally unstructured to completely structured. The advantages of an unstructured interview stem from the lack of constraints (there is not an agenda or at least a detailed one). It can be used when the knowledge engineer wants to: 1) establish a good relationship with the expert, 2) gain a broad view of a topic, 3) allow the expert to describe the domain and discuss familiar to him/her topics. On the other hand, the lack of constraints leads to pitfalls as well. The expert may focus on topics whose significance s/he exaggerates, and also the data integration may be difficult due to inconsistencies, especially in cases where many experts were interviewed by the knowledge engineer. A structured interview facilitates the analysis of the gathered results; however, the expert is restricted to express his/her opinion only on the questions and scenarios presented by the interviewer (Schreiber et al., 2000).

Browne et al. (2006) described the phases of knowledge elicitation. Phase 0 is a political requirement, whose importance cannot be underestimated. If the employees at all levels are not fully supportive of the project, then the latter will have low impact. Additionally, the developed system should be cost-effective and measures should show improvement on delivery times, perceived product quality, and ultimately customer satisfaction. Phase 1 involves an initial presentation so that the main concepts regarding the knowledge elicitation are introduced and a culture of openness and honesty is created. Phase 2 encompasses the identification of irrelevant sources of information and the focus of the knowledge elicitation on areas considered as important by the organisation's employees. Phase 3 involves the 'questioning' of the experts and aims at completing the system scope and generating an initial rule-base. Phase 4 includes the evaluation of the initial rule-base and considers gaps within the elicited knowledge. Phase 5 deals with the utilisation of the knowledge base; the results are fed back to the experts to enhance the rules.

Furthermore, there are several methods of intermediate as well as implementation knowledge representation. According to Soltan (2006) the natural language (text), tables/charts/graphs, decision tables and decision trees are used for the former one (intermediate); heuristics and semantic networks for the latter one (implementation).

2.2.5 Knowledge Re-use

Markus (2001) pioneered the theory of knowledge re-use, emphasising the role of Knowledge Management Systems (KMS) and the repositories. Knowledge re-use was defined by him as the sharing of best practices for people to resolve common technical issues. Another definition given by Weise (1996) is that knowledge re-use is the sharing of information, and documentation.

Therefore, the knowledge is systematically processed and stored, then re-used repeatedly when any similar situation occurs. As a result, the value of knowledge is enhanced, the time to develop new products is minimised and the cost of carrying out business is decreased (Markus, 2001). Hansen et al. (1999), Markus (2001), Majchrzak et al. (2004), and Lin (2003) have explored the theme of knowledge re-use related to creation and innovation. Huerta et al. (2003) emphasised that the final target of KM is to re-use the knowledge created within an organisation. The initial stage of KM implementation is the building of knowledge repositories.

So and Bolloju (2005) investigated the theme of knowledge sharing and re-use. The two researchers classified the studies according to the following perspectives: conceptual framework, knowledge transfer processes, knowledge ownership, and knowledge sharing. In total, eleven studies were found. They were mainly focused on the key factors affecting the knowledge transfer within an organisation, the employees' attitudes towards organisational knowledge sharing, and the identification of motivation factors and difficulties in knowledge sharing.

It seems though that the reuse of tacit knowledge is still an unanswered issue in the KM community. Nunes et al. (2009) claimed that contextual knowledge will substantially improve the understanding and focus of the knowledge use. Many people use contextual information while being unaware of it. Contextual knowledge is essential, since it provides a better understanding of activities, facts, and decisions made. Consequently, increased awareness of contextual knowledge will lead to substantial support in the performance of work process activities. To improve this awareness, it is crucial to make contextual knowledge explicit, represent it, centralise it for easy access and maintenance, and allow all the involved parties access it. As Han and Park (2009) mentioned, without relevant contextual information, knowledge can be remote from other relevant knowledge; thus, leading to a partial or mistaken understanding.

Despite the existence of numerous studies on knowledge re-use in various fields, such as design, IT, consultancy, there was only a limited number found on the re-use of service knowledge within the context of technical services (e.g. maintenance). The results from few existing studies are presented in the Section 'Design for service' later on in this Chapter; ways to support product design with service knowledge are discussed.

2.2.6 Why is knowledge re-used?

Ma (2005) said that there are two reasons for organisations to perform knowledge re-use. These are:

1. Limited resources: Hatami et al. (2002) found out in their research that in spite of the technological resources, knowledge re-use is a human process and its contribution to organisational effectiveness highly depends on users. Owen et al. (2004) state that better identification, transfer, and management of knowledge can result in effective maintenance of the intellectual capital and its re-use in other projects; thus, reducing the amount of time spent on recreating what has already been learnt.
2. Leveraging created knowledge for corporation competitive advantage: It becomes more cost effective to re-use knowledge that has been created. The process of learning from past mistakes and successes can radically reduce design and related production costs (Ma, 2005).

Therefore, service knowledge re-use by designers can significantly impact the required time and cost for product design. In order for this to be achieved the designers need to access and re-use the right service knowledge; they can then incorporate it in the design. This will result in avoiding past mistakes and possible future re-designs; thus, in a reduction of design time and costs.

Organisations in mature markets can benefit from knowledge re-use for three main reasons (Baxter et al., 2008):

1. They have a good knowledge of the product, therefore are able to produce high quality reusable knowledge.
2. The next generation product is likely to have a considerable amount of common characteristics with the previous one.

3. Knowledge re-use allows more time for innovation, which is of great importance as competitive advantage is hard to achieve in mature domains.

2.2.7 Issues of knowledge re-use

Despite the benefits of knowledge re-use, there are five drawbacks of it identified in the literature (Ma, 2005):

- *Information overload*: If the repository proves to be too heavy, there are fewer chances of finding useful information in a timely manner; also, the search costs for the re-usable knowledge will be higher (Garud and Kumaraswamy, 2005).
- *Different requirements of knowledge re-users*: Different knowledge re-users have different needs as far as their knowledge repositories are concerned. For instance, expertise-seeking novices need de-contextualised knowledge, whereas shared work producers seek for contextual knowledge (Markus, 2001). Also, knowledge requirements vary depending on the level of product complexity (Bailey, 2003).
- *Knowledge re-user unawareness of knowledge sources*: Since knowledge sources are widely distributed throughout an organisation, the knowledge re-user might find it difficult to locate and use these sources (Galup et al., 2003).
- *Issues of motivation and reward*: Individuals or groups of employees may prefer to develop a unique solution rather than re-use knowledge already available in repositories, since it is perceived that those who provide help are more competent than the ones receiving help (Sambamurthy and Subramani, 2005).
- *Overemphasis on explicit/tacit knowledge*: Both tacit and explicit knowledge need to be transferred to make comprehensive knowledge sharing happen. In the case of over-reliance on tacit knowledge, the leverage that can be gained from transferring explicit knowledge is lost; likewise, an overemphasis on explicit knowledge will lead to a loss of tacit elements, which are a critical component of the added value (Gibbert et al., 2002).

The author of this thesis has recognised that there is a lack of research in identifying ways of overcoming the aforementioned obstacles. Moreover, organisations that actively re-use knowledge, and the effects (positive and/or negative) it has on their employees' performance and the product itself have not been investigated. Specifically with regards to service knowledge, exploration of its re-use impact on product design, along with the ways of providing the designers with access to the right service knowledge needs to take place; this constitutes the context of this research.

2.2.8 Barriers for knowledge re-use

Nunes et al. (2009) elaborated on the barriers associated with knowledge re-use and focused on two issues:

1. The cost associated with the introduction and maintenance of contextual KM environments needs to be considered. Moreover, political problems and the competitive work nature can affect greatly the information that will be stored. In addition to this, employees may be unwilling to share their knowledge fearing that they might become redundant or put their positions at risk.
2. A shift in the employees' mentality must be made for knowledge sharing and re-use to be promoted in an organisation. Their role should be altered from knowledge receivers to 'knowledge researchers, builders, and communicators'. Despite the fact that each project is unique, similar experiences can facilitate the accomplishment of the employees' activities within an organisation.

Bailey (2003) highlighted the fact that the knowledge needed to undertake a complex task is very intensive and entails several years of experience within the related domain. This statement leads to the need of overcoming the barriers and successfully re-using knowledge.

2.2.9 Ontology- means of knowledge re-use

Ontologies are considered to be another means of sharing and reusing information (Nunes et al., 2009). A key use of ontology is the sharing of information between people, databases, and applications (Kabilan, 2007).

Ontology definitions

The term ‘ontology’ was borrowed from philosophy, where it meant the description of existence; it has been, however, changed. Gruber (1995) defined ontology as ‘a representation of a conceptualisation and as a formal specification of the concepts and terms of the information universe of a specific domain’. Garcia Castro et al. (2006) believe that the application of an ontologically-based approach should be more powerful for information retrieval than keyword-based methods, since semantic queries can be created and relationship among concepts can be formed within an ontology. It should be mentioned that the creation of an ontology that intends to provide a basic understanding of a domain might entail less effort than the one that aims at supporting formal logical arguments and proofs within a domain.

Kabilan (2007) said that ontologies aim at making implicit domain knowledge explicit. Therefore, it can be concluded that ontology is a form of knowledge representation. However, ontology is not synonymous to a knowledge base; a knowledge base is an ontology populated with data.

Han and Park (2009) claimed that ontology is ‘the basis for a context-aware content description of knowledge sources’. The concept of ontology has been used and applied in areas, such as KM, knowledge acquisition, information retrieval and mining, and knowledge modelling.

Ontology categories

As it can be seen in Figure 2.4, ontologies can exist at three different levels of abstraction: upper, mid-level, and domain (Semy et al., 2004):

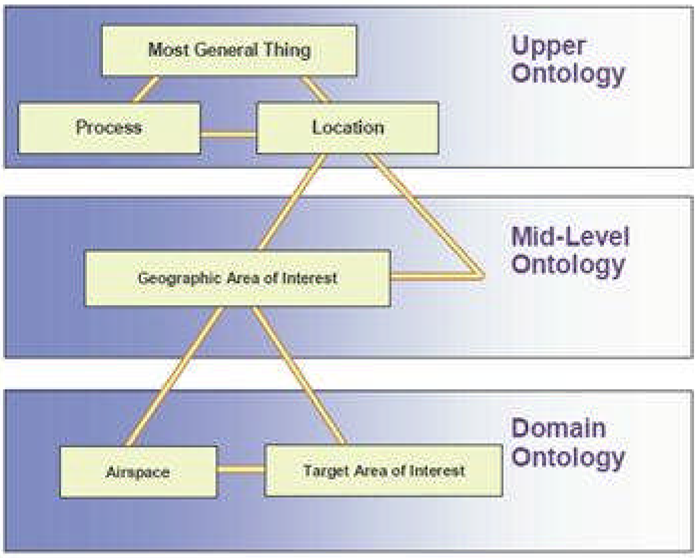

Figure 2.4: Ontology levels (Source: Semy et al., 2004)

- An upper ontology is independent of a particular domain and provides a framework, from which domain ontologies can be derived and by which unrelated systems can use a common knowledge base. The concepts used in an upper ontology are universal, intending to ensure generality. Such ontologies are often mentioned as foundational or universal ontologies.
- A mid-level ontology can be used as a link between abstract concepts used in an upper ontology and low-level specific concepts found in a domain ontology. Such ontologies provide a more tangible representation of the abstract concepts defined in the upper ontology. Mid-level ontologies are also sometimes referred to as utility ontologies.
- A domain ontology specifies concepts distinct to a particular domain and represents their relationships from a domain viewpoint.

The classification of ontologies by Semy et al. (2004) was based on the level of abstraction. Uschold and Gruninger (1996) categorised the ontologies according to their formality and complexity in the following types:

- *Highly informal:* expressed loosely in a natural language
- *Semi-informal:* expressed in a structured form of natural language
- *Semi-formal:* expressed in a formally defined language
- *Rigidly formal:* expressed in clearly defined terms, such as theorems and proofs.

The ontology developed as part of this research can be described as domain (based on the abstraction level), and semi-informal (based on the formality).

2.2.10 Knowledge Management

According to Diaz Gonzalez (2007) the importance of knowledge has always been present; nonetheless, the recognition of knowledge as a corporate asset is what has changed. Taylor (2002) stated that the significance of knowledge in business has always been recognised, but organisations did not manage it because they did not understand either the issues and the opportunities or the strategies and the solutions. Nowadays, knowledge is a main source of competitive advantage for organisations. There is, however, a highly diversified appreciation of what knowledge is and as a result, various strategies for its management have been developed. The majority of these strategies are mostly based on technologies; therefore, they overlook the characteristics that define the human nature of the knowledge by considering only the part of it that has been made explicit. However, the critical knowledge in an organisation is found in the skills and talents of its employees (Garcia-Perez and Mitra, 2007). Many KM efforts have been mostly focused on the capture, coding, storage, and dissemination of knowledge that is held by individuals within an organisation with the ultimate aim of achieving strategic competitiveness (Han and Park, 2009).

KM can be defined as the effort to secure the experience along with the work of individuals who belong to an organisation (Bible, 2002). Malhotra (2001) considered KM as 'a crucial construct in understanding how humans convert information into thought and consequently into action'. Another definition given by Collison and Parcell (2004) is that 'KM is about capturing, creating, distilling, sharing and using know-how'. It is not a static snapshot at a certain point of time, but a developing set of know-how influenced by people who recurrently use it. Han and Park (2009) described KM as a deliberate and systematic approach to ensure the maximum utilisation of an organisation's knowledge base. Wenig (2002) said that organisational KM comprises activities related to the organisation getting knowledge from its own experience and from the experience of other individuals, and to the cautious application of that knowledge to accomplish the mission of the organisation. Liang (2002) stated that KM is an activity for using information technology in order to systematically classify, store, and apply organisational and personal data and information so that: (1) quality and quantity of the creative knowledge within an organisation is promoted, (2) the feasibility of knowledge is improved, and (3) value is created for the organisation. As stated by Alavi and Leidner (2001) KM is the identification and leverage of the collective knowledge in an organisation to enhance its competitiveness.

Several commonalities and differences can be noticed among the definitions of KM mentioned above. Bible (2002) and Wenig (2002) mostly mentioned the knowledge of individuals stemming from their experiences as the focal point of KM. Malhotra (2001) and Liang (2002) considered the conversion of data and information, as a key aspect of KM; the latter included also the use of IT as part of the KM activity. Finally, Bible (2002), Han and Park (2009), Wenig (2002), Liang (2002), and Alavi and Leidner (2001) talked about organisational KM, while Malhotra (2001), and Collinson and Parcell (2004) did not use the term.

Wilson (2002) and Lambe (2002) seem to doubt the usefulness of KM. They strongly believe that KM along with Total Quality Management (TQM), Quality Circles (QC), and

Business Process Reengineering (BPR) were created by consultancy companies and will fade away, since 'knowledge can never be managed, except by the individual knower'.

On the other hand an empirical study, conducted by Ponzi and Koenig (2002), showed that the management movements which are just fashions or trends vanish within five years. If this result can be applied to KM, then it seems that KM has been present for longer.

Knowledge Management history

Individuals and organisations started to recognise the importance of knowledge in the competitive environment in the mid-1980s. In the late 1980s various studies, websites, publications and reports on knowledge and its management emerged. In 1997, journals focused on KM were launched, such as the Journal of Knowledge Management, Knowledge Management and Knowledge Management Review. Since then, many companies started to focus on their knowledge resources and appoint managers responsible for KM (Diaz Gonzalez, 2007).

Knowledge Management activities

Holsapple and Singh (2001) described five principal activities that can be performed within the KM context and on which organisations can focus so that they are competitive. They are described below:

1. *Knowledge acquisition*: It refers to the identification of the appropriate knowledge in the external environment and its capture. Knowledge can be altered and internalised within the organisation or can be used for the creation of new knowledge. There are several sub-activities that are involved in knowledge acquisition, and more specifically in:

    - Identifying appropriate knowledge: locating, accessing, valuing and/or filtering.

- Capturing knowledge: extracting, collecting and/or gathering.
- Organising the captured knowledge: distilling, refining, orienting, packaging, assembling, and transforming it into usable representations.
- Transferring the organised knowledge.

2. *Knowledge selection*: It refers to the identification of needed knowledge within the existing resources. The sub-activities involved are the same as in the knowledge acquisition activity; the main difference is that in the knowledge selection, the knowledge is existent within the organisation, whereas in the knowledge acquisition, the knowledge can be found in the environment.
3. *Knowledge generation*: It refers to the creation of new knowledge through discovering or obtaining it from existing knowledge. Examples of knowledge generation are the invention of a process or a solution given to a problem. The sub-activities of knowledge generation are:

    - Monitoring of the external environment and the organisation's resources.
    - Evaluation of the knowledge that has been acquired and selected.
    - Generation of knowledge by creating, synthesising, analysing, and constructing.
    - Transfer of the generated knowledge for externalisation and/or internalisation.

4. *Knowledge internalisation*: The acquired, selected or generated knowledge is internalised within the organisation. The sub-activities involved are:

    - Assessment of the knowledge to be internalised.
    - Targeting of knowledge resources that will be impacted by knowledge internalisation.
    - Creation of a knowledge structure.

- Delivery of the knowledge representations to targeted knowledge resources.

5. *Knowledge externalisation*: It refers to the release of the organisational knowledge to the external environment. Its sub-activities are:

    - Identification of what needs to be produced for the environment.
    - Creation of the output by applying, representing, controlling and leveraging existing knowledge.
    - Transfer of the output to the environment.

The realisation of each stage is a prerequisite for proceeding to the following one, and eventually resulting in the externalisation of knowledge. It should be noted that there are additional related approaches in literature; however, their in-depth study is out of the scope of this thesis.

KM strategies

Ma (2005) claimed that an organisation chooses its KM strategy depending on the way it serves its customers, the economics of the business, its employees, and its overall competitive advantage. As it can be seen in Table 2.2, there are two KM strategies: codification and personalisation (Hansen et al., 1999):

Codification strategy is focused on developing knowledge databases or expert systems to codify and store the explicit knowledge, and heuristic rules to be accessed by employees and customers in an organisation that deals with repetitive customer problems. Knowledge is extracted from the person that owns it and can be retrieved by others without having to contact the original knowledge creator.

Items / Strategy	Codification	Personalisation
Competitive strategy	Provide high quality, reliable and fast information systems' implementation via codified knowledge re-use	Provide creative, analytically rigorous advice on high level strategic problems via individual expertise
Economic model	Re-use economics: ▪ Invest once in a knowledge asset and re-use it many times ▪ Use large items with a high ratio of associates to partners ▪ Focus on generating large overall revenues	Expert economics: ▪ Charge high fees for highly customised solutions to unique problems ▪ Use small teams with a low ratio of associates to partners ▪ Focus on maintaining high profit margins
KM strategy	People-to-Documents: Develop an e-document system that codifies, stores, disseminates, and allows re-use of knowledge	Person-to-Person: Develop networks for connecting people so that tacit knowledge can be shared
IT	Invest heavily in IT aiming to connect people with reusable codified knowledge	Invest moderately in IT aiming to facilitate conversations and the exchange of tacit knowledge
HR	▪ Hire new graduates who are well-suited to the re-use of knowledge and the implementation of solutions ▪ Train people in groups and through computer-based distance learning ▪ Rewarding people for using and contributing to document databases	▪ Hire MBAs who enjoy problem solving and can tolerate ambiguity ▪ Train people through one-on-one mentoring ▪ Reward people for directly sharing knowledge with others
Examples	Andersen Consulting, Ernst & Young	McKinsey & Company, Bain & Company

Table 2.2: How consulting firms manage their knowledge (Adapted from Hansen et al., 1999)

As an example, Ernst & Young have established sophisticated ways to codify, store and re-use knowledge. The 250 people at the Centre for Business Knowledge within Ernst

& Young manage the electronic repository and aid consultants find and re-use information. In addition to this, each of Ernst & Young's more than forty practice areas has a staff member allocated to help codify and store documents. The resultant area databases are connected through a network.

Personalisation strategy concentrates on using different methods and information technologies to support communication and contact among employees for knowledge sharing in cases where the organisation needs to deal with unique customer issues. For instance, Boston Consulting Group and McKinsey invest a great deal in building networks of people; there, knowledge can be shared face-to-face, via the telephone, e-mail or video conferences.

Research (Hansen et al., 1999; Lin, 2003) has shown that successful companies focus on one approach and use the other in a supportive role. They suggest a ratio of 80:20 between the two strategies. For instance, Hewlett-Packard (HP) product development team put 80% of their effort in building networks of people and they use the remaining 20% to structure knowledge bases.

Benefits of knowledge management

Balaji (2005) stated that there are several issues to be taken into account before adopting a KM initiative. A cost-benefit analysis should be conducted and the return or value obtained should be studied in advance. It might appear that KM initiatives are costly for an organisation, but in a long-term perspective they will improve the organisation's performance.

Skyrme (2002) and Balaji (2005) divided the benefits of KM into three categories:

- *Knowledge benefits*: benefits attained for the organisation when information and knowledge are efficiently processed, e.g. saving time.

- *Intermediate benefits*: they can be expressed in terms of effectiveness or efficiency, e.g. best practice databases eliminating less efficient operations.
- *Organisational benefits*: they affect the method by which the organisation accomplishes its goals, e.g. less knowledge loss, improved customer service.

Figure 2.5 attempts to illustrate clearly the aforesaid benefits:

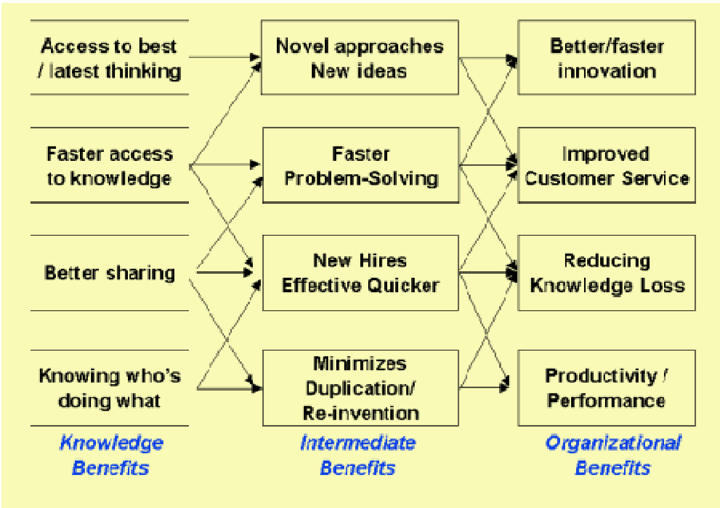

Figure 2.5: Benefits tree (Source: Skyrme, 2002)

2.2.11 Knowledge Management Systems (KMS)

KMS are IT-based systems developed to sustain and improve the organisational processes of knowledge creation, storage/retrieval, transfer, and application (Alavi and Leidner, 2001). They can be classified into three major categories (Imaginatik website, 2006):

- *Informational Knowledge Systems:* They primarily store and manage knowledge on a 'just in case it's needed' basis. Databases or directories used are examples of these systems.
- *Knowledge Management Tools:* They endeavour to simplify the access or to provide direction to knowledge and information within KMS by decreasing the

amount of time needed for the user. This is achieved through the provision of the relevant only to the quest information to the user. Search tools or portal applications are examples of these tools.

- *Dynamic Knowledge Systems:* They elicit timely, on demand and in context information and knowledge from people when it is demanded by somebody else. Typical examples of these systems are Idea management systems and some KM helpdesks.

2.3 Services

The second main focal point of this literature review is services. Since the theme is quite broad, it should be mentioned that the author's focus converges mainly onto the topic of technical services later on in this Chapter.

2.3.1 History of services

Agriculture and manufacturing used to be the major elements of the modern world's economies. However, since the World War II Britain has become a 'service economy' (Cowell, 1991). Also, nowadays, services represent 74% of the UK's gross domestic product (National statistics website, 2007) and 80% of US economic activity is service-sector based (BBC news website, 2007). The traditional border between manufacturing and services is becoming increasingly vague. Of the employees that are working in traditional manufacturing companies, 65-75% carry out service activities ranging from production-related tasks like research, logistics, planning and maintenance, as well as product and process design, to the all-supportive services existing at any organisation (e.g. accounting, finance, law services and personnel functions) (Mont, 2002). Spohrer and Maglio (2008) provided an additional evidence of services' dominance: over 80% of employed people in the UK and the US are now employed in the service sector. Neely (2008) implied the high dependence of the economy on service sector mentioning British Prime Minister Margaret Thatcher's statement about whether developed economies should follow and live on services abandoning manufacturing.

2.3.2 Service definition

A service can be defined as a change in the condition of a person or a good belonging to some economic entity, brought about as the result of the activity of some other economic entity, with the approval of the first person or economic entity (Hill, 1977). IBM has defined it as 'a provider/client interaction that creates and captures value'. Another definition by Brian et al. (1987) described the service as all economic activity whose output is not a physical product or a construction. Finally, Gronroos (2000) said that service is an activity or series of activities provided as a solution to customer problems (IBM website, 2006).

From a narrow perspective, definitions mostly consider organisational memberships in the service sector, whilst broader definitions offer explanations of what constitutes a service (Metter and Marucheck, 2007). A broad definition was provided by the UN in 2002:

> 'Services are not separate entities over which ownership rights can be established. They cannot be traded separately from their production. Services are heterogeneous outputs produced to order and typically consist of changes in the condition of the consuming units realised by the activities of the producers at the demand of the customers. By the time their production is completed they must have been provided to the consumers' (UN, 2002).

An alternative approach was provided in defining services as deeds, processes, and performances (Cook et al., 1999).

Government statistics traditionally define services by industries (Metter and Marucheck, 2007). The weakness of this approach relates to the underestimation of services as many services, such as accounting and marketing carried out by manufacturing industries, are not represented. Furthermore, service has also been referred to as customer support, product support, after-sales service, and technical support (Goffin and New, 2001). Overall, a service is defined as activities, benefits, and satisfaction which creates returns directly or in relation to the sale of a good (Kamponpan, 2007).

2.3.3 Characteristics of services

The most commonly cited characteristics of services are customer influence, intangibility, inseparability of production and consumption, heterogeneity, perishability, and labour intensity (Nie and Kellog, 1999; Johnston and Clark, 2001; Chase and Erikson, 1988, Ellram, 2004; Kamponpan, 2007). However, there is an additional range of studies found in the literature, which define service characteristics.

According to Cowell (1991) there are a number of characteristics that distinguish goods and services. These are the following:

- *Intangibility:* It is usually not possible to taste, feel, hear or smell services before their purchase. However, there are services that are essentially intangible, as education services; also, services giving added value to a tangible product, like insurance or maintenance; and, finally, services that make a tangible product available, such as transport.
- *Inseparability:* Services often cannot be separated from the seller. The creation of a service can happen simultaneously with partial or full consumption of it.
- *Heterogeneity:* Standardisation of services' output is difficult to be achieved; each 'unit' of a service may be different from the others.

- *Perishability:* Services cannot be stored. For instance, an empty hotel room represents capacity that is lost. Therefore, the maximum capacity level available to cope with the fluctuations in demand should be defined.
- *Ownership:* Lack of ownership characterises the services, as customers only have access to or use of a facility.

Lindberg and Nordin (2008) stated that the most important service characteristic, where all the others stem from, is intangibility. It was also stated by them that a service should be transformed into something objectified so that it can be exchanged; this 'object' can be a specification or a contract.

Further characteristics were found in the literature, which are distinct for services (Edelman, 2003). Firstly, determining the cost of a service is more complex than determining the cost of a product due to the fact that the former mostly expresses value given to the customer. Secondly, a service is unable to be transported. Thus, the customer needs to engage with the service delivery system, and the service process needs the customer's participation. Finally, services have more credibility and experience qualities in comparison with goods, and they are more labour intensive.

In addition to these, Lovelock and Yip (1996) influenced by the service delivery process suggested eight characteristics: customer involvement in production, people as part of the service experience, greater likelihood of quality control problems, difficulties for customer to evaluate, lack of inventories for services, greater importance of the time factor, and availability of electronic channels of distribution. It is commonly accepted though that not all services contain the same degree of service characteristics.

2.3.4 Service types

There has never been a consensus on a generic categorisation or classification of service operations (Metter and Marucheck, 2007). Classifications have been made dependent on industries. Moreover, service characteristics have commonly been used to make distinctions among services. The value in making such categorisations lies in the development of strategies and measures for services (Heineke and Davis, 2007).

Generally, the classification approaches differ depending on whether it is a marketing or an operations approach:

1. The marketing approach regularly stresses the intangible nature of services. This type of research commonly specifies lack of ability to touch, see and taste services.

Table 2.3 illustrates the nature of service offering based on the target of a service (people or things) and the nature of the actions (tangible or intangible).

2. Operations management literature views the dimensions of services from a customer influence perspective. The major focus involves lack of customer presence in manufacturing settings (Nie and Kellog, 1999). Other operations approaches involve customer contact, capital intensity, customer involvement or production processes (Cook et al., 1999). Schmenner (1986) categorises services based on customer contact and customisation with labour intensity (ratio of labour as opposed to the value of plant and equipment). There are four types of services that can be found in this study:

    - Service factory: Low labour intensity and low customer interaction/customisation
    - Service shop: Low labour intensity and high customer interaction/customisation
    - Mass service: High labour intensity and low customer interaction/customisation
    - Professional service: High labour intensity and high customer interaction/customisation

	People	Things
Tangible actions	Service directed at people's bodies: ▪ Health care ▪ Passenger transportation ▪ Beauty salons ▪ Exercise clinics ▪ Restaurants ▪ Haircutting	Service directed at goods and other physical possessions: ▪ Freight transportation ▪ Industrial equipment repair and maintenance ▪ Laundry and dry cleaning ▪ Landscaping/lawn care ▪ Veterinary care
Intangible actions	Service directed at people's minds: ▪ Education ▪ Broadcasting ▪ Information services ▪ Theaters ▪ Museums	Services directed at intangible assets: ▪ Banking ▪ Legal services ▪ Accounting ▪ Securities ▪ Insurance

Table 2.3: Understanding the nature of the service act (Source: Lovelock , 1983)

Mathieu (2001b) presented two types of services that manufacturers provide:

1. Services that provide product support and focus on making certain that the equipment functions properly. These include maintenance, repair and overhaul, spares provisioning, technical publications, and technical support (Ward and Graves, 2005).
2. Services that provide support to the customer. Examples of such services are supply and support chain management, integrated logistics support, asset management, equipment health monitoring, and reliability trend analysis (Ward and Graves, 2005).

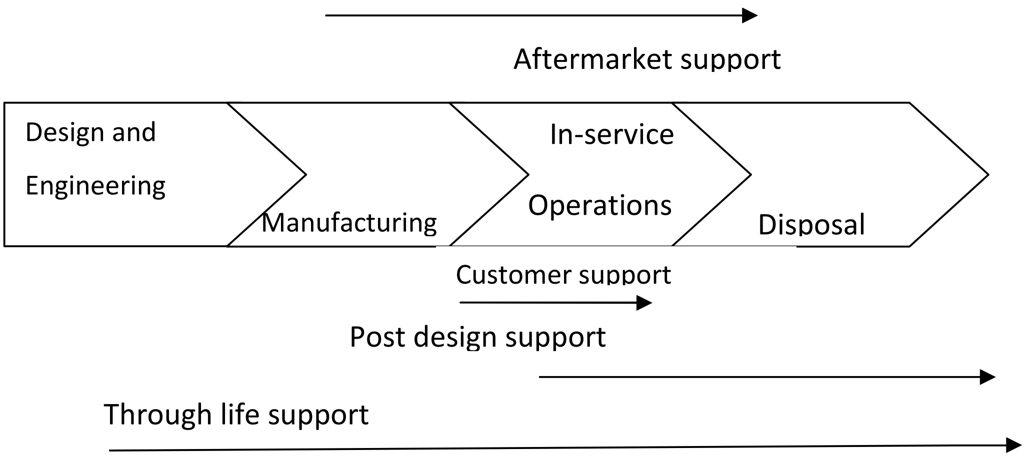

Figure 2.6: Components of Through-life cycle management (Source: Ward and Graves, 2005)

The weakness of the first approach is related to its reactive nature and ignorance of customer operations. In the second approach, a closer relationship along the service supply chain is needed.

Fitzsimmons et al. (1998) based on the degree of service intangibility classify business services into property, people and process services, and they believe that more complex services that focus on processes (e.g. professional services) or people (e.g. training) are relatively hard to specify and evaluate prior to their delivery. Specifying complex services can be very time-consuming, since every eventuality needs to be covered and at the same time, remain flexible in order for the suppliers to be enabled to be creative and make improvements. Moreover, services are preferably exchanged in close customer-supplier relationship, where trust plays an important role (Lindberg and Nordin, 2008). This implies that the value is created through the interaction with the customer.

However, the properties of a service do not only depend on the service category, but will also be altered during the procurement process.

Table 2.4 presents the types of services according to Oliva and Kallenberg (2003):

	Product-oriented services	**End-user's process-oriented services**
Transaction-based services	Basic installed base services (e.g. helpdesk, refurbishing)	Professional services (e.g. spare parts management, process-oriented training)
Relationship-based services	Maintenance services (e.g. preventive maintenance, condition monitoring)	Operational services (e.g. managing maintenance function, managing operations)

Table 2.4: Service types (Source: Oliva and Kallenberg, 2003)

Another categorisation of services can be made based on traditional offerings and supplementary ones provided to the customer, i.e. traditional technical services (maintenance, repair and overhaul), new additions in traditional services (fixed price repairs, preventive maintenance contracts) and value-added services (asset management, equipment health monitoring) (Bath working paper, 2005).

Kumar et al. (2004) refer to services to support the product, services to support the utilisation of the product/planned services, unplanned services, as well as warranty services.

Overall, services that are often mentioned are: consulting services, design and development services, financial services, installation and implementation services, leasing services, maintenance and support services, outsourcing and operating services, procurement services, property and real estate, retail and distribution services, systems and solutions, transportation and tracking services (Neely, 2008). With regard to technical services, several types of service activity can be identified. The key service activities (supported by a case study) are: planned maintenance, unplanned maintenance, service exchange, product repair and overhaul, retrofitting and upgrading, product installation, commissioning, and monitoring (Doultsinou et al., 2007). Figure 2.7 represents a graphical summary of the services found in the literature and presented in this Section.

2.3.5 Service paradox

Gebauer et al. (2005) surveyed over 30 equipment manufacturers to examine what they mention as a paradox, which is why investments in servitization hardly ever pay back. It seems that managers of manufacturing organisations are often un-motivated to servitize, since an investment in production is believed to be less risky than a similar investment in services. This is the outcome of mainly two factors; the internal risks, such as the organisation's unfamiliarity with service delivery and the external risks, such as the risk that customers will not be willing to share 'sensitive' knowledge of product performance with suppliers fearing that they give away knowledge to their competitors. The authors argue that this can be surmounted by fostering service awareness, recognising the risk of expanding the service business and believing in the economic potential of services.

In Neely's study (2008) it is revealed that servitized organisations are less profitable than pure manufacturing ones. The reason for this is the higher average labour costs, working capital and net assets of the servitized firms.

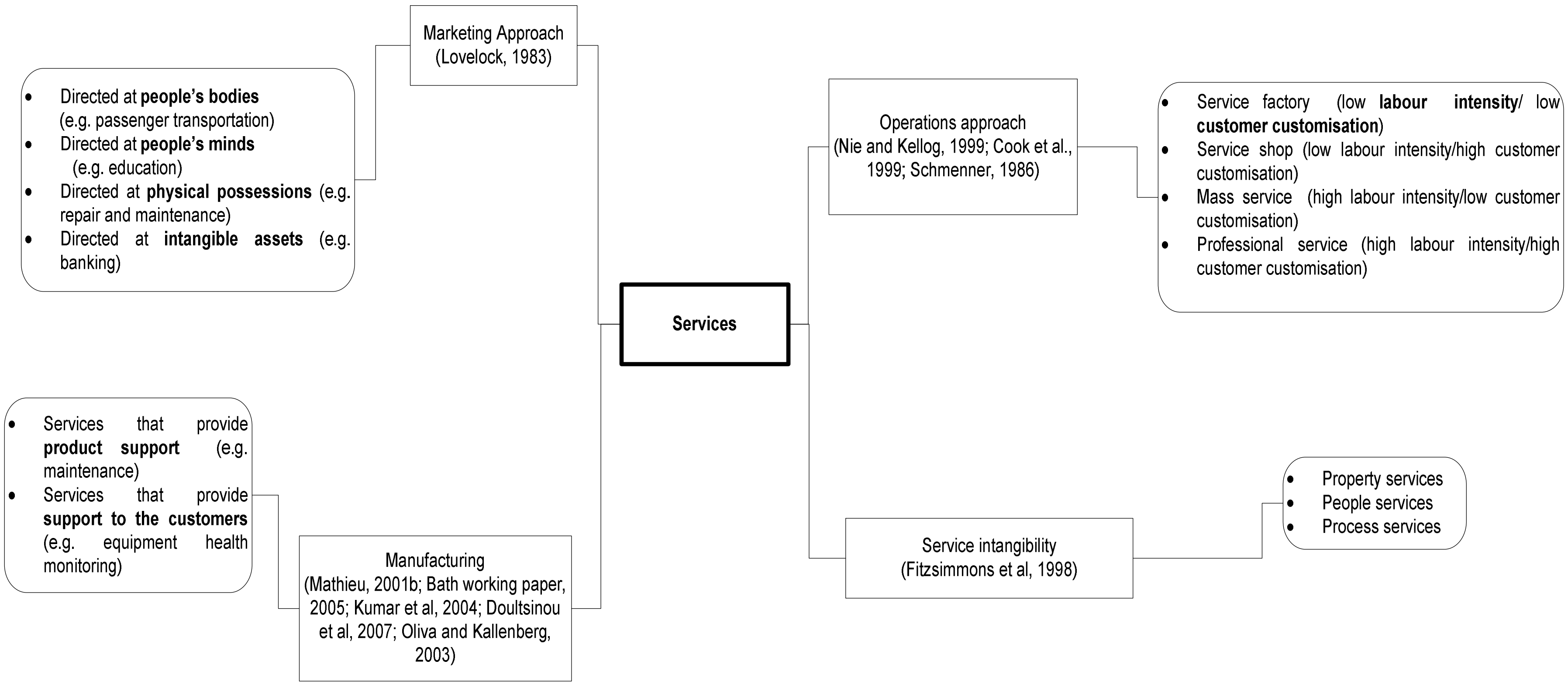

Figure 2.7: Services' categorisation based on different approaches

Table 2.5 gives a summary of the statistics for profitability and sales revenue figures with regards to whether or not the organisations involved have servitized. The servitized organisations comprise 55.46% of 2004 sales revenues, but only 49.87% of 2004 net profit. However, it is entirely possible that averages are prone to concealing significant oscillations.

	Number of firms	Total 2004 sales revenues (US$ billion)	2004 sales revenues (% of sample total)	Total 2004 net profit (US$ billion)	2004 net profit (% of sample total)
Total firms	7,836	13,353		764	
Pure manufacturing	5,307	5,948	44.54%	383	50.13%
Servitized	2,529	7,405	55.46%	381	49.87%

Table 2.5: The financial consequences of servitization (Source: Neely, 2008)

Service paradox challenges

Neely (2008) claimed that the most significant challenges for organisations that want to servitize are (see also Table 2.6):

- Challenge of shifting mindsets
- Challenge of timescale
- Challenge of business models/customer offerings.

Shifting mindsets	Of marketing- from transactional to relational marketing
	Of sales- from selling multi-million dollar products to selling service contracts and capability
	Of customers- from wanting to own the product to be happy with the service
Timescale	Managing and delivering multi-year partnerships
	Managing and controlling long-term risk and exposure
	Modelling and understanding the cost and profitability implications of long-term partnerships
Business model and customer offering	Understanding what value means to customers and consumers, not producers and suppliers
	Developing the capability to design and deliver services rather than products
	Developing a service culture
	Embedding all of the above into a service organisation

Table 2.6: The challenges of servitization (Source: Neely, 2008)

2.4 Maintenance

It was mentioned in Section 2.3.4 that maintenance is one of the major service activities; therefore, beyond a doubt a central element of this research. Maintenance is a requirement for a variety of products: mechanical, electrical, and hydraulic. The aim of a maintenance service should be an increase in equipment availability, which in turn boosts their reliability and cuts down their repairing time (Viles et al, 2007).

A change in the role of maintenance could also affect the business models of manufacturing companies. With new monitoring and service methods, new opportunities of product use and service providing appear (Swanson, 2001).

Kinnison (2004) stated that maintenance is the process of ensuring that a system continually performs its intended function as its designed-in level of reliability and safety. This implies the servicing, adjusting, replacement, restoration, overhaul, and anything else needed to ensure the accurate and constant operation of the system or equipment. However, it emphasises the notion that the equipment was designed for a specific purpose (or purposes in the case of multifunction systems) with an inherent or designed-in level of reliability and safety. Another definition given by Kececioglu (1995) says that maintenance is any action which keeps non-failed units in a satisfactory, operational condition in terms of reliability and safety; and if they have failed, it brings them back to an operating condition. It can be noted that the aforementioned definitions focus on the goal of maintenance to ensure the operational condition of a product.

2.4.1 Maintenance types and strategies

Dhillon and Liu (2006) classified maintenance into the following three categories:

- Preventive maintenance: all tasks performed on a planned, recurring, and detailed schedule to keep an item/equipment in working condition through the procedure of checking and reconditioning.
- Corrective maintenance: unplanned maintenance or repair of item/equipment carried out because maintenance crew or users noticed defects or failures.
- Predictive maintenance: the use of modern measurement methods to precisely detect item/equipment condition during operation.

Some other classifications can be found in the literature. Swanson (2001) categorised maintenance as reactive, proactive, and aggressive. Huang et al. (2005) used the terms corrective, scheduled, predictive, Intelligent Maintenance Systems (IMS), whereas Kim et al. (2004) elaborated on warranty and predictive maintenance.

It is also important to present the evolution of maintenance strategies. This will reveal the path to today's trend, 'servitization'. The steps of maintenance strategies' progression are summarised as follows (Ahuje and Khamba, 2007; Garg and Deshmukh, 2006; and Lee, 2006):

- *Before 1950s: Breakdown maintenance:* Service takes place after the equipment fails/stops or drastic performance deterioration happens. The disadvantage of this strategy is the unplanned failures, excessive damage, spare parts' issues, high repair costs, time-consuming maintenance and difficult troubleshooting of problems.
- *1951: Preventive maintenance:* It consists of maintenance activities that occur after a certain period of time or specified equipment use. This strategy depends on the estimated probability that the equipment will breakdown or experience severe performance decline in the specified interval. Examples of activities undertaken as part of the preventive work are equipment lubrication, cleaning, parts' replacement, adjustment, and also inspection for deterioration indications.
- *1957: Corrective maintenance:* Its aim is the improvement of equipment reliability, maintainability and safety, the elimination of design weaknesses, the reduction of deterioration and failures, targeting at maintenance-free equipment. The main difference between preventive and corrective maintenance is that an issue should exist before corrective actions are taken. The feedback of maintenance information is also important for the next equipment and the enhancement of existing manufacturing facilities.
- *1960: Maintenance prevention and Reliability Centered Maintenance (RCM):* In maintenance prevention strategy the equipment is designed so that it is maintenance-free and user-friendly. RCM was initially utilised in the aerospace industry and can be defined as a structured procedure to determine the

maintenance requirements of any equipment by spotting the equipment functions and causes and effects of failures.

- *1971: Total Productive Maintenance (TPM):* It is an innovative Japanese approach that aims at optimising equipment effectiveness, eliminating breakdowns, and promoting autonomous maintenance through daily activities by operators engaging employees from all departments and levels of the organisation.
- *1988: Productive maintenance:* It is the combination of preventive maintenance, corrective maintenance, and maintenance prevention that aims at increasing the productivity of an organisation by decreasing the total cost of equipment through its entire life-cycle.
- *1990: Predictive maintenance:* It is often mentioned as condition-based maintenance and based on the same principle as preventive maintenance; however, it identifies the need for maintenance activities in response to a certain equipment condition or performance decline. The criteria for the maintenance activities to take place are the temperature, noise, vibration and lubrication levels.
- *1991: Computerised Maintenance Management Systems (CMMS):* These systems are employed to manage a broad variety of information on maintenance workforce, inventory of spare parts, repair schedules, and equipment past record. Managing maintenance information results in better communication and coordination, improved maintenance responsiveness and decision-making capabilities.
- *1997: Maintenance outsourcing:* This strategy describes the transfer of workload to contractors that do not belong to the organisation so that the latter focuses on its core competencies. The ultimate goal is that the maintenance provided is of high quality, fast, safe, and cheap.
- *Prognostics:* The prognostic approaches can be divided into three types: model-based prognostics, data-driven prognostics, and hybrid prognostics. They can be defined as a systematic approach that can constantly track performance

deterioration and through noticing the indicators' behaviour it can forecast risks of improper trends, and identify the exact components of the equipment that are likely to fail.

- *Effectiveness Centered Maintenance (ECM):* This strategy entails quality management concepts, TPM and RCM, and it focuses on 'doing the right things' instead of 'doing things right'. ECM encompasses workforce involvement, quality enhancement, and maintenance strategy development and performance measurement.
- *Strategic Maintenance Management (SMM):* It is mostly a quantitative approach that employs mathematical models that amalgamate technical, commercial, and operational features from a business perspective. SMM is perceived to be a multi-disciplinary activity that manages issues, such as operating load on the equipment and its impact on degradation, maintenance outsourcing, and long-term strategic matters.
- *Risk-based maintenance:* This strategy focuses on minimising the risks of unexpected equipment failure as well as on being cost-effective.
- *Service engineering:* It started to be used in the mid-nineties in Germany and Israel. Service engineering can be described as 'a technical discipline which is related to the systematic development and design of services using suitable procedures, methods and tools' (Bullinger et al, 2003). Compared to new service development, which is marketing-oriented, service engineering tries to effectively use existing engineering know-how in the traditional product development sector to build up innovative services by implementing a more technical-methodological approach (Bullinger et al, 2003). Another definition provided by Sakao and Shimomura (2007) describes service engineering as 'a discipline that increases the value of artefacts and decreases the load on the environment by reason of focusing service. Service engineering aims at intensifying, improving, and automating this whole framework of service creation, service delivery and service consumption'. Moreover, the functions and the meaning of contents of the

products must correspond to the specifications given by the customers (cited in Doultsinou et al., 2007).

- *Services science:* It is a multidisciplinary field that tries to connect knowledge from various areas to improve the service industry's operations, performance, and innovation. Manchester University's lecturer Liping Zhao argued that it is a shift from a technology-centric view to a holistic view that encompasses both technology and business (Paulson, 2006).

The author has developed a timeline, which depicts the evolution of maintenance strategies (Figure 2.8):

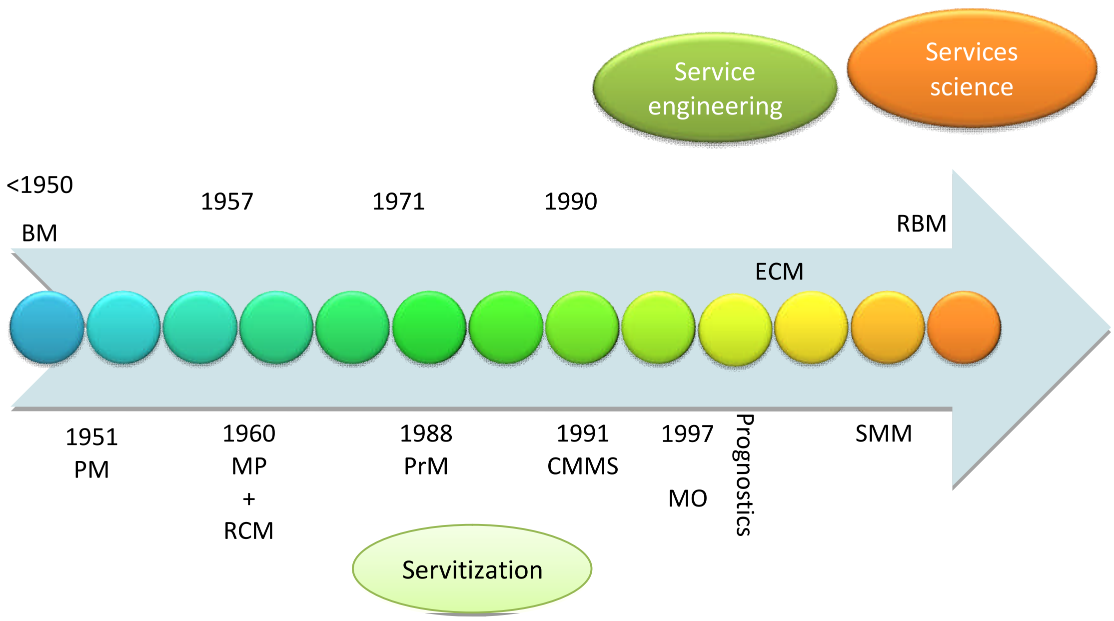

Figure 2.8: Maintenance strategies' timeline

2.5 Servitization

Existing literature suggests that the transition from basic product offerings to service-base value concepts will be the key for regaining competitiveness in a PSS context (Matthyssens and Vandenbempt, 2008). According to Ulaga and Eggert (2006) product and price do not constitute the most critical differentiating factors nowadays; however, service support and personal interaction become of higher importance. Governments around the globe now state that they will contract for capability rather than buy products (Ministry of Defense, 2005).

Servitization concept was first introduced by Vandermerwe and Rada in the late 1980s (Neely, 2008). Auguste et al. (2006) discuss the necessity and the complexity of adding services to a product offering and they conclude that services will develop into being the core element of value creation within the next years. Companies though will have to form a clearer understanding of the strategic new rules in order to ‘realise the promise of these fast-growing businesses’. Following a service-dominant logic, the focus of marketing should be shifted from goods’ exchange towards the exchange of intangible resources (Vargo and Lusch, 2004).

Servitization literature makes a significant distinction among four concepts (Neely, 2008):

1. Product-Service Systems (PSS): the term will be explained in the following Section.
2. Servitization: includes the innovation of the capabilities and processes within an organisation that can lead to a better value creation through a change from selling products to selling PSS.
3. Servitized organisation: it designs, constructs, and delivers one or more PSS.

4. Global value system: is a global network involving suppliers, customers, and partners who have to collaborate in order to make sure that integrated product and service offerings deliver value in use.

Slack (2005) mentioned that both suppliers and customers benefit from servitization. From a supplier perspective, servitization aids at increasing sales revenues, whilst from a customer perspective, servitization is a way of reducing risk and making maintenance and support costs predictable. Apart from the discussions in the management and economics literature, servitization has been studied in view of the environmental literature as an approach to increase environmental performance (Goedkoop et al., 1999). It is claimed that the negative environmental impact of products is likely to be minimised if organisations amend their business models and customers change their notion of ownership.

2.6 Product-Service Systems (PSS)

2.6.1 PSS definition

PSS originated in Scandinavia in the late 1990s and can be defined as a marketable set of products and services capable of jointly fulfilling a user's needs. The product/service ratio in this set can vary, either in terms of function fulfillment or economic value (Mont, 2002). Baines et al. (2007) have conducted an extensive state-of-the-art literature review on PSS and the following definitions stem from this source. ELIMA (2005) described PSS as 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. Brandsotter (2003) said that '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'. Manzini (2003) defined PSS as an innovation strategy; moving the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly competent to satisfy specific customer needs.

This research is mainly related to technical PSS (t-PSS) due to the nature of the products studied. Technical PSS are defined as PSS having the following characteristics:

- a physical product core (e.g. aero engine) enhanced and customised by a mainly non-physical service shell (e.g. maintenance, training, operation, disposal)
- relatively higher monetary value and importance of the physical PSS core, and
- ‘business to business’ relation between PSS manufacturers and customers (Aurich et. al., 2006).

It has been observed in literature that the term industrial PSS is also used in the same sense as t-PSS (Roy and Cheruvu, 2009).

2.6.2 PSS types

There are various PSS categories and sub-categories, which could be applied to almost every business sector. Roy (2000) has concentrated on sustainable and eco-efficient systems, and proposes four PSS models: result services, shared utilisation services, product-life extension services and demand side management. The principal ideas are the minimisation of material consumption, the re-use of renewable and recycled materials, and the decrease of the environmental impact caused by production, packaging, distribution, utilisation, and disposal. Moreover, designers are supported to develop a long-term model, which considers all producers’ and customers’ requirements for business performance in order for the system to deliver a function rather than products (Shehab and Roy, 2006).

More common examples were given by Tukker (2004), Cook et al. (2006), and Morey (2003). A thorough description of all the possible PSS approaches has been given by Tukker (2004) (see Figure 2.9).

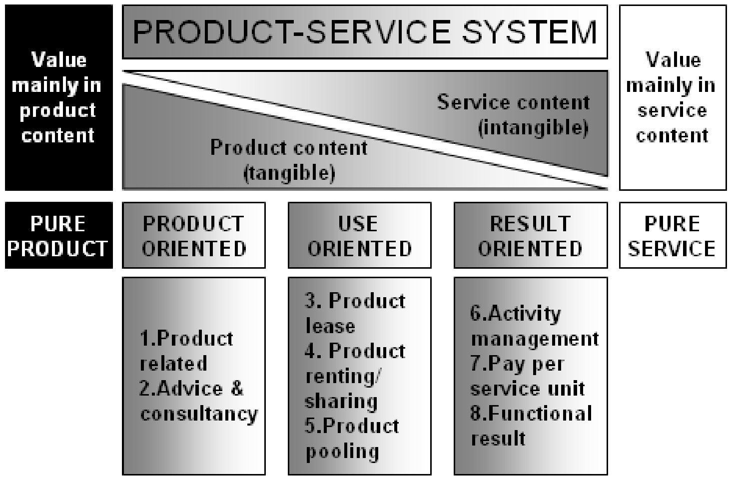

Figure 2.9: Main and subcategories of PSS (Source: Tukker, 2004)

The PSS model can boost value and competitiveness when the system's provider makes an effort to (Azarenko, 2007):

- Fulfil customer needs in an integrated and customised way.
- Permit customers to focus on their original goals.
- Establish mutual relationships with customers and augment their loyalty.
- Create an innovative system faster according to customer requirements and market conditions.
- Diminish overall system costs.

As shown in Figure 2.9, Tukker (2004) has divided the three main PSS categories into eight subcategories, which in reality, at times cannot stand as separate and independent models without being supported from the rest (e.g. it is almost unrealistic that a company will offer advice and consultancy without giving a product to the customer).

Product-oriented PSS

Two types of product-oriented PSS have been identified:

- *Product-related service:* The provider not only sells a product, but also provides a set of activities such as service, consumables' management, and monitoring. Furthermore, a take-back agreement is offered when the product arrives at the end-of-life point. Nevertheless, since the property rights of the product are transferred to the customer, the latter has all the responsibilities of the utilisation mode.
- *Advice and consultancy:* The customer receives advice with regards to the most efficient product use, gets staff training, and optimised utilisation or production phases related to the product purchased.

Use-oriented PSS

This Section presents three types of use-oriented services:

- *Product lease:* The provider keeps hold of the property rights of the product and is liable for its utilisation conditions (timely installation, maintenance, upgrading, etc.) during a given period of time. The lessee pays a standard amount for the use of the product and has an exclusive access to it. The whole payment for the overall leasing period is commonly higher than traditional purchasing. On the other hand, there are minimum initial investments at the start of the product, and also zero uncertain expenses regarding the product degradation or breakdown. The pitfall for the provider can be the potential irresponsible user behaviour; consequently, this can lead to increased expenses for maintenance or product replacing for the former.
- *Product renting or sharing:* It resembles leasing; however, the customer does not have unrestrained sole access to the product and buys the use of it for a short period of time (varying from a few hours to a couple of months); whilst, the leasing period lasts usually for more than a year. Various conflicting views are outlined by Hirschl et al., (2002): 'If I rented products on demand instead of owning them myself, I would benefit from the fact that I have nothing to do with

maintenance, repair and disposal', (64.3%), 'If there were more possibilities to rent products on demand simply and at a favourable price, I wouldn't buy them myself', (56.7%), 'If I share goods with other people, I can never be sure that they are returned when I need them myself', (72.8%), 'I would like to own things that are very important to me, even though I do not use them very often', (69.3%).

- *Product pooling:* It is similar to the idea of renting and sharing, but the product in this type is used simultaneously.

Result-oriented PSS

Two types of result-oriented PSS are presented in this Section:

- *Activity management/outsourcing:* an organisation outsources an activity (or a range of activities) to third party companies either to perform it (them) in a more resourceful way or/and to focus on the most important goals. Two types of outsourcing were found in the literature: firstly, indirect activities, which are not linked to production and final product/service offering, like catering and cleaning, and direct activities, which are vital for the supply of a functional result to the customer.
- *Pay per service unit:* The customer payment is made in accordance with the output of the product (level of use). The advantage for the customer is that he/she does not face any risk associated with the performing task, as the result is agreed; in case the provider does not achieve the set goal, the customer can be compensated.

Baines et al. (2007) mentioned the same three types of PSS presented with slight variations and in a more concise manner, summarised as:

1. Product-oriented PSS: traditional sale of a product embracing additional services, such as warranty, repair, maintenance, upgrades, re-use, and recycling.

2. Use-oriented PSS: sale of the use or availability of a product (e.g. leasing). The ownership is retained by the supplier/manufacturer and the company is encouraged to offer a PSS with maximised use period, and to extend the life of the product and the materials for its manufacture.
3. Result-oriented PSS: sale of the result or capability of a product. The company retains the ownership of the product and the customer pays only for the provision of the agreed results.

Based on Neely's (2008) study on servitization, it seems that some of the aforementioned types of services map onto these three PSS types. For instance, design and development services, installation and implementation services, and maintenance and support services map onto product-oriented PSS. However, an extension of the PSS types is required to represent the full range of servitization strategies that organisations pursue nowadays. Accordingly, two new types can be added; 'integration oriented PSS', which are the results of organisations trying to add services by going downstream and vertically integrating, and 'service oriented PSS', which result when organisations add services to products through the integration of these services into the product, e.g. Intelligent Vehicle Health Monitoring (IVHM) services.

2.6.3 PSS benefits

The drivers of the PSS concept are the sustainable production and consumption and improved competitiveness through improved environmental performance. According to Mont (2002), the concept might be beneficial for manufacturing and service companies, government, consumers, and the environment.

- *For manufacturing companies:* PSS add value to a product, for example, refurbishing, and they improve relationships with customers due to increased contact and information about customer preferences. Furthermore, according to Aurich et al (2006), companies are enabled to flexibly provide their customers the individualised service they need; thus, new market potentials and higher profit margins become possible.

- *For service companies:* PSS can diversify the service, keep a certain level of quality, and safeguard market share.
- *For the government:* As the economy moves from being a 'throw away' to a 'repair' one, new jobs seem to be created.
- *For consumers:* Consumers receive a bigger variety of services, maintenance and repair services and they do not have the responsibility of a product for its whole lifecycle as they do not have its ownership. Moreover, consumers can learn how they can contribute to a less polluting consumption.
- *For the environment:* It is possible that the total amount of products will be reduced, as alternative scenarios of product use, such as sharing/leasing schemes, will be introduced. Therefore, less waste will be created or land filled. For example, in the case of the lawnmower's maintenance, exchange of air filter, exchange of motor oil, exchange of spark plug, and application of fuel additive take place. As a result, fuel consumption is decreased by 30% and CO_2 emissions are decreased by 50%.

2.6.4 Barriers for PSS and conditions for success

Despite the benefits of the PSS, some barriers to their development and application were described. These are the following (Mont, 2002):

- Difficult development of alternative scenarios of product use.
- Opposition of the organisations to extend involvement with a product beyond point-of-sale.
- Need for time and resources for the re-orientation of the companies.
- Consumers may not be enthusiastic about ownerless consumption.
- Customer demands and purchasing behaviour appears to be more complicated than expected.

- Environmental characteristics of PSS are not yet studied.
- Need for new infrastructure.

There are certain conditions under which PSS might be profitable. Firstly, the costs of use and disposal phases should be internalised. Secondly, the product should have a high market value at the disposal stage. Thirdly, the alternative scenario of product use should generate additional profit (Mont, 2002).

2.7 Customer Value

Since servitization shifts towards the provision of individualised solutions, customer value becomes a critical element; thus, a need for the exploration of its meaning, and forms of existence materialised. Barney (2002) stated that one of the prerequisites to achieve superior economic performance is the maximisation of the customer returns.

2.7.1 Customer value definitions

Customer value is often defined as the value received by the customer, where value is the difference between the actual and perceived benefits and costs for the customer, such as price paid, maintenance and installation costs (Matthyssens and Vandenbempt, 2008). Hamilton (2002) gave five definitions of value: price value (price), cost value (cost), esteem value (want), exchange value (worth) and utility value (need); he also pointed out the different viewpoints on value between seller and buyer. Taguchi's methods for enhancing product quality also indirectly affect customer value. He persisted that higher quality costs less, and the Taguchi loss function calculates cost as a function of product variation (Taguchi, 1986).

Author	Definition
Zeithaml (1988)	'Perceived value is the consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given'.
Butz and Goodstein (1996)	'Customer value is the emotional bond established between a customer and a producer after the customer has used a salient product or service produced by that supplier and found the product to provide an added value'.
Ravald and Grönroos (1996)	Customer perceived value is highly situation specific and is 'an offering seen through the eyes of the customer and related to his own value chain'.
Flint et al (1997)	'The customer assessment of the value that has been created for them by a supplier given the trade-offs between all relevant benefits and sacrifices in a specific use situation'.

Table 2.7: Value definitions

Table 2.7 delineates some of the customer value definitions found in the relevant literature. As it can be easily remarked, customer value is linked to a specific situation, and affected by individual perceptions, beliefs, and experiences.

Matthyssens and Vandenbempt (2008) in their study of the electro-technical industry have identified two dimensions in which service-base value addition efforts can be mapped (Figure 2.10):

1. The business process integration dimension (x-axis): a supplier attempts to add customer value via the integration of a solution into the customer service supply

chain or business processes, e.g. by taking over specific administrative, logistical or engineering tasks. The general aim is the provision of a (partial) outsourcing solution to decrease the total cost of ownership or operation.

2. The technical application integration dimension (y-axis): a supplier seeks to add value via a technical solution adjusted to the specific customer needs, e.g. by providing customised solutions with further processing, programming, and engineering in order to achieve optimisation of the customer's technical process.

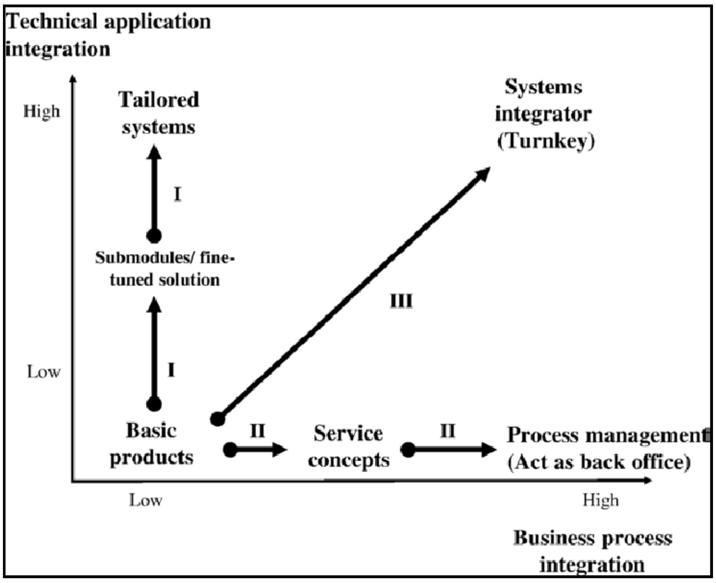

Figure 2.10: Paths to service-based value addition (Source: Matthyssens and Vandenbempt, 2008)

2.7.2 Customer value types

The studied literature demonstrates the use of the term customer value within various contexts:

- Customer value-value is perceived by the end customer: value is the customer's perceived liking for product/service attributes (Flint et al., 2002; Groonroos, 2004)

- Customer value-creation and delivery of superior customer value: focus is given on the supplier and the means by which he/she can achieve superior value for the end customer (Nicholls, 1994; Moller, 2006; Eggert et al., 2006).
- Customer value-value brought to the supplier by the customer: the value of the end customers is connected with the monetary value that those customers bring to the supplier (Ryals, 2006).

2.8 Design

This Section outlines briefly the various design methodologies that exist in the literature with regards to product and PSS design. It also describes the types of service information which are needed by designers, as identified through a limited number of available literature sources.

2.8.1 Product design methodologies

Many of the design methodologies that exist include elements that are linked with the transformation of customer needs into engineering specifications (Baxter et al., 2008):

- *Systematic design* is a structured approach to product design, where the central element in the development process is a product specification describing product subsystems, assemblies, and details of their requirements (Pahl and Beitz, 1988 cited in Baxter et al., 2008).
- *Quality Function Deployment (QFD*) necessitates the identification of customer needs; also, these needs should be quantified, translated into technical requirements and measured. QFD aims at enhancing the design quality (Chan and Wu, 2002). Ullman (2003) described in his work that poor product definition is an influencing factor in 80% of all time-to-market delays and 35% of all product development delays are caused by specification defects. QFD can be helpful in these instances by establishing measurable design targets and emphasising gaps in knowledge of the problem.

- *Axiomatic design* is a method regarding the application of basic principles that make designs good. The design requirements need to be addressed in such a way that the functional requirements remain independent (Suh, 1990).

There are also few methods utilising customer preferences or satisfaction to assist product design. Du et al. (2006) used adaptive conjoint analysis for the identification of feasible product options derived from customer preferences. Dawson and Askin (1999) used a QFD based method for compromising customer preferences with technical feasibility and economic reality. Keeney (2004) presented a method of using customer values as the foundation to generate design alternatives for mass-customised products; he employed a mapping technique to convert customer needs into product functionalities. Hamilton (2002) recommended a value planning approach to create practicable customer-oriented products based on ‘a value tree of product wants and needs’ with allocated weightings to prioritise the different elements.

2.8.2 PSS design methodologies

PSS represent an integrated system with product and service elements. This requires an integrated development approach for products and services (Doultsinou et al, 2009). Therefore, there is a requirement for a methodology to support PSS design. As Morelli (2003) stated, from the designer’s perspective designing a PSS is a challenge since an extension of his traditional know-how into new domains is needed. The designer has to consider and synthesise solutions emanating from the comparison of different opinions, and different customer needs.

In the context of product and service design there are three approaches that need to be considered (Aurich and Fuchs, 2004, cited in Doultsinou et al., 2009). These approaches are presented in Figure 2.11.

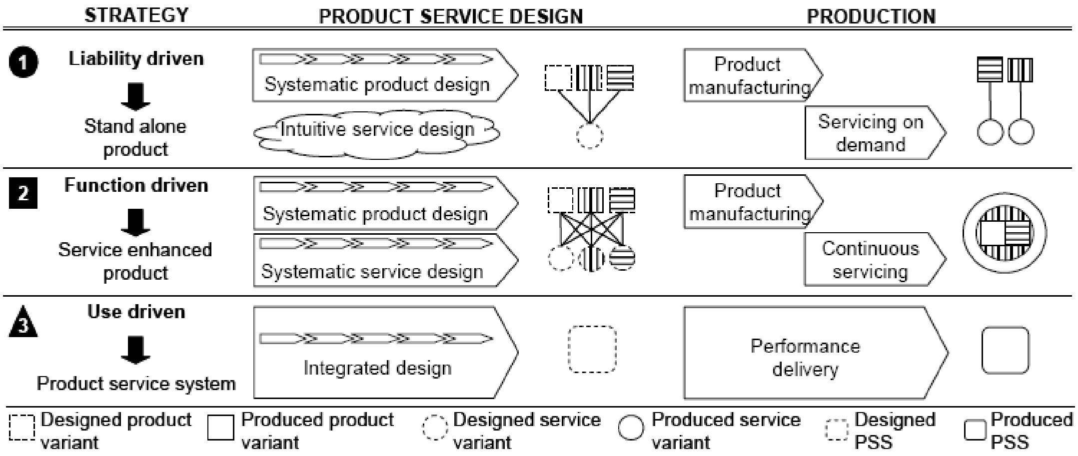

Figure 2.11: Product-service design strategies (Aurich and Fuchs, 2004)

The first approach is derived from the traditional view of manufacturing companies, whose core competencies are the development and production of innovative and highly reliable products. In this case, the product design processes are well-structured, whereas the service design process, if existent at all, is highly intuitive and mainly liability oriented. The services are offered to guarantee the product functions. This approach can be named as 'liability driven'.

The second approach has the offering of service enhanced products as a main target. Systematic product design leads to the development of product variants, each of them supported by a service package. These service packages are the outcome of systematic service design. Products and services are not regarded as distinct artefacts; they can be combined according to the customer requirements. This approach can be named as 'function driven', where still the focus is on the physical product, but its function is accomplished through services.

The third approach aims at offering an individualised solution to each customer. It is 'use driven' and in this case products and services are undividable artefacts. Consequently, the design of each solution requires the integration of service elements into the product design process. As Aurich et al (2004) suggest this covers a description of the physical product core with its main functions as well as a description of the customer requirements regarding the physical product, operator qualifications, production processes plus related logistics and financing possibilities.

Aurich et al. (2006) suggested that in industrial practice, product design is typically performed by technical staff. In contrast, service design is often carried out by marketing and distribution personnel. As far as the integrated PSS design is concerned, a common understanding of the design object and its elements is needed. It can be concluded from the related literature that manufacturing companies frequently adopt the second, 'function driven' approach. However, the ultimate goal is the integrated design process, where product and service design is performed simultaneously.

Another example of PSS design methodology is the MEPPS handbook (Baines et al, 2007), which was created under the Fifth Framework Programme supported by the European Commission. However, these approaches lack a critical assessment in practice, since only Aurich et al. supported their tool with a case study.

2.8.3 Design for Manufacture

The Design for Manufacture and Assembly (DFMA) methodology aims at enabling greater consideration of production and assembly requirements before the detailed design stage (Boothroyd et al., 2002). The ultimate aim is the design of products that are easier to manufacture and assemble, and can consequently be produced at a lower cost. Examination of appropriate manufacturing processes is again encouraged early in the design process, since a process selection needs to have taken place prior to the detailed design stage.

O'Driscoll (2002) described a practical application of the DFM methodology, where a number of checkpoints were built into the existing design process to ensure the provision of the required knowledge. There were three stages of increasing detail: definition, development, and validation/scale up. The type of manufacturing product considered was not discussed.

Lovatt and Shercliff (1998) also considered process selection in mechanical engineering design; the main driver for the selection is cost assuming all relevant technologies are available. They mentioned that material selection is usually based on technical considerations; however, the considerations for production are often economic.

Chen (1999) investigated the DFMA methodology extending it to improve support for designers, having observed that they often lacked the relevant experience and knowledge to make informed decisions about process selection.

Nowack (1997) explored in particular the assessment of 'manufacturability' during the early stages of the design process, and developed guidelines for the assistance in initial assessments. Manufacturability was defined as being 'a capable process to meet the product attributes'.

2.8.4 Design for Service

The ultimate aim of this research is to support product design with service information. For that reason, the 'design for service' literature field has been explored.

Janakiraman et al. (2003) investigated the theme from an Information Technology (IT) perspective. They stated that management for service availability should be a vital component of self-managing IT infrastructures, as degraded service availability can result in major loss of business. Human system designers manually generate system design alternatives based on their expertise and experience. To evaluate these alternatives, they use an availability modelling tool and databases of component failure rates and repair times. The modelling tool predicts the service downtime and the cost of this downtime based on a business mission. However, Janakiraman et al. (2003) described AVED, which is intended for the automated design of services that have the automated multi-tier structure. AVED automatically generates designs and evaluates them with the use of an availability modelling tool within an execution loop that iterates to find a design that fulfils availability and performance requirements at the minimum cost. AVED can be faster than human designers and also, may ameliorate solution quality by covering a broader range of design alternatives when compared to a manual approach. Nevertheless, the idea of automating the design of systems in order to meet user availability requirements is fairly recent. Only few examples can be found; each one focusing on a specific domain. Researchers at HP laboratories have recommended automated design of storage systems to meet user requirements for data dependability. Moreover, the Oracle database employs a function that automatically verifies when to flush data and logs to persistent storage so that it is possible for the recovery time after a failure to meet a value set by the user. Other relevant work on system automation for managing availability has been focused on automated monitoring and automated response to failures.

From a different perspective, Jagtap et al. (2006, 2007a, 2007b) extended the 'design for service' field. They conducted case studies to discover the information flows to designers and also, comprehend how in-service experience informs design modifications. Sander and Brombacher (2000), with regards to high volume consumer products, stated that the service experience products should be evaluated as a whole, stored and used. Five levels have been identified for the analysis and handling of problems in the future products: level 0 (no information available); level 1 (number of problems); level 2 (where they are derived from); level 3 (what the root cause is); level 4 (measures that can be taken to avoid repetition). Brombacher et al. (1998) pinpointed the required information classes for the evaluation of information flows in order to achieve improved product quality and reliability. These classes are as follows: quantification (quantitative information per product should be available); identification (whether the failure location is within the development process or the product); cause (all main failures should be investigated to root cause level); improvement (methods and tools to predict, and eradicate risks for future products).

Thomson (1999) focused on the 'maintainability' and 'reliability' aspects of the service and stated that customer feedback will identify weaknesses in products and consequently, specific design improvements could be made. Also, he pinpointed that it is useful to differentiate between *mean time to repair* (required total time to return equipment to a working condition) and *mean corrective repair time* (required time to identify the fault, and carry out the repair presuming that tooling, spares and personnel are available). This is because the latter is usually shorter than the former, and according to Thompson (1999) designers should be mainly concerned with the mean corrective repair time.

Case et al. (2010) developed a diagnostic service tool that uses existing failure data to determine future failures. FMEA elements were used as a basis for the tool development, and its evaluations within the context of automotive systems showed that the repair and diagnosis times had significantly shortened. More importantly, designers can re-use the actual failure knowledge to improve existing product design or create a new design; thus, a step towards bridging the gap between field service and design is made.

Markeset and Kumar (2003) identified the aspects that need to be taken into account when ‘designing for maintenance’ (illustrated in Figure 2.12). They mentioned that tradeoffs will always be present among these aspects. Also, lifecycle cost (LCC) analysis can be used for the comparison of design alternatives and its results have to be balanced against the customer/ market needs. In addition, they examined the factors that are important for achieving the required reliability and maintainability, and explored various types of product support, such as installation and commissioning, training, documentation, etc.

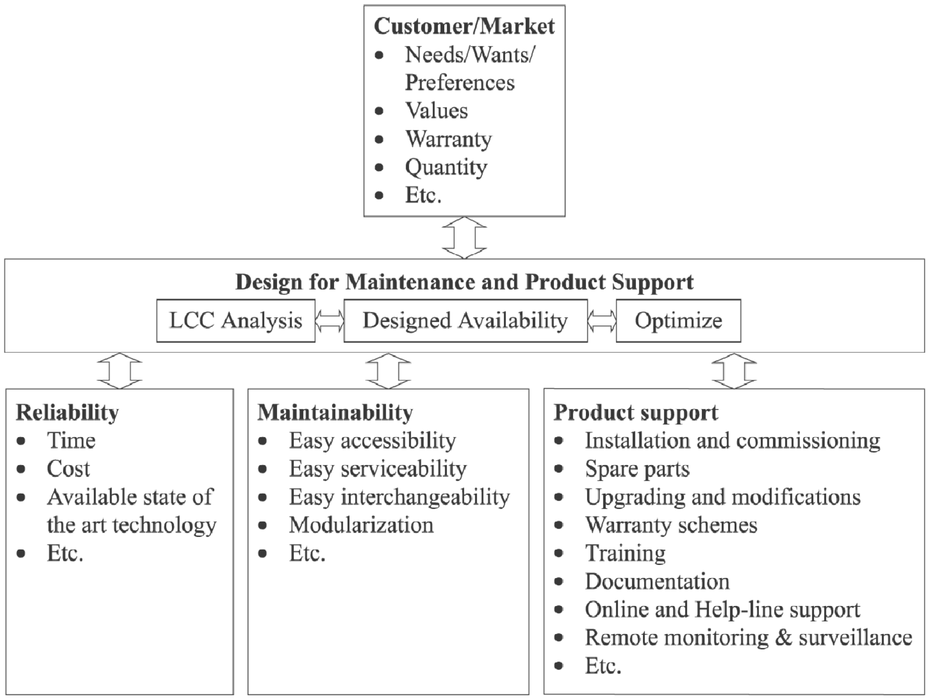

Figure 2.12: Design for maintenance and product support (Source: Markeset and Kumar, 2003)

Types of 'Design for Service' information

The reviewed literature has revealed that the constructive in-service information in product design includes: spares' cost, in-service component life, failure types, failure causes, deterioration mechanisms regarding various components, the occurrence rate and impact of these mechanisms, and reliability data (Jagtap et al., 2007b).

In particular, the service information that designers are interested in is linked with (Jagtap et al., 2007a):

- Maintainability (e.g. accessibility)
- Reliability (e.g. Weibull analysis of reliability)
- Failure mechanisms (e.g. failure mode)
- Service instructions (e.g. inspection recommendations)
- Operating data (e.g. difference of various performance parameters with operator)

- Component cost (e.g. repair cost)
- Design information (e.g. technical diagrams)
- Component life (e.g. average life)

Benefits of in-service information availability

Jagtap et al. (2007b) mention that the in-service information can help in:

- The reduction of maintenance costs
- The evaluation of product reliability in the field
- The prediction of product reliability/ availability
- Maintenance optimisation
- The reliability improvement of future products
- The fulfilment of the maintainability and reliability requirements.

In addition to these benefits, several other authors focus on certain aspects of, beneficial to designers, service information. Norman (1988) mentioned that availability/reliability forecasts can be dependent on past operating experience and their accuracy relies on the sample size. Jones and Hayes (1997) highlighted the value of collecting field failure information during a product's life, and of the analysis of this data to assess the product's reliability. Finally, Petkova (2003) described in her research the flow of in-service information back to the manufacturer (within the context of the consumer electronics industry) and stressed the significance of the failure root causes for the improvement of product quality.

2.9 Summary and Key Observations

In Section 2.1, the author presented the focal points of the literature review. Commencing from Section 2.2, the knowledge concept was explored; knowledge definitions, types and differences between them were provided. Also, there was a description of the knowledge pyramid, and then, knowledge elicitation, representation, and re-use themes were reviewed. With regards to knowledge re-use, the author identified in the literature the reasons for this happening, along with the issues and barriers for it. It can be observed that knowledge re-use saves time and allows for innovation and improved new product development, since there is a large amount of characteristics, which are common among product generations. Thus, the author feels that the creation of a service knowledge re-use methodology within the context of complex mechanical products will be beneficial for both service personnel and designers. In Section 2.2.9, ontology was presented as a means of knowledge representation and re-use; additionally, definitions and types were provided. Section 2.2.10 explored the theme of KM; this involved its history, activities, strategies, and benefits.

In Section 2.3, the author explored the second main literature theme; services. Apart from presenting the history, definitions, characteristics and types, this Section described the 'service paradox': why servitized companies are less profitable than the pure manufacturing ones. As suggested in the literature, the explanation for this is the higher average labour costs, working capital, and net assets of the servitized companies.

Section 2.4 focused on maintenance, which comprises one of the services and focal points of this research.

Going along the evolution of maintenance strategies, the author reaches servitization, which was described in Section 2.5. One of the core concepts of it is PSS.

Section 2.6 presented definitions of the concept, its types, benefits, and barriers. One of the most common definitions describes PSS as an integrated product and service solution that aims at delivering value to the customer. Hence, the author included the study of customer value in the literature review. More specifically, customer value definitions and types were given in Section 2.7.

The next Section (2.8) was associated with design, which is the last major element of the reviewed literature. The author presented product, and PSS methodologies. It was noticed that there is a gap regarding PSS design methodologies; these were found to be highly intuitive. Besides, the areas of DFM and 'Design for Service' were also investigated. The key observations are summarised as follows:

- There is a paucity in literature as far as the feedback from field to manufacturer is concerned (Petkova, 2003), and
- The provision of the appropriate in-service information to designers will lead to improved quality of future products.

The following Chapter describes the formulation of the aim and objectives of this research based on the gaps identified in the literature.

3 Research Objectives & Methodology

3.1 Introduction

The purpose of this Chapter is to provide the reader with the rationale towards selecting a suitable research strategy and to outline the research methodology that has been followed to achieve the aim and objectives of this study.

3.2 Research Objectives

The aim of this research study as stated in Chapter 1 is:

> To develop methodologies to capture, represent, and re-use service knowledge to support product design.

The literature review in Chapter 2 was the source of identification for the current research trends and challenging areas within the whole domain. The main research gaps can be summarised as follows:

- Although service is a core part of the product lifecycle, there is a lack of focus on the service knowledge requirements for design, especially in the case of complex mechanical hardware products.
- There is a lack of available structured methodologies for eliciting and structuring service knowledge.
- There is a lack of an in-depth study into the mapping between service knowledge and design requirements.

As a result, the following objectives were defined in order to fulfil the aim of this study. The research objectives can be summarised as:

1. To understand current practice and state of the art in the design for service domain and identify terminologies used in practice to define a service.

2. To develop a representation for the service knowledge that can be used by designers to improve product design.
3. To identify the SK required by designers at the product conceptual and detailed design stages.
4. To develop an effective methodology to re-use service knowledge for product design.
5. To validate the representation and the methodology using detailed case studies.

In the following Section, the author reviews the available research strategies, heading towards the development of this study's research methodology.

3.3 Research Methodology development

This Section outlines the alternative approaches to conduct the proposed research. First, the perspective of the research is defined, then a research strategy is chosen, and conclusively, issues about the data collection techniques used are considered.

3.3.1 Research Context

It is crucial to outline the context of this research, so that the research methodology is 'moulded' accordingly. This research is focused on the interaction between service and design, and in particular in the case of the complex mechanical hardware products. The study was carried out by dividing the design stage of the product lifecycle into conceptual and detailed design stage, and trying to identify links between these two and the service provided. The factors defining this research's context were the gaps identified within the overall domain of the study and the available industrial support to the researcher (collaborating organisations).

3.3.2 Qualitative and Quantitative Approach

There are two distinct approaches to research design: quantitative and qualitative (Gummesson, 1991), which are also referred to as fixed or flexible designs (Robson, 2002; Johnson and Harris, 2002).

A quantitative approach always involves the numerical analysis of data (Johnson and Harris, 2002) and it is strictly specified before the main data collection stage; thus, there is the alternative 'fixed design' term (Robson, 2002). A typical characteristic of quantitative research is the use of a controlled environment, where the researcher has both the environment and the experimental conditions under control, and is 'detached' so that s/he minimises the influence on the research findings (Robson, 2002).

Johnson and Harris (2002) state that in qualitative research the data is collected in the format of words and observations, rather than in a numerical format. A qualitative approach is chosen when the phenomena of interest typically require an exploration of detailed in-depth data (Robson, 2002). As opposed to the controlled environment of the quantitative approach, the researcher here conducts the study in a 'natural setting' (Creswell, 1998). The term 'flexible design', used by Robson (2002), stems from the fact that the research questions and ideas evolve as the research progresses.

It is not likely to undertake qualitative and quantitative research at the same time; however, it is possible for a study to be divided in various phases, where either qualitative or quantitative approaches can be applied. A major difference between qualitative and quantitative research is that researchers adopting the first approach rely on few variables and many cases, whereas researchers adopting the second approach work with many variables and a few cases (Creswell, 1998). For this reason, it is hard to follow a quantitative patterned approach in the study of a social or natural setting, since there are many variables that are out of the researcher's control.

A number of factors led to the adoption of a qualitative approach in this study. Firstly, the overall topic calls for further exploration, in order to create ideas and meet the research objectives. Secondly, the topic needs to be studied in depth by using individuals in their natural setting and not in a controlled environment.

3.3.3 Research purpose

After having presented the research objectives and the research context, the next step in the research methodology design is the selection of a research strategy. Nevertheless, prior to this selection, the purpose of the research needs to be understood, since it will aid clarifying which research strategy is the most appropriate for the nature of the research. According to Robson (2002), the purpose of a research can be exploratory, descriptive, and/or explanatory.

Taking into account the aim, objectives, and the perspective of this research, its overall purpose can be best characterised as exploratory. Moreover, as Creswell (1998) and Robson (2002) mention a qualitative approach is usually linked with exploratory research.

3.3.4 Research Strategy selection

There is a range of references to the traditional research strategies within a qualitative research context throughout literature. Creswell (1998) concludes on five qualitative design research strategies: *biography, phenomenology, grounded theory, ethnography,* and *case study*. Likewise, Robson (2002) categorised the acceptable for qualitative inquiries strategies into *case study, ethnographic study,* and *grounded theory study*. Table 3.1 illustrates the comparison of the five strategies introduced by Creswell (1998).

	Biography	**Phenomenology**	**Grounded theory**	**Ethnography**	**Case study**
Focus	Exploration of an individual's life	Understanding of a phenomenon's experiences	Development of a theory grounded in data from the field	Description and interpretation of a cultural and social group	Development of a comprehensive analysis of a single or multiple cases
Discipline origin	Anthropology, Literature, History, Sociology, Psychology	Philosophy, Sociology, Psychology	Sociology	Cultural, Anthropology, Sociology	Political Sciences, Sociology, Urban studies, other Social sciences
Data collection	Mainly interviews and documents	Long interviews with up to 10 people	Interviews with 20-30 individuals to 'saturate' categories and detail a theory	Mainly observations and interviews with additional artefacts during long time spent in the field	Various sources– documents, archival records, interviews, observations, physical artefacts
Data analysis	Stories, Epiphanies, Historical content	Statements, Meanings, Meaning themes	Open Coding, Axial Coding, Selective Coding, Conditional Matrix	Description, Analysis, Interpretation	Description, Themes, Assertions
Narrative form	Thorough illustration of an individual's life	Description of the 'essence' of the experience	Theory or theoretical model	Description of the cultural group behaviour	In-depth study of a single 'case' or multiple 'cases'

Table 3.1: Comparison of five research strategies (Source: Creswell, 1998)

Table 3.2 provides a description of the three qualitative design research strategies presented by Robson (2002), p. 89-90.

Qualitative research strategy	**Definition**	**Typical features**
Case study	Detailed, intensive knowledge development about a single case, or a small number of related cases.	▪ Single case selection ▪ Study of the case within its context ▪ Use of various data collection techniques, such as observation and interviews.
Ethnographic study	Aims to capture, analyse, and explain how a group, organisation or community live and experience the world.	▪ Selection of a group, organization, and community ▪ Researcher involvement in the setting ▪ Use of observation.
Grounded theory study	Aims to generate theory based on the data collected from the study.	▪ Applicable to a broad range of phenomena ▪ Mainly interview-based ▪ Provides comprehensive recommendations for data analysis and theory generation.

Table 3.2: Three qualitative research strategies (Source: Robson, 2002)

Comparing among the different research strategies, the case study approach seems to be the most suitable one. A number of factors were considered for the selection: the context of the research, the available, to the researcher, data collection methods, and the involvement of the collaborating organisations. In addition, as Gummesson (1991) and Robson (2002) stated, case studies are linked to exploratory work, which is the characteristic of this study.

Case Studies

As Gerring and McDermott (2007) stated, Case Study is a form of analysis where one or a few units are studied rigorously in order to clarify a broader class of units. Units may consist of any phenomena provided that each unit is relatively well confined and that these units are positioned at the same level of analysis as the principal assumption. Description, understanding, prediction or control can be the objectives for Case Study research (Woodside and Wilson, 2003). According to Remenyi et al (2003), there are two circumstances within the boundaries of the research world, where the term Case Study can be used. The first one is where the case study is used as a framework to gather and explore evidence about a phenomenon and the second is where the researcher is not especially concerned about the particular circumstances of the case that is investigated. Case studies usually combine data collection methods, including archives, interviews, questionnaires, and observations. The evidence may be qualitative, quantitative or combination of these two (Eisenhardt, 1989).

The author also employed the critical incident technique during the conduct of the case studies. Gremler (2004) stated that this technique has been used in many different service contexts in recent years to investigate service research issues. It was introduced to the social sciences by Flanagan in 1954 and it can be described as a qualitative interview procedure that assists the exploration of important occurrences (events, incidents, processes or issues) pinpointed by the interviewee, the way they are handled, and the results in terms of observed effects (Gremler, 2004). As stated by Edvardsson and Roos (2001), the recall of critical incidents relies on people's memories and perceptions of past memorised incidents.

Due to the involvement of the researcher and the nature of the subjects, there is a possibility of bringing bias in the study. The researcher needs to prove that her research is trustworthy by minimising bias and other possible risks. Therefore, the potential risks need to be identified and actions to be taken in order for the validity and trustworthiness of the study to be established. These actions are presented in the following Section.

Trustworthiness

Two key areas, that have to be addressed so that the trustworthiness of the study is established, are validity and generalisability.

Validity deals with identifying whether a piece of qualitative (flexible) research is accurate, correct, or true (Robson, 2002). The main threats to validity, as listed by Robson (2002), are as follows and can be minimised or eliminated if addressed well in advance by the researcher:

- Reactivity: refers to the way in which the researcher's presence may interfere with the case setting.
- Respondent bias: refers to the cases, where the respondents treat the researcher as a threat; thus, try to hide information from him/her. Also, it refers to instances, where the respondent gives the answer which would please the researcher.
- Researcher bias: refers to the assumptions and preconceptions that the researcher may bring and lead to a selection of certain people for interview and of specific interview questions.

Creswell (1998) and Robson (2002) developed some strategies to deal with these threats. These are the following:

- Prolonged involvement- the researcher spends time within the research setting, trying to create relationships with the participants and understanding the culture of the setting. Prolonged involvement could increase the researcher bias.

- Triangulation- the use of different methods and sources to improve the research rigour.
- Peer debriefing and support- debriefing sessions after long period within the research setting can aid reduce researcher bias.
- Member checking- getting feedback from the participants is crucial for the research credibility.
- Negative case analysis- using the working hypothesis under negative evidence.
- Audit trail- keeping a full track of the activities taking place during the research.

Reliability, within a qualitative research context, is concerned with the reliability of the methods and practices used; the data collection methods should be structured and consistent, as well as the research strategy. A research study is valid when it is reliable. However, if the study is reliable, it is not necessarily valid at the same time. The researcher will need to be honest and provide an audit trail in order to achieve reliability (Robson, 2002).

Generalisability is concerned with the general applicability of the results of a research study; it could be to people indirectly involved, or other situations and times (Maxwell, 2002; Robson, 2002). There are two types of generalisability within a qualitative research context: internal and external.

The internal generalisability is related to whether the findings can be extended to a community that was not directly involved in the initial study. The external generalisability is related to whether the conclusions can be extended to other research groups or institutions. It is perceived that external generalisability is hard to achieve within a qualitative research context, because the findings make sense for specific individuals or settings studied.

Bias Reduction

The qualitative research approach requires the researcher's participation or observation of events and eventually their interpretation. To reduce the bias involved in this process the researcher had to:

- Triangulate by using different data collection methods, including interviews, observations, talk-through case study analysis and 'member checking' within the case study strategy.
- Conduct a literature review, which represents the state-of-the-art in the domain and contributes to the creation of the initial ideas via the domain understanding.
- Keep an audit trail of all the activities that take place throughout the research (keep notes, record interviews where possible).
- Debrief peers after visits, which included observations and interviews, to ensure that all the necessary information was captured.
- Prolong her involvement in the research settings where the case studies will take place. The prolonged involvement enhances the relationships with the participants and minimises respondent bias, since the researcher will not be treated as a threat or an 'outsider'.

3.4 Research Methodology Followed in the Thesis

The researcher described her rationale regarding the decisions made for the selection of the research approach, design, and strategy, taking the widely accepted approaches that can be found in the literature into account. The proposed research methodology is represented in Figure 3.1. It is divided into three main stages: *research approach, data collection and idea creation,* and *data analysis and validation.*

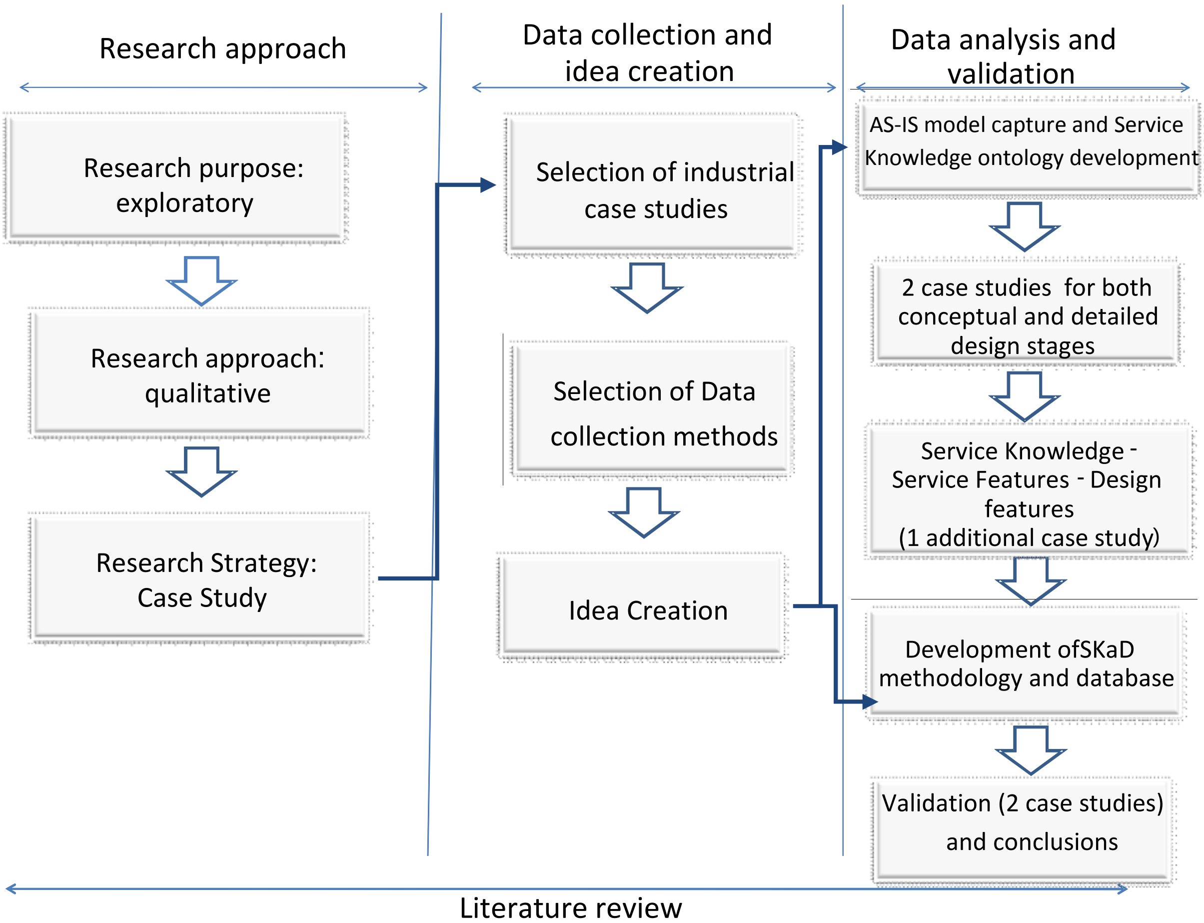

Figure 3.1: Design of Thesis Research Methodology

The first stage is related to the review and selection of an appropriate research strategy. The nature of the research objectives led to the research purpose being defined as exploratory. Also, the qualitative approach was chosen and the Case Study was selected as the most suitable research strategy.

The second stage is concerned with the selection of suitable data collection methods in order to pinpoint research issues and create new ideas on how to resolve these issues. In order to increase the validity of her work, the researcher used the Bias Reduction approaches that were mentioned before. The literature review was an on-going process throughout the research that enabled the researcher to gain a theoretical understanding of the research issues and also to obtain a broad picture of similar issues dealt with by other research groups. The case study selection took place according to the general research context and the availability of resources for the researcher.

The third stage is concerned with the development and validation of the proposed framework. Combining the results of the interviews and the findings of the literature, a representation for service knowledge was developed (ontology) and the impact of service knowledge availability on the conceptual and detailed design stages of the product was identified. Finally, the researcher conducted two case studies within the collaborating companies in order to develop and validate an effective methodology to reuse service knowledge for product design (Service Knowledge and Design- *SKaD*- methodology). The first case study was conducted within a pump manufacturing company, whereas the second one took place within an aerospace setting in order to prove the potential generalisability to other industries. An additional case study was conducted with a UK machine tool manufacturer for the detailed definition of service features. Validation took place during various phases of the research and the final one (methodology implementation within a database) was carried out with the collaboration of the two main industrial partners (pump and aerospace manufacturers). Finally, the research conclusions, limitations, and areas for future research are presented in Chapter 9.

3.5 Summary and Key Observations

In this Chapter the aim and objectives of this research study were presented. In addition, the research context was set, and the qualitative and quantitative approaches were described; a qualitative approach was selected due to the exploratory nature of this study. Moreover, a case study strategy was chosen among five research strategies as categorised by Robson (2002). The issue of trustworthiness and in particular, validity, reliability and generalisability were discussed. Finally, the research methodology followed in this research was presented. Each of the three stages was described in detail, along with the actions taken by the researcher to minimise the bias, thus the threats to the validity of this study.

Chapter 4 focuses on the service knowledge capture and representation. To achieve this, detailed case studies were undertaken in collaboration with three industrial organisations; an additional organisation participated in the validation of the obtained results.

4 Service Knowledge Capture and Representation

4.1 Introduction

The previous Chapter described the aim and objectives of this research, as well as the selection of a suitable research strategy by the author. This Chapter explains the path that the author followed in order to capture and represent service knowledge (SK) for the support of product design within the context of technical services (e.g. planned and unplanned maintenance, service exchange, commissioning and monitoring). To achieve this, a case study research approach was adopted. Overall, three UK manufacturing companies participated in the SK capture and representation. The validation took place at various stages with the collaboration of one manufacturing company in addition to the previous three that aided with the SK capture. The entire path is shown in Figure 4.1. At this point, it is essential to mention the definition of SK within the context of this research.

Service Knowledge (SK) can be defined as the amalgamation of processed information, which is required by service personnel for the execution of their activities (i.e. planned and unplanned maintenance, service exchange, product repair and overhaul, retrofitting and upgrades, training) stored by them to be re-used when needed. Experiences of service personnel, gained through their tasks, should also be integrated into SK.

4.2 Service Knowledge Capture

In order to capture the service knowledge, within a technical services context, the author conducted a detailed case study with three UK manufacturing companies. Within this case study, semi-structured interviews have been used as the primary method of the investigation. The author made notes of important findings, and company documents were also used.

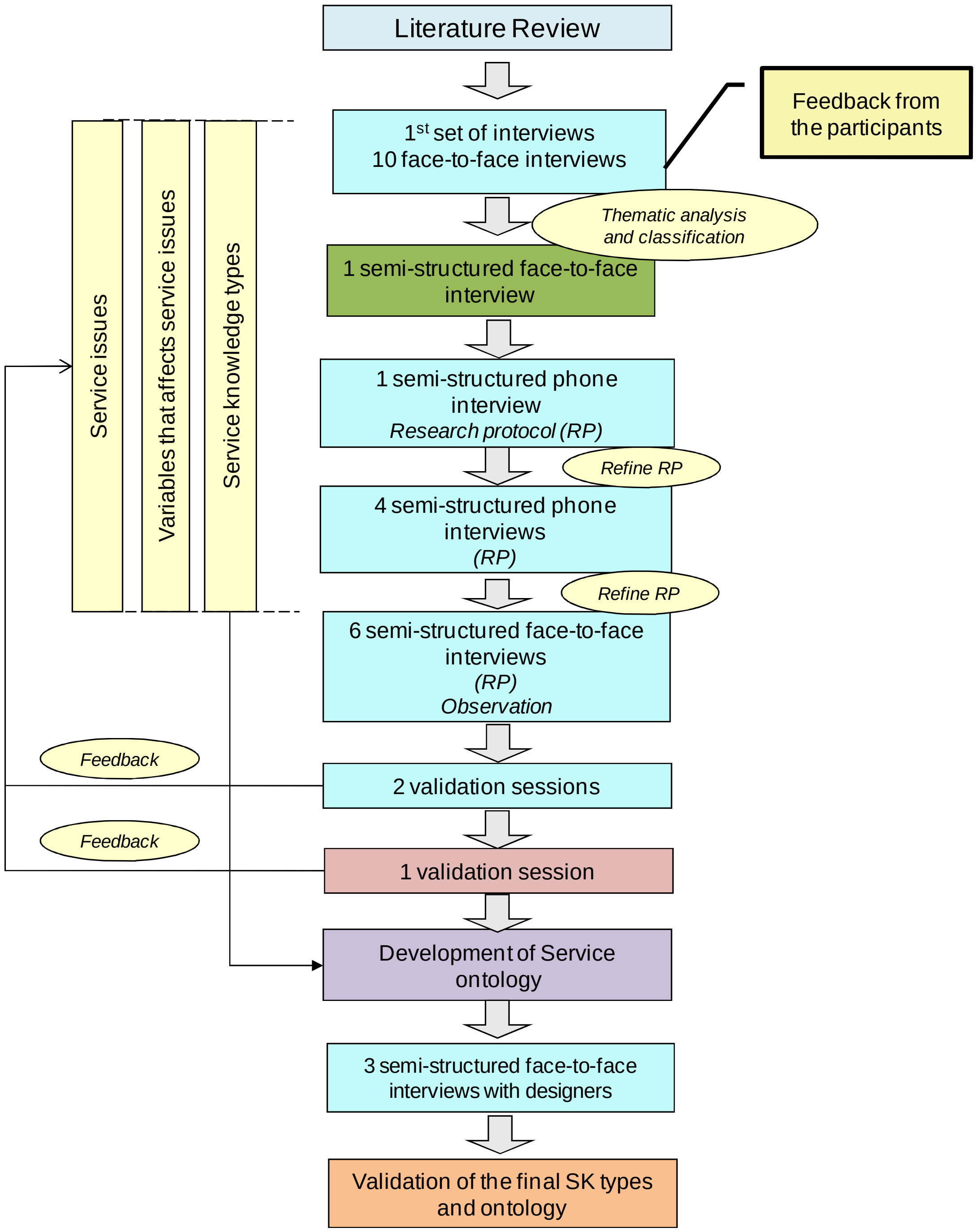

Figure 4.1: SK capture and representation methodology

As seen in Figure 4.1, a literature review on themes related to the study had been conducted before the investigation at Company 1 started. Where new themes were identified, additional aspects of the literature were explored.

The next Sections illustrate the findings related to the service issues from the industrial case studies. The use of different colours in Figure 4.1 aims to facilitate the reader in distinguishing among the stages and the companies, which participated at this stage of the research. As depicted in Figure 4.1, the case study at Company 1 was split into three main parts: the first part consisted of ten interviews, which were conducted face-to-face mostly with New Product Development (NPD) personnel in the UK. The second part included five interviews conducted by phone with service personnel based in the USA, and six interviews which took place at one of the company's customer site in Germany. The reason for dividing the case study into three series of interviews was driven by the fact that the company provides two types of service: product repair and maintenance in service facilities (hubs), and on-site service. The first set of interviews, conducted with NPD personnel, provided information regarding the company's service provision and the service knowledge applied. The following eleven interviews enhanced the knowledge captured previously, and clarified the issues that had been mentioned in the earlier sets of interviews. The final three interviews with the designers were carried out in order to clarify the role of service knowledge in product design.

The roles of the people that were interviewed were (see Table 4.1):

Job role	Years of experience
Labour support manager	20
Manufacturing engineer	11
Technical support manager	16
NPD engineer	6
Product manager	18
Team leader	14

Lead technician	17
3 Service technicians	5, 3, 9
4 Service engineers	10, 9, 12, 4
Project engineer	12
2 Project managers	19, 16
Vacuum manager	22
Operations site engineer	4
Team leader	7
Senior mechanical designer	14
Designer	5
Control system designer	9
Business development manager	15

Table 4.1: Job roles and years of experience of the interviewees (Company 1)

The aim of the first investigation was to develop an initial framework describing service knowledge types. The participants were asked to describe a situation from a current or recent project where they had encountered difficulties or had overcome obstacles in reaching a solution. This exercise was intended to provide a description of the knowledge requirements.

According to the critical incident technique, the interviewees were asked to describe positive and negative examples of behaviours or actions that happened during a project from the service knowledge application perspective. The key themes identified from these interviews were related to service knowledge types, as applied within the two projects studied at Company 1. These themes, which were developed during the analysis, are described in Table 4.3. The frequency of the occurrence of the various knowledge types during the interviews is also presented in the table.

In the second set of interviews the Service Product Manager for semiconductor dry pumps was also involved in the interviews and he gave answers to some fundamental questions about the company’s operations. The aim of the interviews was the capture of service knowledge applied within the service facility located in the USA. This set of interviews focused on the first project only; whereas the NPD interviews included both projects. The objectives were the following:

- Recording issues faced during the service of product 1,
- Identifying relationships between service and design or manufacturing, and
- Assessing and enhancing the service knowledge types captured as a result of the interviews with NPD personnel.

The third (last) set in the case study had the same objectives as the second one; however, it should be mentioned that the research protocol used was modified and enhanced after the second set of interviews had finished.

4.2.1 First set of interviews at Company 1

The first set of ten semi-structured interviews were conducted using the critical incident technique (The full research protocol (RP) used can be found in Appendix A). The aim of the first set of interviews was exploratory; to develop an initial framework describing service knowledge types applied in practice. This is the first stage of SK capture and representation. The overall objective was to identify what service knowledge the designers need, what is currently available, and what is missing. Through describing a critical task, knowledge that was required and applied during that task can be identified. Therefore, according to the critical incident technique, the interviewees were asked to describe positive and negative examples of behaviours or actions that happened during a design project, focusing on the application of service knowledge.

The interviews were transcribed, and the transcripts were coded using a thematic analysis technique. The key themes identified from these interviews were related to service knowledge types, as applied to this specific company within the duration of two particular projects. Precisely, the analysis of the transcripts started with the identification of the service issues mentioned by the interviewees and their categorisation along with the frequency they appeared and the product they refer to. The analysis was carried out using NVivo, which is a qualitative analysis software. The themes identified were classified, combined and generalised in order to develop a set of service knowledge types. Thus, an initial, quite simplistic service knowledge framework was created. Having proposed a service knowledge structure, it was possible to perform an analysis of the proposed structure. NVivo software facilitated the classification of the issues by product, along with the frequency with which they were reported in the interviews. A further analysis of the most commonly reported themes took place after the first set of interviews. Then, having conducted the last two sets, the researcher modified and enriched the SK types.

Case study products

The research focused on two products for the service knowledge capture. They are both manufactured by Company 1, a global supplier of vacuum pumps with UK design and manufacturing operations, and a global service network. The first project was the design and launch of a compact and light semi-conductor pump with low utility costs and long service intervals. The second one was concerned with a totally dry, lubricant-free small vacuum pump. The products are shown in Figure 4.2 and Figure 4.3.

Figure 4.2: Product 1

Figure 4.3: Product 2

The two products have been developed by two different project teams. Their main differences are highlighted in Table 4.2:

Key characteristics	**Project 1**	**Project 2**
Market	Semi-conductor	Scientific
Serviced by	The company	Mostly the user
Service cost/ product cost	10%-14%	8%
NPD team size	20 people plus purchasing, manufacturing and support functions	8 dedicated people plus support functions
Service resource allocation to NPD team	1.5 persons	0.25-0.5 persons
Service integration in NPD process	Attendance at weekly reviews	Attendance at weekly reviews

Table 4.2: Comparison of Project 1 and Project 2

Service Issues and Comparison between the Two Projects

The analysis of the first set of interviews led to the identification of the themes related to the application of service knowledge. These themes (service issues) are presented in Table 4.3. The author analysed thoroughly all the transcripts and managed to isolate the issues faced in the servicing of the two case study products. Then, NVivo software was used as a supporting tool to define the frequency of the service issues that had been mentioned in Project 1 and 2 by the experts. A comparison between the issues identified and their frequency in these two projects is useful for the understanding of the creation of the knowledge framework.

Service issue	Project 1 Frequency	Project 2 Frequency
Lack of link between service and NPD, engineering, marketing, service	20	5
Lack of service personnel in the NPD team	8	1
Service difficult for 3rd parties due to design	4	2
User serviceable wear parts	0	9
Documentation	3	5
Training	4	0
Manufacturing system design	3	0
Design changes post-launch	3	0
Spares availability	2	2
Access to components	1	0
Unrealistic designer requirements	1	2

Need for sensors	1	0
Service testing	1	0
Existence of a dedicated person	1	2
Painting	0	2
Packaging	0	1
Service station characteristics	1	0

Table 4.3 : Service issues identified and their frequency

The most frequently identified themes were the lack of link among the service, design, and manufacturing departments during the NPD project, and the lack of a link between the service and NPD team. They came up twenty times in project 1 and five times in project 2, having been mentioned by six out of ten interviewees. In part, the difference in frequency is due to the nature of the market served by project 2: the product is generally serviced by the user. It is also in part due to the better communication taking place in a significantly smaller NPD team. A lack of service personnel was also highlighted as an important issue in the first project. This also reflects the size of the project and the increased focus on service as an important revenue source for the company. The recognition of the requirement to involve service personnel in design resulted in a high workload for the small team dedicated to service issues. Also, the inclusion of service in the NPD process is still at a development stage at Company 1. Service engineers are currently required to attend design review meetings. A further development of the role that has been identified within the company is the inclusion of service engineers in earlier NPD stages, to enable their participation in developing the design concepts. Thus, an industrial need for the support of product design with service knowledge is recognised; this constitutes the main issue that this research attempts to address. Since the role is developing, the resource allocation is also developing. There are currently not enough people to support all of the identified areas where service should be involved.

It was also reported that some service activities may require specialist tooling that may not be available to third parties. It is sometimes inevitable in a complex product that there are only a few things that can be done by the customer or by non-expert people. This was a characteristic more frequently mentioned for the first product, because this product is serviced by the company and as a result the design can allow for specialist tooling requirements. Such requirements must take into account the desire of the customer to carry out service themselves, the balance of service cost against product cost, and the likely effect on service revenue.

Another theme identified specifically in the second project was a focused effort to make the exchange of wear parts simple and fast. For example, a target time was produced in the design project for the exchange of seals. This theme was not mentioned in the first product due to the differences in who carries out service in the markets that these products are provided to. Product 1 serves the semiconductor market, where products are generally serviced by the company's own service teams. Product 2 serves the scientific market, where products are generally serviced by in-house technicians, at least for routine maintenance. Thus, serviceability is taken into account by the designers to ensure that the product is serviceable by the user. This relates to the fundamental aspects of the product design, since the disassembly and assembly operations must be possible with basic tools and minimal training.

Documentation, for example product manuals for site service, spares manuals, and service equipment specification, was also a major issue in a service department. This was identified as an important issue in both projects. It was generally stated that service documentation is good and clear, but in a product development scenario it is time-consuming to produce and review. In the case of a global organisation, the issue of interpretation by different people all around the world is important.

Training was only mentioned by the interviewees related to the first project. This does not mean that training is not a part of each project, but that most possibly it is more essential in these, where the company provides service with its own in-house service centre personnel. It is to be provided to service people by field engineers on installation, commissioning, planned maintenance, and product exchange. The delivery of the training was emphasised to be an important aspect, as it depends on individuals' capabilities of presentation and explanation of the material used. There are also 'training centre' based courses available to customers for product repair.

Manufacturing system design refers to the development of the various processes of assembly and disassembly in the manufacturing facility and the service centres. Previous products have been optimised for a production environment, resulting in a suboptimal scenario in the service facility. Specifically, a product can be optimised for a flow line but may not be optimal in a job shop. This relates to assembly methods and equipment, disassembly methods and equipment, and testing methods and equipment. Of special interest to service are the cleaning methods and equipment. Since safe cleaning procedures are not a requirement in production (products are not contaminated), a product optimised for production may neglect the cleaning activity.

When a design change takes place after product launch, the service process may also need to be updated. It was reported that in some cases, a change was made in the manufacturing method and the design/service documents were not updated. Design changes led by the design team were propagated through the system in the usual way; however, service personnel were not informed of manufacturing method changes.

Problems were reported with the availability of service tooling and spares. They should be available prior to product launch; however, in some cases an optimistic view was taken that the products would not require service immediately and there was a time delay between product launch and service tooling launch. There was also an issue with the variation between sales' regions and customer presence: a phased regional roll-out may result in a customer unable to get spares if they purchase in one region that has spares in place and install in another that is yet to implement the spares logistics operation. It is also necessary for service people to define which parts will be sold as a spare. Not all parts are available as spares (you do not necessarily build a whole pump from the spares list). Company 1 also sell spares kits, e.g., disassembly kit consisting of all required seals and parts that need to be changed every time it is taken apart. Furthermore, the cost should be defined so as for the company to achieve the targeted margin. Another aspect that was emphasised was the numbering of the spares. Because they want to sell them as spare parts, they cannot use the same part number as in the production.

Then, the access to components, the need for sensors, service testing, and the station characteristics were mentioned only in the first project. These issues are important in Product 1, because this product is serviceable by the company, whereas the second one is user serviceable and the company conduct only the major services.

The presence of a dedicated service person in the NPD team can significantly aid the on-time product launch and improve the communication among the team members (designers, service people, and manufacturing engineers).

Finally, an issue that appeared in only one of the two projects was painting and packaging of the product. It was stated that the scientific market likes ‘pretty products’, so they were painted to improve the appearance. This is an issue for both production and service, since production must be careful not to damage the finish of the product, and service may require a painting facility if the finish has been damaged during operation or disassembly. The issue of painting was only mentioned in project 2, since product 1 has metal enclosures that protect the painted pump body, thus these problems are less of an issue.

In addition to painting, packaging is also a typical problem. Due to the low value and high shipping costs, packaging is sourced regionally by the service centres in order that they can repackage the products.

Service issues	**Variables**
Lack of link between service and NPD	Size of the project, location of the project team
Cooperation of engineering, marketing, service	Size of the project
Lack of/bad allocation of service personnel in the NPD team	Size of the project, number of projects running in parallel, availability of personnel
Service difficult for 3rd parties due to design	Importance of service income for the business, safety issues
User serviceable (easy/difficult) wear parts	Market type, user experience, customer requirements
Documentation	Time, language, market location
Training	Market type, customer requirements, language
Manufacturing system design	Easiness of service at the service hubs, manufacturing location, setup costs, budget ownership
Design changes post-launch	Closeness of market and service hubs, pressure for launch, product quality at launch, quality plan
Spares availability	Need for pre-launch availability, launch plan
Access to components	Product design
Unrealistic designer requirements	Design experience
Need for sensors	Customer requirements, cost

Service testing	Cost implications labour vs. automation
Existence of a dedicated person	Need for interaction between service, design and manufacturing, project size
Painting	Product type, customer requirements
Packaging	Packaging supplier's location
Service stations characteristics	Product type

Table 4.4: Service issues and variables

Variables affecting the service issues

A deeper understanding of the variables that affect the service issues was needed after the analysis of the transcripts and the identification of the service issues. This assisted the comprehension of the reasons causing the existence of issues in the service operation. Therefore, during the industrial investigation, a table was created to present all the issues and the captured variables that seem to affect each of them (see Table 4.4). This was done by taking into consideration the facts that were stated by the interviewees in order to identify the reasons that cause the similarities and differences between issues in the two projects.

As it can be seen in Table 4.4, aspects related to the project itself, such as size, location, budget, number of projects in parallel, and personnel availability are important variables which generate the difference in service issues. However, other variables are closely related to the market, i.e. market type, language, customer requirements and experience, pressure for launch; and others to the product, i.e. product type, product quality, design, and cost.

Below, the process followed at Company 1 when a product failure occurs, from a service and design interaction perspective, is described (AS-IS model). It was captured during the conduct of interviews with personnel from Company 1 (see Table 4.1). Following this, clarifications were provided to the author by the service marketing manager.

Figure 4.4 illustrates a graphical representation of this process. The occurrence of the product failure is the first step. Following this, the service team receives a notification from the monitoring system (Fabworks); this happens only in the cases where the system is installed on the customer's site, otherwise the customer notifies Company 1 regarding the failure. Fabworks is a system, which monitors the pump performance, and automatically notifies the service team when a failure or significant performance deterioration occurs. After the receipt of notification, a technician needs to investigate what exactly has happened, and in addition to this, there is a set target by the company for the repair to be accomplished within 30 minutes while the pump is on the customer's site. Then, depending on whether the repair is feasible within the time limit, there are two options: 1) to repair the pump on-site using spares and service equipment, and create a report regarding the failure and the repair process, and 2) to remove the pump, replace it with a working unit, and send the faulty one to a service centre in order for the repair to take place. As far as the first option is concerned, the author did not have any specific information about the content of the report that the technician creates; also, designers do not access these reports. With regards to the second option, the product is sent to the service centre, where the service process takes place (The processes, which are conducted at a service centre, are presented in Appendix H). Also, at the end of the repair, a report is created. It was added by the service marketing manager that there are three levels of pump strip reports (the term is used to signify the reports created after a pump failure).

1. Level 1: It just informs the customer that the pump was stripped, re-built and tested (basic information).

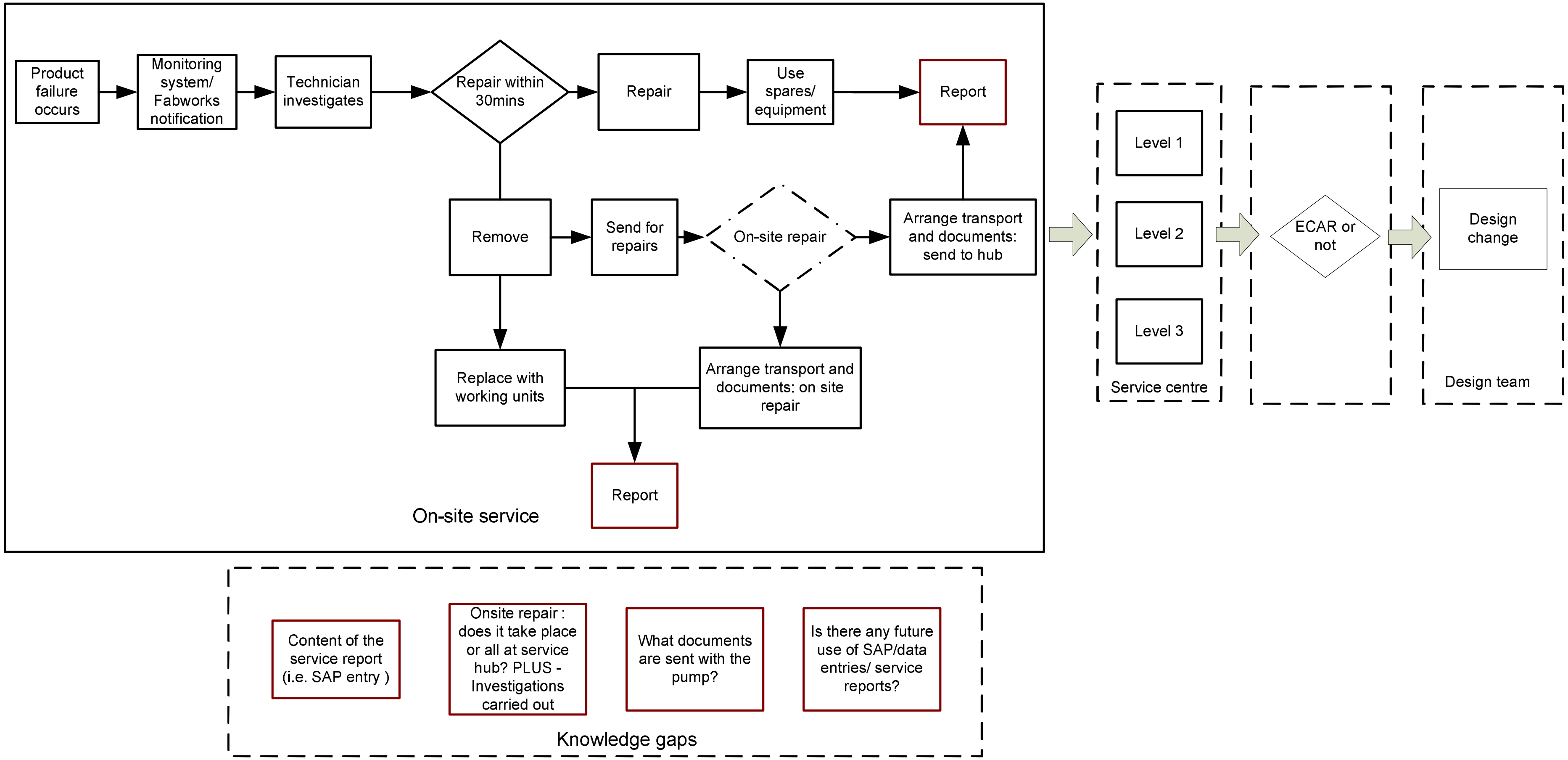

Figure 4.4: AS-IS process followed when a failure occurs

2. Level 2 (warranty claims): The customer asked for an investigation for the causes of the pump's failure (the service technicians and leaders make an assessment of what was found; photos of the pump are included too).
3. Level 3: Full-detailed technical investigation; somebody from the UK service department analyses in detail the root cause of the failure.

Following the report completion, a decision needs to be made on whether there will be an Electronic Corrective Active Request (ECAR), which will possibly lead to a design change. It can be noticed in the process described above and presented in Figure 4.4 that the only case when design gets service feedback is after a serious failure has happened and a corrective request has been formed.

4.2.2 Interview at Company 2

After the first set of ten interviews, a face-to-face interview with an Engineering Manager (30+ years of work experience) of Company 2 was conducted. The interview lasted for two hours. A research protocol (RP) had been sent in advance to the interviewee so that he could prepare himself regarding the issues that would be addressed; part of the RP and the answers given is presented below (Doultsinou et al., 2008) (see Appendix B for the full RP).

Selecting a case study company

Case justification: why this company? How does this company match the research aim? Why this business unit?

Company 2 represents a capital intensive, mature and complex aerospace domain, which is suited to a formal knowledge reuse methodology.

Questions to be covered in the interview

1. How important is service to Company 2 as a business?
2. Types of service carried out.

3. How is service knowledge taken into account into the design process?
4. Could you give some feedback on the SK types?

Snapshot interview results

Company 2 focuses on selling capability rather than selling equipment. They supply equipment, they are responsible for keeping it in a working condition (repair and upgrades), they supply spare parts, and they train the crew. Their service agreements focus on the application of the service rather than just the product.

The most important thing in an extended enterprise is the sharing of information about obsolescence and anything that can affect PSS long-term across the company. In terms of technology update and obsolescence it would be good for manufacturing and design to focus on the high-value components and make sure that there is always an alternative. Also, the system should be as modular as possible and the components should be more standardised, so that the availability is increased.

In terms of service quality, it is assessed by technical criteria related to the performance of the equipment and by criteria related to 'abilities'. The term 'abilities' is used to describe reliability, availability (proportion of time that the system is available), maintainability, supportability (how easily you keep the system working), failure rates, and mean time to repair.

It has also been stated that at Company 2 there is a feedback process from service to design and manufacturing. Typically, the customer records problems that occur. There are always periodic review meetings, depending on the type of contract that each customer has. Therefore, the responsibility is shared between the end user and the supplier. If there is a high rate of failures on specific equipment, then the service level agreement places the emphasis on the supplier to rectify it. Condition monitoring also takes place especially for components that are expensive to be replaced. So, they have introduced innovation to detect the time when the equipment is likely to fail in its design. They also have built-in tests to warn the operator about a fault that can happen. The issue is that these systems are very complex and when a function is off, you cannot notice a problem until you use this specific function.

The author made a comparison of the main characteristics and issues between Company 1 and 2, and the results are as follows:

Commonalities:

- Training of the service crew is essential in one of the projects in Company 1 and it seems essential in Company 2 as well.
- Spares' availability is very important in both companies.
- It has been mentioned that sensors are essential for the diagnosis of product defects in some projects in Company 1. In Company 2, they have built-in tests to warn the operator about a fault that can happen.
- Service testing seems to be an issue in both companies; specifically, Company 2 builds simulation prototypes, where they test the equipment.
- Serviceability of the components is also taken into account in both companies. In Company 1, there are some wear parts that are very easily user serviceable. Additionally, in Company 2 the equipment should not require any special tooling to be fixed, apart from the tooling that the customer has on board.

Differences:

- It seems that there is a better feedback process from service to design and manufacturing taking place in Company 2, where the customer records any problems and review meetings are held on a one, six, twelve-month basis according to the contract that the customer has signed.
- Obsolescence of the equipment is a major issue in Company 2 due to the long lifetime of the products.
- Painting and packaging were not mentioned as service issues in Company 2 (Doultsinou et al., 2008).

The author feels the need to emphasise that the case study conducted in Company 1 was an in-depth investigation of the service operation, which led to the identification of service issues, and eventually the elicitation of the SK types. On the other hand, merely an initial understanding of the service provision and its role within Company 2 was gained. This was the purpose that the interview at Company 2 served, whereas the series of interviews with experts from Company 1 aimed at obtaining a detailed and comprehensive view on the service and design interaction. The latter would aid in the identification of SK types and ultimately the development of the framework to support product design with service knowledge.

Also, a definition for service was provided by the interviewee at Company 2: 'Understanding of the customer's mission requirements and the need to make sure that they are addressed successfully'. In addition to this, SK was defined as 'The understanding of how the system will be used and the ways in which it will be stressed and an anticipation of the likely ways the system could fail under stress along with methods to mitigate these failures'. At a first look, this definition of SK is different from the one that the author gave in the Section 4.2. However, the author's phrase 'processed information and experiences' can encompass possible failures and ways in which the system/product can be stressed, and how these can be tackled and/or have been under similar circumstances in the past. Thus, the two definitions express the same idea, but in a different way.

Apart from the general understanding that the author gained from this interview, she managed to get feedback on the SK types that had been captured until this point of research, too (This initial structure is shown in Figure 1, Doultsinou et al., 2007). The interviewee suggested that more details can be added to the 'planned maintenance' and 'unplanned maintenance' knowledge types, such as time, which can be included as overhaul interval in the case of planned maintenance, and time when the failure/ malfunction happened in the case of unplanned maintenance. Additionally, the interviewee highlighted that the types of tooling may vary in different organisations and types of industry, but the general idea is captured in the structure created by the author. The final comment was made with regards to serviceability. It was stated that within an aerospace setting due to the long product lifecycles, obsolescence should be taken into account when serviceability issues are tackled. The author made the necessary amendments to the SK types and continued with the next step of this piece of research.

4.2.3 Two sets of interviews at Company 1

At this stage, two other sets of interviews took place. These consisted of five telephone interviews and six interviews on a customer site (see Figure 4.1). Combined, these interviews represented an in-depth investigation into service knowledge applied in the service operation. The first phone interview took place as a pilot. Prior to that, a research protocol describing aim, objectives, questions to be covered and analysis techniques was sent to the interviewee in order for this person to prepare. After the first phone interview, the research protocol was refined and the next four interviews were conducted according to it (see Appendix C for the full RP). A sample of the questions included in the RP is presented here:

- What triggers a service (failure, time period, other indications)?
- What are the common causes for pump 1 failure?
- How could design be modified to reduce these failures?
- Is there any interaction between service and design or manufacturing? If yes, give examples.

The answers of the interviewees to the aforementioned questions were combined and are the following:

- A *service requirement can be triggered* due to two factors: failure and time period. Regarding failure, it can be caused by two main reasons: either by pump 'crash', in which a build-up of process material causes the pump to stop; or by a reduction in vacuum achieved due to wear to the pump internals caused by abrasive process material and aggressive cleaning chemicals. Company 1 recommends overhaul intervals based on the applications, where the pumps are used. For pump 1 the recommended interval is 3 years, between which the pump is designed to run without being maintained. The time period indicator for service is supported by embedded counters on the pump. There are two counters: one that records the total-run time (from the moment that the pump was manufactured) and another one that counts down until next service and it gives an indication to the customer (message alert) that the pump needs service and it gets reset after service.

- The *customer returns a pump* either because this is what is defined in his/her contract or because the pump does not achieve the targets illustrated in its specification. The majority of pumps (type 1) were returned due to accumulation of process material in them. Sometimes the customers use the pumps in harsher processes than the ones that are designed for or take the risk to run them beyond the 3-year recommended service interval (until they fail). Therefore, the pump stops and it needs servicing. A number of new pumps were returned due to electrical problems.
- Pump 1 was designed to be easily serviced. Therefore, there are only few *design aspects that cause difficulty* in service and they have been changed in order to smoothen the service process. Generally, the product is compact and the more compact a product is, the more labour it requires for assembly and disassembly, and sometimes the access to components is difficult. Specifically, the water system has been changed because the water valves were failing; this, consequently, resulted in the combination of the valves and, thus, their number was reduced. Subsequently, the number of the water lines was also decreased and this design change finally led to easier service, due to less time spent on the

removal of the water lines. There were not any suggestions for additional changes to the design of the pump.

- It has been clear from the interviews that only the lead technician *interacts with design* and manufacturing up to a certain extent.

The responses to the entire list of the questions addressed to the interviewees (RP in Appendix C) can be found in Appendix D.

The final six semi-structured interviews were conducted at a customer site. A refined version of the research protocol describing the aim, objectives and questions to be covered was sent to the interviewees before the visit (see Appendix E). A sample of the questions used in the RP as well as the combined answers from all the participants in these interviews is presented here:

- What are the common causes for pump 1 failure?
- How could design be modified to reduce these failures?
- Is there any interaction between service and design or manufacturing? If yes, give examples.
- What design aspects of the pump 1 cause difficulty in service?

- The *common cause* of most pump 1 failures to date is the accumulation of process material. Sometimes the customers use the pumps in harsher processes than specified. When the pump fails, it needs to be removed and sent for repair. Various minor causes were also identified, including problems faced with the pump Ethernet interface, and faulty electrical connections.
- Product 1 has only three wheels, so all three wheels are in contact with the surface and according to one of the interviewees, this is better than having four wheels. However, other interviewees did not mention the lack of the fourth wheel as a design advantage of Product 1. A *design change* that was suggested during the interview was the reduction of the 'difficult' parts of the pump. However, it was not stated which parts are perceived to be the 'difficult' ones.

- It has been clear from the interviews that the project manager of the site and the operations site manager are the people that *contact the design* or manufacturing departments in the UK. Nevertheless, it has been mentioned that people from all over the world exchange knowledge and experience via e-mails or in face-to-face meetings. There are also forums, where everybody can have access, but mainly because of the time pressure, people cannot report all the problems. Lastly, if there are serious problems, they report them in ECAR (Electronic Corrective Active Request). Also, when a new product is launched, some of the service technicians go to Crawley (UK) to get trained.

The responses of the interviews to all the questions, which were included in the full RP (Appendix E), are presented in Appendix F.

The SK types identified and the service process models developed during the interviews were validated. In both cases the validation was conducted by phone due to the location of the participants. In each case the company service manager, based in the UK, participated in the session. The on-site service manager, based at the customer site in Germany, was asked to comment on the proposed SK types and some specific data captured in Germany. The validation document was sent in advance to allow preparation and discussion with the other participants (see Appendix G). During the validation session, regarding the SK types, some additions were proposed: on-site tooling as an extra type of tooling, mechanical problems as an additional cause of unplanned maintenance. Besides, it was said that the packaging can be wooden, paper or plastic boxes and that the reduction of cost and the continuous improvement of value-added features can be added to the service feature list.

The second validation session took place with the lead technician of the US service centre. The same process was followed in this case, i.e. the validation document was sent beforehand and the interviewers went through it with the interviewees so as to investigate whether the findings presented were representative of the scenario presented during the interviews (see Appendix H). In this case, there were some minor amendments suggested for the sequence of activities in the service, DCI (decontamination- clean- inspection), build, and test processes and explanations given when asked with regards to specific activities. As far as the SK structure and the service features (the latter are presented in detail in Chapter 6) are concerned, the interviewees did not suggest any changes or additions.

4.2.4 Validation of SK types at Company 3

Company 3 is a machine tool manufacturer. The researcher had the opportunity to get feedback on the knowledge types that had been identified after the collaboration with Company 1 and 2. The customer service manager and the service coordinator of the company were asked to comment on whether the SK types were comprehensive and useful to service and design personnel. The knowledge types presented to them are graphically illustrated in Figure 4.5:

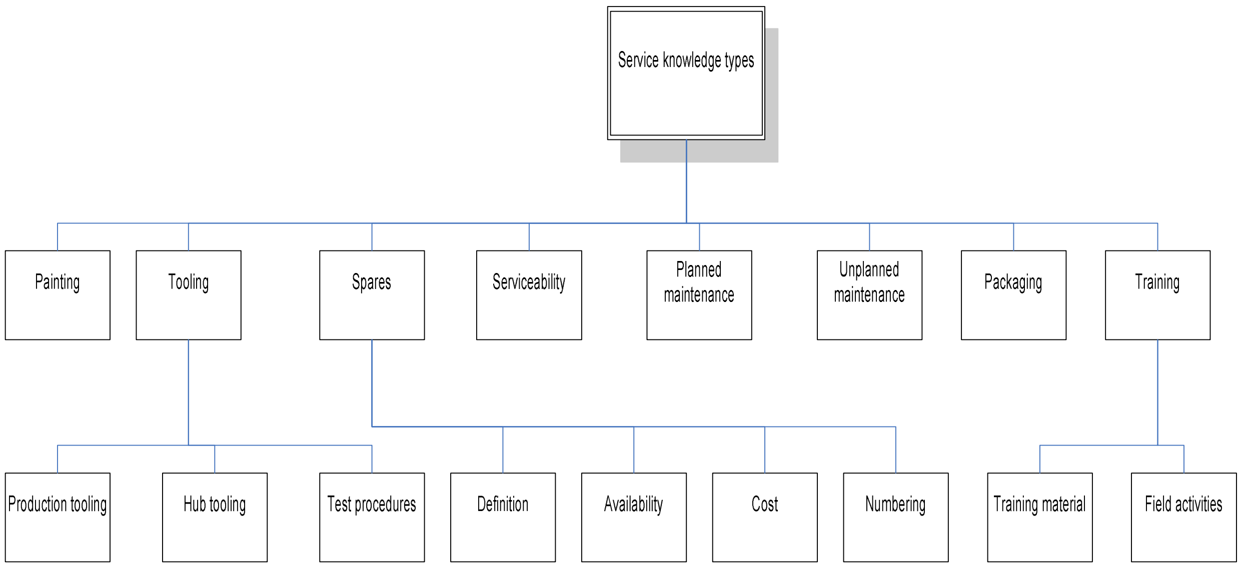

Figure 4.5: Initial service knowledge types (Source: Doultsinou et al., 2007)

The author took into account the comments of the participants and along with a further analysis of the previous results obtained from Company 1 and 2 proceeded to the enrichment of the knowledge types. The finalised version of the service knowledge types is shown in Figure 4.6.

4.2.5 Description of the service knowledge types

Product type- it is divided based on the aspects of the product, which are relevant to service and need to be accessed by the designers. These are:

- ***Product attributes***- they include painting, packaging, maintainability, serviceability, and password protection. Specifically, painting is an issue for service, as service centres need to have painting centres and this brings in more activities for them. Packaging is regional and it depends on the customer requirements. Remanufactured products get new packaging. Serviceability can be defined as 'the adequate fulfilment of a product's function' (Oxford dictionary website, 2007) quality of 'being able to provide good service'.

The aim is to cut down service time and labour and as a result to reduce maintenance and overall operating costs (Drickhamer, 2005). Password protection was an important attribute within Company 1 and 3, because some settings of the remote monitoring software should not be re-adjusted by the customer; therefore, it is protected by a password.

- ***Subsystems***- these are the various systems that the product is comprised of (e.g. pump cartridge, control system, drive system, cooling system, electrical system, gas system, body). Subsystems are made up of ***components.*** As far as the components are concerned, the knowledge types related to them are: component ID, recyclability of the components, difference between actual and expected life, and issues faced.

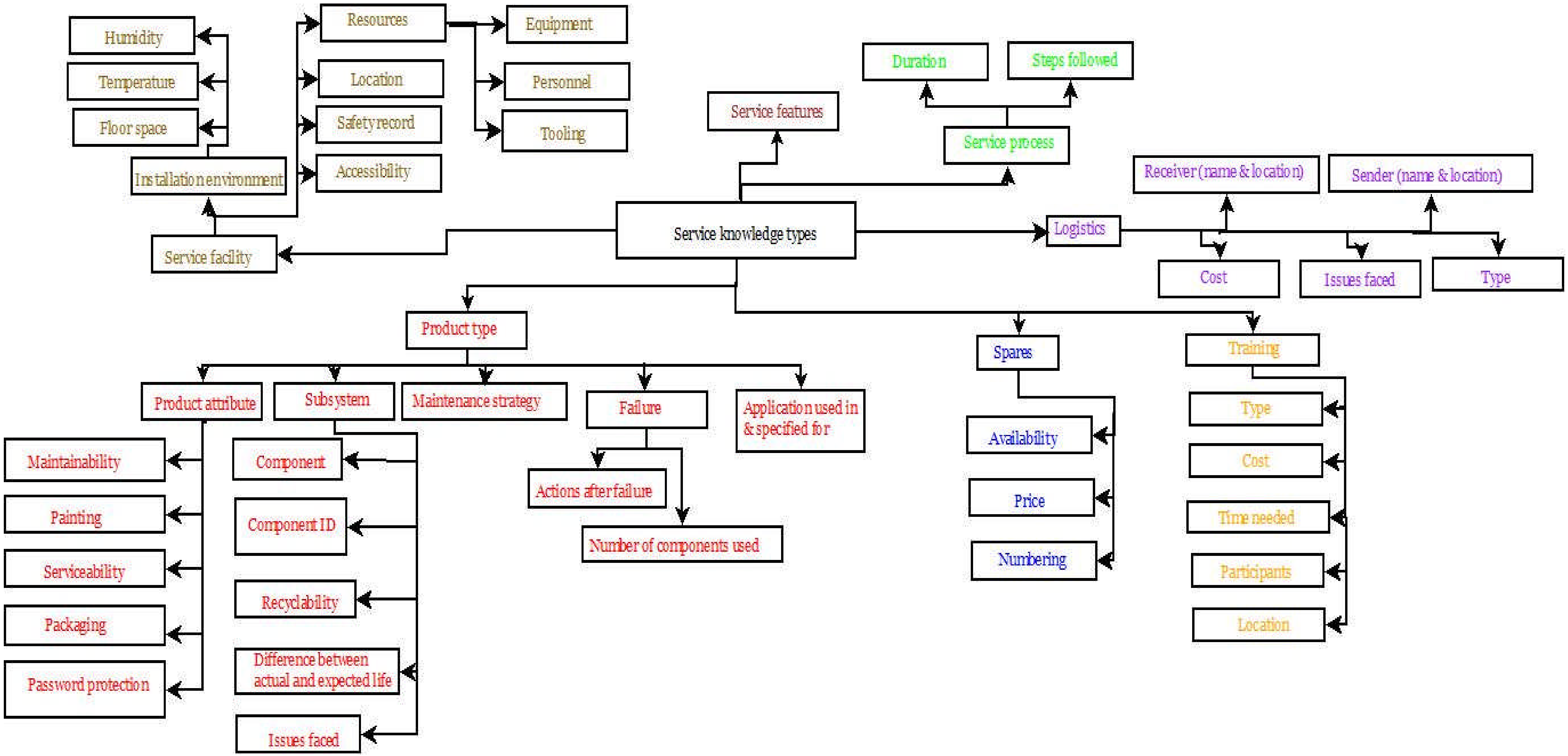

Figure 4.6: Final service knowledge types

- ***Maintenance strategy***- Planned and unplanned maintenance are the two major types of maintenance strategy within the collaborating organisations. Planned maintenance is designed to facilitate rapid and safe execution of all maintenance activities. The aforementioned activities are planned to be done after the specified period of the product's usage. Unplanned maintenance refers to the specific methods and targets (e.g. to respond to a customer problem within four hours, or to provide a replacement within 24 hours).
- ***Failure:*** a designer needs to know the actions that the service personnel took after the failure occurred and the components that were used for the resolution of the issue (captured examples are presented in Chapter 5).
- ***Application used in and specified for:*** Participants from Company 1 and 3 mentioned that it is crucial for the service personnel to know whether the product was used in an application that had been designed for before the occurrence of a failure. There were cases, where the customers used the products outside the specified guidelines; as a result, few of the components failed or the product stopped functioning. However, the failure was the outcome of the usage by the customer and not caused by a design defect.

Spares - Regarding spares, the knowledge types can be identified as spares availability, cost and numbering.

Training – It includes: type (e.g. theory course or hands-on experience), cost, time needed, participants, and the location where it takes place.

Logistics – It is an important element of service since the products need to be shipped to the service centres and returned to the customer's site. For this reason, it is important to specify the type, cost, issues faced during the transportation of the product, the name and location of the sender and the receiver.

Service process- Describes the various processes involved in the service of the product. Examples of captured processes are: 'on-site service processes' (which includes installation, swap out and removal), and ‘service facility service processes’ (e.g. receipt, cleaning, disassembly, inspection, build, test). Additionally, the steps followed and the duration of each service process were mentioned by the experts as characteristics of a service process. Service process documents, (e.g. procedure documents, health and safety forms) issued by the companies, also include service knowledge, which is used by the service personnel.

Service features- They are attributes of service that deliver value to the customer (they will be further explained in Chapter 6).

Service facility- this knowledge type includes the description of the installation environment of the product (floor space required, temperature, and humidity). Other aspects taken into account include the accessibility of the products, the safety record, the location of the service facility, and the resources of it. The resources can be classified into equipment, personnel (e.g. service technicians, service manager, and manufacturing engineers), and tooling. The service tooling is usually different to the production tooling.

In general, the experts at Company 3 thought that the structure can be applied to their organisation too, despite the fact that it had been developed from case studies in Company 1. They found the terms used to describe the knowledge types generalisable and applicable to their industrial sector (machine tool manufacturing). As a result, the author proceeded to the next step: SK representation.

4.3 Service Knowledge Representation

After the initial categorisation of service knowledge, the use of ontology to fully represent the service knowledge was considered. During the last few years the development of ontologies – explicit formal specifications of the terms in the domain and relations among them (Gruber 1993)–has been moving from the area of artificial intelligence laboratories to the desktops of domain experts. An ontology outlines a common vocabulary for researchers who want to share information in a domain. It consists of machine-interpretable definitions of basic concepts in the domain and relations among them. The decision of using an ontology was made due to its ability to represent concepts of a domain at the level of detail defined by the researcher along with defining the relationships among them. This was essential for this research. It should also be taken into account that the ontology was used as the common platform for the representation of service, design and manufacturing knowledge within the context of the 'U-KNOW' project.

The validated service knowledge types (presented in Figure 4.6) provided the basis for the development of a service ontology. The ontology was developed using the Protégé knowledge base editor software (Noy and McGuinness, 2001). The initial version was presented to designers at Company 1 for initial feedback: they were invited to comment on the structure and how well it might support them in their roles. Semi-structured interviews were carried out with three designers. This validation exercise also highlighted design tasks and scenarios in which service knowledge can be applied to improve product design. The findings of the investigation, including the role of service knowledge design and the proposed service ontology, are presented in the following Sections.

4.3.1 Reasons for using ontology, and steps followed

Noy and McGuinness (2001) state the following reasons for using ontology:

- To share common understanding of the structure of information among people or software agents
- To facilitate reuse of domain knowledge
- To make domain assumptions explicit
- To disconnect domain knowledge from the operational knowledge
- To explore domain knowledge.

The main reasons for the usage of ontology in this research are the sharing of information among people (enable designers to access service knowledge) and the re-use of service knowledge (service personnel can re-use the knowledge captured in past projects).

The artificial intelligence literature embraces various definitions of ontology; many of these oppose one another. For the purposes of this paper an **ontology** is ‘a formal description of concepts in a domain’. These concepts are described by **classes**. The properties of those classes, describing the various features and attributes of the concept are called **slots**. An ontology along with a set of individual **instances** of classes forms a **knowledge base**. There is a blurred line where the ontology finishes and the knowledge base starts (Noy and McGuinness, 2001).

The steps followed for the service knowledge ontology are described below. The steps followed by the author are in accordance with Ontology 101 (Noy and McGuinness, 2001).

Step 1. Determine the domain and scope of the ontology

What is the domain?

- Service knowledge in manufacturing domain

What can it be used for?

- Planning the service activities
- Planning service in NPD
- Improving the product design by the use of specific service knowledge.

What questions should the ontology answer?

- Which are the main failures for each product type?
- What types of tooling are used for the maintenance of the products?

- Which are the common strategies for planned maintenance?
- Which are the common failure causes for unplanned maintenance?
- What are the important factors for effective training?

Who will use and maintain it?

- It will be used by members of the NPD team, designers and service personnel
- It will be populated by service people
- It will be maintained by IT people

Step 2. Consider reusing existing ontologies

Ontologies describing service knowledge related to service provision within a manufacturing setting were not found.

Step 3. Define the classes and the class hierarchy

The service knowledge types were rearranged so that they fit the ontology structure. Some of them were combined and a higher level of detail was represented in the context of the ontology. An 'operation' subclass was created in the ontology, which does not exist as a service knowledge type, and includes operation methods, running times and failure types.

Overall, two main classes were considered: 'product' (Figure 4.7) and 'service organisation' (Figure 4.8), which consist of more detailed subclasses.

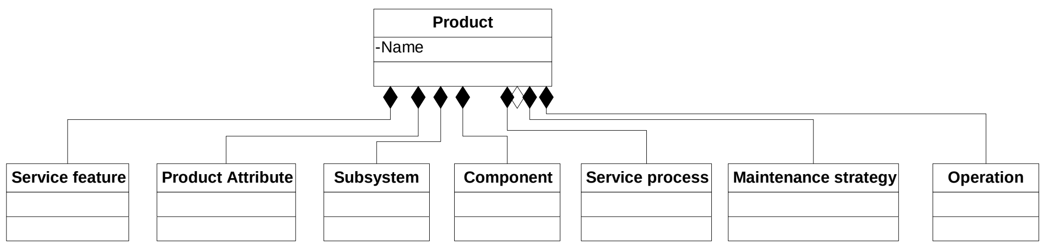

Figure 4.7: 'Product' class structure (Source: Doultsinou et al., 2009)

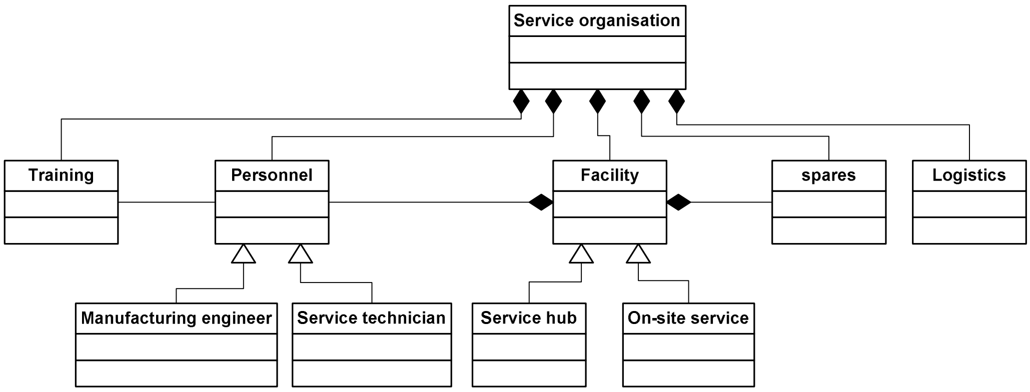

Figure 4.8: 'Service organisation' class structure (Source: Doultsinou et al., 2009)

Step 4. Define the properties of classes – slots

For each of the classes and subclasses, slots were created. The slot of a class is inherited by the subclass. The screenshot (Figure 4.9) illustrates the slots of the 'product' class:

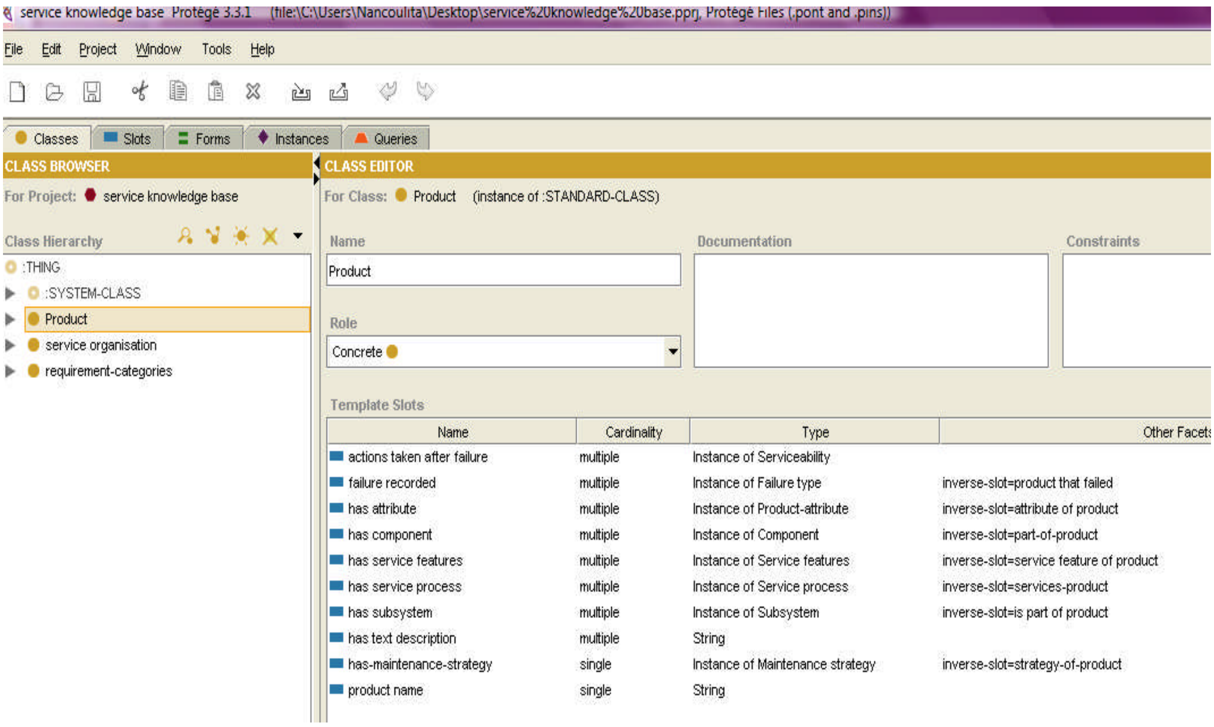

Figure 4.9: Slots of the 'product' class

Step 5. Create instances

Instances are created regarding the knowledge captured in one of the two products studied for demonstration purposes, and also the service processes (build, disassemble, clean, inspect and test) are represented in the knowledge base. The instances built in the ontology do not aim at being filled out by service engineers; their aim of existence is to show few examples of SK types. The reason for the creation of this service ontology was the SK representation. However, if desired, the ontology can be populated with service information (hence become a knowledge base) and then can be used to plan the service activities, plan service at the NPD stage, and finally to improve the product design by the use of specific service knowledge. Therefore, the population of the ontology with service information serves as the storage of service knowledge.

A screenshot of the ontology illustrating an instance can be seen in Figure 4.10. The base classes and a small selection of the subclasses are shown. The product name is not shown due to confidentiality reasons.

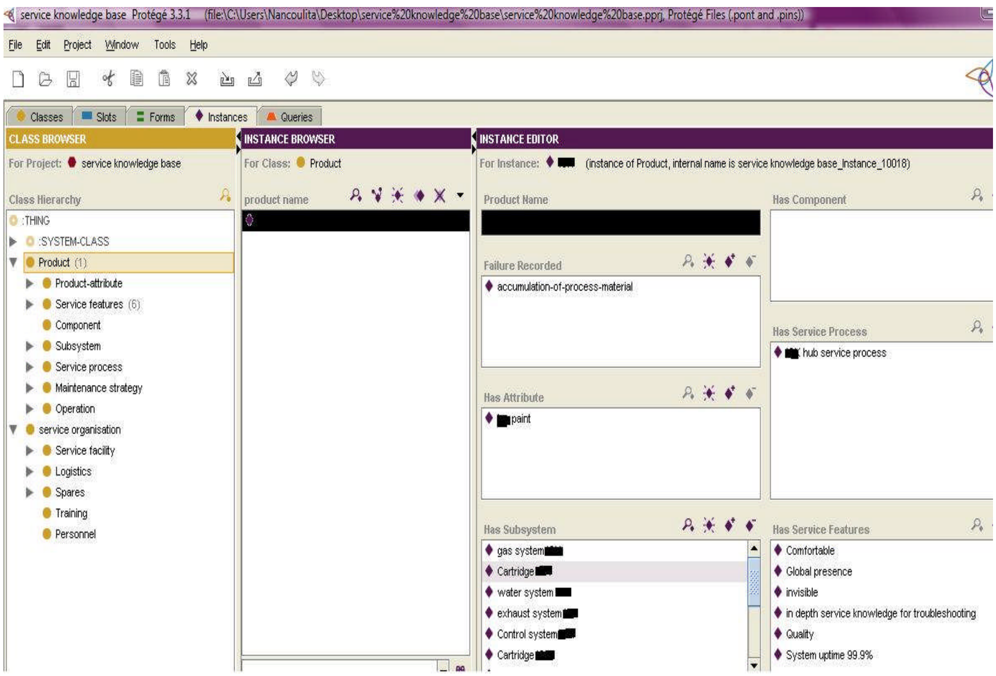

Figure 4.10: Service ontology instance screenshot

4.3.2 Location of service knowledge in the ontology

As mentioned in the previous Sections, the service ontology was created in order for the SK types to be represented. At the first stages of knowledge capture the author had drawn quite simplistic diagrams of SK; however, since a significant level of detail was present at later stages, the ontology was used. For this reason, it was necessary that the ontology was derived from the same SK types. Table 4.5 is an illustration of the location of the SK types within the ontology.

Service knowledge type	**Location in the ontology**
Product type	Slightly changed- represented as 'product name' (product slot)
Product attribute	As a subclass of 'product'
Maintainability, painting, packaging, serviceability	As subclasses of 'product attribute'
Password protection	*Not represented in the ontology*
Subsystem, component	As subclasses of 'product'
Component ID, difference between actual and expected life	*Not represented in the ontology*
Recyclability	As a slot of 'component' (can be recycled)
Maintenance strategy	As subclass of 'product'
Failure	As subclass of 'operation'
Actions after failure, number of components used	As a slot of 'failure type'
Application used in & specified for	As a slot of 'failure type'

Spares	As subclass of 'service organisation'
Spares' availability, price, numbering	As slots of 'spares' (availability, cost, ID)
Training	As subclass of 'service organisation'
Training type, cost, time needed, participants, location	Slots in the ontology: cost, delivery method, skills of people involved, time needed, training material
Logistics	As subclass of 'service organisation'
Logistics' type, cost, issues faced, sender and receiver	Slots in the ontology: name, sender, receiver, feedback from shipping
Service process	As subclass of 'service organisation'
Service process (steps followed and duration)	Service activity as a slot of 'service process'
Service features	As a subclass of 'product'
Service facility	As a subclass of 'service organisation'
Installation environment	As a subclass of 'service facility'
Floor space, humidity, temperature, accessibility	As subclasses of 'installation environment'
Safety record	*Not represented in the ontology*
Resources (equipment, personnel)	Subclasses of 'installation environment': utilities,

	human resources needed
Resources (tooling)	Subclass of 'service equipment'

Table 4.5: Mapping SK types to elements of the ontology

As it can be seen in Table 4.5, some elements that are part of the service knowledge types were not represented in the ontology. These are: *password protection, component ID, difference between actual and expected life,* and *safety record.* This happened due to two reasons: 1) additions to the knowledge types were made after the final validation of the ontology; thus, not incorporated in it, 2) some of these elements were later included in the common ontology (service, design and manufacturing) developed for the 'U-KNOW' project.

4.4 Validation of the ontology at Company 1 and 4

This Section describes the validation of the final version of the ontology. The author conducted it with the collaboration of Company 1 and 4. Company 4 belongs to the aerospace sector and participated in the validation of the ontology, and also at further stages of this research. In both cases, the validation took place through a workshop, which lasted two hours. A scenario was described, and in each case a demonstration was given to indicate the operations required to access the system and the system content. In each case, the participants were asked to rate the utility of the system on a scale of 0-5, with 0 representing no value and 5 representing very high value.

The questions asked were:

- Could you rate how useful the system is going to be for your organisation (facilitation of the access to service knowledge)?
- Any implementation issues?
- Is the system comprehensive?

The first validation session was held at Company 1, lasted for two hours and as mentioned before, it was a workshop. The participants were:

Participants	Years of experience
Manufacturing technologist	14
Service Product Manager	15
Senior CAD designer	19

Table 4.6: Participants in workshop at Company 1

The workshop started with the author giving a short presentation about the research and the achievements until that stage. During the presentation, a scenario of usage for the service ontology was described. The scenario used to develop and validate the service knowledge structure was taken from a service facing perspective. Four scenarios were considered during the development of the ontology: service feedback to design; ramping up the service activity after the product has been in the field for 12 months; on-site product monitoring within an availability contract; and implementing a new product into the service operation. The last scenario was described and validated in the session.

An outline process model describing the service implementation scenario is shown in Figure 4.11.

The first activity is linked to the product description. Inputs from the knowledge framework include the 'product architecture' class (BOM, modules) and inputs from the 'resource' class (e.g. drawing). The product description probably, in practice, represents a family of products with numerous variants.

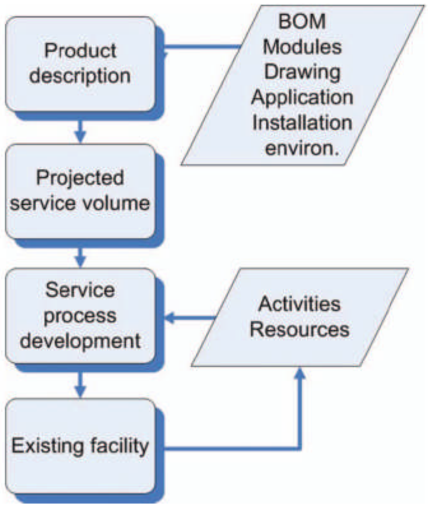

Figure 4.11: Knowledge requirements of the service implementation scenario (Source: Baxter et al., 2009)

A further critical element is the anticipated customer application, defined using the 'installation environment' class. This includes references to resources including equipment and personnel. The product size and application type dictate the requirements for floor space and chemical treatment facilities. A template service (disassembly and rebuild) process is part of the product release documentation. In Figure 4.11 this is supported by the two classes: 'activities' and 'resources'. This process will have been evaluated by service personnel at the prototype stage. In tandem with the projected volume, this input is applied to the development of the service process. Activities and resources (personnel, information, tooling) required by the process are compared against the existing facility. Tooling, training, and test procedures are developed according to the existing facility, in line with the volume of products expected. A low volume of products, say between 1 and 5 per week, can be serviced with the use of generalist tooling in a flexible workshop, carried out by personnel with a varied and wide ranging expertise. A medium volume of products, say between 10 and 50 per week, may warrant some specialist service bays and a division of the various activities (e.g. receive, disassemble, clean, inspect, rebuild, test). A higher volume of products may warrant further division of these activities and the application of flow line design principles. The description of this scenario identified that the knowledge requirements for the service implementation activity are supported by the knowledge structure. At a detailed level, the author's ontology does not encompass customer applications (installation environment), BOM, or product modules thoroughly (Baxter et al., 2009). Activities and resources for service process development can be described in detail, as shown in Figure 4.12.

After the presentation of the scenario, the three participants from Company 1 were asked to evaluate its usefulness on a scale of 0-5 (0: no improvement to the current process, 5: major improvement). The results were:

1. Major improvement (5)
2. Major improvement to a NPD process (4-5)
3. Major improvement (4)

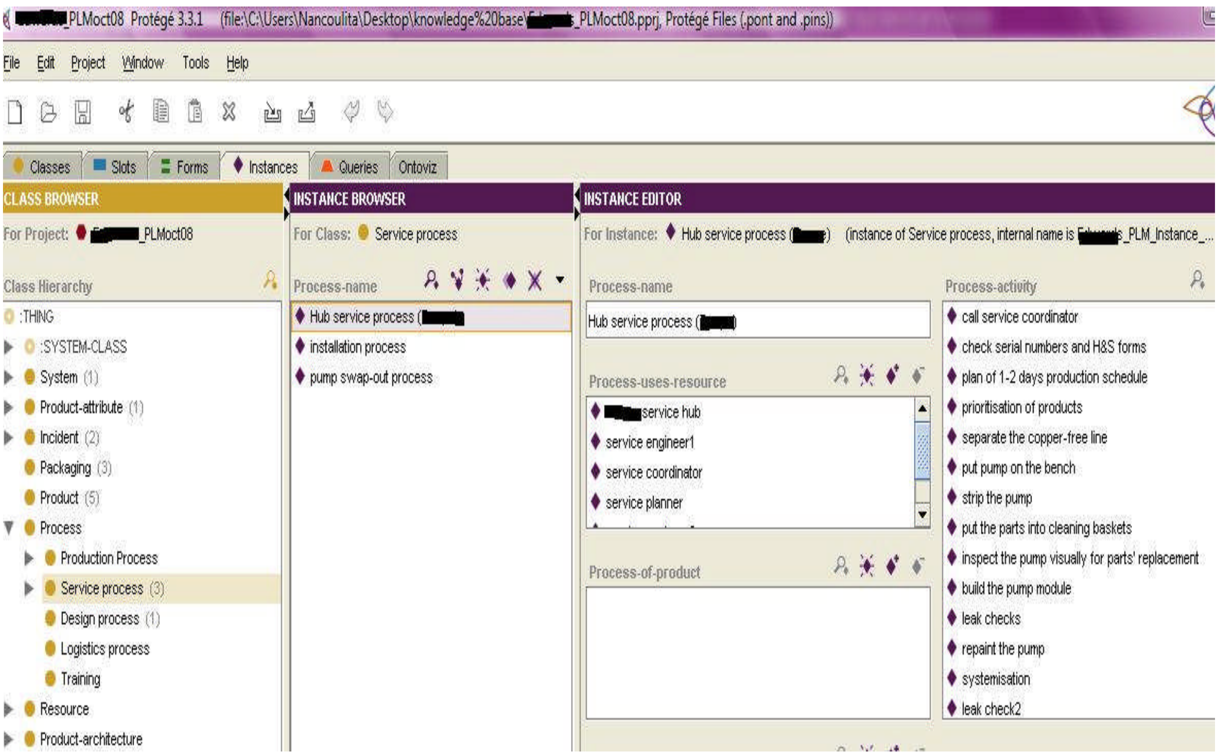

Figure 4.12: Partial service process represented in the ontology

The manufacturing technologist stated: '*I am really impressed by the development of the ontology- it captures most aspects of service knowledge*'. In addition to this, the service product manager said: *'The ontology is useful, can be used to capture service knowledge used in practice, designers can access it, but how do we engage people? Who is going to be responsible for its population with data and the updates?'*

Therefore, it can be concluded that the ontology has been perceived as useful within Company 1; the only drawback mentioned was the challenge of engaging the appropriate personnel and convincing them to fill in the required fields.

The second validation session was held at Company 4, which lasted for two hours and as mentioned before, it was a workshop. The participants were:

Participants	**Years of experience**
Process Development Manager	19
Services Capability Development Manager	18

Table 4.7: Participants in workshop at Company 4

The same process was followed during this workshop (same questions addressed to the participants) and the same ranking was used for the evaluation of the ontology. The results were:

1. Average improvement (3)
2. Major improvement (4)

According to the participants at Company 4, the ontology developed by the author represents the essential SK types at a great level of detail. Thus, it can improve the current situation within the NPD team quite significantly. However, the recording of service issues can be a challenge; this seems to be a common issue in Company 1 and 4. All the participants mentioned that their service personnel have to meet very tight deadlines and keep the customer satisfied; therefore, their top priority is the provision of timely response and solutions to customer issues. As a result, they can often complain that there are time constraints regarding the filling out of the necessary forms/fields when planned and/or unplanned maintenance occur. More precisely, the process development manager stated: *'A system like this definitely improves the recording and re-use of knowledge, but am not sure that the service and design personnel will be willing to familiarise themselves with it'*. The Services capability development manager said: '*The aspects of service knowledge captured in the ontology are fundamentally important*'.

4.5 Summary and Key Observations

This Chapter aimed at presenting the path followed by the author in order to capture the knowledge types that are required by service personnel within manufacturing companies in the execution of their activities, and then represent them in a way that can be re-used by them and designers to support product design.

Section 4.1 gave a definition of SK based on the particular research context. Section 4.2 described the SK capture process, which was illustrated in Figure 4.1, and was conducted in collaboration with three UK manufacturing companies. Company 1 was the main collaborator; the case study with them was split into 3 main parts:

1. The first part was exploratory, and
2. The second and third parts were arranged according to the types of service provision within Company 1 (service centre and on-site servicing).

The author studied in detail two company products and for these, service issues were identified, their frequency of occurrence was calculated according to the times that each issue had been mentioned by the interviewees, reasons for the differences spotted among the frequencies were explored, and finally variables affecting the service issues were discovered. The case study involved people from service, design, and NPD teams, since there is a great importance of depicting different perspectives in order for the overall research aim to be attained. Company 2 also collaborated at this stage, which it operates in a different sector from Company 1 (Company 1 operates in pump manufacturing; whereas, Company 2 in the aerospace sector); thus, its cooperation was needed in order for commonalities and differences between the two sectors to be recognised. Finally, the validation of the SK structure at Company 3 and the other two aforementioned companies was presented in Section 4.2.

Section 4.3 was related to SK representation by means of Ontology 101. The reason for choosing the ontology, the steps followed, and the main structure were explained in this Section. Also, the author recognised the necessity of the exact transfer of the SK types to the ontology so that any possible mismatch is avoided.

Section 4.4 described the validation workshops, which took place at Companies 1 and 4 and lasted two hours each. The final structure of the developed ontology was presented to the participants and the general feedback was positive. The main challenge, highlighted by both companies, was the effort that needs to be made in order to engage the necessary employees to fill in the appropriate fields so that knowledge can be re-used.

The next Chapter describes the service involvement at the first stage of the design: the conceptual design stage. The author makes an attempt to map design requirements with SK types, and develop tools to enable designers to access the relevant service knowledge.

5 Service involvement at the conceptual design stage

5.1 Introduction

Chapter 4 presented the process of capturing and representing service knowledge within a manufacturing context. The concept of SK was defined with regards to this piece of research and the path that the author followed in order to capture, validate, and then represent these knowledge types using an ontology was described.

This Chapter describes the role of SK in design, focusing on the application of service knowledge in the conceptual design stage; in particular, the development and validation of a tool to support designers in incorporating service knowledge at the conceptual design stage are presented. An objective of this research is to identify the means by which SK can enhance the design of a product. In the examined industrial cases, it seems that there is not an adequate mechanism of interaction and feedback between the design and service groups in place at the moment. However, it is encouraging that both groups recognise the need for cooperation and the positive effect of such collaboration on the product's final performance.

A number of companies participated at this stage of the research; one provided service knowledge in detail, two gave an overview of their service/design interactions, and a fourth gave feedback on the proposed tool. Past service issues were identified in Company 1, the way in which these have been taken into account by the designers, the development of requirements, along with the validation of the knowledge audit tool that the author developed. Company 2 and 3 were marginally involved at this stage of research confirming the finding that there is a lack of communication between service engineers and designers. Company 4 participated in the validation of the knowledge audit tool; finally, an independent consultant collaborated for the validation of the aforementioned tool.

5.1.1 Methodology followed

This Section gives an overall description of the methodology followed for the exploration of the ways in which SK can be used at the conceptual design stage (see Figure 5.1). The author identified the service issues that were faced in the past for Product 1 and 2 using the findings of the case study conducted in Company 1. A detailed description of the case study was given in Chapter 4; the participants and their job roles were presented in Table 4.1, and the products studied were introduced in Section 4.2.1. Since at the conceptual design stage the designers deal with a set of requirements, the author developed a generic list of requirements based on literature and industrial findings (Company 1 documentation). Having confirmed the limited communication existing between the design and service teams from Company 1, 2, and 3, the author, in order to enhance the current communication, proceeded towards the development of the SK audit tool. The tool maps the generic design requirements with the SK types, as captured in the case studies. Following the development stage, three validation sessions took place with experts from Company 1, 4, and an independent consultant (details of the participants are presented in Section 5.5.3).

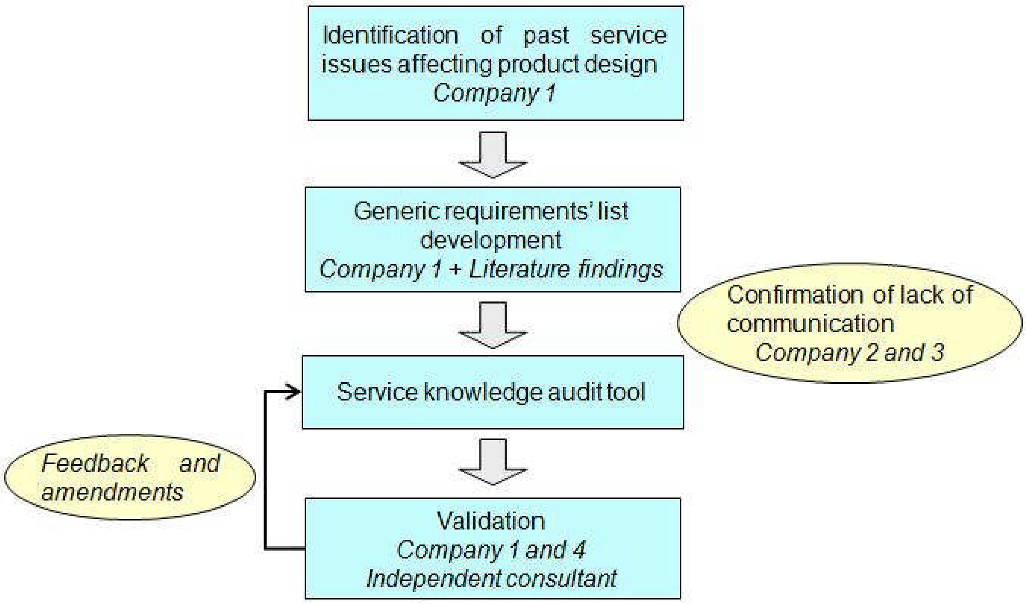

Figure 5.1: Methodology at the conceptual design stage

5.2 Past issues affecting product design

This Section presents issues that occurred during the operational and service phases of product 1 and 2 (Company 1) and the actions taken (if any) after these issues have been recognised. The raison d'être of mentioning past issues is to prove that the cooperation between service engineers and designers is a vital factor that can affect the design of existing, and mostly future products. Having studied past malfunctions and/or failures of a product can enable the design team to create better performing products, which satisfy closely the customer needs (The details of the participants were presented in Table 4.1 and the methodology followed can be found in Section 4.1).

In Company 1 it was mentioned that several informal brainstorming sessions were held at the conceptual design stage of the product to enable service requirements to be captured and service problems that have been faced in the past to be pointed out. However, there is not an established way, in which the designers can access SK at Company 1. In the course of the case study, some issues faced in the past with regards to the selected products from Company 1 were mentioned, such as that the electrical connectors were easily damaged on the field and they had to change the particular type of connectors; also, some faulty contacts were observed between the wires, several valves were getting hotter than anticipated, and finally some problems with accessibility to the pump modules. The fact that these problems were mentioned would directly lead the designers to some modifications in the design of a new product in order to avoid similar issues with the new product.

Following that, the designers mentioned various other aspects, which were related to service and were taken into account during the design process. Firstly, product 1 was relatively small and compact; as a result, accessibility to its modules was an issue bearing in mind that when the pumps are installed at the customer's site, a gap is left between them to make the sides accessible too. In this example, service knowledge regarding the accessibility of particular modules and the installation environment of the pump is needed. Secondly, when this pump was designed each subsystem had to be studied separately after the trial assembly was done and several problems were identified. So, each subsystem and possible interactions among all of them should have been studied at an earlier design stage. Thirdly, it has been stated that some of the components are very small and should be handled with care by the service people; but, this does not happen all the time. Therefore, it is crucial for the designers to receive the feedback of the service personnel on the easiness and risk in the use of all pump components.

Another example, where service knowledge can be applied in the design of the product, is the issue of long disassembly time due to the high number of water pipes. This issue is directly related to the 'serviceability' knowledge type and it can be recorded in the ontology by the service engineers. Moreover, it relates to the 'subsystem issues faced' (i.e. water system) and the 'actions taken' knowledge types, where again the issue and the actions taken to sort it out can be recorded by the service personnel and then accessed by the designers, since the latter need to take actions so that this serviceability issue is tackled.

In addition to this, the small size of the pumps was the reason for the discussion of ergonomics issues raised by the service engineers. Since the pumps were quite small and low, it was difficult for the personnel at the service centres to wheel them any distance across the customer site or the service facility, e.g. taking the replaced pump back to the service area following a swap-out. As a result, this specific series of pumps needed to be re-designed and a handle was added to them as an accessory in order for the pump transfer to be facilitated. This issue can be recorded in the ontology as an issue related to ergonomics in the 'incident' class, where as the instance is built there, the service engineers have to fill in fields, such as 'name of incident', 'actions taken after failure', 'incident-of-product', 'incident-of-module', 'additional notes'. The design team can have access to this issue recorded in the ontology and it can then be considered in the design of a next series of product.

Generally, the designers think that service knowledge regarding the installation environment will be very useful to them, since they do not have the resources- in terms of money and time- to visit the service centres or the customer sites. Also, failure types and their causes along with past changes in product design will help them to avoid repeating mistakes of the past.

Table 5.1 represents the most commonly faced issues in the pumps used for the case study. These were extracted from the series of interviews conducted within the collaborating Company 1. The interviewees (see Table 4.1) provided examples of product failures and/or issues they faced with Product 1 and 2. Each issue is generally categorised, then there is a detailed text description, along with the component/subsystem that is affected, and the actions taken after the issue was reported (see Table 5.1).

Issues faced (recorded in the corresponding knowledge type)	**Free text description**	**Related component/subsystem**	**Actions taken**
Subsystem	The number of the water lines was high; as a result, it was time-consuming and difficult for the service engineers to remove them during the pump disassembly	Water system	A change in water valves resulted in the reduction of the number of the water lines.
Manoeuvrability	The pump was small and low for the service personnel to move it around/ back pain reported.	Pump body	A handle was added as an accessory
Tooling	The size of the tool used to remove the shaft was too big; it couldn't even enter	Shaft removal tool	They had to re-design it.

	the pump.		
Serviceability	The silencer is a solid can; they cannot see inside to make sure that it is not contaminated.	Silencer	N/A

Table 5.1: Some of the issues faced in the case study pump (Adapted from Doultsinou et al., 2009)

5.3 Mapping between design requirements and service knowledge types

The author, after her extensive involvement with the industrial collaborators, recognised that one of the main factors hindering the cooperation between designers and service engineers during the NPD process is time pressure. Hence, the identification of a common focal point would facilitate their cooperation. Since conceptual designers work with design requirements, the author decided to focus on the mapping between design requirements and service knowledge types, in order to provide service knowledge in the most contextually relevant (relevant to the conceptual design) and most easily accessible way (related to a specific design activity, and so, easy to find and retrieve). In addition, a tool was developed that can help them identify the service knowledge needed for a specific design requirement, then check if this knowledge is available or not. This tool is presented in one of the following Sections and aims at saving time for the NPD team members, while enhancing their cooperation at the same time.

5.3.1 Development of a generic requirements list

This Section describes the process of developing a generic requirements list (see Figure 5.2).

The term requirement may refer to various types of requirements depending on the lifecycle stage and the engineering task presently being performed (Rios et al., 2006). Kontoya and Somerville (1998) define requirements as 'descriptions of how the system should behave, application domain information, constraints on the system's operation, or specifications of a system property or attribute. Sometimes they are constraints on the development process of the system'. Alexander and Stevens (2002) describe requirement as 'a statement of need, something that some class of user or other stakeholder wants' from a stakeholder-oriented point of view.

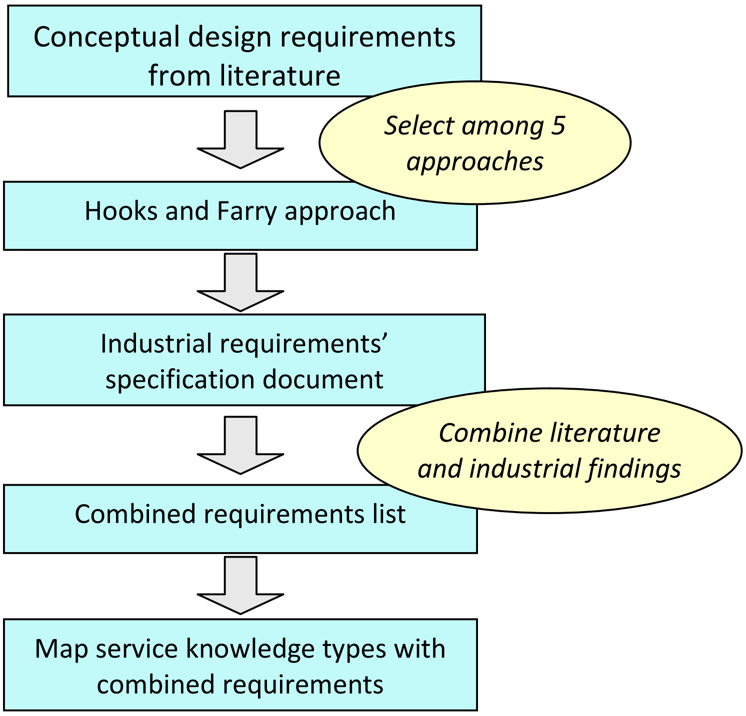

Figure 5.2: Procedure of selecting requirements and mapping with service knowledge

Within the scope of this research, requirements are specifications related to designers' needs as well as customer-oriented ones, since the author took into consideration the value that the customers receive from the service provision (Doultsinou et al., 2009). Five typical approaches were described by Rios et al. (2006). These include Hooks and Farry (2001), Kontoya and Somerville (1998), ECSS-E-10A (1996), Pahl and Beitz (1996), and Robertson and Robertson (1999). Rios et al (2006) suggest that the most appropriate approach for a manufacturing engineering environment is that proposed by Hooks and Farry. The list of Kontoya and Somerville does not include requirements, such as maintainability, serviceability, reuse and refurbishment, and disposability, which are important aspects of design from a service perspective. Also, ECSS-E-10A presented a short list of generic categories (e.g. functional, interfaces, environmental, etc.) without considering the servicing of the product. The list of Pahl and Beitz is quite comprehensive including maintenance and ergonomics; however, some of the requirements did not seem applicable in the research domain (i.e. forces, energy, signals, and schedules).; Finally, Robertson and Robertson did not consider logistics, test equipment, packaging, environmental conditions, re-use and refurbishment, and disposability as part of their list of requirements. The author, having taken into account the definition of requirements for this piece of research, and the content of each of the five requirements lists, selected the Hooks and Farry approach. The set of requirements proposed by Hooks and Farry is shown in Table 5.2.

Hooks and Farry design requirements
Functional and performance
Physical
Environmental conditions and survivability
Reliability
Maintainability
Availability
Serviceability
Transportability and mobility
Logistic
Usability (human operability)

Security
Reuse and refurbishment
Safety
Testability
Electromagnetic interference
Materials, processes and parts use
Labeling
Design
Interchangeability
Workmanship
Manufacturing cost and affordability
Producibility
Disposability
Packing
Support (manufacturing, test and use) equipment and facility

Table 5.2: Hooks and Farry design requirements (Source: Rios et al., 2006)

Having identified a set of requirements from the literature, the next step was to make a comparison with the requirements applied by the case study in Company 1. The requirements (as found in the Requirements' Specification document of Company 1) are presented in Table 5.3.

Company 1 design requirements
Financial/marketing
Functional requirements
Physical requirements
Interface requirements
System quality
Standards
Scope of supply
Territorial
Verification and testing
Production requirements
Installation and service

Table 5.3: Requirements' categories applied by the case study Company 1

Table 5.3 represents the top level categories of requirements applied by the case study company 1. The final step was the combination of the industrial requirements (Table 5.3) and the ones found in the literature (Table 5.2) in order for the author to create a list of design requirements that suits better the application domain (see Table 5.4).

Table 5.4 represents the combined product requirements for the conceptual design stage as an outcome of the literature, and the industrial findings. These requirements are compared against the service knowledge, as identified in the case study within Company 1 (see Table 5.5).

Combined design requirements
Functional and performance
Physical
Materials, applications and parts use
Interface requirements
Ergonomics and usability
Logistics
Test equipment
Packaging
Serviceability
Maintainability
Reliability
Safety
Security
Environmental conditions
Survivability
Re-use and refurbishment
Disposability

Table 5.4: Combined design requirements' list

The author suggests that the mapping presented in Table 5.5 can be used as guidance for the NPD team and that the connections should not be followed strictly. This provides the design and service personnel with flexibility in the mapping usage; they are enabled to customise it according to each project's specific requirements.

Combined requirements	Service knowledge types
Functional and performance	subsystem, component, product availability failure types
Physical: size, colour, styling	paint
Materials, applications and parts' use	service process (spare parts' use), maintenance strategy
Interface requirements	subsystem
Ergonomics + Usability	accessibility, tooling, training
Logistics	logistics (shipping)
Packaging	packaging
Serviceability	serviceability
Maintainability	maintainability
Availability	machine uptime, product failure record
Reliability	reliability
Safety	safety record / accidents / near misses
Security	Password protection
Environmental conditions	temperature, humidity
Survivability	Difference between actual and expected life
Reuse and refurbishment	component (reusability, yes or no), subsystem, service cost, spares
Disposability	packaging, component, subsystem (non-recyclable materials)

Table 5.5: Mapping design requirements and service knowledge types (Source: Doultsinou et al., 2009)

5.4 Knowledge base and design requirements

The following scenario (Doultsinou et al., 2009) shows how the knowledge base can be applied in conceptual design. The knowledge base was developed using the Protégé knowledge base editor tool according to the ontology presented in Chapter 4, along with the combined requirements as described in this Section. The knowledge base therefore supports two aspects of the conceptual design. First, it provides a view of the requirements which should be considered. Second, it enables designers to access previous examples of service knowledge associated with these requirements. The relationships defined by the ontology enable this to take place. For instance, where a designer selects a previously applied component, they will have access to the past record: a component description, failures or issues identified, recyclability, which product it belongs to etc. Figure 5.3 describes an example, using a 'water system' issue that has occurred and was recorded by service engineers. Some of the fields are intentionally obscured due to confidentiality issues.

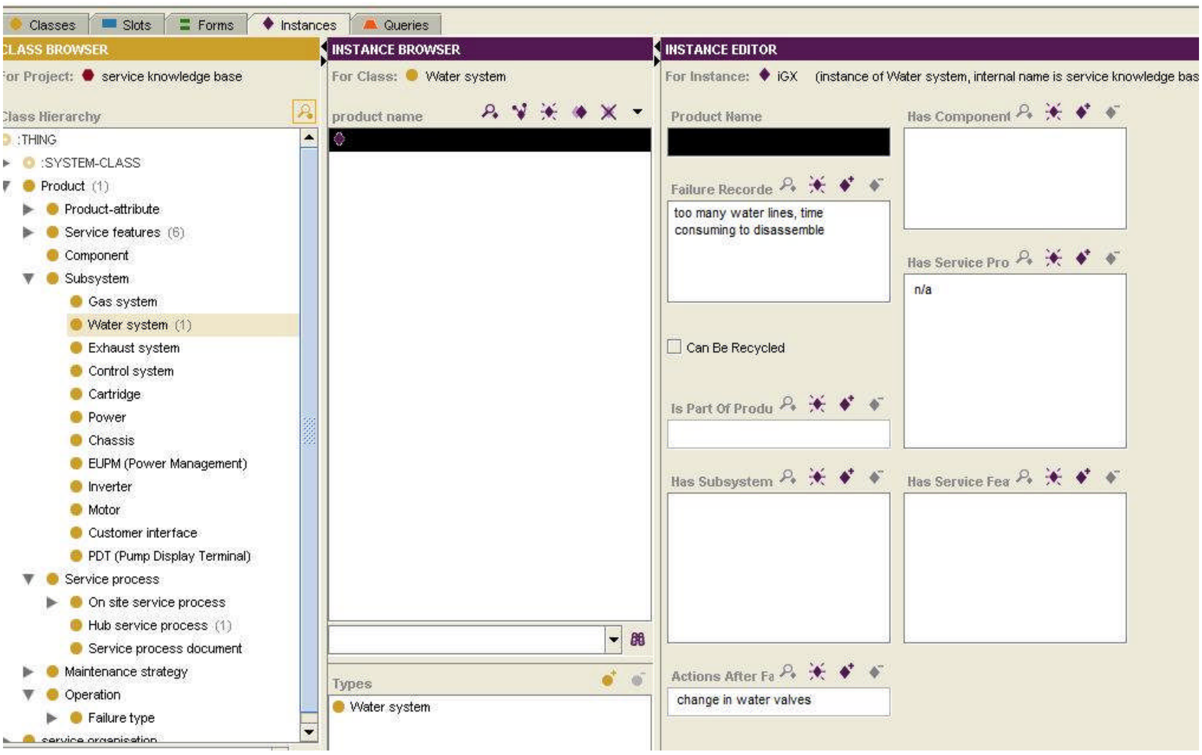

Figure 5.3: Knowledge base screenshot – water system issue

The designer then can access the knowledge base and identify easily all what he/she needs for a specific product subsystem from a service perspective. The example in the screenshot is provided for demonstration purposes only.

For each type of requirement there are SK types required by the people in conceptual design. Since the latter require a more detailed level in the knowledge needed, the researcher created knowledge templates, which consist of detailed elements for each service knowledge type. Some of these templates are implemented in the knowledge base using the 'slots' of the relevant classes. An example is shown in Figure 5.4.

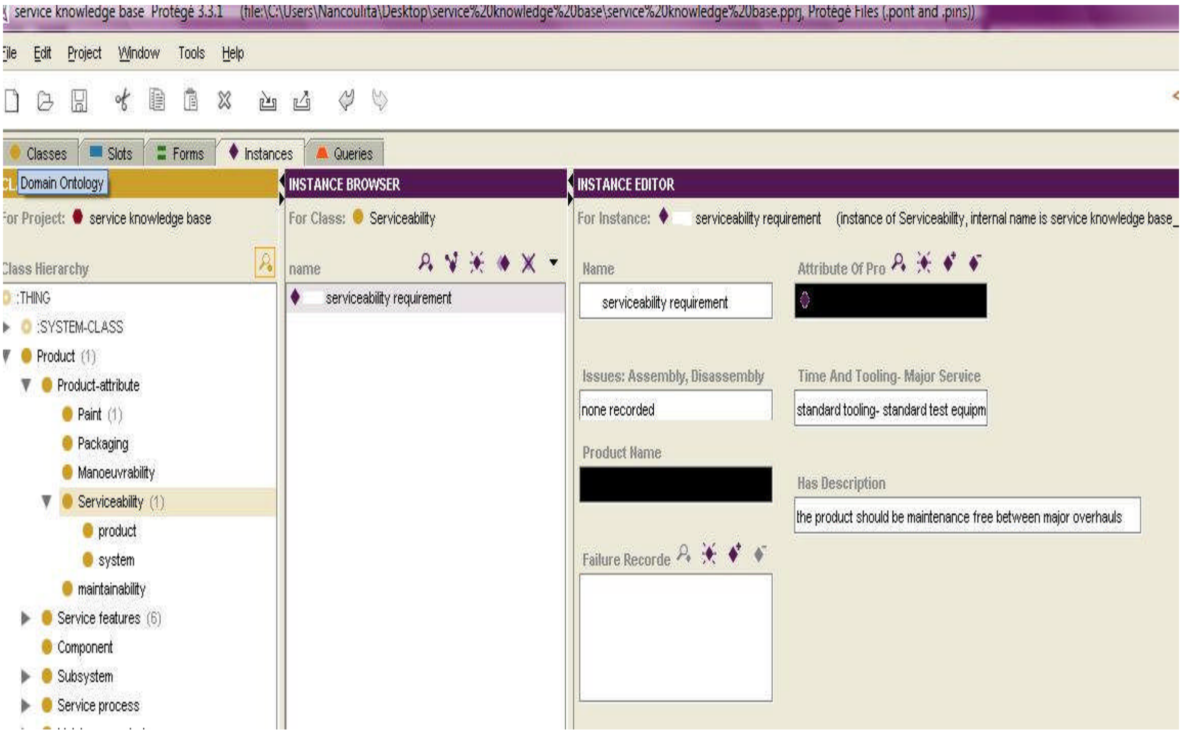

Figure 5.4: 'Serviceability' knowledge template

As suggested by the knowledge template, in the case of 'serviceability' as a requirement, the designers need to know issues faced with disassembly and reassembly, as well as the time required for the product or the product subsystem to be serviced and the special tooling (wherever needed).

Moreover, additional knowledge templates were developed by the author for the capture of service information. The templates are named: general info, issues faced, failure, installation environment, and application. The knowledge templates were created with the use of MS Excel in order to facilitate the process of data capture and recording by the service engineers. The ontology, which was developed in Protégé software, was not used by the service engineers for the completion of the templates. This happened due to two reasons: 1) They did not have the software installed within the Company, and 2) They were not familiar with the use of it.

The example shown here is the 'product failure' knowledge template. Product failures are perceived to be as one of the most important aspects which a designer needs to be aware of; therefore, the author decided to create detailed knowledge templates for enabling the service engineers to capture the failures in an easier and comprehensive manner. This data needs to be accessed and then thoroughly examined by the designers. An example is shown below (Table 5.6), where the left column illustrates the knowledge types that are related to a product failure, and the right column needs to be filled in by the service engineers each time that a failure occurs. All the knowledge templates, which are linked to product failure, can be found in Appendix I.

Knowledge types	**Instances**
Failure type (specify component or subsystem if possible) Actions taken after failure Number of components replaced Replaced component ID Recyclability of materials used	

Table 5.6: Failure knowledge template

Table 5.7 and Table 5.8 demonstrate two instances of real-life product failures, as completed by a service engineer at Company 1. The component ID cannot be disclosed due to confidentiality issues.

Knowledge types	**Instance1**
Failure type (specify component or subsystem if possible)	cannot restart pump after a 3912 alarm; doesn't reach the full speed
Actions taken after failure	swap elbow and check valve, they are nearly blocked
Number of components used	Check valve kit
Component ID	AXXX-XX-XXX
Recyclability of materials used	Yes, blocked parts cleaned locally

Table 5.7: Instance 1- product failure

Knowledge types	**Instance2**
Failure type (specify component or subsystem if possible)	Dry pump temperature high
Actions taken after failure	Check the cooling water system; identify blocked Bürkert water control valves; uninstall, cleaning and install the cooling water manifold and water control valves
Number of components used	
Component ID	unknown
Recyclability of materials used	unknown

Table 5.8: Instance 2- product failure

5.5 Service knowledge audit tool

After having mapped the design requirements and the SK types at the conceptual design stage, the author developed a SK audit tool, the aim of which is to assist the NPD team in identifying SK gaps within an organisation that are needed for the design requirements. The development process of the tool is shown in Figure 5.5.

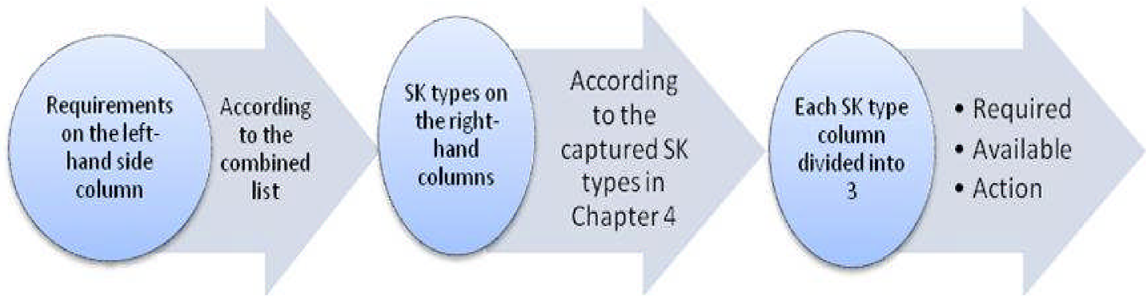

Figure 5.5: SK audit tool development process

The tool is comprised of a column (left-hand), which describes the design requirements, and also all the SK types are listed in the right-hand columns. Then, there are three columns underneath each of the SK types. The first one describes the strength of the relationship between the requirement and knowledge type (strong, loose, no relationship). The second one indicates the availability of the knowledge (high, medium, none), and finally the last column shows the action that needs to be taken by the NPD team.

5.5.1 Service knowledge audit tool use

The audit tool was developed by the author in an attempt to facilitate the NPD team to identify gaps in the SK that already exists within the organisation. Hence, it is intended that the users of the tool are the members of the NPD team; conceptual designers and service engineers.

The former (conceptual designers) need to check the list of the design requirements, make sure that it is appropriate for the project which they are involved in, and make any amendments if necessary. After having examined the requirements list, the conceptual designers must compare it against the SK types and define the relationships that exist between the two (strong, loose or no relationship). The service engineers have to define the degree of availability for the SK types that have been related to design requirements by the designers. The availability degree can be 2 (high), 1 (medium), and 0 (none). Then, the third column will automatically indicate the action that needs to be taken. If the relationship equals to 1 or 2 (loose or strong) and the availability of knowledge is 0 or 1 (none or medium), then extra knowledge is needed and the column will flash red; otherwise, the NPD team does not need to take any action (see Figure 5.7).

The use of the SK audit tool is displayed more clearly in the following flowchart (Figure 5.6).

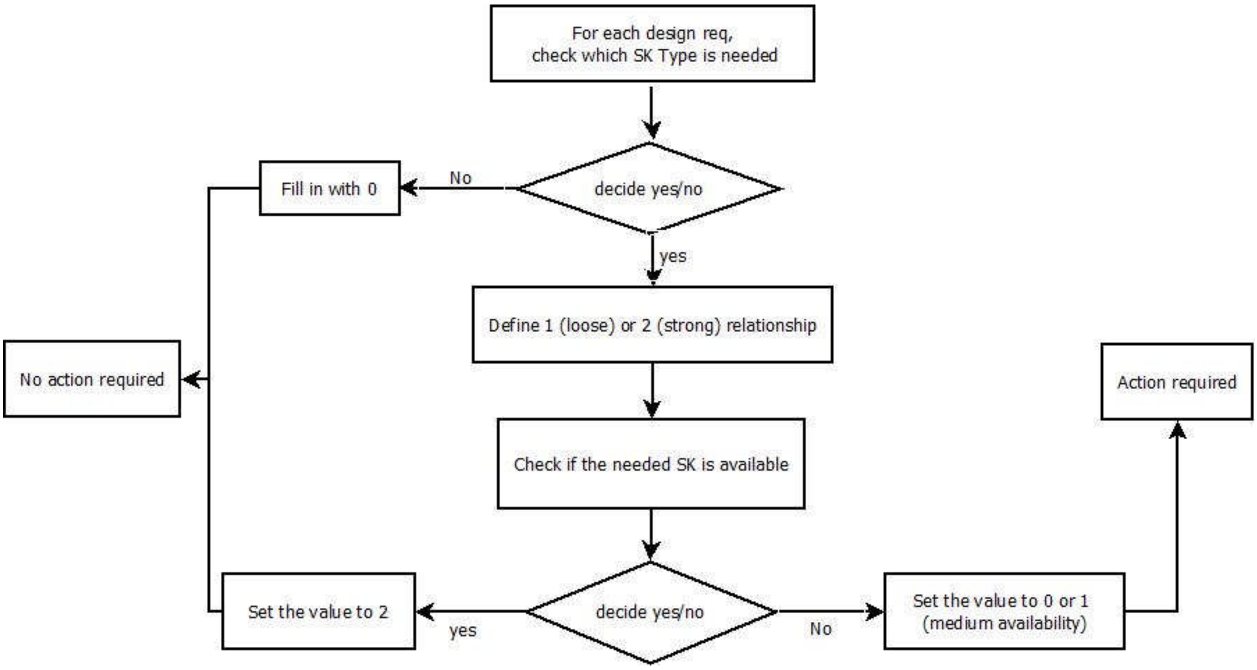

Figure 5.6: Use process of the SK audit tool

A screenshot of the SK audit tool is presented below (see Figure 5.7). The requirements- SK types' relationship has been defined in the relevant column ('req.' Column), and the availability of the knowledge has been indicated ('avail.' Column).

Finally, the action required is shown in the 'action' column, which is situated underneath the SK types.

Requirements/ service knowledge types	Product type			Issues faced		
	Req.	Avail.	Action	Req.	Avail.	Action
Functional and performance	0	1	OK	0	1	OK
Physical	1	1	Need knowledge	0	0	OK
Materials, applications and parts use	1	1	Need knowledge	0	0	OK
Interface requirements	2	1	Need knowledge	0	0	OK
Ergonomics and usability	1	1	Need knowledge	2	1	Need knowledge
Logistics	1	1	Need knowledge	2	1	Need knowledge
Test equipment	1	2	OK	0	0	OK
Packaging	1	2	OK	0	0	OK
Serviceability	0	2	OK	0	0	OK
Maintainability	0	2	OK	0	0	OK
Reliability	0	2	OK	2	1	Need knowledge
Safety	1	1	Need knowledge	1	2	OK
Security	2	1	Need knowledge	0	0	OK
Environmental conditions	0	2	OK	0	0	OK
Survivability	0	0	OK	0	0	OK
Re-use and refurbishment	1	0	Need knowledge	0	0	OK
Disposability	1	2	OK	0	0	OK
Competitor knowledge	2	1	Need knowledge	0	0	OK

Figure 5.7: Screenshot of the SK audit tool

In addition to the detection of the SK types that are not available, but necessary for the conduct of a project, the author suggests that the SK audit tool can be used for the operation of two supplementary functions. She added macros that will allow the users to extract the top 5 design requirements in terms of the frequency that the actions 'OK' and 'Need Knowledge' appear. The 'top 5 OK' button shows the five design requirements that have the most 'OKs'. The same can be done with the 'Top 5 NK' button on the SK audit tool; this will provide the user with the five requirements that have the most 'Need Knowledge' actions. It should be noted that 'Top 5' will often return more than 5 records due to the presence of joint values in the list. The users can identify (using the macro) the top 5 design requirements that have 'OK' or 'Need Knowledge' in two ways. Firstly, the majority of 'OK'/'Need Knowledge' can be summed up horizontally; thus, the frequency of 'OK'/'Need Knowledge' in all SK types is calculated. A screenshot- example is shown in Figure 5.8. Secondly, they can see the top 5 design requirements when the sum is the outcome of a vertical calculation (requirements with the majority of 'OK'/'Need Knowledge' per each SK type). Figure 5.9 illustrates a screenshot as an example.

Top 5 OK Top 5 NK Restore **Requirements/ service knowledge types**		
Description	Total OK	Total NK
Packaging	9	12
Security	9	12
Serviceability	8	13
Maintainability	8	13
Reliability	8	13
Environmental conditions	8	13

Figure 5.8: Screenshot- example for Top 5 'OK' and 'Need Knowledge' requirements' frequency (horizontal sum up)

Top 5 OK Top 5 NK Restore		
Description	**OK**	**NK**
Resources needed	17	1
Issues faced	15	3
Product type	9	9
Difference between actual and expected life	6	12
Training	6	12
Safety record	6	12

Figure 5.9: - example for Top 5 'OK' and 'Need Knowledge' requirements' frequency (vertical sum up)

5.5.2 Service knowledge audit tool expected benefits

This Section describes the expected benefits that the users of the SK audit tool will gain. Thus, it is anticipated that the tool will:

1. Ease the mapping between design requirements and service knowledge types.
2. Assist in assigning tasks to different team members to retrieve the stored knowledge or simply store the required knowledge.
3. Improve the communication between designers and service engineers during the NPD process.
4. Give an overview of the product regarding its own requirements, and
5. Provide a quick overview of a competitor's similar product, since the list of design requirements encompasses 'competitor knowledge' from a service perspective.

5.5.3 Tool validation

A validation of the SK audit tool was needed so that the author would be enabled to carry on with the next steps of this research. Therefore, three interviews were organised in order for accomplishment of the validation exercise.

The first one was conducted with Company 1. It lasted two hours and the participants were asked to express their expectations about the possible improvement that the use of the developed tool can provide when used by the NPD team. The details of the participants are shown in Table 5.9.

Participants	Years of experience
1. Manufacturing technologist	14
2. Service Product Manager	15
3. Senior CAD designer	19

Table 5.9: Participants- tool validation at Company 1

The tool was presented to them by the author; she also explained the way it was built and how it can be used; then, the participants were asked to mark the tool from 1 to 5 (1: minor improvement, and 5: major improvement). Two of them thought that it can improve the current NPD process significantly (4), and the third participant marked the tool as 3. All of them mentioned that the tool is good due to its simplicity and its user interface, which was developed in MS Excel. With regards to the weaknesses of the tool, the service product manager said: *'It is important to change the mentality of people and make them work together; otherwise, the usefulness of the tool is minor'*. Hence, it is critical that the two teams will be convinced of the tool's positive effect on the NPD team collaboration.

The second interview was conducted with one participant from Company 4.

Participants	**Years of experience**
1. Services Capability Development	18

Table 5.10: Participant- tool validation at Company 4

The same process was followed, the interview lasted for one hour, and the participant reckoned that the improvement, which can be gained by the developed tool, is of average importance. He rated it as (3) (The rating used was the same as in Company 1; 1: minor improvement, and 5: major improvement). He also mentioned that the tool is likely to attract the attention of the NPD team members and be used by them. Specifically, he stated that *'it is a nice and simple system with high potential of improving the interaction between designers and service personnel'*.

The third interview was conducted with the participation of an independent consultant, who has an extensive experience in the development of various tools for enhancing the team performance within organisations. The interview lasted one hour and after the presentation and the explanations given by the author, the interviewee suggested that the tool can improve significantly (4-5) the NPD process. However, he clarified that in his opinion, it should be used within the context of mature engineering products. He thought that the range of the SK types is comprehensive and representative of most manufacturing organisations. Finally, he did not suggest any amendments relating the design requirements.

5.6 Summary and Key Observations

Chapter 5 aimed at exploring the service involvement at the conceptual design stage, and ways by which the designers can access SK. It becomes apparent from the examples described before that cooperation between service and design is essential for the enhancement of the product performance and the customer satisfaction up to an extent. The use of the developed ontology could support this cooperation, since it incorporates knowledge of service personnel regarding a product, which could be accessed by the designers. As a result, this knowledge can aid them in extracting useful information for the past issues and performance of the product, and using it in the design activities within the same project or before starting a new one. Another factor influencing positively the interaction between service and design personnel is the use of the SK audit tool, since it requires the two teams working together.

More specifically, Section 5.2 presented past issues affecting product design, which were mainly extracted from Company 1; the author tried to identify the related components/subsystems, and also actions taken after the issue had been detected. An example of a design change was the high number of water lines, which caused a time-consuming disassembly of the pump. It eventually led to the change of the water valves used, which resulted in a lower number of water lines.

Section 5.3 described how the list of design requirements that are necessary at the conceptual design stage was created, and the mapping between this and the SK types. This mapping revealed that there is a number of relationships between the designer needs and the information that gets/needs to be recorded by the service personnel.

Section 5.4 showed how the ontology can incorporate design requirements in the possible scenario of this being used by designers. Also, the knowledge templates, which have been created by the author, were presented. These are focused on capturing product failures and other malfunctions noticed by service personnel during the operation phase of the product.

Section 5.5 presented the SK audit tool: its development process, the way it can be used by the NPD team members, the expected benefits of its use, and its validation via three face-to-face interviews as a final point. All interviewees stated that it is a simple-to-use tool, which can, in general, improve at a major degree the NPD process within a manufacturing organisation. However, the prerequisite for the realisation of the tool's benefits is a cultural change among the employees; designers and service engineers would have to cooperate.

Concluding, since at the conceptual design stage the designers work with product requirements, the mapping between the latter and the SK is an effective way of giving the designers access to SK. Therefore, the audit tool will be used to achieve this.

Chapter 6 describes the service involvement at the detailed design stage; the author explores the ways by which designers can access SK at this stage.

6 Service involvement at the detailed design stage

6.1 Introduction

In Chapter 5 the author explained the involvement of service at the conceptual design stage, focusing in particular on the mapping between design requirements and service knowledge types. This Chapter is focused on the detailed design stage and investigates the ways, by which the designers can retrieve service knowledge. The author, having recognised the different focus between conceptual and detailed design and also based on the designers' view in Company 1 and 4, decided that the two elements that need to be linked are the design features (DF) and the service features (SF). A region of a part with some interesting geometric or topological patterns can be called a DF (Pratt and Wilson, 1985). SF is defined in Section 6.3. However, due to the different level of granularity, the direct linkage between the two elements seems invalid (at least within the scope of this research). The researcher observed through previous findings that a link can be established through the SK types.

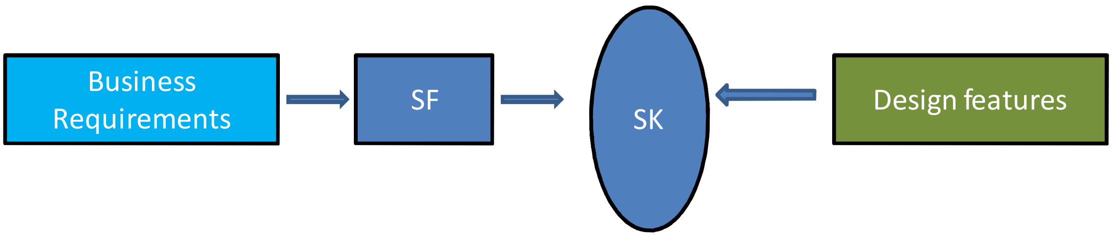

Figure 6.1: Linkage between service and design at the detailed design stage

Chapter 6 is divided into two main sections: the first one describes the path that the author followed to develop the list of the SF; the second one explains the various links between SF, SK, and DF, as identified through two case studies undertaken to compliment this research.

6.2 Benefits of linking service features- service knowledge- design features

This Section describes the benefits that the designers and the service personnel can gain when they share a common understanding of the issues at the detailed design stage. An approach to achieve this is the establishment of a linkage between design features and service features, which is the main theme under exploration in this Chapter. The benefits are as follows:

<u>For the designers</u>:

1. Identification of the exact SK types needed for the realisation of each DF.
2. Reduced time spent on trying to explore the links between DF and SK types.
3. Better communication between design and service departments.
4. Elimination of unnecessary service feedback to them.

<u>For the service engineers</u>:

1. Identification of the SK types needed for the realisation of each SF.
2. Focus on the most important aspects of SF realisation.
3. Exploration of gap existence in service knowledge needed for the SF.

<u>For the service manager</u>:

1. Ability to know the resources needed for the realisation of each SF.
2. Easy identification of missing/overloaded/faulty resources.
3. Tracking of resources when the SF are achieved/fail to be achieved.
4. Broader picture of the business, since the resources are part of the whole supply chain.

6.3 Service Features

This Section illustrates the capture process of SF. The overall methodology followed by the author is shown in Figure 6.2. Then, the detailed tasks that were carried out in each step are described, and finally the conclusive list of SF is presented.

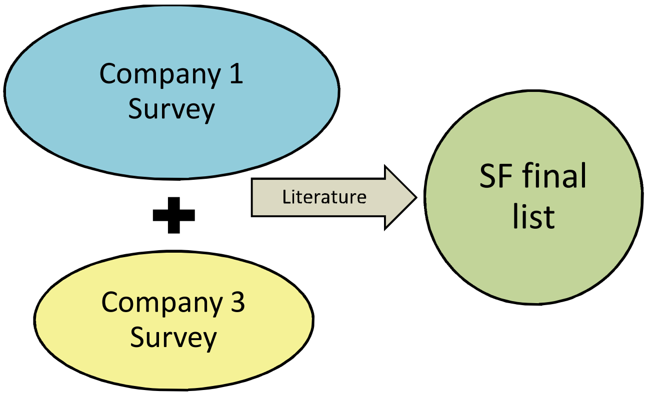

Figure 6.2: Overall SF methodology

It is essential at this point to provide a definition of service feature, which was developed by the author within the context of this piece of research.

> ***Service feature*** is an attribute of service that delivers value to the customer.

6.3.1 Service features at Company 1

The first part of the study for the SF was conducted at Company 1. Eleven of the interviewees, which participated in the case study regarding the SK capture and representation, were also selected for the exploration of the SF theme. The author chose the participants based on their job role (individuals with service experience and exposure to customer requirements were needed), and the suggestions made by the key contact within the Company. Table 6.1 shows the participants within Company 1:

Job roles	Years of experience
3 Service technicians	5, 3, 9
4 Service engineers	10, 9, 12, 4
Project manager	19
Vacuum manager	22
Operations site engineer	4
Team leader	7

Table 6.1: SF survey participants- Company 1

The methodology followed at Company 1 in order for the SF to be captured is shown in Figure 6.3.

The author developed a set of questions, which were addressed to the participants; they were the following:

- Does the developed, by the author, definition cover your understanding on what a SF is?
- What do you perceive as being a SF?

Each of the interviews lasted one hour and the author first presented her definition of a SF. Using the two aforementioned questions as a guideline, a discussion took place with each of the participants for the exploration of SF.

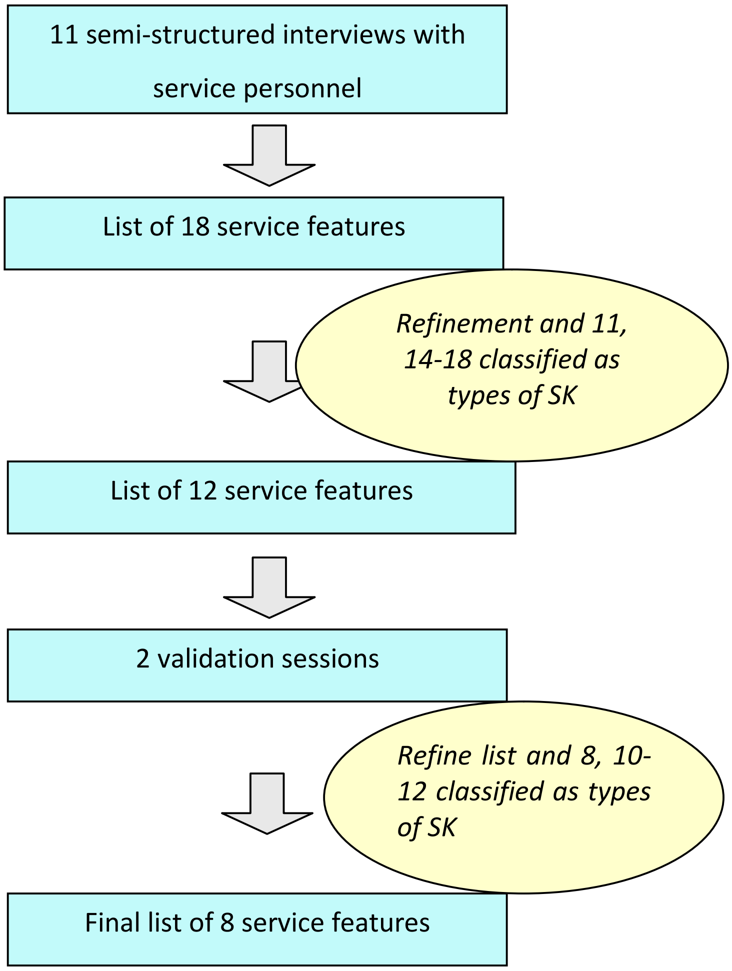

Figure 6.3: SF capture process at Company 1

After having conducted eleven semi-structured interviews with service personnel (see Table 6.1), the author created a list of eighteen SF, which was refined (six of the features mentioned were categorised in other types of SK) and then presented in two validation sessions; after the participants' comments, a further refinement took place and a final list of 8 SF was generated, as these having been identified at Company 1. The list is as follows (the three developed lists of 18, 12 and 8 features can be found in Appendix J):

Final list of 8 features:

1. Global presence with the same level of service provided everywhere in the world
2. Quality
3. Value-added features (features that differentiate from the competitors) and continuous improvement of them
4. Detailed knowledge to quickly troubleshoot the problems
5. Invisible
6. Comfortable
7. Worldwide consistency of the methods and procedures used
8. Availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up.

6.3.2 Service Features at Company 3

The second part of the study for the SF took place at Company 3. The survey was part of a broader investigation conducted within the company; however, the overall results describe the service operation at Company 3 and are out of the scope of this Chapter (they are presented in Appendix K). This Section covers the outcome of the SF investigation. In total, thirteen people were interviewed; these are (see Table 6.2):

Job roles	Years of experience
Customer service manager	25
Service coordinator	17
Customer service director	32
Customer support manager	19
Applications manager	22

3 Service engineers	8, 12, 6
Spare parts' coordinator	23
Administration for spares	12
Technical Support manager- NPD group	19
Stores manager	15
Purchasing manager	17

Table 6.2: SF survey participants- Company 3

The whole study was carried out in three days, with 4, 5 and 4 interviews taking place on each day respectively. The author presented the same questions as in Company 1 to the participants of this survey.

Figure 6.4 illustrates the methodology followed for the SF capture within Company 3. Firstly, thirteen interviews were conducted (duration: one hour each); the participants had either service experience or held posts that involved contact with customers. Also, three of the company's customers were interviewed so as to inform the author about the features that they expect to receive from a service provision. Following an analysis of the interviewees' responses, the author developed initially a list of eleven features, which was then refined and a list of seven features was the final outcome.

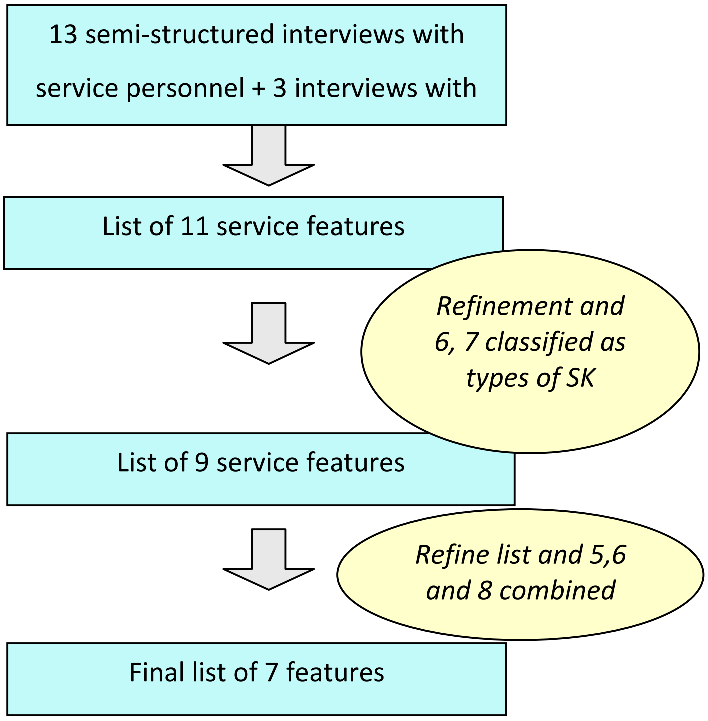

Figure 6.4: SF capture process at Company 3

The list of SF, which was created after the case study at Company 3, is the following:

List of 7 features

1. Machines' uptime (achieve minimum downtime)
2. Offer of cheap service packages to the customers so that they can afford
3. Speed in response
4. Ability of engineers (well-trained and informed engineers arrive punctually with the correct parts)
5. Attitude of the engineers and all the people that the customer is in contact with (honesty, politeness, tidiness, professionalism)
6. Provision of the necessary documentation
7. Quality

6.3.3 Service feature final list

The author combined the two lists that had been developed after the collaboration with Company 1 and 3, and created the following comprehensive set of SF:

Combined list

1. Global presence with the same level of service provided everywhere in the world and worldwide consistency of the methods and procedures used
2. Quality
3. Value-added features (features that differentiate from the competitors) and continuous improvement of them
4. Invisible
5. Comfortable
6. Machine uptime (achieve minimum downtime)
7. Offer of cheap service packages to the customers so that they can afford
8. Speed in response
9. Ability of engineers (well-trained and informed engineers arrive punctually with the correct parts)
10. Attitude of the engineers and all the people that the customer is in contact with (honesty, politeness, tidiness, professionalism)
11. Provision of the necessary documentation

The comparison between the two separate lists revealed several commonalities. These are:

- Quality is a common SF.
- The detailed knowledge to quickly troubleshoot the problems (Company 1) is equivalent to the ability of engineers and the provision of the necessary documentation (Company 3).

- The availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up (Company 1) is mentioned in Company 3 as machine uptime.

However, differences can be spotted also and they are mostly linked to the 'philosophy' of each company. As a result, important SF in Company 1 are associated with the global provision of the same service level, and the worldwide consistency of the methods and procedures followed within the service department; there is not a similar concept in Company 3. On the other hand, Company 3 emphasises the importance of the service price, which does not appear as a SF in Company 1. Another difference is the fact that the features differentiating the organisation from the competitors are considered as SF in Company 1, while they seem to be overlooked in Company 3. Finally, the SF 'invisible' and 'comfortable', as mentioned by the interviewees at Company 1, are similar to the 'speed in response' and 'engineers' attitude' in Company 3, because when the service is provided in a professional, fast and polite manner, then it can be perceived as invisible and comfortable by the customer.

Further refinement

The above list of SF, as stemmed from the survey within two UK manufacturing companies, can be further refined according to similar frameworks found in the literature. Subsequently, this will result in a more generic set of SF that can be applicable to more industrial sectors than the ones that were studied for the identification of the initial SF. The author adopted and expanded the dimensions that the SERVQUAL framework (Buttle, 1996) uses. These are summarised in Table 6.3.

Dimensions	Definition
Reliability	The ability to perform the promised service dependably and accurately
Assurance	The knowledge and courtesy of employees and their ability to convey trust and confidence
Tangibles	The appearance of physical facilities, equipment, personnel and communication materials
Empathy	The provision of caring, individualised attention to customers
Responsiveness	The willingness to help customers and to provide prompt service

Table 6.3: Dimensions of SERVQUAL framework (Source: Buttle, 1996)

Therefore, the refined and final list is:

1. Reliability: the ability to deliver the promised service.
2. Assurance:
   - Ability of engineers (well-trained and informed engineers arrive punctually with the correct parts).
   - Attitude of the engineers and all the people that the customer is in contact with (honesty, politeness, professionalism).
3. Tangibles:
   - Provision of the necessary documentation
   - Tidiness
4. Empathy:
   - Value-added features (features that differentiate from the competitors) and continuous improvement of them
5. Responsiveness:

    - Speed in response
    - Global presence with the same level of service provided everywhere in the world and worldwide consistency of the methods and procedures used
6. Service price:
    - Offer of cheap service packages to the customers so that they can afford
7. Perceived impact of service
    - Invisible
    - Comfortable
8. Product availability

Comparing the list of SF that the author developed and the SERVQUAL framework, many similarities can be spotted. The first five SF are the same as the dimensions of the literature framework, enriched though by the findings of the industrial survey. For instance, the ‘assurance’ was defined in a more comprehensive way; the author added aspects, such as honesty, politeness, professionalism,and punctuality. Also, the ‘empathy’ encompasses all these features that differentiate from the competitors (the SERVQUAL framework mentions only the provision of individualised solutions to the customers). In addition to this, ‘responsiveness’ includes an additional aspect: the global presence with the same service level around the globe and the existence of consistent methods and procedures, which was not mentioned in SERVQUAL. The SF 6, 7 and 8 are not part of the SERVQUAL framework, but purely derived from the responses of the survey, which the author conducted. They were included in the list of SF, since they were mentioned by a number of participants and were perceived to be important in delivering value to the customer through the service provision.

6.4 Links among Service Features- Service Knowledge- Design Features

This Section comprises the second part of the investigation concerning the service involvement at the detailed design stage. It describes the results that stem from six interviews and one half-day workshop conducted with people from the service and design departments of two UK manufacturing companies; Company 1 is a pump manufacturer and Company 4 belongs to the aerospace sector. More specifically, this part concerns the detailed design stage and explores the links that exist among SF, SK, and DF. The exploration of the aforementioned links is a crucial aspect, since the designers' access to service knowledge can be achieved through these links at the detailed design stage.

6.4.1 Interview method and participants

The researcher elaborated mostly on the 'feature' aspect of both design and service. Three interviews were conducted by phone due to the distant location and the busy schedule of the interviewees; the workshop and the rest of the interviews took place at the collaborating companies. The interviews were semi-structured and the first one was used to pilot the questions. This would help to improve and use the questions for the rest of the interviewees. The methodology followed is shown in Figure 6.5.

As it is illustrated in Figure 6.5, the author developed the basic framework based on the available literature and previous industrial findings. There are three main areas that were deeply investigated: service features and resources, service features and service knowledge, and design features and service knowledge. Then, the research protocol was created and sent to the first interviewee prior to the interview. It consisted of three word documents; the first one described the resources needed for the accomplishment of each of the SF, the second one included the relationships between SF and SK types, and the third one was in relation to the links between DF and SK types (Appendix L).

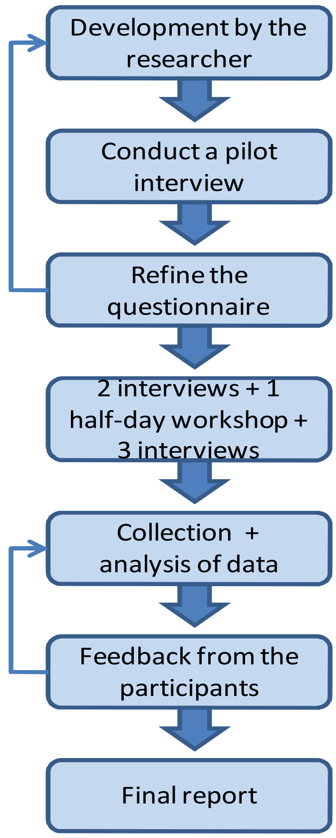

Figure 6.5: SF-DF-SK research methodology

It was decided after this pilot interview that the last two word documents should be converted to excel sheets so that the interviewees would be facilitated to determine the relationships between the design/service features and service knowledge types and also provide examples of the strongest relationships. Thus, after the first phone interview and the refinement of the questionnaire the author conducted two additional phone interviews and one half-day workshop, where two designers and a product manager participated. The last three interviews took place at one of the sites of the collaborating companies. Each interview (both phone and face-to-face) lasted one to one and a half hours. After the completion of the data collection phase, the author gathered the results, and analysed them according to the three main themes; this is how they are presented below. The main findings were sent back to the participants in order for the author to get feedback and make any necessary amendments to the findings.

The roles of the people that were interviewed and their years of experience are the following (see Table 6.4):

Job role	Years of experience
Service manager	30
Chief design engineer	30
Engineering associate fellow- lifecycle engineering	24
Product manager	20
Design engineer	16
Senior designer	13
Business Development Manager	25
Lead designer	20
Fleet transmissions design technical lead	30

Table 6.4: Participants at the SF-SK-DF case study

6.4.2 Service features- resources

This Section presents the final table of SF- resources, after this had been amended based on the comments made by the participants regarding the resources that are identified as necessary for the realisation of each SF. The ultimate aim is that the resources are used in such a way, that the service provided by the company meets the customer requirements. This study is mostly useful for the service managers, since they are responsible for the overall service provision, through which customer satisfaction can be achieved.

After the presentation of Table 6.5, the comments of the participants pertaining to each SF are presented in detail.

Service feature	**Resources**
Reliability (the ability to deliver the promised service)	▪ Service manager: he/she is the main responsible person of the service facility (not for an on-site service provision) ▪ Service engineers: they are the people delivering the service/ should also identify needs for parts, training and maintenance manuals ▪ Spare parts department: they need to be punctual ▪ Supplier: needs to provide the spare parts on time ▪ People that are in contact with the customer: extract the correct information from the customer and convey it precisely and on time to the company's responsible team ▪ Customers ▪ Service engineers' support team
Assurance (service engineers' behaviour and knowledge)	▪ Service engineers: need to be polite, discrete, professional and knowledgeable ▪ Employees who provide the training so that the service engineers know their job well
Tangibles (documentation + tidiness)	▪ Documentation: the responsible team for the creation of the documentation (the latter needs to be comprehensive and accurate; attention needs to be paid on the language used within a multinational company) ▪ Tidiness: Service engineers, company's policy
Empathy (attributes that differentiate	▪ Benchmarking team

from the customer)	▪ Product itself ▪ NPD team: they need to define the requirements for the next generation of products
Responsiveness (speed in response + global presence)	▪ <u>Speed in response</u>: People who define the service policy, service engineers, people who are in contact with the customer ▪ <u>Global presence</u>: service management team
Service price	▪ Customer ▪ Service management team who define the policy ▪ Benchmarking team
Perceived impact of service (invisible + comfortable)	▪ Customer ▪ Service engineers ▪ Service management team
Product availability	▪ Product itself ▪ Service team that sets the correct service intervals ▪ Service engineers: they have to provide the needed service on time when a failure occurs ▪ Spare management team ▪ Supplier

Table 6.5: SF- resources

<u>Reliability</u>: The service manager is not an essential resource if the service is provided on a customer's site; in this case, service is organised by the organisation (e.g. Company 4) and provided on the customer's site by service engineers or performed by the customers themselves. Also, customers should be added as a resource, since quite often they perform part of the overall service activity themselves. The service engineers should also identify what is needed in terms of parts, training, and maintenance manuals apart from delivering the service. Another resource that can be added is the service engineers support team, which is the team providing the training.

<u>Assurance</u>: It was emphasised that often there are occasions, where people have been trained and have the knowledge, but they are unable to use it in an effective manner.

Also, discretion should be one of the service engineers attributes, since while working on the customer's site, they have access to sensitive data.

Tangibles: With reference to the documentation, it was mentioned by all interviewees that it needs to be focused on the user needs and that within a multinational organisation, there are always issues with the language both within the strict borders of the company and out of it, i.e. customers and suppliers. Moreover, the documentation should be accurate and compliant with the standards and the corresponding contract.

Empathy: It was highlighted that empathy is one factor that differentiates from the competitor. There is a crucial need of convincing the customer that the service provided to him/her brings a benefit to his/her business. Therefore, the NPD team needs to understand and define the customer needs as part of its activities.

Responsiveness: According to the interviewees, a measurable target should be set and achieved; for instance, there should be availability of any part all over the world within 24 hours. The existence of a clear vision is also important; customers should know what to expect and not have false expectations. In addition, it needs to be ensured that the company's systems are in place to support what has been promised to the customer. It was also mentioned that after their occurrence, the service issues are prioritised according to their severity and the customer importance.

Service price: The participants mentioned that the customer is the greatest determining factor along with the competition. The service price should not be necessarily lower than the one of the competitors, but it should clearly reflect the value given to the customer.

Perceived impact of service: Customers are an additional resource needed, since they are the ones recognising the value attributed to the service.

Product availability: This feature was re-named after the interviewees' suggestion. The original SF was named 'machine uptime'; however, it refers to product availability, which is more generic as a title and, therefore, adopted as the SF type. Customer needs should also be understood; the service provider needs to know how the customer intends to use the product (for instance, overnight service might be needed). Resources that were added according to the interviewees' suggestions are the spare management team and the supplier, which needs to provide the right parts at the right time.

Overall, except for the aforementioned comments and additions to the SF, and the necessary resources for their realisation, the interviewees agreed with the list that the author had created prior to the interviews.

6.4.3 Linking Service features and Service knowledge types

After the refinement of the questionnaire, an excel sheet was presented to the interviewees and they were asked to identify the links between SF and SK types, and also to provide some examples of the strongest links. The author collected all the responses given through the excel sheets and aggregated the times that each SK type was mentioned by the interviewees (frequencies) as being necessary for the realisation of the SF. The final excel sheet is presented in Figure 6.6.

Service features/ service knowledge types	Product type	Issues faced	Resources needed	Failure type	Actions after failure	Planned/ unplanned maintenance	Difference between actual and expected life	Paint	Number of components used	Component ID	Accessibility	Training	Location (customer / service facility)	Recyclability of materials used	Serviceability	Maintainability	Safety record	Password protection	Installation environment (temperature, humidity)	Application used in	Application specified for
Reliability of service	4	3	4	3	3	5	4		2	3	4	4	4	1	5	5	4		4	3	1
Assurance (service engineers' ability and attitude)	1	4	5	3	5		1				1	4	1		2	2	1		1		1
Tangibles (documentation and tidiness)	1		3		3	2	1		1	3		2	1	1	2	3	1				
Empathy (attributes that differentiate from the customer)	3	3	2	2	5	1	2				1	3	2	1	2	2	1				
Responsiveness (speed in response + global presence)	2	1	4	3	3	4	1			1	1	1	4	1	2	2	1		1		
Service price	4	1	3	2	2	4	3		4		2	2	3	2	3	3	1		2	2	2
Perceived impact of service (invisible + comfortable)	1	3	4	2	4	3	3		2			1	2		3	3	1				
Product availability	4	3	4	4	5	3	4		1		3	3	1		4	4	1		2	1	1

Figure 6.6: SF and SK types' frequencies

Below, the five most necessary (highest frequency) SK types for each SF are presented and examples of the links are given (see Table 6.6):

Service features	Top 5 SK types
Reliability of service	Planned/unplanned maintenance, serviceability, maintainability, resources needed, difference between actual and expected life
Assurance (service engineers' ability and attitude)	Resources needed, actions after failure, issues faced, training, failure type
Tangibles (documentation and tidiness)	Resources needed, actions after failure, component ID, planned/unplanned maintenance, maintainability
Empathy (attributes that differentiate from the customer)	Actions after failure, product type, issues faced, training, resources needed
Responsiveness (speed in response + global presence)	Resources needed, planned/unplanned maintenance, location (customer/service facility), failure type, actions after failure
Service price	Product type, planned/unplanned maintenance, number of components used, failure type, difference between actual and expected life
Perceived impact of service (invisible + comfortable)	Resources needed, actions after failure, issues faced, planned/unplanned maintenance, difference between actual and expected life
Product availability	Actions after failure, product type, resources needed, failure type, difference between expected and actual life

Table 6.6: Top 5 SK types for each SF

The next Section describes examples showing the necessity of the specific SK types for each SF. An example for each of the links is described in this Section.

- *Reliability of service- serviceability/maintainability*: Product 1 was designed to be maintenance free between the major overhauls; however, at a certain point, the service personnel were worried of oil leakage, but they had no means to check the oil level. As a result, they had to stop the pump and conduct the check.

- *Assurance- training*: when a non-common issue occurs, a well-trained engineer can deal with it.
- *Tangibles- component ID*: all the components are serial numbered. Therefore, if there is an issue faced, it can be traced back to the batch, supplier, etc.
- *Empathy- product type*: one of the main factors that can help to differentiate from the competitor is the product itself; the more reliable a product is, the more satisfied a customer will be.
- *Responsiveness- actions after failure*: the quicker the company responds, the better the customer feels. The customer wants to know the reasons of a failure as well as to get a prompt response and have the product functioning properly as quickly as possible.
- *Service price- number of components used*: For instance, the pump manufacturer offers two types of service: firstly, 'cost plus' service, where certain failures are included in the service package and it is the customer that can decide if s/he wants additional checks and repairs; thus, the more components used, the bigger the payable amount gets. Secondly, an 'all inclusive' service package is offered, where the customer pays a standard amount of money, and this covers every failure that can occur.
- *Perceived impact of service- planned/unplanned maintenance*: When a product is designed to be maintenance free between major overhauls, there are no service people on the customer's site and also, the service costs less for the customer.
- *Product availability- resources needed*: The service provider needs to have the necessary resources in order to keep the level of product availability as high as possible (at least to comply with the availability level that has been agreed on the contract with the customer).

6.4.4 Design features- service knowledge types

The interviewees were asked to identify the links between DF and SK types based on an excel sheet that had been developed by the researcher and illustrated both DF and SK types (see Appendix M). They were also asked to comment on the DF list and to provide examples of the strongest relationships. It should be mentioned that the list of DF is re-used from the findings of the 'U-KNOW' project in the area of design knowledge[2]; however, the researcher removed the specific-to-the-project/product features. The list presented here is the outcome of the amendments made following the interviewees' recommendations.

The author collected the answers and identified the frequency, with which each SK type was mentioned by the interviewees as necessary for each DF. An example of the SK types' frequency for each DF is shown in Figure 6.7.

Table 6.7 shows the five most necessary SK types for each DF. The significance of the SK types for the DF is defined by the times that each type was mentioned by the interviewees, when the latter were asked to establish the links between the two.

Design features	Service knowledge types
Cleanable	Product type, planned/unplanned maintenance, accessibility, maintainability, resources
Cost	Failure type, serviceability, maintainability, product type, resources
Ergonomics handling	Maintainability, product type, serviceability, accessibility, training

[2] The design features were captured, in collaboration with Company 1 during the data collection phase, by Dr David Baxter, who was the project manager of the 'U-KNOW' project.

Design features/ service knowledge types	Product type	Issues faced	Resources needed	Failure type	Actions after failure	Planned/ unplanned maintenance	Difference between actual and expected life	Paint	Number of components used	Component ID	Accessibility	Training	Location (customer / service facility)	Recyclability of materials used	Serviceability	Maintainability	Safety record	Password protection	Installation environment (temperature, humidity)	Application used in	Application specified for
Cleanable	3	1	2		2	3	1	2	1	2	3	2	1	2	2	3	1		2	1	1
Cost	4	3	4	5	4	4	3	1	4	1	2	4	3	3	5	5	4		2	3	3
Ergonomics handling	4	1	2		1	1			1	1	3	3	1		4	5	2		3	2	2
Manoeuvrability	4	2	1		1																
Manufacturability	4	1	2	2		1	3	2	2	2	1	1			1					1	1
Serviceability	5	2	4	2	1	2	2		4	3	3	4	4	1	5	2	3		2	2	1
Surface finish	2	1	1	1		1															1
Thermal control	2	2	1	3		2	1		1		1	1			1	1	1		1	1	1
Traceability (parts ID, machining data)	3	3	1	3	3	1	3		2	4	1					2	1				1
Weight and dimensions	2	1	1		1	1	1		1		1		1		1	1	1		1		2
Packaging	1	1	1	1	1			1	1	1	1	1	1	1			1		1		
Maintainability	1	1	1	1	1	1	1	1	1	1	1	1		1			1		1	1	1
Life	1					1	1								1	1			1	1	1
Safety	1	1		1	1												1		1	1	1
Error proofing		1		1								1			1	1	1				
Material type	1													1	1	1			1	1	1

Figure 6.7: DF and SK types' frequencies

Manoeuvrability	Product type, issues faced, resources, actions after failure
Manufacturability	Product type, difference between actual and expected life, resources, failure type, component ID
Serviceability	Product type, serviceability, resources, number of components used, training
Surface finish	Product type, issues faced, resources, failure type, planned/unplanned maintenance
Thermal control	Failure type, product type, issues faced, planned/ unplanned maintenance, resources
Traceability	Component ID, product type, issues faced, failure type, actions after failure
Weight and dimensions	Product type, issues faced, accessibility, serviceability, maintainability
Maintainability	Product type, issues faced, resources, failure type, actions after failure
Life	Product type, planned/unplanned maintenance, difference between actual and expected life, serviceability, maintainability
Safety	Product type, issues faced, safety record, application used in, application specified for
Error proofing	Issues faced, failure type, training, serviceability, maintainability
Material type	Product type, recyclability of materials, installation environment, application used in, application specified for

Table 6.7: Top 5 SK types for each DF

As mentioned before, the interviewees were asked to provide the author with some examples of the links among SK and DF that they specified. This Section illustrates some of these examples:

- *Cleanable- resources*: In some cases, there are special facilities used for the cleaning of products or specific components.
- *Cost- failure type*: Depending on the severity and frequency of a failure, the cost is increased (e.g. re-design costs).
- *Ergonomics handling- training*: The service engineers need to be trained on how to handle components/products, especially when their size is big.
- *Manoeuvrability- issues faced*: The NPD team needs to be aware of issues faced in the past, e.g. a pump could not be moved around easily due to its very small size.
- *Manufacturability- difference between actual and expected life*: If a product/component is not very 'manufacturable', it is quite difficult to predict its life.
- *Serviceability- training*: The service engineers need to be well-trained and have the ability to face any issues regardless of their commonality.
- *Surface finish- resources*: The resources needed for each specific task are described in detail in the documentation.
- *Thermal control- issues faced*: Unexpected failures occurred when a pump needed to run at a high temperature for an extended period of time.
- *Traceability- component ID*: It is absolutely crucial for the components to have a unique ID so that they can be traced back to the supplier, batch, etc. Then, the organisation can control all the aspects of a component; for instance, if a component needs to be replaced before its expected end of life because it failed, the organisation can trace its batch, cost, supplier, and other features as long as it is serial numbered.
- *Weight and dimensions- product type*: depending on the market that the product is targeted, the size and weight of it may vary.
- *Maintainability- failure type*: many failures were caused because the product was not maintained properly (i.e. the customer did not abide by the recommended service overhauls).

- *Life- planned/unplanned maintenance*: The life of a product/component can be highly affected by the compliance with the planned maintenance schedule defined by the service provider.
- *Safety- safety record*: The safety record can be an indication of how safe a component/product is. For instance, if there has been an explosion in one of the components, the service engineers and designers need to be aware of this event.
- *Error proofing- training*: the more trained a service engineer is, the easier the diagnosis of a faced issue becomes.
- *Material type- recyclability of materials*: The designers and the service engineers should know whether the material of a component is recyclable or not and handle it in an appropriate manner.

6.5 Summary and Key Observations

In Section 6.1 the author presented the overall framework of linkage between Service Features and Design Features (at the detailed design stage); the linking of these two concepts was achieved through SK types. Two main tasks were undertaken to achieve this outcome: the development of the SF list, and the identification of links among SF, DF, and SK types through the industrial case studies with Company 1 and 4.

In Section 6.2 the author presented the benefits that designers, service managers, and service engineers are expected to gain from the development of the links mentioned in this Chapter. Enhancement of the communication among these groups, easier exploration of gap existence in SK, tracking of the resources that are needed/overloaded/have contributed for the attainment of the SF are some of the benefits to be gained.

In Section 6.3 the methodology to capture the SF was described step-by-step. The survey in Company 1 resulted in the creation of a list of eight SF. Then, the author conducted a second survey with Company 3 and based on these findings, she developed a list of seven SF. By comparing the features of both lists and combining them with the elements of the SERVQUAL framework, a final set of eleven SF was obtained.

Finally, in Section 6.4 explained the second main task of this Chapter: the identification of links among SF, DF, and SK types. Firstly, the research methodology, which was followed to accomplish the task, was presented. Then, the necessary resources for the realisation of each SF were identified. Another subtask was the establishment of links between SF and SK types; the participants in the case studies were asked to link these two elements. Following this, the author analysed the responses and identified for each SF the five strongest relationships with the SK types. The same process was followed in the case of building up the links between DF and SK types.

The next Chapter describes the development of the Service Knowledge and Design (SKaD) framework, which designers could use to access service knowledge. The author presents the requirements for the framework development, the elements it comprises, and its implementation in an Access database.

7 Service Knowledge and Design (SKaD) Framework Development

7.1 Introduction

The review of the literature brought to light a lack of available methodologies, which designers could use in order to access the necessary service knowledge for creating an improved product design. Additionally, informal discussions with key experts from the collaborating organisations highlighted the fact that there are no formal methods as such applied in the manufacturing industry. The interaction between service personnel and designers (in the cases it takes place) is rather informal and depends on the particular team members and their willingness to collaborate within the NPD team. Therefore, access to service knowledge is limited and largely dependent on the level of interaction and communication between the two teams.

These observations were verified by the results of the interviews with experienced personnel from industry, as presented in Chapter 4. Several remarks were also made during the conduct of the case studies and the survey described in Chapter 5 and 6. A number of the designers that participated in this study commented that they do not tend to follow a structured method in accessing and utilising SK from past projects; some of them mentioned that they contacted service personnel through e-mails or telephone to discuss about issues faced in servicing past products in order to take them into account in the design of a new product. However, the process was not formalised and took place as a result of the individuals' initiative. In addition, both service and design personnel believe that formalisation of the process to access past SK would positively contribute towards the enhancement of product design.

In this Chapter, the author presents the development of the Service Knowledge and Design (SKaD) methodology, which designers could use in order to access the critical types of SK for supporting product design. The fundamental requirements for the development of an effective and suitable methodology were initially identified. Then, the process of the SKaD methodology development is presented. The findings from Chapter 4, 5, and 6 regarding the SK types and the ways of service involvement at the conceptual and detailed design stages are integrated within the methodology resulting in the overall SKaD framework. Following this, the developed framework is implemented in a database, and templates are designed to capture the appropriate SK that is suggested in the SKaD methodology. Hence, this will enable designers to access the SK types they need in a structured way. The purpose of the overall framework is to address the lack of formalised communication between designers and service personnel by enabling the former to access the SK types relevant to their tasks. As a result, this will improve the design of future products since service issues will be taken into account.

Figure 7.1 graphically depicts the three parts of the proposed framework. These parts were identified in Chapters 4, 5, and 6.

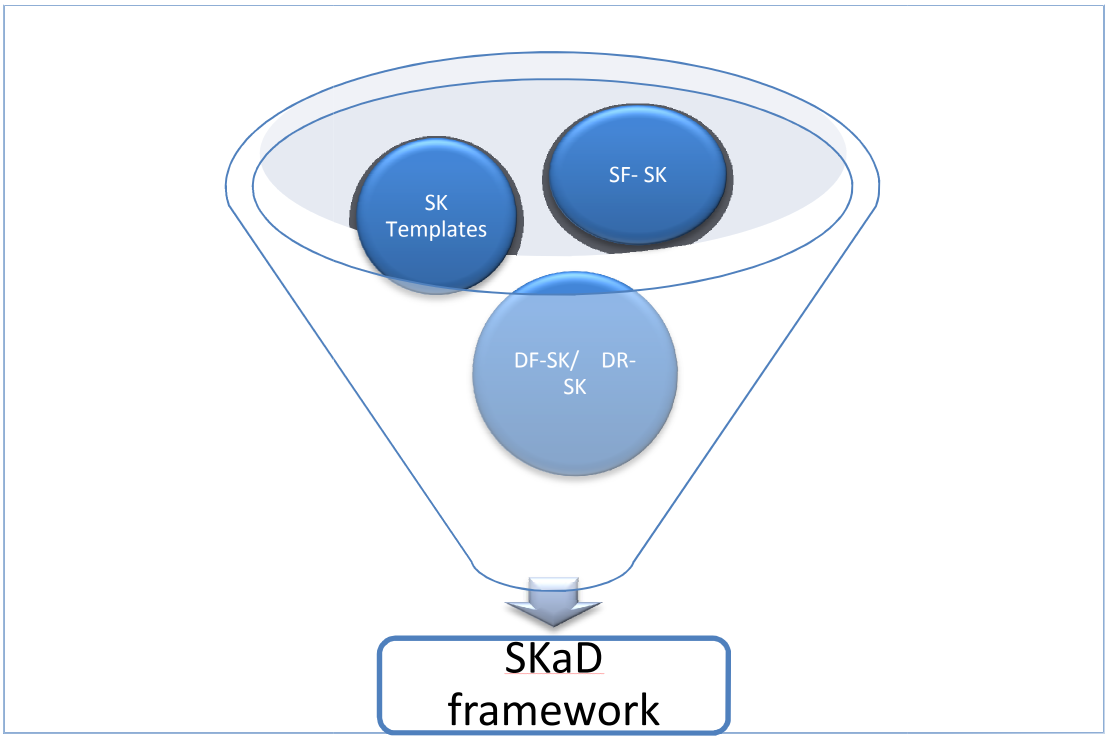

Figure 7.1: SKaD Framework parts

7.2 Requirements for SKaD Framework

A number of criteria were identified during the industrial investigation to be essential towards the elicitation and re-use of the key SK types by designers; the development of the proposed framework was based on them. In order for the framework to be effective and beneficial mostly to designers (it can also be used by service personnel), the use of it should result in the capture of the key information related to product and service organisation issues that are needed by the designers in their attempt to enhance product design. The framework should also embrace the tools described in Chapters 5 and 6 concerning the mapping between DR-SK, DF-SK, and SF-SK. The use of the tools requires the collaboration of both design and service personnel**.**

7.2.1 Generic requirements

The creation of a list of generic requirements was identified as being a necessity prior to the development of the proposed framework. The requirements were defined based on the findings from the industrial case studies and the views of the key contacts within the collaborating organisations. Moreover, the end-users of this framework, along with views expressed by a number of interviewees when capturing the SK and developing the tools, were taken into account during the identification and definition of these requirements.

The list of the generic requirements/criteria is presented in Table 7.1. The potential users of the proposed framework are designers, who are going to access the SK; also, service engineers and managers will provide the data and access all the information they need too. Based on the different nature of job roles, specific to them criteria were additionally considered.

Criteria	Description
Usage simplicity	The tools developed as part of the methodology should be simple to use entailing minimal training/instructions.
Capture/ re-use	SK should be captured in a way that can be re-used within a different project.
Generic approach	It can be applicable to complex mechanical products that belong to various industrial sectors.
Flexibility	In each case (project) the participants should be able to complete the parts of the methodology that are relevant (necessary). Completion of the entire process should not be required.

Table 7.1: Generic requirements of the SKaD framework

7.2.2 Requirements based on the research findings

Apart from the identified generic requirements/criteria, which were described in Section 7.2.1, the framework should encompass the findings from Chapter 4. The addition of these will establish a strong link between service and design personnel, and will intensify the usage of SK by the latter. In Chapter 4, the types of knowledge, used by service staff and required by designers in order to support product design, were identified. Therefore, the design of the proposed framework should facilitate the capture of these types of SK. The major knowledge types as identified in Chapter 4 are:

- Product type
- Spares
- Training
- Logistics

- Service process
- Service features
- Service facility

The capture of the aforementioned knowledge can be accomplished by encouraging the service personnel to record all data and information that may be required by designers.

A major consideration upon designing the proposed methodology was to ensure that the designers access only the relevant knowledge for their task. To achieve this, the author divided the methodology steps into the ones related to product issues, and others associated with issues faced in the service organisation.

Two additional criteria were taken into consideration in the design of the methodology. These were:

- *Use of language*: Due to the global presence of the collaborating organisations, the interviewees mentioned the possibility of using different terminology to describe the same process or product component. Hence, they emphasised the importance of avoiding the use of terms that can be confusing. Also, it is common for an organisation that operates worldwide to have employees, whose first language is not English. As a result, effort should be made in order for simple terms to be used to the maximum possible extent.
- *Different users*: Designers will be the main users of the methodology; however, it is possible for service engineers and service managers to also use it. Therefore, the requirements of each group were considered in the methodology development.

7.3 SKaD methodology development

This Section presents the SKaD methodology structure and explains how this methodology is going to affect the current practice followed in a design process.

Figure 7.2 illustrates the steps of the proposed methodology. It should be highlighted that it is not binding for the designers to follow all the steps of the methodology. Since flexibility is one of the generic requirements, the completion of the entire process is not imperative; the user is enabled to select the steps s/he wants to follow.

The first step is the creation of a broad description for the product to be designed; this task needs to be carried out by the NPD team. Some of the major elements that have to be defined are: the market this product is addressed to, whether it is the next generation of one of the product families, and its functionality.

The second step is the consideration of similar past products (or the previous generation if the product is its evolution). In the case of non-existence of similar past products, the designers need to start a new design process. However, in many instances of NPD, the new product is the advancement of its predecessor(s). In this case, the designers should check for past product failures. It should be mentioned that this work is mostly suitable for variant design. Variant design signifies the technique of adapting existing design specifications to meet new design aims and restraints (Fowler, 1996). The author's exposure to the industrial environment and her interaction with key practitioners has revealed that the majority of the products experience malfunctions and failures in several phases during their lifetime. Therefore, some fundamental aspects that need to be delved into are: related to the failure subsystem/component, the application where the product was used in as opposed to the application which was specified for, and finally the actions taken after the failure/malfunction had been spotted. These four areas that the designers need to take into account are product related issues, as reported by the service personnel. After taking into consideration the findings in these four areas, the designers can proceed with any amendments perceived as essential towards the improvement of the past design process, which is intended to be used.

The second part of the SKaD methodology consists of the steps that designers should follow in order to identify issues linked to the service organisation. Firstly, they should explore the issues within the service facility and pay special attention to the ones that are related to the design process, e.g. a recorded issue about the necessary floor space can be relevant to the designers because they can possibly adapt the product size. Secondly, issues faced during the service process and/or maintenance strategy may be pertinent. Tooling and spares' issues are definitely two of the aspects that designers ought to consider due to the fact that several of the issues mentioned in the course of this research belong to these two areas and stem from design imperfections. Also, logistics issues may be relevant. However, these are mainly useful for the service manager. For instance, a product might get delivered with a fault to the customer; if this incident gets recorded, then the service manager will be able to identify the cause of the problem in the case of recurring events. Additional modifications can be made to the past design process in accordance with the relevant issues that need to be addressed.

It is absolutely essential that the service engineers provide the data and information related to each of the methodology steps. Another potential user is the service manager, who can access past product failures and get informed about their details, along with information regarding the service organisation. Being aware of the issues faced within the service organisation enables the service manager to make an attempt towards their resolution. Awareness of the issues can also contribute to the identification of their cause.

It becomes apparent from the description of the SKaD methodology steps that the product design can get significantly improved, since the designers are enabled to access SK. Issues in relation to product and/or service organisation malfunctions can be examined by the designers and they, subsequently, will use them as lessons learnt in the current design process. As a result, mistakes of the past will be avoided and the product design will be enhanced.

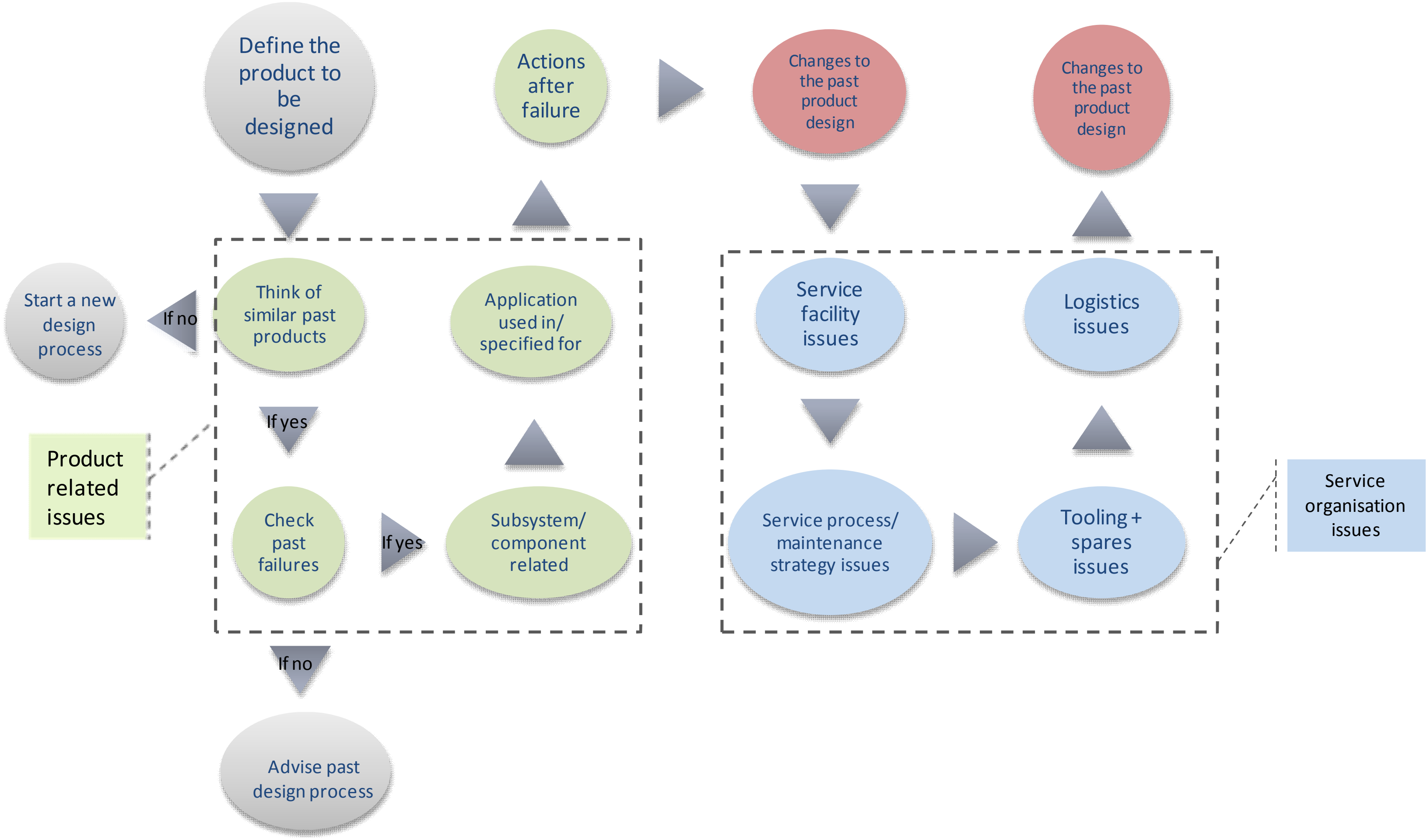

Figure 7.2: SKaD methodology

7.4 Development of Service Knowledge Templates

In Chapter 4, the author described the process of capturing SK and there, it was also mentioned that several templates, which can be used to capture details of failure events, were developed. However, after the development of the SKaD methodology and in the course of the framework creation it was realised that a method was needed to aid the service engineers in capturing the knowledge involved in the successful execution of their tasks. This knowledge is also accessed and re-used by the service manager and the designers of an organisation. The selection of the method was mostly based on its actual applicability within an industrial environment and its ease of use. To achieve this requirement, structured templates as a method were found to be the most practicable and the most effective approach. The knowledge requirements were analysed by the author in order to define the number of templates that had to be developed.

Figure 7.3 presents the main SK types and their relationships, which are represented in templates and can be accessed by their users (service and design personnel). The knowledge types illustrated in Figure 7.3 were captured in the case study of Chapter 4. The shaded boxes denote the higher level knowledge types, for which a template was created. These are:

1. Product
2. Maintenance strategy
3. Service process
4. Training
5. Service facility
6. Service organisation

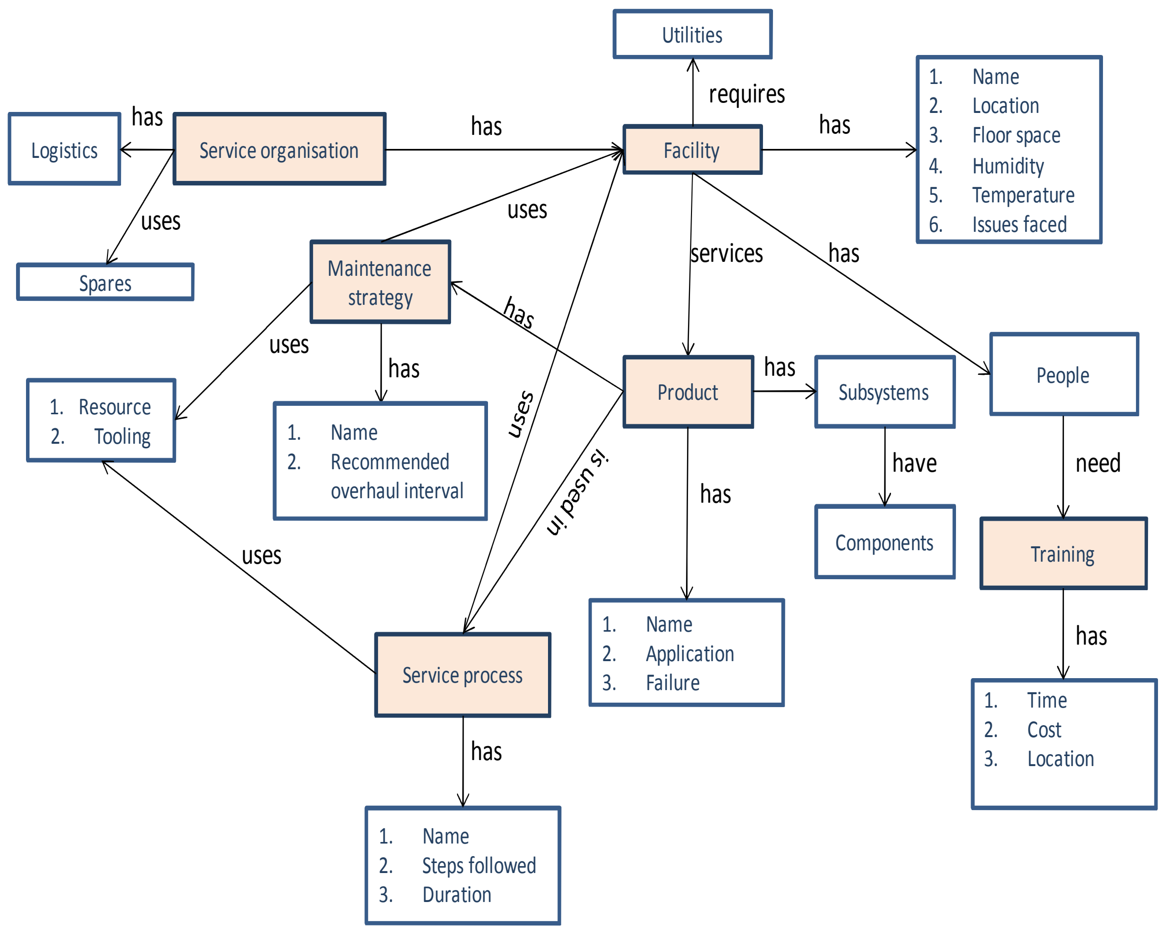

Figure 7.3: Main SK types in the templates

Each template also includes lower level knowledge types; these are represented by the non-shaded boxes in Figure 7.3. In addition to these, the templates comprise few knowledge types that are not shown in the Figure above, and a completion field. The user needs to fill in the date of completion, and his/her name and signature. The completion field is of major importance in ensuring that the knowledge was captured by an appropriate person in each case. Traceability is essential in every sort of elicitation activity.

7.4.1 Product template

The product template was created in order to capture any information related to the product after a failure has occurred. Some of the fields of this template are *name*, *subsystem, components, application* and *failure.* As in every knowledge template, the product template comprises its *completion* details: *date, name* and *signature* of the person who completed it. Figure 7.4 shows the product template.

Product		
Name		
Subsystem	Name	
	Components *	
	Can be recycled	
	Issues faced	
* Components	Name	
	Serial number	
	Actual life	
	Expected life	
	Can be recycled	
	Issues faced	
Application	Used in	
	Specified for	
Failure	Code	
	Location	
	Component related	
	Subsystem related	
	Root cause	
	Actions after	
Completion	Date	
	Name	
	Signature	

Figure 7.4: Product template

A list of questions complements the product template and is given to the user before the completion takes place. This can help him/her to complete it quickly, and also be certain that s/he provides the right information for the corresponding template. The questions are:

- What is the name of the product that had a malfunction/failure?
- Is the failure/malfunction related to a particular subsystem?

    - If yes, what is the name of the subsystem? Which of its components are affected? Can the subsystem be recycled if it is totally damaged? Any other issues faced?
    - If no, go to the 'components' section.
- What are the names and serial numbers of the components that need to be replaced?
- What is the actual and expected life in the components that were replaced? This is needed in order for the designers to measure the difference and make any investigation needed when the components failed a lot earlier than were expected to.
- Can the replaced components be recycled? Any other issues faced?
- What was the application that the product was used in by the customer? Was the product specified to be used in a different application by the manufacturer?
- Is there any specific code used for the failure that occurred?
- Where did the failure happen?
- Was the failure related to any particular component or subsystem?
- Was the root cause identified?
    - If yes, please give a brief description.
- Which were the actions taken after the failure of the product?

7.4.2 Maintenance strategy template

The maintenance strategy template was developed to facilitate the capture of any information related to the maintenance strategy formed for a product. Some of the fields of this template are *name*, *recommended overhaul interval, resource* and *tooling.* As in every knowledge template, the maintenance strategy template includes its *completion* details: *date, name* and *signature* of the person who completed it. Figure 7.5 shows the maintenance strategy template.

Maintenance strategy		
Name		
Recommended overhaul interval		
Product	Name	
Facility	Name	
	Location	
Resource	Type	
	Name	
	Cost	
Tooling	Name	
	Availability	
	Issues	
	Cost	
	Lifetime	
Completion	Date	
	Name	
	Signature	

Figure 7.5: Maintenance strategy template

The maintenance strategy template is accompanied by a list of questions. These are as follows:

- What is the name of the maintenance strategy?
- What is the recommended overhaul interval by the product manufacturer?
- What is the product that follows the maintenance strategy described in the template?
- What is the name and location of the facility, where the maintenance strategy takes place?
- Which are the resources used? Are they people, equipment or documentation? And, if known, what is their cost?
- Is any tooling required in the maintenance strategy?
    - If so, please give details regarding its name, availability, cost, lifetime, and issues faced.

7.4.3 Service process template

The service process template was created for capturing any information with regards to a service process that a product needs to follow; for instance the Decontamination-Clean- Inspection (DCI) process. Some of the fields associated with this template are *name*, *steps followed, duration* and *tooling.* Similarly to the previous knowledge templates, the service process template has its *completion* details in the end: *date, name* and *signature* of the person who completed it. Figure 7.6 illustrates the service process template.

Service process		
Name		
Steps followed		
Duration (start to finish)		
Product	**Name**	
Facility	**Name**	
	Location	
Resource	**Type**	
	Name	
	Cost	
Tooling	**Name**	
	Availability	
	Issues	
	Cost	
	Lifetime	
Completion	**Date**	
	Name	
	Signature	

Figure 7.6: Service process template

The questions, specific to the service process template, are:

- What is the name of the service process?
- Could you describe the steps followed? What kind of tasks do they include?
- What is the duration of this particular service process?
- What is the name of the product that goes through the service process?

- What is the name and the location of the facility, where the service process takes place?
- Which are the resources used? Are they people, equipment or documentation? And, if known, what is their cost?
- Is any tooling required in the service process?
    - If so, please give details regarding its name, availability, cost, lifetime, and issues faced.

7.4.4 Training template

As identified in Chapter 4, training is part of SK. However, it is not directly related to the knowledge that designers need to access; thus, it is not included in the SKaD methodology. However, it is valuable for the service manager, who can monitor the training that his personnel have received. The training template can be filled in by a service engineer or the service manager and is illustrated in Figure 7.7.

Training		
Type		
Cost		
Time needed		
Location		
Participant	Name	
	Job role	
	Years of experience	
Issues faced		
Completion	Date	
	Name	
	Signature	

Figure 7.7: Training template

The training template can be used for the capture of all the information linked with training. Therefore, some of its fields are: *type, cost, location*, and *participant*. It also includes the completion field; there, the date of completion, along with the name and the signature of the person, who completed it, need to be added. The questions accompanying the training template are:

- What is the type of training?
  - ❖ For instance, is that a short course, a presentation or a hands-on teaching?
- What is the cost of the training?
  - ❖ What does it include (accommodation, fees, transportation)?
- What is the time needed for the completion of the training?
- Where does the training take place?
  - ❖ Is it in-house or outsourced?
- List the participants in the training, including name, job role, and years of experience.
- Are there any issues faced during the training?
  - ❖ Was the material comprehended?
  - ❖ Did the participants state that the duration of the training was sufficient to familiarise themselves with the new concepts?

7.4.5 Service facility template

In Chapter 4, the installation environment of a service facility was identified as an important aspect that the designers need to be aware of. This is the result of various factors affecting the servicing of a product, such as the floor space required, and the average humidity and temperature in the region where the facility is located. Consequently, before a product gets designed, the designers need to consider the aforementioned factors in order to be able to define its features.

Figure 7.8 shows the service facility template.

Service facility		
Name		
Location		
Floor space		
Humidity (%)		
Temperature (°C)		
Utilities required		
People	**Name**	
	Job role	
	Years of experience	
Product	**Name**	
Issues faced		
Completion	**Date**	
	Name	
	Signature	

Figure 7.8: Service facility template

The questions designed to facilitate the completion of the service facility template are:

- What are the name and the location of the service facility?
- What is the required floor space (m^2) for the installation of each product?
- What are the average humidity (%) and temperature (°C) values at the location where the facility is located?
- Which are the utilities needed (electricity, water supply)?
- List the details of the people, who are based at the facility: name, job role and years of experience.
- What is the product (s) serviced in the facility?
- List any issues faced at the facility regarding the installation environment, the utilities, any accidents or near misses.

7.4.6 Service organisation template

The main target user of the knowledge types, that are included in the service organisation template, is the service manager. Some of the fields are: *facility, spares,* and *logistics*. There is also a 'completion' field, which comprises the date, name, and signature of the person who filled in the template.

Service organisation		
Facility	Name	
	Location	
Spares	Name	
	Availability	
	Cost	
	Serial number	
Logistics	Type	
	Receiver (name + location)	
	Sender (name + location)	
	Cost	
	Issues faced	
Completion	Date	
	Name	
	Signature	

Figure 7.9: Service organisation template

Figure 7.9 illustrates the service organisation template. The questions developed to accompany it, are:

- What are the names and locations of the facilities belonging to the service organisation?
- List the existing spares (name, serial number, availability, and cost).
- What are the types of logistics involved?
    - When a product is transported, what are the name and the location of the sender and the receiver? What is the cost?
    - Any issues faced? For instance, is the packaging used appropriate for the type of transportation? Are there any occurrences mentioned when the product was received having been damaged?

7.5 SKaD framework development

This Section describes the resulting SKaD framework. Figure 7.11 graphically depicts the framework structure. The developed framework is the outcome of the combination of the ***SKaD methodology*** (Figure 7.2), the ***knowledge templates***, and the ***tools*** developed by the author, as presented in ***Chapter 5 and 6***.

Initially, the knowledge templates and their associated fields have to be filled in (mainly by service engineers and occasionally by the service manager). The questions of the templates can be used in order to guide the users and facilitate the, population with data, process. The information provided needs to be as accurate and comprehensive as possible.

The next step involves the use of the service knowledge audit tool (presented in Chapter 5), where the designers define the DR, and then they map them with the SK types; SK is already captured within the knowledge templates. At this step, gaps in SK can be identified. Additionally, the communication between designers and service personnel is enhanced, since the effective use of the tool requires their collaboration.

Upon the completion of the knowledge templates and the usage of the knowledge audit tools, the designers can make any necessary amendments to the design process in order to incorporate lessons learnt from past projects, and integrate service issues within the product design. Following this, they need to define the DF and check how the DF map with SK using the tool developed in Chapter 6.

In addition to this, the service manager can use the SKaD framework so as to populate the relevant templates with data or access the SK that has already been captured. Moreover, the use of the tool, which links the SK types and the SF and was developed in Chapter 6, can be integrated within the framework and used by the service manager. S/he is enabled to utilise the SK captured in the templates and check which of the knowledge types are needed for the realisation of each SF. The aforementioned process of the SKaD framework usage is presented in Figure 7.10.

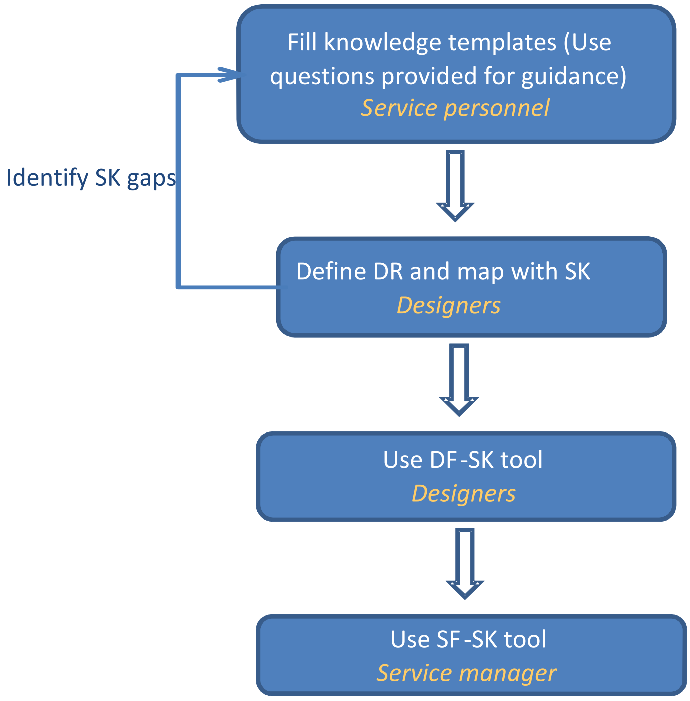

Figure 7.10: Usage of SKaD framework

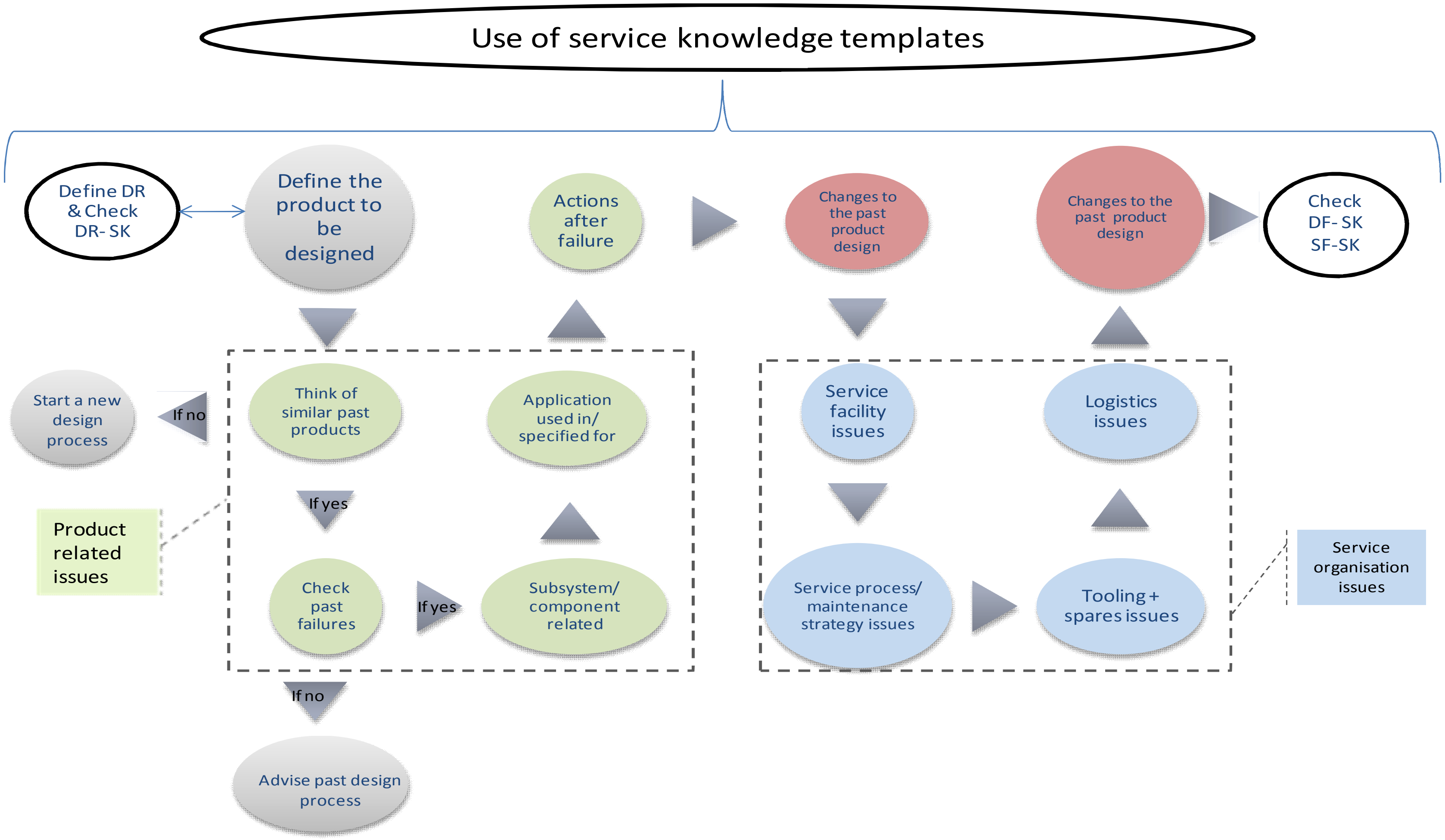

Figure 7.11: SKaD framework structure

7.6 Implementation in a database

The author, having considered the possibility of the SKaD framework for industrial implementation, decided to develop a database using Microsoft Access 2007 software. This specific software was selected because, unlike the Protégé software, the former is popular in the industrial environment. While Protégé is a well-accepted tool by practitioners in academia, experts in industry do not seem to be familiar with its concepts and usage. At this point, it needs to be emphasised that the author developed the main structure, and the existing relationships between the tables of the database; due to time restrictions, only three scenarios (i.e. product failure, training, and service facility) were created to demonstrate how the database can be used.

The knowledge types, as captured in Chapter 4, were used for the creation of seventeen main tables. The tables represent the higher level SK types; whereas, the table fields denote lower level knowledge types. These are shown in Table 7.2.

Tables	Fields
Application	ID, name, used in, specified for, product ID
Component	ID, name, serial number, price, actual life, expected life, recycled, issues faced, subsystem ID
Failure	ID, code, location, actions after, root cause
Logistics	ID, type, name, receiver name, receiver location, sender name, sender location, issues faced, cost, service organisation ID
Maintenance strategy	ID, name, recommended overhaul interval, product ID

Person	ID, job role, name, years of experience, location
Product	ID, name
Product attribute	ID, name, subsystem related, component related
Resource	ID, name, resource type ID, cost, service organisation ID
Resource type	ID, name
Service facility	ID, name, issues faced, service organisation ID, floor space required, temperature, humidity, utilities required, location
Service feature	ID, name, SF-SK
Service organisation	ID, name
Spares	ID, name, availability, cost, service organisation ID
Subsystem	ID, name, recycled, issues faced
Tooling	ID, name, cost, issues faced, availability, lifetime
Training	ID, type, cost, time needed, issues faced, service organisation ID

Table 7.2: Tables and fields of the database

As it can be noticed in Table 7.2, the field ID is common in all the tables. This happens due to the fact that the ID is important for technical reasons in the database; its usefulness lies mostly to the fact that it is used in the relationships between the tables. The tables' content also reflects the classes and subclasses of the developed ontology; however, few differences can be spotted reflecting the amendments that have been made to the knowledge types after the experts' suggestions. These are summarised in Table 7.3. The difference in knowledge types is illustrated by different colour. However, 'tooling' exists in the ontology, as a subclass of 'service equipment', which is part of the 'service facility' class. Also, 'application' and 'failure' are part of the 'operation' in the ontology. 'Resource' and 'resource type' are represented in the ontology by more specific terminology, i.e. human resources needed and utilities. Hence, there are differences due to the use of slightly different terminology; the real knowledge represented remains the same.

Ontology knowledge types	Database knowledge types
▪ Product ▪ Product attribute ▪ Subsystem ▪ Component ▪ Service process ▪ Maintenance strategy ▪ Operation ▪ Service organisation ▪ Training ▪ Personnel ▪ Facility ▪ Spares ▪ Logistics ▪ Service feature	▪ Product ▪ Product attribute ▪ Subsystem ▪ Component ▪ Tooling ▪ Maintenance strategy ▪ Application ▪ Failure ▪ Service organisation ▪ Training ▪ Person ▪ Resource ▪ Resource type ▪ Service facility ▪ Spares ▪ Logistics ▪ Service feature

Table 7.3: Knowledge types in the ontology and the database

After the creation of all the database tables, the author created the relationships among them. To do this, all the findings from the case studies were considered. A major consideration during the creation of relationships process was the existence of relationships between the SK types, as these were represented in the ontology. There are three types of relationships that can exist in a database: one-to-one, one-to-many, and many-to-many. In order for the many-to-many type of relationship to be created, an additional table needed to be created to link the two tables, which were linked in reality. As a result, in the database relationship diagram (Figure 7.13) there are more tables than the ones shown in Table 7.2. However, these tables exist for practicality reasons; therefore, they are not part of the SK types.

An example of how the author dealt with the *many-to-many* relationship issue can be seen in Figure 7.12.

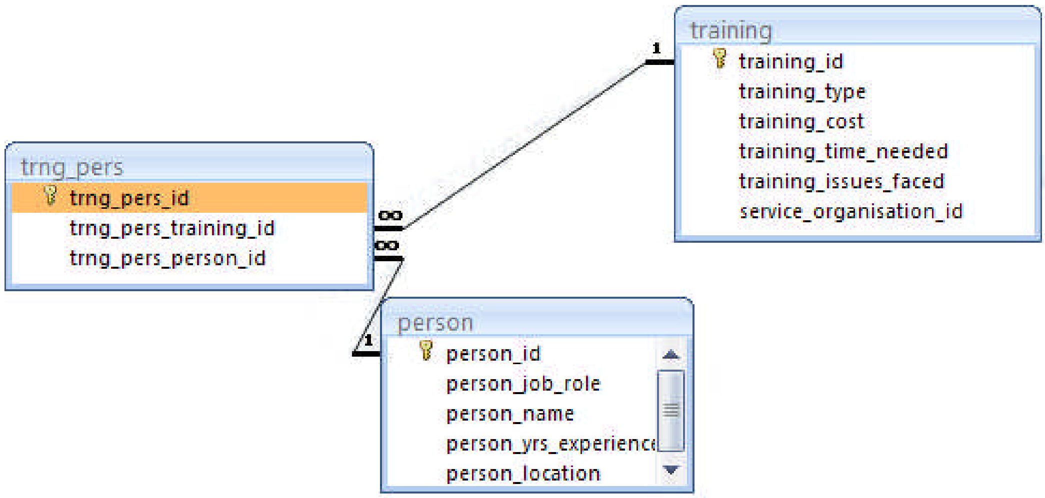

Figure 7.12: Training-person relationship

Figure 7.12 illustrates the relationship between 'training' and 'person'. Since the relationship between them is many-to-many, the author created the additional table 'trng_pers'. The fields of this table are: 'trng_pers_id', 'trng_pers_training_id', 'trng_pers_person_id'. Therefore, the ID is again the main field (*primary key*), and the two other fields are the primary keys of the two tables which are connected, i.e. 'training_id' and 'person_id'.

Figure 7.13 graphically depicts all the relationships that are existent within the database. The number of them is quite substantial; this indicates that the majority of the SK types are interrelated. Hence, the combination of two or more leads to a meaningful set of knowledge types, which can be used by designers and service personnel in the execution of their tasks.

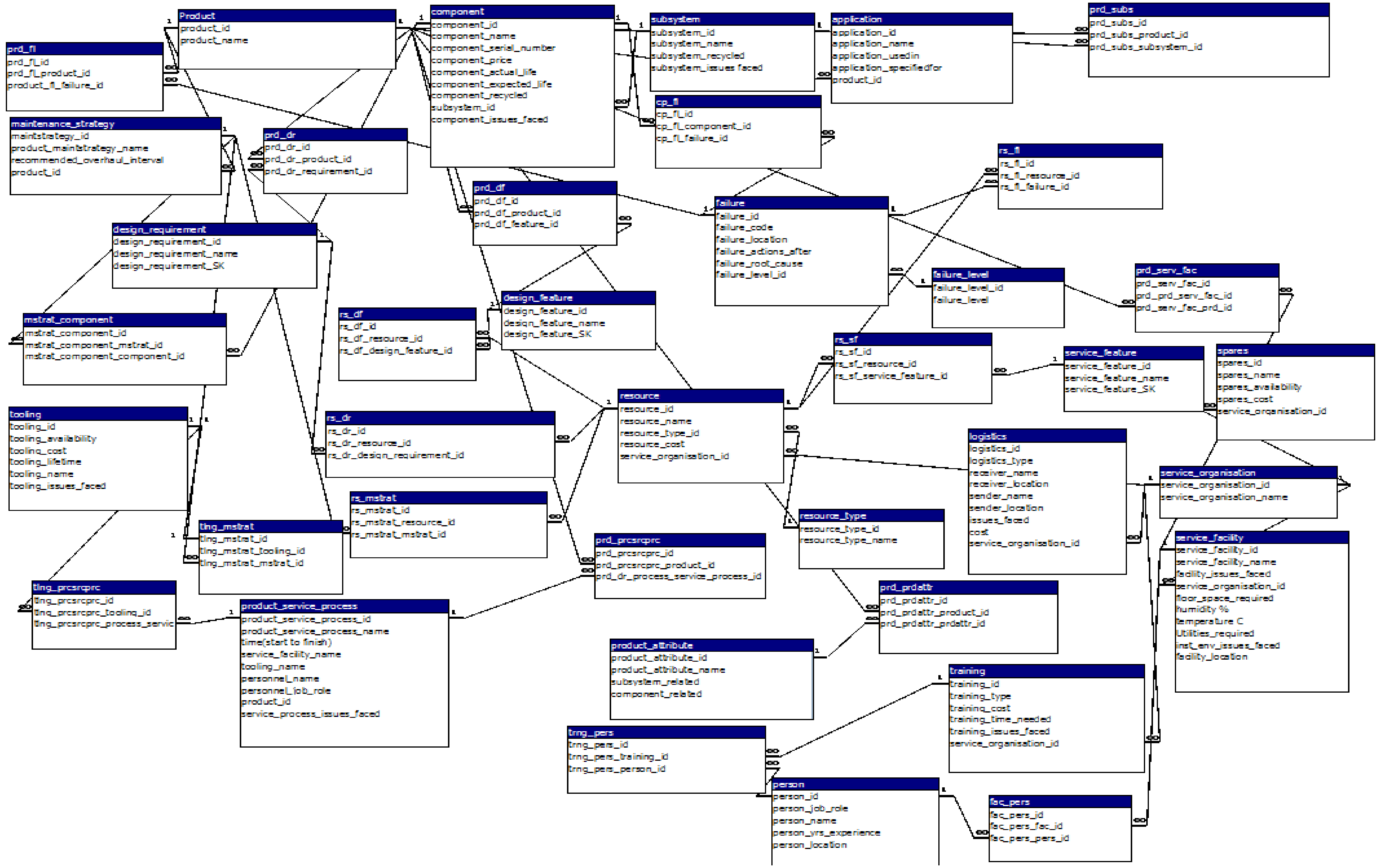

Figure 7.13: Database relationship diagram

7.6.1 Use scenarios of the database

As described in Section 7.6, due to time restrictions the author developed three scenarios, which illustrate how the database can be used. The first one is related to product failure and is shown in Figure 7.14.

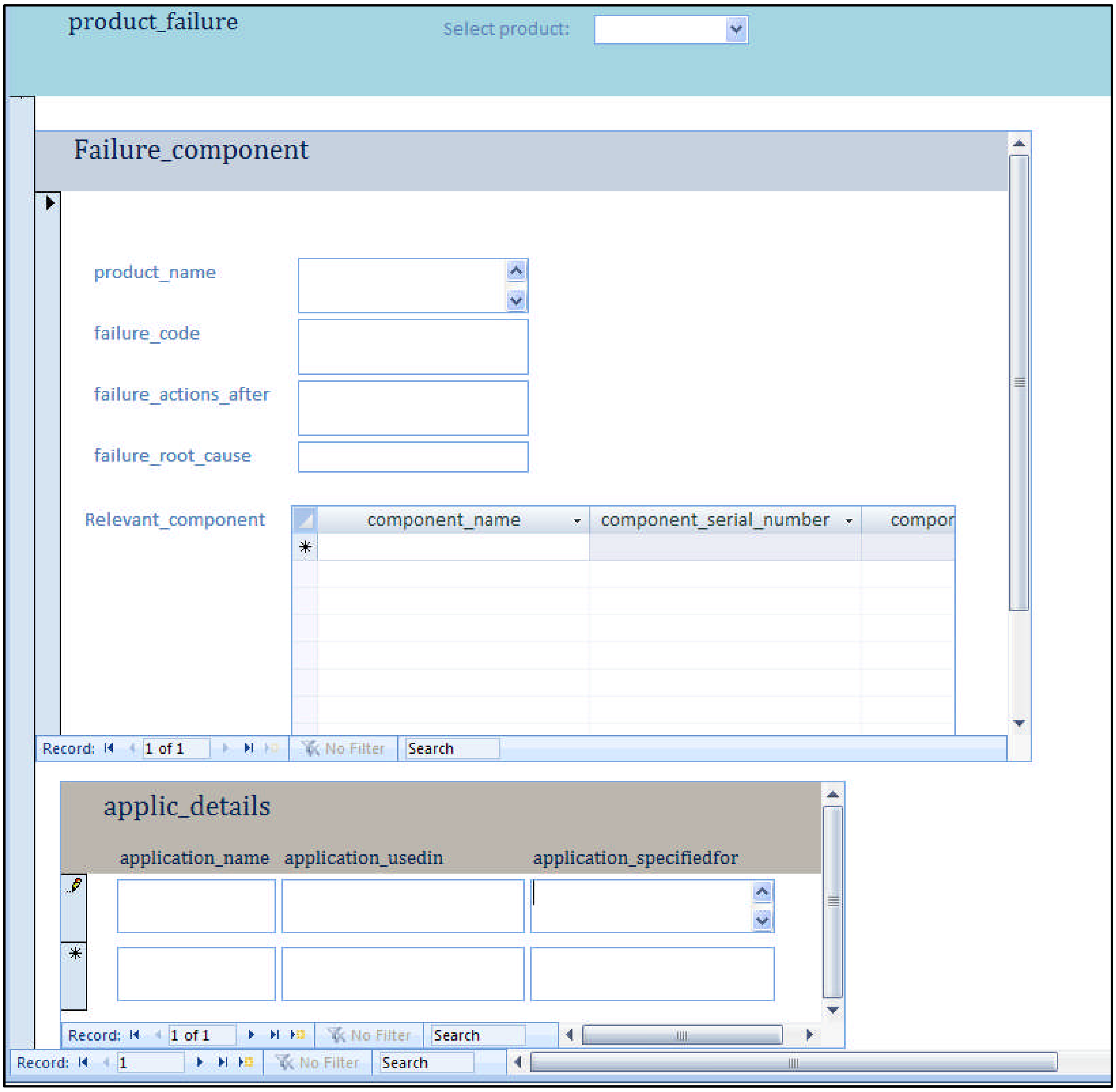

Figure 7.14: Product failure form

The form developed aims at providing information about a product failure. The *target user* groups in this case are the *designers* and the *service manager*; the data in the form needs to be populated by the service engineers. As it can be seen in Figure 7.14 the user can select the product, which he is interested in checking the failures. As soon as the product is selected, details of the failure are available: the failure code, actions taken after the occurrence of the failure, the failure root cause, and the related component. With regards to the component, the user is enabled to access additional information (in the case that the failure is related to a particular component). This information is: component name, serial number, actual and expected life, recyclability of the component. Finally, details regarding the application, where the product was used in, are accessible; the application name along with the application, where the product was used in, and the one, where it was specified to be used in, can be found in the form. Therefore, the user can evaluate whether the failure was caused by a customer's fault (using the product in a non-specified application).

The second scenario is about the training of a person working in the service organisation and is illustrated in Figure 7.15.

The form endeavours to provide information regarding the training of an employee within the service organisation. The *target user* is the *service manager*; the data in the form needs to be populated by him/her or the service engineers, who undertake the training. The resulting form enables the service manager to select a person and then, have access to details about both the person and the training undertaken. The personal details are: person id, job role, name, years of experience, and location. With reference to the training, the service manager can retrieve information about the training type, cost, time needed, and issues faced during the training.

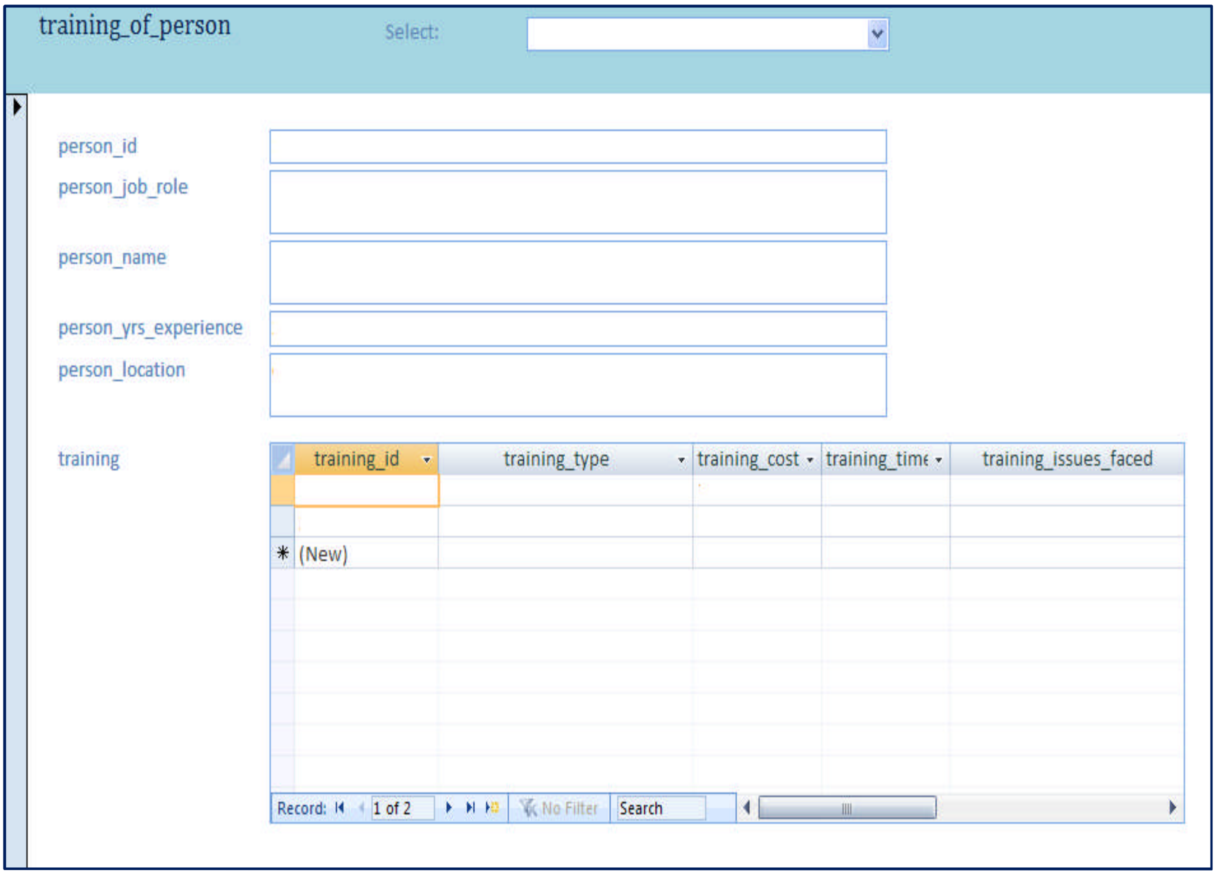

Figure 7.15: Training form

The third scenario is created in relation to the service facility of a service organisation (Figure 7.16) and the *target user groups* are the *designers* and the *service manager*. The data needs to be populated by the service manager of the service facility. The form, which is developed by the author in the Access software, allows the user to access information about the facility installation environment: location, humidity, temperature, and also information regarding issues faced within the service facility. It should be mentioned that the user can select which service facility s/he wants to get information about. In addition to the installation environment details, the user can see the products that are serviced in the selected facility. Finally, the details of the employees of the service facility are also included in the form. These are: person id, name, job role, and years of experience.

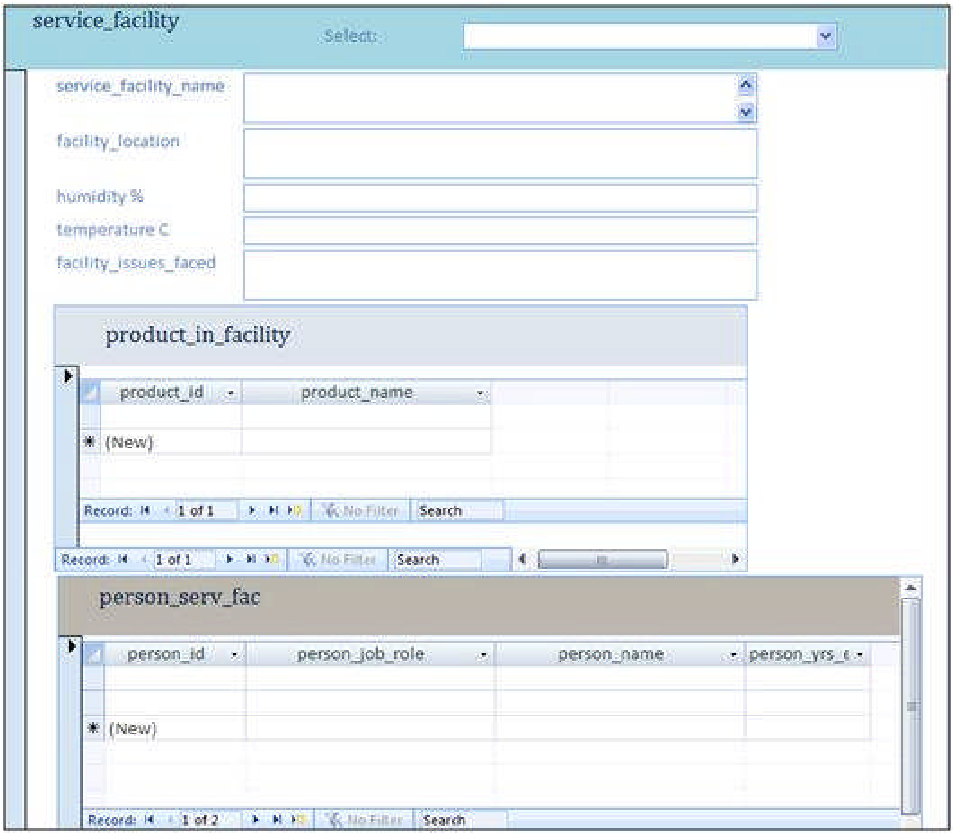

Figure 7.16: Service facility form

7.7 Summary and Key Observations

In this Chapter, the development of the SKaD methodology was presented. In addition to this, it was shown how the combination of the methodology, the developed knowledge templates and the tools to map DR, DF and SF with the SK types form the SKaD framework. This framework can enable designers to access service knowledge; hence, improve product design by considering issues about the product performance as recorded by the service personnel.

In Section 7.1, the reasons for developing the SKaD methodology were presented, along with the main parts comprising the SKaD framework.

In Section 7.2, the author described the requirements for the SKaD framework. These were divided into two main categories:

- Generic: usage simplicity, capture/re-use of knowledge, generic approach, flexibility, and
- Specific to the research findings:
    - ❖ The designers should access only those relevant to their enquiry SK,
    - ❖ Use of language: the studied organisations operate worldwide; therefore, there are occasions, where a different term is used to describe the same process depending on the location.
    - ❖ Different users: each user group has its own requirements.

Section 7.3 presented the development of the SKaD methodology in detail. The methodology consists of two core parts: a) issues related to the product, and b) issues linked with the service organisation. When the designers take them into consideration, changes in the product design may ensue.

In Section 7.4, the creation of the knowledge templates was explained. In total, six templates were formed; their purpose is to capture and re-use SK regarding the service organisation, the service facility, the maintenance strategies, the product, the service process, and the training of the service personnel. The templates are also accompanied by a set of generic questions, which can be used in order to guide the user how to capture or re-use the knowledge.

In Section 7.5, the SKaD framework was presented as the outcome of the combination between the SKaD methodology and the knowledge templates in conjunction with the tools developed in Chapters 5 and 6. Conclusively, the framework implementation in a database using the MS Access software was shown. Seventeen main tables were created in the database; the tables and their fields represent SK types. Moreover, the relationships among them were formed, and three usage scenarios were illustrated for demonstration purposes. The scenarios display the types of knowledge that the users can access through the database with regards to product failure, training, and service facility.

In the following Chapter, the framework will be applied onto two case studies in order to assess the effectiveness to capture and re-use service knowledge. Moreover, additional validation sessions with industrial experts on several themes of this study will be presented to illustrate the credibility of the research.

8 Validation

8.1 Introduction

In Chapter 7, the author presented the development of the SKaD methodology, the creation of service knowledge templates, and the resulting SKaD framework. The latter is a combination of these two elements along with the tools developed in Chapters 5 and 6. Moreover, the SK types were implemented using the MS Excel and MS Access software. However, due to time restrictions that the author faced, only three scenarios were created in terms of the database usage. These were used to demonstrate the way in which the database can be used by service and design personnel when:

1. They want to get information regarding a product failure, the related failed component(s) if there are any, and the application where the product was used in.
2. They are in need for knowing details related to a service facility, i.e. its installation environment, the products that are serviced, and the personnel working in the facility.
3. They seek information about the training that a specific employee has received.

The purpose of this Chapter is to describe the final validation sessions that took place at the concluding stage of this research. Figure 8.1 is a graphical illustration of the contributing elements to the overall validation. The latter was split into four sessions:

- The validation of the final SK types, as captured and presented in Chapter 4.
- The final validation of the DR-SK tool and the ontology structure with experts at Company 1.
- A feedback session on the SF-SK and DF-SK tools with a knowledge management specialist, a design engineer, and a business development manager at Company 4.

- The validation of the service knowledge templates, which proves the effectiveness of the proposed SKaD framework, through their application on two case studies.

At this point it should be mentioned that the validation took place in two stages: a preliminary validation immediately after the development of each tool or finding, e.g., SK types, and a final validation of all the findings and of the overall framework into case studies.

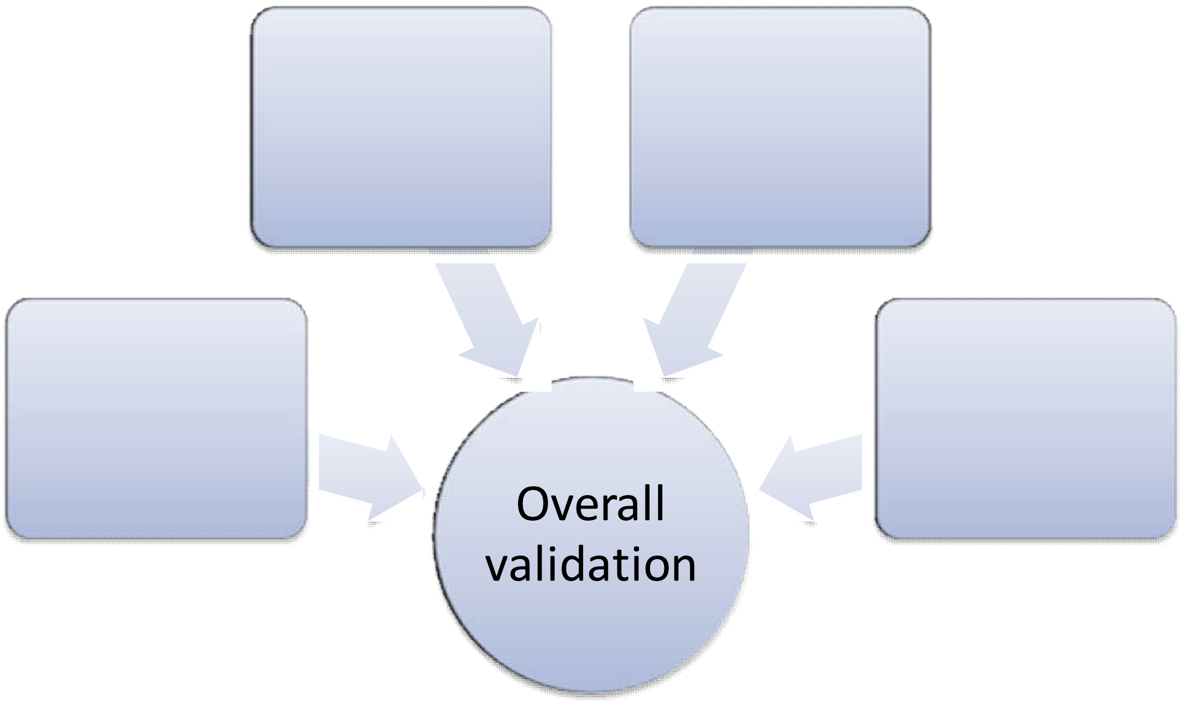

Figure 8.1: Elements of the overall validation

8.2 Validation of the final SK types

As a last step of validation for the SK types, the author presented the finalised list (as in Chapter 4) to Company 1 and 4 experts. Overall, two interviews were held; the first one was conducted at Company 1 with the service manager, and the second one took place at Company 4 with a knowledge management specialist. Each interview lasted for one hour; the author had forwarded the SK diagram to the interviewees prior to the interview.

The first interviewee stated that the knowledge types, as captured by the author, represent a comprehensive and well-organised set, which will be valuable to designers when they first attempt to access SK.

The second interviewee found the knowledge types representative of the SK existing at Company 4; however, he mentioned that 'packaging' and 'password protection' may not be relevant in an aerospace setting. Moreover, he suggested that the author divides the knowledge types in three levels: business, product, and component level. Therefore, the author proceeded with the recommended classification. The SK types, as classified in three levels, according to the second interviewee's suggestion are presented in Figure 8.2.

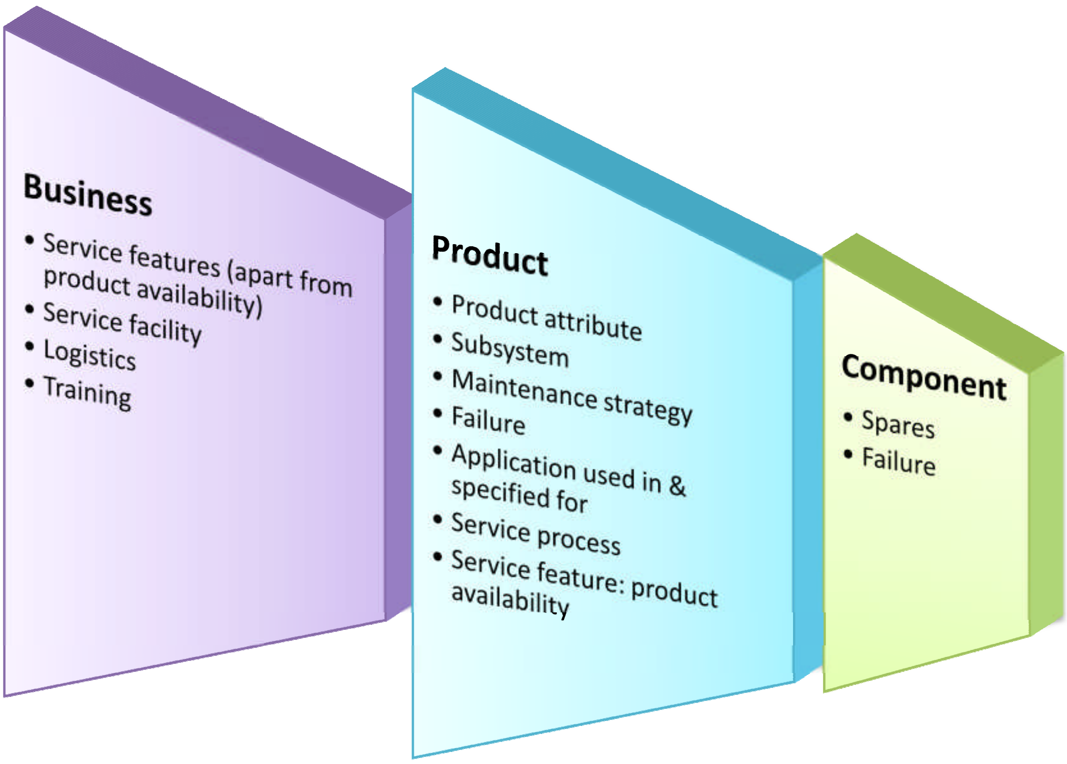

Figure 8.2: SK classification in 3 levels

8.3 Final validation of the DR-SK tool and the ontology structure

This Section describes the final validation session about the DR-SK tool and the ontology structure, which took place at Company 1. The session was divided into two parts; the first part aimed at validating the knowledge audit tool (DR-SK) and lasted two hours. The participants were (see Table 8.1):

Job roles	Years of experience
On-site manager for Europe	9
Service marketing manager	19
CAD designer (1)	10
Designer	13
CAD designer (2)	5

Table 8.1: Participants in the final DR-SK tool validation

The participants were selected after careful consideration by both the researcher and the service marketing manager. The two criteria for the selection were the experts' background (both designers and service personnel were needed) and their previous involvement with the products that had been chosen to be used in the case study.

During the session, the author gave a brief description of the work that had been undertaken with the collaborating company and presented the service knowledge (DR-SK) audit tool. Then, further explanations were given to the participants regarding the session expectations. It should be mentioned that a document describing the aim of the session and the main results of the research had been sent to the experts prior to the meeting, so that they have the opportunity to prepare themselves.

After the introduction, the experts described their background and then the tool was presented. When the presentation ended, the experts were asked to:

- comment on the structure of the tool
- describe its advantages and disadvantages, and
- give recommendations for its improvement (see Appendix N for the RP).

DR-SK tool

The **on-site manager** highlighted that the list of the SK types is comprehensive and very useful. He also made comments on specific SK types, which, in his opinion, are critical. Firstly, the component ID should be recorded and also, the information about the spares should be available when the product is launched. Then, he mentioned that serviceability is a very important factor especially when the product is integrated in a larger system (e.g. pump and abatement), because the change of the oil can be quite challenging and also the check of the control module may be difficult too. Regarding the password protection, it was mentioned that the company uses it to restrict the amendment of the pump parameters; thus, it is crucial to include it in the SK types. His last comment was related to logistics; at the moment, when new products are launched, logistics face difficulties in finding out where the pumps are; and as a result, they do not know how much stock they should have and where. So, logistics is another important aspect of service knowledge.

The knowledge audit tool had already been presented to the **service marketing manager** in a previous session. His overall impression was positive and he focused mainly on two aspects: the addition of the 'competitor knowledge' in the list of requirements, and the implementation of the tool within the collaborating company. The author had not included the 'knowledge of the competitor'; however, it was pinpointed that it should become an additional item in the list of requirements, because the company needs to make sure that their product is competitive and to explore how easy would be for the competitors to take on the service business. This opinion was adopted by the rest of the experts. As a result, the researcher added the 'competitor knowledge' in the list of requirements. Moreover, as far as the implementation of the tool is concerned, it was stated that due to the software used

(MS Excel) it will be easy for every person at the company to have it installed and start to use it; they need to consider though, where exactly they should use it. The suggestion from the author was that the tool should be used within the NPD team at the first meetings for the development of a new product so that they gain an overview of the relationship between the DR and the SK types.

The **on-site manager for Europe** stated that at the moment a big amount of information is not available at the right time and the tool is going to be helpful in this issue, since it encompasses all the SK types that are needed by the service engineers.

The **CAD designer (1)** commented more on the list of requirements rather than on the SK types. In general, he said that the big advantage of the tool is that it can be used as a 'tick list' and give an overview of the requirements both in terms of design and service. According to him, after identifying gaps in knowledge, tasks could be assigned to various people, so that they either find the knowledge that is already stored, or they start storing the service knowledge needed for a design requirement. He also considered the list as comprehensive and applicable to every product in the company. Additionally, he stressed the importance of the different use of words, e.g. safety and security, by people all around the globe; therefore, he suggested that a brief description of the requirements should be carefully created by a responsible team, before the tool starts to be used.

The **designer** gave few general comments on the tool. Firstly, he mentioned that the tool seems very useful in business nowadays, since in every project many different disciplines need to collaborate and this can be a challenge most of the times. The tool would facilitate this process, since it brings together and enables the collaboration between designers and service engineers. Secondly, he suggested that the tool should show 'need knowledge' when the knowledge type is related (strongly or loosely) with the DR, but the availability of the knowledge is medium. As a result, the researcher changed it in the functions of the audit tool.

The **CAD designer (2)** agreed with the rest of the participants on the usefulness of the tool and he made just two remarks. The first one was that the tool is going to help filling the gaps in SK that they already have, and the second one was related to a specific DR. He suggested that in the 'materials, processes and parts' use', the word 'processes' should be substituted by 'applications'. The other experts agreed, so the researcher changed it in the list of requirements.

Ontology

The second part aimed at validating the structure of the developed ontology and lasted one and a half hours. There were five participants and a separate meeting, which lasted one hour, was held with the company's reliability expert. The participants' job roles, and their years of experience are shown in Table 8.2 as follows :

Job roles	Years of experience
Service marketing manager	19
CAD designer (1)	10
Designer	13
CAD designer (2)	5
On-site manager, Germany	12
Reliability expert	20

Table 8.2: Participants in the final ontology structure validation

The author explained the process via which the ontology was created, its purpose, and allowed half an hour for the interviewees to explore the ontology themselves. Subsequently, she asked the participants to comment on its structure, mention advantages and disadvantages of its use, and highlight the challenges for its implementation (see Appendix O for the RP).

The **service marketing manager** thought that, overall, the structure is clear and comprehensive. He suggested to change the word 'cost', wherever it was mentioned, and replace it with the word 'price', since the description in the ontology is related to the amount of money that the customer pays to the company when s/he buys the spares or the products. He also commented on the spares' availability; some of the spares are not available for the customers to buy; they are purchased internally in order for the service engineers to use them in on-site maintenance. Considering the implementation of the ontology within the company, he highlighted the issue of creating a common interface for design and service personnel, because at the moment these two disciplines use different tools; and if the ontology is created to be used by both groups, it needs to be transformed so that the data, that the two groups store in their systems, can be imported in it. The positive point is that the Protégé software, which has been used for the development of the ontology, does not require a licence; it can be downloaded for free by the users.

The **CAD designer (1)** emphasised the importance of the ontology for the structuring of SK within the service department. However, he mentioned that due to the ontology's capability to capture failures and issues, it could be used by designers in order for them to avoid past mistakes and enhance future product performance. He finally highlighted that the language used should be as simple and clear as possible taking into account that the ontology will be used by the company's personnel around the globe, whose first language might not be English. Thus, the author made an effort to include simple and clearly defined terms in the ontology.

The **designer** stated that the ontology structure is comprehensive; however, he suggested that the fields, which are aimed to be completed by service engineers, should be reduced to the minimum number and be described in a simple language, mainly due to the fact that the service personnel is extremely busy and there is not enough time for report completion. Also, he added that it would be useful if track of the actions taken (e.g. amendments or population with data) by each of the people accessing the ontology is kept; thus, there will be a control of its use. Finally, he thought that the implementation of the system is possible, but it needs to be integrated within the software that the company has already in place.

The **CAD designer (2)** made some general comments; according to him, a system like the one developed by the author would help the structuring of the service department and give a better overview of the issues and failures of the pumps. However, he suggested that its implementation can be an issue, since it needs to be integrated with at least the SAP software that the service personnel use at the time being.

The **on-site manager (Germany)** agreed with the other participants that the ontology includes a comprehensive range of SK types, and this would enable the designers to access data and information that were not able to when the SK was unstructured. However, he expressed his concerns regarding the ontology implementation, since the employees are not familiar with the Protégé software and such an implementation would require additional training.

The **reliability expert** said that the structure seems to cover the most important aspects of a product in service. In his opinion, the biggest advantage of the system is that it can give an overview of the issues faced and the failures, as well as other issues that the customer and/or the service engineers face. He also stated that such a system would be more beneficial for products at the early stages of their development, because at this point the need for information about previous issues and the solution given is increased. As far as the use and implementation of the ontology is concerned, he pinpointed the issue of finding the suitable people entering the data into the system and maintaining it.

Summary of feedback

As far as the DR-SK tool is concerned, the overall impression of the interviewees was that it is a useful tool, which can enhance the collaboration between designers and service engineers. It was also mentioned that its implementation within the organisation is relatively easy due to its development in MS Excel. Overall, some minor amendments related to the SK types and the design requirements were suggested.

With regards to the ontology, the interviewees stated in general that its structure is clear and comprehensive. Moreover, they believe that its implementation is possible, since no licence is required for the Protégé software. On the other hand, the drawbacks of the ontology are that:

- It will need to be integrated with the SAP software that Company 1 has already in place.
- The majority of the employees are not familiar with the Protégé software; therefore, additional training will be required.
- The creation of 'classes', 'subclasses', 'slots', and 'instances' can get complicated. For instance, a subclass 'inherits' the slots of its class, which are sometimes not absolutely relevant; thus, difficult to complete by service engineers. More specifically, a product (class) has a failure recorded (slot). A product attribute (subclass of product class) will also have the same slot inherited merely by its class (i.e. product).

8.4 Feedback on the SF-SK and DF-SK tools

The SF-SK and DF-SK tools were presented in Chapter 6. This Section aims at presenting the feedback given on them by experts at Company 4 (see Table 8.3 for their job roles and years of experience).

Job role	Years of experience
Knowledge management expert	24
Design engineer	16
Business Development Manager	25

Table 8.3: Participants in the final validation of the SF-SK and DF-SK tools

The experts were familiar with the author's research, and with the development and usage of the tools. A face-to-face interview, which lasted for two hours, was conducted. Its outcome was the provision of feedback for both of the tools concerning their validity and implementation. Prior to the interview, the Excel sheets of the tools had been sent to the interviewees.

SF-SK tool

The interviewees were asked by the author to comment on the list of SF, the top five SK types identified for each of the SF, and finally the benefits of the developed tool. Overall, they thought that the list of SF was comprehensive and could be applicable to a range of manufacturing industries, since the terminology used is generic. However, they remarked that the terminology would be confusing for the user of the tool without the explanation of each of the SF by the author. The latter explained that the list of SF was the amalgamation of industrial findings and a literature framework; nevertheless, there were definitions provided for each of the SF, since the industrial practitioners did not seem familiar with the terminology used in the literature. At a more detailed level, they stated that the empathy is just one of the elements that differentiate from the competitor. Additionally, in their opinion, the difference between actual and expected life is not a necessary SK type for the realisation of the 'reliability' SF, since this SF refers to the ability of the organisation to provide the agreed with the customer service and is not directly related to the product/component life. Finally, they said that the tool could help the service department, when the organisation creates tailored to the customer service requirements. Then, the tool could be used as an initial checklist by the service personnel in order for them to identify the SK types that they need for the realisation of the SF.

DF-SK tool

The author asked the experts to comment on the validity of the strongest links identified between the DF and the SK types. Since one of the interviewees was a knowledge management expert, and the second was a business development manager, they pointed out that DF are not their area of expertise; hence, they did not make any specific comments on the DF list itself. Nevertheless, there were observations made concerning the relationships between the DF and the SK types. Firstly, ‘resources needed’ were a recurring knowledge type needed for the realisation of the majority of DF. This fact makes the right allocation of resources crucial within the organisation. Secondly, the experts noticed that the product type is an influencing factor on the DF; thus, they expressed the view that the DF list might significantly change, when the product to be designed is radically different from a previous family/range. Thirdly, the experts showed their contentment regarding the inclusion of recyclability within the SK types, because nowadays organisations take environmental impact into serious consideration. In addition to the general comments, the design engineer mentioned that the DF list used in the DF-SK tool is generic; however, his view was that the list would need to be adjusted according to the requirements of each project. This would result in the addition or exclusion of some of the DF that are currently included in the list.

8.5 Validation of the SK templates- Case study (Company 1)

This Section provides a description of the case study that was carried out at Company 1 and aimed at getting validation results regarding the SK capture templates developed by the author (as presented in Chapter 7). The product selected for the case study was Product 1 (see Figure 4.2), since the author was already familiar with its maintenance, service issues, and overall performance. Also, its involvement was substantial at every stage of the research; therefore, validating the templates with the use of relevant to Product 1 data was found to be the most appropriate approach. Figure 8.3 shows the process followed for the validation exercise at Company 1.

The author, after having prepared the SK capture templates, had to forward these along with the questions that accompany each one to the relevant person for completion. For this purpose, an experienced service engineer was selected based on the availability of resources and the main contact's suggestion (Service marketing manager at Company 1). It was described that the templates would be used to capture service knowledge related to Product 1. The author contacted the service marketing manager and the latter provided further explanations about the research project to the service engineer. However, only the 'product' and the 'maintenance strategy' templates were aimed to be completed by the service engineer.

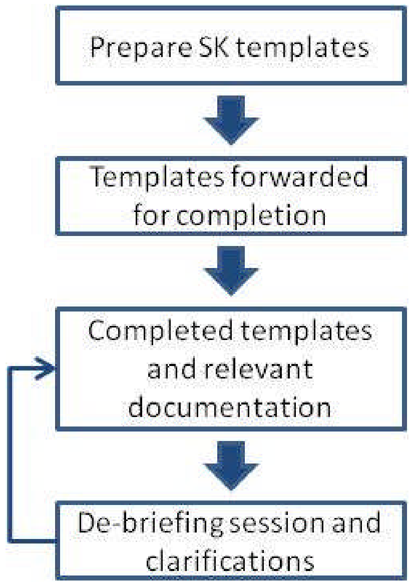

Figure 8.3: Validation process at Company 1

The rest of the templates were filled in by the service marketing manager and the author via the use of the relevant product documentation and data captured from interviews throughout the duration of this research. Regarding the data captured from the interviews conducted with US personnel, the lead technician validated the completion after it had been done by the author. In total, the participants at this stage of the research (Company 1) are presented in Table 8.4.

Job role	Years of experience
Service engineer	8
Service marketing manager	19
Lead technician (US)	17

Table 8.4: Participants in the templates' completion (Company 1)

8.5.1 Templates' completion

Product template

In the first template, the service engineer was asked to complete the fields considering Product 1; then, he was asked to provide the relevant data based on one of the failures that had occurred in the past. The completed template is presented in Figure 8.4.

As it can been seen on the template, the service engineer filled it in with data related to a booster failure that occurred in Product 1. The 'name' field is covered due to confidentiality issues. Moreover, the service engineer could not provide details about the root cause of the failure; he mentioned that normally a root cause analysis (RCA) is not carried out unless it is required by the customer. It was added by the service marketing manager that there are three levels (See Section 7.1) of pump strip reports (the term is used to signify the reports created after a pump failure).

Product		
Name	Product 1	
Subsystem	**Name**	see component
	Components *	booster
	Can be recycled	n/a
	Issues faced	n/a
*** Components**	**Name**	booster
	Serial number	unknown
	Actual life	7 monhts
	Expected life	2-3 years before major overhaul
	Can be recycled	yes
	Issues faced	no other issues before the failure
Application	**Used in**	Load lock (clean application)
	Specified for	clean to medium-duty processes
Failure	**Code- description**	n/a- booster problem
	Location	Germany
	Component related	booster
	Subsystem related	n/a
	Root cause	unknown
	Actions after	pump replacement
Completion	**Date**	Jun-09
	Name	[redacted]
	Signature	

Figure 8.4: Product template (completed)

Service process template

The service process template was filled in by the author using the data captured from the interviews conducted with the personnel in the US service centre. Then, few details, which were missing, were completed by the service engineer and the service manager. The template, once fully completed, was verified by the lead technician in the US. Figure 8.5 depicts the service process template.

Service process		
Name	Build process	
Steps followed	see diagram below	
Duration (start to finish)	around 3 hours	
Product	**Name**	Product 1
Facility	**Name**	Tempe
	Location	USA
Resource	**Type**	service engineers, documentation
	Name	Product 1 Instruction Manual
	Cost	unknown
Tooling	**Name**	inspection, assembly and disassembly tools, TDS (Tool Drawing System) tools, hydraulic press to remove the shafts and the rotor
	Availability	ok
	Issues	n/a
	Cost	unknown
	Lifetime	unknown
Completion	**Date**	Jun-09
	Name	[redacted]
	Signature	

Figure 8.5: Service process template (completed)

The service process steps are shown in Figure 8.6. The author felt that a graphical representation of the steps provides a clearer process view.

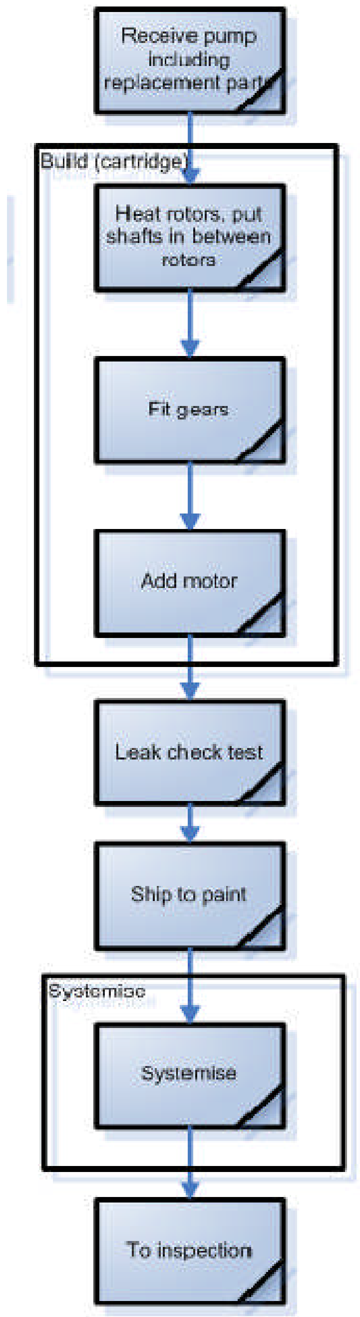

Figure 8.6: Service build process

Maintenance strategy template

The maintenance strategy template was filled in by the service engineer, who participated in this validation exercise (Figure 8.7).

Maintenance strategy		
Name	unplanned maintenance	
Recommended overhaul interval	n/a	
Product	**Name**	Product 1
Facility	**Name**	Infineon
	Location	Germany
Resource	**Type**	documentation, service engineers, tooling depending on the breakdown
	Name	n/a
	Cost	unknown
Tooling	**Name**	special tooling required for the removal of the enclosure panels
	Availability	yes
	Issues	in some cases, tooling couldn't fit- pumps too close one to the other
	Cost	[redacted]
	Lifetime	unknown
Completion	**Date**	Jun-09
	Name	[redacted]
	Signature	

Figure 8.7: Maintenance strategy template

The service engineer selected the unplanned maintenance as the maintenance strategy in this case. The tooling cost and the name are not provided due to confidentiality issues.

Training template

The next template, which was filled as part of the validation exercise, was the training. Some of the data in it stems from the company's documentation (type, cost, time needed, and location). The training template is presented in Figure 8.8. It describes one of the courses that Company 1 provides to its service engineers. There are also courses that are designed for their customers and are part of the service provision.

Training		
Type	Practical vacuum technology: The course is designed for personnel with little or no knowledge of vacuum technology and gives an extensive introduction into the essential elements of vacuum science & technology.	
Cost	£950 (+VAT) per person	
Time needed	3 days	
Location	Crawley, UK	
Participant	**Name**	[redacted]
	Job role	Service engineer
	Years of experience	0
Issues faced	none	
Completion	**Date**	Jun-09
	Name	[redacted]
	Signature	

Figure 8.8: Training template completed

Service facility template

The lead technician of the US service facility in conjunction with the service marketing manager in the UK provided the data for the completion of the service facility template, which is presented in Figure 8.9.

Service facility		
Name	Tempe	
Location	Arizona, USA	
Floor space (m^2)	3,810	
Humidity (%)	20%	
Temperature (^oC)	min. 11/ max.24	
Utilities required	power, water, nitrogen supply	
People	**Name**	[redacted]
	Job role	service engineers, lead technician, service manager
	Years of experience	
Product	**Name**	Product 1
Issues faced	spares arrive late sometimes (2-3 weeks to get stators or rotors), lack of space when they have big product volume	
Completion	**Date**	Jun-09
	Name	[redacted]
	Signature	

Figure 8.9: Service facility template completed

It was mentioned that one of the major issues that they faced in the specific facility was the late arrival of particular spares, such as the stators or the rotors. Additionally, it should be noted that when the service of Product 1 started, all the service activities were undertaken by one person due to the very low volumes of pumps that required service. The division of the Product 1 service now includes three operations: DCI, build, and test; if the volume increases, the build operation may be further divided and set up on a conveyor line.

Service organisation template

The last template (part of the SKaD framework) was the service organisation template. It was completed with the use of the data from the interviews conducted with the service engineers at the US service centre. It is illustrated in Figure 8.10.

Service organisation		
Facility	Name	Tempe
	Location	Arizona, USA
Spares	Name	rotors, shafts
	Availability	2-3 weeks late sometimes
	Cost	unknown
	Serial number	[redacted]
Logistics	Type	shipping
	Receiver (name + location)	Grand Island (New York State)
	Sender (name + location)	Shoreham, UK
	Cost	[redacted]
	Issues faced	few pumps received partially damaged
Completion	Date	Jun-09
	Name	[redacted]
	Signature	

Figure 8.10: Service organisation template

8.5.2 De-briefing session and feedback

A de-briefing session took place following the completion of the templates. The author sent the templates back to the experts, who had participated in the validation process, and asked them to confirm that the fields represented correct and accurate information. The experts did not suggest any changes; however, the on-site service team in Germany provided the author with a list of additional issues relating to Product 1 that they face in the customer facility. These are as follows:

- The customer installs the pumps very close to each other, whereas the service technicians require a reasonable space between them so that they can access all of their sides and access the components that need to be replaced. As such, there is a conflict between the customer installation and the product access requirements for service. Moreover, sometimes they face problems with the fuses of the customers, who, in an attempt to save money, install wrong fuses; as a result, when the performance of the pump does not reach the desired level, the service team has to face their complaints.

- While Product 1 check valves are moving, there is a very small distance between them and the enclosure; hence, sometimes the exhaust gets stuck.
- All the interviewees stated that they do not receive adequate number of pumps from the service centre (in Czech Republic). Most refurbished pumps that are received are re-tested by Company's 1 personnel in Dresden due to low confidence in the service centre operation. The service marketing manager explained that this happens because the service centre team there is now in its learning curve without any previous substantial experience.
- The vibration and the noise level of Product 1 should be reduced to a minimum. The noise level can be reduced by the installation of a silencer; however, this process is expensive and occurs as an additional cost to the customer.

The last part of the overall validation exercise at Company 1 was a teleconference session with the service marketing manager, and a senior CAD designer based in the UK. On the whole, the participants of the validation were (see Table 8.5):

Job role	Years of experience
Service marketing manager	19
Senior CAD designer	19

Table 8.5: Participants in the teleconference validation (Company 1)

The aim of the teleconference session was for the author to get feedback on the usage of the knowledge templates and it lasted one hour. Table 8.6 presents the results of the session.

Question	Service marketing manager	Senior CAD designer
Are the templates simple to use?	Yes.	Yes, definitely.
Have you experienced any issues when using them?	No.	Sometimes needed to contact the person that completed it for clarifications. Therefore, the existence of the completion fields is very important.
After using the templates, do you think that the information about service is more easily accessible by designers?	I think it enables them to access quickly the most relevant information.	Yes. If the company uses similar templates for all its products, designers will have easy access to SK.
Any suggestions for improvement?	No. The templates include a comprehensive set of SK.	The company needs to make sure that they keep a track of who fills in the templates and when.

Table 8.6: Templates' validation results (Company 1)

Based on the feedback received by the two participants at Company 1, the author believes that the access to SK by designers at the detailed design stage is enhanced through the templates' use. It is also important that track of the people who complete the templates is kept, since further clarifications might be needed.

8.6 Validation of the SK templates- Case study (Company 4)

The author in order to further explore the effectiveness of the developed knowledge templates conducted a second case study at Company 4, which lasted six months. The process followed in this case slightly differs from the one at Company 1 and is presented in Figure 8.11.

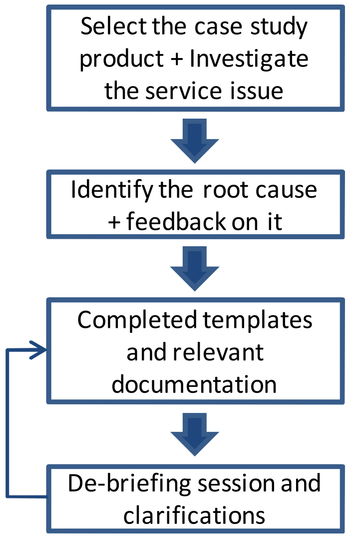

Figure 8.11: Validation process at Company4

At the start of the case study, the case study product was selected. The selection was based on the suggestion of the company's knowledge management specialist. He mentioned to the author that there had been a cabin odour issue on Product X005, and that it would be valuable for both this piece of research and Company 4 to investigate the root cause of the issue. The data collected during this phase would enable the completion of the knowledge templates, and eventually their validation. The case study product is shown in Figure 8.12. It should be mentioned that the name of the product has been altered due to confidentiality issues.

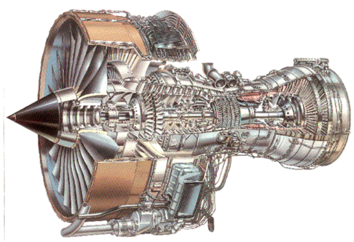

Figure 8.12: X005 case study product (Source: www.jet-engine.net, 2010)

X005 is an engine that was designed to provide the power for the ultra-long range of the Airbus A340. To suit these long range operations, X005 was designed with a high bypass ratio; thus, fuel efficiency and quietness were achieved. Also, the engine abided by Company's 4 commitments of reducing the environmental impact; as a result, the engine's attributes of low noise and low pollution conform to all current legislation (R-R website, 2010).

8.6.1 Investigating the service issue

Following the selection of the case study product, four face-to-face semi-structured interviews took place within Company 4. There were five participants in total, and each of the interviews lasted one and a half hours. It should be noted that the main contact within Company 4 (KM specialist) assisted with the preparation of the interviews. Table 8.7 presents the participants of the case study.

Job role	Years of experience
Service engineer- product support	35
Fleet designer	26
2 designers of new engine parts	19, 14
Knowledge management specialist	24

Table 8.7: Participants- validation at Company 4

The interviews revealed the sequence of the events that eventually led to the cabin odour issue of the X005. The timeline is graphically depicted in Figure 8.13, and is the outcome of the interview results after their validation from the participants. The author presented the timeline and she got feedback on the events' description, and clarifications on the sequence of them.

The design of this engine was based on the X007. As Figure 8.13 illustrates, soon after the X007 entered into service (EIS), it faced a cabin odour issue. It was found that oil was leaking from the labyrinth seals in the front bearing housing (FBH); this leakage caused an unpleasant smell in the cabin. The issue was resolved by the introduction of a baffle. When the X005 FBH was designed, it was decided that a new technology would be adopted; carbon seals instead of the conventional labyrinth seals because of their performance, weight and cost benefits. However, during the development and test process, oil leakage at the FBH was spotted. On disassembly, the carbon seals were found to be broken but the engineers were not sure whether the breakage was caused by the engine test or was a result of the assembly. Time pressures to finish the overall design were huge; the design team decided to revert to a more traditional labyrinth seal design, but without the baffle introduced as a modification into the X007. The rationale for the decision to omit the baffle is unclear, but it is likely that the final design was either based upon the X005 carbon seal design, or the original X007 labyrinth seal design, neither of which had a baffle. Subsequently, three years after the X005 EIS, cabin odour became an issue for the X005 too. After the occurrence of the event, a number of root cause analysis (RCA) sessions took place: Several low-impact modifications were introduced before the true root cause was fully understood. The seal requires a positive pressure (ΔP**)** between gas and oil to prevent leakage. The ratio at design and development was acceptable but after a period of normal service, the ΔP sometimes reached a negative value at idle (dependent upon a number of operating factors). The solution determined was the modification of pipes on-wing and the addition of the baffle off-wing.

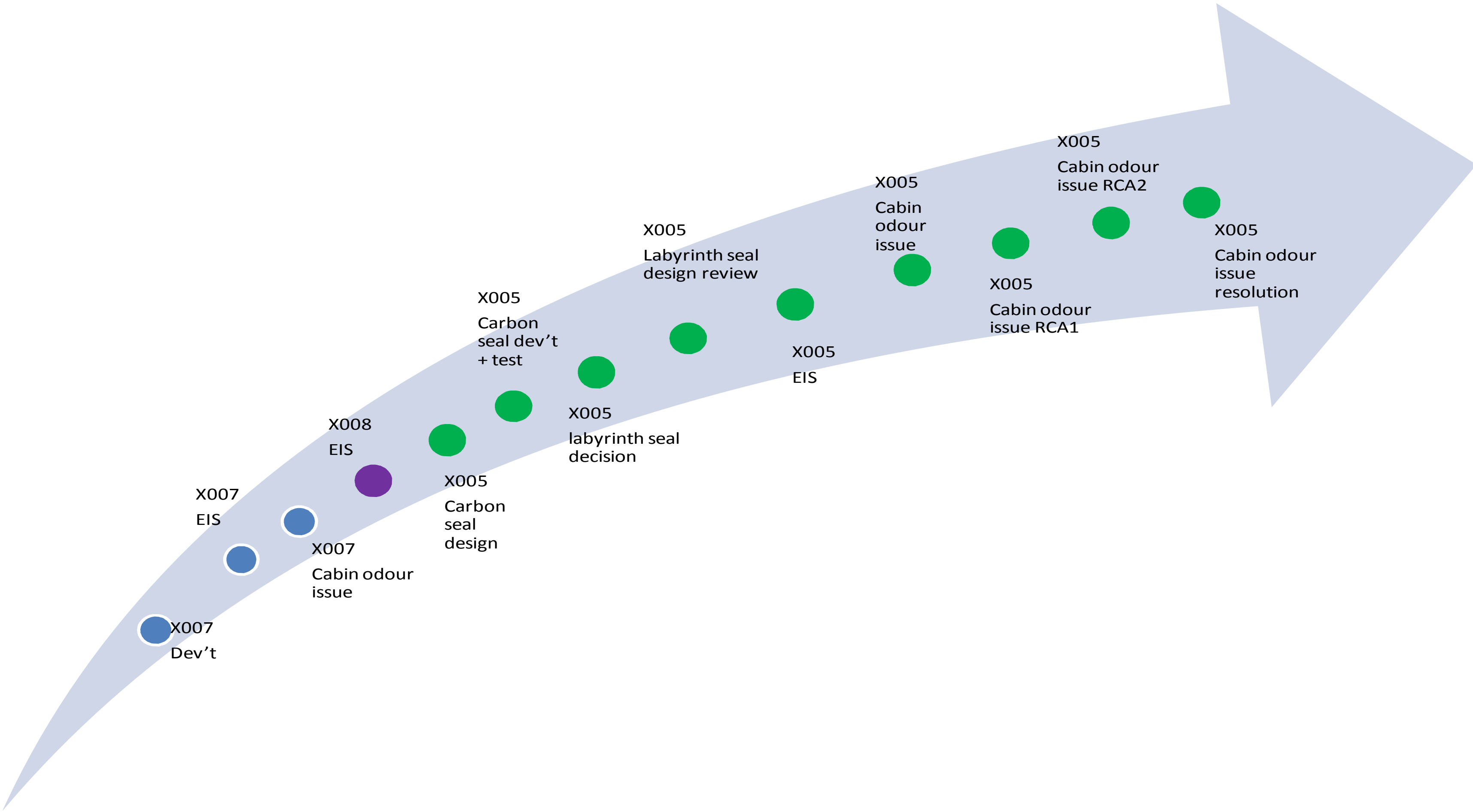

Figure 8.13: X005 issue timeline

8.6.2 Templates' completion

This Section is related to the completion of the templates within Company 4. The data, which the templates are filled with, is linked with the engine X005, and more specifically with the cabin odour issue that the author investigated.

Product template

Product		
Name	X005	
Subsystem	**Name**	front bearing housing
	Components *	
	Can be recycled	
	Issues faced	oil leakage
*** Components**	**Name**	carbon seal
	Serial number	[redacted]
	Actual life	3-4 years after EIS
	Expected life	not expected to leak
	Can be recycled	
	Issues faced	broken
Application	**Used in**	Airbus A340-600 (long-range operations)
	Specified for	Airbus A340-600 (long-range operations)
Failure	**Code- description**	cabin odour
	Location	various
	Component related	carbon seal
	Subsystem related	FBH
	Root cause	negative pressure ratio between gas and oil
	Actions after	Modify pipes on wing, add baffle off wing
Completion	**Date**	Aug-09
	Name	[redacted]
	Signature	

Figure 8.14: Product template (Company 4)

In the first template, the service engineer was asked to complete the fields considering Product X005; then, he was asked to provide the relevant data based on the cabin odour issue. The completed template is presented in Figure 8.14.

Maintenance strategy template

The template that was completed next was the one describing the maintenance strategy. It is based on the Total Care service package, and more specifically on the planned shop visit. This service includes: engine overhaul planning, work scoping and overhaul work, all engine strip labour, module rework labour, rebuild and test labour, replacement material, and incorporation of all alert and recommended service bulletins and airworthiness directives throughout the specified term in the Total Care package. The service engineer did not complete the 'tooling' fields, since he stated that a maintenance strategy involves a range of activities, which in turn are split in sub-tasks. For this reason, it would not be of any usefulness to the designers to have details of the tooling used. As far as the service engineers are concerned, they have access to the relevant documentation that specifies the corresponding tooling for each of the tasks.

Maintenance strategy		
Name	Planned shop visit	
Recommended overhaul interval	as specified in the TotalCare agreement	
Product	**Name**	X005
Facility	**Name**	Derby
	Location	Derby, UK
Resource	**Type**	documentation, service engineers
	Name	TotalCare agreement
	Cost	unknown
Tooling	**Name**	n/a
	Availability	n/a
	Issues	n/a
	Cost	n/a
	Lifetime	n/a
Completion	**Date**	Aug-09
	Name	[redacted]
	Signature	

Figure 8.15: Maintenance strategy template (Company 4)

Training template

The author, using the relevant documentation from Company 4, populated the training template with data. This is shown in Figure 8.16. The training course, whose details are captured in the template, targets all personnel involved with maintenance activities. The expert filled it in with the details of a service engineer who joined the company fairly recently.

Training		
Type	Line and base maintenance: description of the engine and its operation/ requirements for planned and unplanned maintenance/ practical training for tasks of line maintenance/ procedures to inspect, check, troubleshoot issues	
Cost	On application	
Time needed	8 days	
Location	Derby, UK	
Participant	**Name**	[redacted]
	Job role	Service engineer
	Years of experience	2
Issues faced	none	
Completion	**Date**	Aug-09
	Name	[redacted]
	Signature	

Figure 8.16: Training template (Company 4)

Service facility template

The service engineer also completed the service facility template. He commented on the fields required suggesting to the author that the designers would be mostly interested in the details of the facility's installation environment and the issues faced (if any) at the facility. The template is shown in Figure 8.17.

Service facility		
Name	Derby	
Location	Derby, UK	
Floor space	not sure	
Humidity (%)	80%	
Temperature (°C)	min. -4/ max. 17	
Utilities required	power and water supply	
People	**Name**	[redacted]
	Job role	service engineers, lead technician, service manager
	Years of experience	
Product	**Name**	X005
Issues faced	none	
Completion	**Date**	Aug-09
	Name	[redacted]
	Signature	

Figure 8.17: Service facility template (Company 4)

8.6.3 De-briefing session and feedback

A de-briefing session took place after the completion of the templates. The author sent the templates back to the service engineer who participated in their completion, and asked him to confirm that the fields represented correct and accurate information. The expert agreed with the finalised version of the templates and did not suggest any changes.

The last part of the overall validation exercise at Company 4 was a two-hour session with the knowledge management specialist and the two designers of new engine parts. The aim of this session was for the author to get feedback on the usage of the knowledge templates by the designers and receive the comments of the KM specialist. Table 8.6 presents the results of the session.

Question	KM specialist	Designer 1	Designer 2
Are the templates simple to use?	Yes.	Yes, definitely.	Yes, quick to get the relevant information.
Have you experienced any issues when using them?	No.	Not really.	No, their use is simple.
After using the templates, do you think that the information about service is more easily accessible by designers?	Yes, definitely the templates will make the designers be aware of issues occurring at the engines.	Yes.	Yes. Especially for our team which is quite remote from the rest of the designers.
Any suggestions for improvement?	Possibly include contact details of the person who completed each template.	Maybe the maintenance strategy template is not needed by designers.	'Service process', 'service organisation' and 'maintenance strategy' templates are not really necessary.

Table 8.8: Templates' validation results (Company 4)

Summarising the feedback given by the participants at Company 4, the templates are simple to use and provide easy access to SK at the detailed design stage for the designers. However, three templates named ‘service process’, ‘service organisation’, and ‘maintenance strategy’ do not seem to provide the designers with SK of their immediate concern.

8.7 Comparison of pump manufacturing and aerospace

During the final validation sessions with Company 1 and 4, the author reached the following conclusions:

- The SK types are applicable to both industries; the only exception concerns the ‘packaging’ and ‘password protection’ knowledge types, which were judged by the experts within the aerospace organisation of being of minor importance to them.
- The DF at their generic level are applicable to both industries; however, differentiations will be made when the DF needs to be specified for a particular product or component.
- The SF list is applicable to pump manufacturing and aerospace, since the author used the combined findings from all the case studies and the literature for the creation of the final list.
- The templates can be used by the designers in either organisation; however, as a result of the higher level of complexity of the aero engines (compared to the pumps), some templates- maintenance strategy, service organisation, and service process- were judged to be not of a high value for the designers and required a significant amount of effort from the service engineers to fill them in. The experts of Company 4 stated that the three aforementioned templates should contain a big amount of information if they target the detailed capture of the knowledge in them. However, the use of instruction manuals for each of the products for the maintenance strategy, and the service process would be more effective and less time consuming in this case. On the other hand, the template, which captures the

product failures and the issues faced, was assessed as highly beneficial. The knowledge templates can provide the designers with a clearer view of the product in comparison with an unstructured document, where the lessons learnt are kept. As a result, accurate information will be accessed by the designers with less effort and time required.

- The DR-SK tool was developed to be used at the conceptual design stage; whereas, the SF-SK and DF-SK tools as well as the knowledge templates were created for use at the detailed design stage.
- The service engineers, who participated in the completion of the knowledge templates, stated that the completion lasted ten minutes on average per template.

8.8 Summary and Key Observations

In Section 8.1 the overall validation process followed was briefly described; then, each of the following Sections of Chapter 8 presented in detail the elements that were validated.

Section 8.2 described the final validation of the SK types by two experts: the service marketing manager at Company 1 and the KM specialist at Company 4. No major changes were suggested except for the classification of the SK types in three levels: business, product, and component level.

In Section 8.3, the author presented the validation of the DR-SK tool and the structure of the ontology. Regarding the DR-SK tool, the overall feedback was positive; few additions were suggested, such as the 'competitor knowledge' as part of the DR. The experts stated that the tool is mostly useful in:

1. Identifying the gaps in SK and thus, assigning the relevant people to either search for the knowledge or start storing the SK that is missing,

2. Improving the collaboration among disciplines, since its use is enabled by the teamwork of conceptual designers and service engineers.

As far as the ontology structure is concerned, the interviewees thought it is comprehensive and gives an overview of the issues and failures of a product. However, they emphasised that the fields, which need to be completed by service engineers and then used by designers, should be reduced to the necessary minimum. Also, they suggested the use of a simple terminology, since the tool (if implemented in the organisation) will be used by employees around the globe. A possible downside of the ontology can be its implementation due to the fact that it needs to be integrated with the software that the company has already in place, and additionally, the resources required for the population and the maintenance of the data need to be considered.

Section 8.4 was related to the validation of SF-SK and DF-SK tools. The SF list developed through the literature and the case studies' findings was found to be generic, thus widely applicable to different manufacturing sectors (pumps, machine tools, and aerospace). The SF-SK tool can be used as a checklist for the identification of SK types that are needed for the realisation of each SF. With regards to the DF-SK tool, two main points were highlighted by the KM specialist: firstly, 'resources needed' is a recurring knowledge type needed for the realisation of each DF. Therefore, the balanced delegation of tasks among the organisation's resources seems to be crucial. Secondly, the 'product type' was recognised as a factor of influence on the DF; the KM specialist expressed the opinion that the DF list may be radically changed in the case of a totally different product compared to the one used as a point of reference.

In Section 8.5, a description of the validation of the knowledge templates at Company 1 was given. Product 1 was used as the case study product; the templates were filled, feedback was provided regarding the accuracy and correctness of the knowledge captured, and finally, the service marketing manager and the service CAD designer reviewed their use and stated that they are easy to use and helpful for the designers in accessing SK about a product's past performance.

In Section 8.6, the validation session of the knowledge templates at Company 4 was described. Product X005 (an engine designed for long-range applications) was used in the case study. The author first investigated the cabin odour issue that had occurred after three years of the product's EIS which was caused by complex fluid interactions following normal service operation. Then, the knowledge templates were filled, and feedback on their use was given by the company's KM specialist and two designers of new engine parts. According to them, the templates were simple to use, nevertheless useful and gave the designers quick access to the information, which they are interested in.

Section 8.7 explored the applicability of the elements of the SKaD framework to the pump manufacturing and aerospace industry and provided a comparison between them.

In the next Chapter, the key observations and findings of this research are further discussed.

9 Discussion and Conclusions

9.1 Introduction

Chapter 8 described the overall validation of the main research findings: the SK types, the developed tools, and the knowledge templates. The application of the SKaD framework on two industrial case studies was also presented.

This Chapter aims to provide the reader with a synopsis of the research findings. Additionally, their quality, generalisabilily, and applicability are discussed, along with the key research contributions and areas of future work. Specifically, Section 9.2 summarises and further discusses all the pieces of work described thus far in the thesis. Section 9.3 explores the quality, and the degree of generalisability and applicability of the research findings. In Section 9.4, the author highlights the main contributions of this research; while in Section 9.5, the limitations of this study are presented. Section 9.6 outlines the work, which can be undertaken as a continuation of this research. Finally, in Section 9.7, the author demonstrates how the research findings lead to the realisation of each of the research objectives.

9.2 Discussion of the Research Findings

This Section presents a discussion of the key findings of this research. The sequence of the Section endeavours to represent the sequence of the work presented within this thesis, facilitating the reader to keep track of it.

9.2.1 Literature Review

The review of the literature covered the main areas, which this study is related to. To begin with, it was identified that at present knowledge re-use is a crucial factor that can impact on an organisation's performance in two ways: firstly, the amount of time spent recreating something that is already known is reduced, and secondly, design and production-related costs are decreased by learning from both mistakes and achievements of the past. Therefore, knowledge re-use can affect time and cost; two aspects that are critical for an organisation's success.

Despite the benefits of knowledge re-use, the shortcomings inherited in the process have also been outlined in literature. There is a potential of information overload due to the fact that the employees are already overly occupied and every piece of additional information is ineffective unless relevant to their tasks. Moreover, it should be taken into consideration that different knowledge re-users have different requirements. It should be added that the difficulty in locating the sources of knowledge can hinder the re-use of it. It was also pinpointed that employees tend to prefer a unique new solution to one that has been previously used, since it is generally perceived that these who offer help are more competent than the ones getting help.

This research focuses on the re-use of service knowledge by designers. Moreover, the services, which provide product support, and ensure that the equipment operates as it should be, are a focal point within the context of this study; these services are: maintenance, repair and overhaul, spares provisioning, technical reports, and technical support. As far as maintenance is concerned, the author studied its strategies that exist in the literature and created a timeline showing their evolution from 1950s until today.

In spite of the existence of an extensive literature in the areas of knowledge, product design, and services, there is a lack of research in the area of 'design for service'. Elements, such as the types of service knowledge required by designers, and their impact on product design seem to have been slightly explored. The literature has identified the categories of service information that designers are interested in. These are: maintainability, reliability, failure mechanisms, service instructions, operating data, component cost, design information, and component life. The reduction of maintenance costs, the improvement of product reliability, and the fulfilment of the maintainability and reliability requirements were recognised as potential benefits of the in-service information availability. However, the author did not find a classification of the knowledge types that are used in the execution of the service personnel's tasks, and can be then re-used by designers according to their needs. Also, a differentiation between the service knowledge required at the conceptual and the detailed stages of product design, and possible ways of linkage between the two areas (service and design) was not available in the published literature.

In summary, it was recognised that the collaboration between product designers and service engineers influences the design of a product and leads to better performance, accurately fulfilling the customer requirements. For instance, it was emphasised that the detection of failure root causes improves product quality. This observation was further confirmed by some of the industrial findings. Therefore, a structured methodology of service knowledge utilisation by the designers would be of a value to both groups, and contribute towards the exploration of 'design for service' research area.

9.2.2 Research methodology

An attempt has been made in this research to ensure that the methodology used does not result in a distorted representation of results. This was mainly achieved through the use of a variety of methods in the data collection phase. The author used face-to-face interviews, phone interviews, observation, and the companies' documentation. Although the use of interviews is useful, it mostly captures the perception of the expert, and not the actual situation. To eliminate this adverse effect, the author used alternative methods in addition, i.e. observation and documentation. It should be mentioned that the author could have used a structured questionnaire, which would be sent to all participants. The analysis of those questionnaire responses could have taken place in a quantitative manner. However, this approach would lack the richness in the responses gained through the methods that the author selected to use (i.e. face-to-face and phone interviews, observation, and technical documentation).

Apart from the variety in the data collection methods, the author chose the case study approach as the most appropriate research strategy; the rationale for this selection was presented in Chapter 3. The author's active involvement in the choice of the particular case studies, which were used in this research, strengthens the research methodology. The reason for this is the fact that the author made sure that the case studies were not solely suggested by the experts, but also in line with the requirements and the context of this study.

Qualitative research is prone to biased interpretation by the researcher, which can lead to subjective results. The researcher completed a number of knowledge templates using the companies' technical documentation, and interview findings; a possible source of bias is the fact that the usage simplicity of the templates may have been overestimated. As these templates were developed, and completed by the researcher, their completion may have seemed easier and faster than it really is. In order to minimise this bias the author organised an overall validation session to get additional feedback regarding the simplicity and usefulness of the templates. Throughout this study, the author prudently designed the research approach in conducting the case studies to reduce any potential bias.

9.2.3 Service knowledge capture and representation

The author, after conducting a series of face-to-face and phone interviews with experts at two UK manufacturing companies, managed to identify a number of service issues. The thematic analysis and classification of these issues according to their significance led to the creation of a service knowledge types list. For the elicitation of the knowledge types two complex mechanical products (Product 1 and 2) were used in the case studies, and the high level knowledge types are: product, service process, service facility, spares, logistics, and training. The author proposed a grouping for the knowledge types related to the product and the service organisation. Therefore, service process, service facility, spares, logistics, and training are part of the knowledge found and used within a service organisation.

The aforementioned separation (product and service organisation) was then applied to the knowledge representation into an ontology. The Protégé software was chosen for the creation of the service knowledge ontology in an attempt to represent the domain knowledge, facilitate its re-use, and illustrate the existing relationships. The development of the ontology structure required a slight re-arrangement of the service knowledge types.

The elicited knowledge was validated with experts of three different industries: the pump manufacturing, the aerospace, and the machine tool manufacturing, and was found to be applicable in all three fields. There were few minor adjustments at the detailed level of the types depending on the particular type of industry.

The outcome of the ontology validation through two workshops at Company 1 and 4 was positive. The scenario of implementing a new product into the service operation was presented with the ontology usage, and the experts expressed the opinion that overall, a major improvement of the NPD team collaboration can be achieved. However, the issue of engaging the necessary personnel to fill in the necessary fields was highlighted.

9.2.4 Service knowledge at the conceptual design stage

The industrial investigation led to the realisation that there is not an adequate mechanism in place to show how service knowledge can be used by conceptual designers. The author selected the design requirements as a linking point between service and conceptual design. The first step was the development of a generic requirements list. To achieve this, a review of the relevant literature was conducted, leading to the selection of the appropriate one, among five approaches. The most comprehensive one within a manufacturing engineering context was found to be the Hooks and Farry approach; hence, it was adopted by the author. In addition to this approach, the related to requirements documentation from Company 1 was reviewed, and a combined list stemming from the literature and the current industrial practice was then developed.

The next step was the mapping between the design requirements at the conceptual design stage and the service knowledge types. This was accomplished through the development of the SK audit tool. The two main purposes of the tool are the knowledge retrieval by designers, and the identification of gaps in service knowledge. The users of the tool need to define the strength of the relationship between its two elements (strong, loose or no relationship). When a relationship is defined, the users have to check the availability of the related knowledge (high, medium, none); the combination of these actions leads to the detection of gaps in the knowledge.

The SK audit tool can serve three additional purposes. It can improve the communication between the designers and the service engineers within the NPD team by providing them with a common ground for collaboration and terminology easily understood by both groups. Moreover, an overview of the product regarding its requirements can be gained through the tool. In addition to the company's products, the tool enables the users to get a brief overview of a competitor's similar product, since 'competitor knowledge' is one of the elements in the requirements list.

The tool could be incorporated within the current practices at the conceptual design stage in industry, for linking the design requirements and the service knowledge types. Its application within an industrial environment will provide the basis for a structured communication between the two groups of interest in this study. The SK tool is a novel proposition for minimising the existing distance among the members of the NPD team and supporting product design requirements via the consideration of service knowledge.

9.2.5 Service knowledge at the detailed design stage

The author made an attempt to create a link between designers and service engineers at the detailed design stage. The means to achieve this was the use of features.

However, it was observed that due to the difference in the level of granularity, the direct connection between the two elements seems void (at least within the scope of this research). For this reason, the author decided to link SF and DF via service knowledge.

Consequently, experts from Company 1 and 3 took part in interviews expressing their opinion on what a SF is. The author had defined a SF as an attribute of service that delivers value to the customer. The participants were asked to specify what this definition means within the context of their organisation. The results of the interviews were analysed, and several categories of SF emerged. Following this, in order to reduce the bias caused by the interviewees' individual perceptions, the author combined the former results with the SERVQUAL framework, as found in the literature. The outcome was a generic list of SF, which seems to be applicable to at least three industries: pump manufacturing, machine tools, and aerospace.

Prior to the development of links between SF and SK, the author considered important to identify the resources necessary for the realisation of each SF. Experts from Company 1 gave feedback to the resources, which the researcher had already recognised as of significant importance with regards to each SF. After this step, links were created between the SF and the SK types. The author, subsequently, created a list with the top five SK types necessary for each SF. As a result, the information overload is avoided, and only the crucial knowledge types need to be captured and then used.

In spite of the usefulness of the SF-SK tool, the designers are not the actual users of it. It is mostly addressed to service personnel: service managers and service engineers. The designers at the detailed design stage are interested in the links between DF and SK. For this reason, the author created a tool, using MS Excel, where the designers can have access to all SK types, and decide which type is necessary for each DF. The whole process is supported by a guide, which includes a generic list of DF and the top five knowledge types that are required for every DF. The designers can amend the DF according to the needs of their project; on the other hand, since the types of knowledge are generic should be applicable regardless of the project.

Since communication between designers and service engineers is essential throughout the design of the product, at the detailed design stage this is attained by the creation of links between DF and SK. Therefore, the main benefit for the designers is the easy and fast access to the SK types. An additional benefit stems from the identification of the top five SK types for each DF; designers save time, since they do not need to identify the strongest links.

9.2.6 SKaD framework development and application

The SKaD framework was created as an outcome of the combination among the SKaD methodology, the knowledge templates, and the tools developed to link SK and DR, SF and DF. After the development of the methodology, a need to capture SK in a structured manner emerged. For this reason, the author developed the knowledge templates, which were utilised to capture various aspects of SK with regards to the product and the service organisation.

In order to capture examples of SK, the templates were applied on two industrial case studies (two products belonging to two different industries were investigated). The first case study took place in a pump manufacturing setting and the second one within an aerospace. In each case study, the templates were filled in by the appropriate experts or the author (using previous industrial findings or data from technical documentation related to the studied product). Upon completion of the knowledge templates, the author asked the participants of the case studies for feedback on the accuracy of the knowledge captured. Their feedback was positive; therefore, no further changes needed to be made. Several additional issues faced at a service facility of Company 1 were mentioned and recorded by the author during the session.

The developed tools were not directly applied on each case study product. However, they have been validated by various interviewees during the course of this research.

These validation sessions proved the applicability of the tools on both the aforementioned industries. The lists of SF, DF, and DR were found to be generic; as a consequence, the design and service personnel could use them in order to define links between the two domains regardless of the product under development.

A questionnaire was presented to the experts at the end of each case study aiming at capturing their viewpoints concerning the effectiveness of the knowledge templates. The experts chosen at Company 1 were the service marketing manager and a senior CAD designer. In brief, they felt that the templates are simple to use, and can provide the designers with a comprehensive set of service knowledge types. At Company 4, three experts were asked to express their view on the templates: a KM specialist and two designers of new engine parts. In summary, they identified that there is a benefit in using the templates, because the latter provide the designers with access to SK. However, due to the complexity of the product and the service organisation, they suggested not to use the 'service process', 'service organisation', and 'maintenance strategy' templates. This recommendation does not affect the effectiveness of the framework, which was created to support product design with SK, because these specific templates were aimed to be used by service personnel and not by designers.

Overall, designers were involved at various stages of the research (i.e. ontology and tool validation, framework development, and validation). Their involvement ensured that the SK captured was of value to them, and the tools developed would support product design. Since they are the main users of the research framework, their feedback on its structure, usability, and usefulness was essential.

9.3 Recommendations for improving the SK re-use

Several ways of improving the re-use of SK have been identified within this research. Firstly, at the conceptual design stage, SK can be re-used through the DR-SK tool. Designers can map the DR with the SK types, and also specify the degree of relationship between the two (strong, medium, and loose). Then, depending on the availability of the SK, they can either re-use the existing knowledge or identify gaps in it so that it can be captured by the appropriate service personnel.

Secondly, at the detailed design stage there are two tools developed by the author to assist the SK re-use. Within the DF-SK tool, SK can be re-used by designers while they are in the process of checking the DF, and then access the types of SK relevant for the realisation of each feature. Also, when designers use the knowledge templates, they can re-use the SK that is already stored in them. For instance, knowledge related to a product failure is stored within the product template; designers can make use of this SK.

Conclusively, the author recommends the aforementioned ways of re-using SK. The re-use can take place at either the conceptual or the detailed design stage, and will assist the designers in taking into account service aspects in the design of a product. Thus, the SKaD framework, which consists of these tools, is a formalised way of SK re-use by designers that results in product design improvement.

9.4 Quality, Generalisability and Applicability of Findings

The author discusses a number of issues regarding the quality of the findings, along with their generalisability in this Section. Moreover, the applicability of the research findings in an industrial environment is explored.

9.4.1 Quality of Findings

The author throughout the course of this research made every attempt to ensure that the entire process, the attainment and the analysis of the results, was carried out in a methodical and systematic way. As far as the case studies are concerned, the main limitation for the author was the time availability for the execution of each case study. Hence, all the necessary steps were taken so as to select cases, where the experts are accessible, and willing to collaborate with the researcher before and during each case study. For instance, the duration of the interviews or the workshops was mutually arranged, and the research protocol was sent to the interviewees in advance so that they familiarise themselves with the research issues. These measures led to a series of feasible activities, which in turn resulted in the successful carrying out of the case studies.

The key research outputs were validated by experts in each field. The adopted validation methods were qualitative due to the nature of the findings. First of all, the elicitation of the SK types was an iterative process; the author, after the completion of each set of interviews, asked the participants for their feedback on the types captured and made the necessary changes. In the end, two experts validated the overall set of knowledge types and a classification in three levels (business, product, and component) was carried out. With regards to the tools created in Excel (DR-SK, SF-SK, and DF-SK), they were all validated during their development. Final validation sessions were held for each of the tools and the experts were asked to comment on both the content and their potential usage within an industrial environment. Lastly, a questionnaire was used to capture the views of the experts regarding the effectiveness of the knowledge templates. The whole set of validation sessions proved that the SKaD framework had enabled the designers to access more easily the SK, and it could, as a consequence, lead to the enhancement of product design by considering past service issues.

The main concern of the author during this study was to keep a high level of reliability as regards the methods used in the attempt to obtain the research findings. The formation of a formal research strategy in conjunction with the use of a range of data collection methods enabled the attainment of this aim. To achieve even higher reliability, a variety of sources were used in reaching this study's findings, and triangulation of data was applied, whenever possible.

9.4.2 Generalisability of Findings

The SKaD framework was shown to be applicable in supporting the design of complex mechanical products through the use of SK within the pump manufacturing and aerospace industries. The author feels that there is a potential for its application to other manufacturing sectors; however, case studies were not undertaken in other domains. Consequently, similar results have not been achieved and a safe claim cannot be made regarding the effectiveness of the proposed framework. Until this occurs, the boundaries for the applicability of the framework are set around the two industries mentioned earlier, in particular the design and service of complex mechanical products within them.

The research findings concerning the SK types are more generally applicable in comparison with the framework. This was demonstrated by their validation from a company belonging to the machine tool manufacturing sector. Yet they represent the knowledge of a service department within a manufacturing domain. Similarly, the list of SF is not bounded to a specific industry due to two reasons. Firstly, its development involved experts from three different industries and informal discussions with some of their customers. Secondly, the list of the features captured from the industrial collaborators was enriched and combined with the SERVQUAL framework found in the literature.

9.4.3 Applicability of Findings

In this Section, the author discusses the applicability of the research findings in industry and their potential business impact when implemented. Specifically, the use of the SKaD methodology (mainly of the knowledge templates), the adoption of the knowledge audit tools, and the implementation of the ontology are explored.

The SKaD methodology and the SK templates in particular, could help designers access quickly and re-use the SK types of their interest; for instance, details of a product failure. However, in order for this to be achieved the templates may need to be customised according to a particular organisation's needs. Following this, the templates will need to be populated and updated. Therefore, the organisation will have to appoint a responsible person, who will be in charge of organising the data captured by the service engineers and ensuring that the users can access it. A benefit of the templates is the fact that they are built in MS Excel; as a result, no additional software licence is required for their implementation.

Designers at the conceptual design stage could also utilise the DR-SK tool that the author has developed. Minor adjustments to the list of DR may be necessary in the case of a similar product and industrial setting. Then, the designers would decide on the types of SK that are needed for each of the requirements and the service engineers, who would be part of the NPD team, would advise them if the knowledge is stored or not. If the knowledge is stored, it will most possibly be located in the knowledge templates or the technical documentation of the organisation. If the SK required by the designers is not available, then it needs to be found and saved in one of the templates. As far as training is concerned, the author believes that one to two hours will be sufficient for the users to familiarise themselves with the tool. This can be done either individually- the tool is sent to each user separately- or in workshops, which could involve groups of designers and service engineers.

Similarly, the DF-SK and SF-SK tools could be easily implemented within any industrial locale matching the boundaries of the research milieu. It has already been acknowledged by the experts, who participated in the tools' validation, that the lists of the design and service features are generic and not bounded to a particular product. Designers can integrate the DF-SK tool within the process they currently follow at the detailed design stage; equally, the service managers could use the SF-SK tool without any need for special training. Both tools were developed in MS Excel; hence, the degree of implementation ease is quite high. Nevertheless, the maintenance of the tools should be considered. An employee should be appointed for updating their content and verifying any changes that the users intend to make.

An organisation could also consider the implementation of the database and its further development in an attempt to support product designers with service knowledge. The use of the tools could complement the database usage and provide the design and service personnel with a complete set of tools to execute their activities in an effective and efficient manner. The author believes that the database is more comprehensive than the developed ontology, and that employees within the manufacturing sector are more familiar with its use. In spite of this, resources for training, further development, population with data, and maintenance will be required. Regarding the development of the database, the knowledge templates could be used as a starting point. Then, the users should specify their exact requirements, and a professional developer could materialise them. The database will be very useful, when a designer wants to check failures related to a specific product or a service manager needs to find out the training that his/her personnel has attended. The aforementioned instances are just two scenarios of the database usage; definitely, the latter can be expanded according to the user requirements.

The author believes that in the case of the developed tools' industrial implementation, these should be owned by the service team. The service manager should be responsible for appointing personnel for updating and maintenance, while designers should have access to the tools and templates. However, any amendments, which need to be made to the content, should be approved by the tool owner prior to their realisation.

Overall, the implementation impact of the tools and framework developed by the author is envisaged to be low, since they do not require the engagement of any major resources. The impact will be mainly cultural due to the fact that the designers and the employees of the service department, along with the policy makers, would need to be persuaded about the tangible benefits that the tools can deliver. The author suggests an initial trial implementation period; resistance should be expected. However, it is anticipated that the communication improvement at least among the members of the NPD team, and the access to SK that the framework can offer, would be the motivating factors for its full implementation.

9.5 Key Research Contributions

This Section describes the key contributions to knowledge made through this research. The main outcome was an increased understanding of the knowledge related to service provision issues and could have an effect on product design. The findings of this research contributed towards the identification and classification of the SK types. Furthermore, the requirements of the designers were identified, depending on the design stage: conceptual and detailed. As a result, tools and the SKaD methodology were developed; their combination with the SK templates led to the formation of the SKaD framework. In general, the framework is a novel way of accessing the SK, and integrating it within the product design.

The key contributions of this research are summarised as follows:

- Identification and categorisation of the types of knowledge within a technical services context. In particular, it was identified that there is a lack of captured and classified SK types, which fit the domain of complex mechanical products. The author captured this knowledge using a variety of research methods.
- Representation of the identified knowledge types and development of knowledge templates. This will facilitate the capture and re-use of SK by service personnel and designers.
- Mapping between SK types and the conceptual and detailed design stages' requirements. At the conceptual design stage, this was achieved through the development of the DR-SK tool, where the designers can specify which knowledge type they need for each requirement. At the detailed design stage, one way for the designers to access SK is to use the DF-SK tool.

- Development of the SKaD framework. Overall, this research has resulted in a formalised method to capture and re-use SK. This is attained by the SKaD methodology coupled with the knowledge templates and the use of the three tools. The designers can then get informed about past service issues and develop the product design integrating SK. On the other hand, service personnel will use the framework to capture the knowledge; parts of it can also be used by them for knowledge re-use.

9.6 Research Limitations

In this Section, the author presents the overall research limitations, as well as the limitations in respect to the research methodology. As it was described in Chapter 3, the research approach followed was the qualitative one. Due to this fact, there are a number of concerns arising related to the limitations of a qualitative study. One of the major issues is associated with the replicability of the obtained results, which cannot be achieved as easily as when following a quantitative approach.

At the start of the research, the author aimed at prolonging her involvement within the collaborating organisations. However, this did not happen due to time limitations, and limited availability of resources. The beneficial outcome of the limited time spent at the organisations was the avoidance of researcher bias in the obtained results of each case study. On the other hand, the author had to ensure that the case studies were conducted to a satisfactory degree. Actions were taken to counteract the potential negative effect of her limited involvement within the research setting. These actions involved: 1) methodical planning prior to the carrying out of the case studies, in collaboration with the experts to ensure that everything was prepared and both sides shared a common understanding of the requirements, 2) involvement of the author in the selection of the case studies to make sure that they satisfy the research needs, and 3) arrangement of de-briefing sessions, where the experts were asked to give comments and feedback on the obtained findings.

With regards to the validation of the SKaD framework, the ideal setting would have included a third case study with an organisation belonging to a different manufacturing sector than the ones studied. This would provide a broader view on the types of SK required by designers, and a clearer understanding of how these affect product design. Capturing a big number of examples from various sources would result in a more generic set of knowledge types. A third case study did not take place due to time limitations of both the researcher and the experts. However, the author feels that creating a set of even more generic knowledge types than the ones captured would potentially not be able to realistically meet the specific requirements of the collaborating organisations. As a result, in this case the designers would not be capable of accessing specific service knowledge types necessary for the enhancement of product design.

9.7 Future Work

This Section describes the potential areas of future work based on this study's findings. Five main areas were spotted by the author; these are:

1. *Service knowledge capture and representation:* Further work can be undertaken in order to capture additional types of SK, potentially at a more detailed level. This could be achieved by conducting case studies in another manufacturing sector; as a result, comparisons can be made with the existing types leading to an enriched understanding of SK. With respect to the representation, ontology was chosen as the initial means by the author. Then, a database was developed, where the knowledge types were implemented. However, further research could identify other possible ways of structuring the knowledge; thus, different relationships among the SK types.
2. *Knowledge templates:* An additional case study will be beneficial for capturing more examples of SK. This case study could be carried out with one of the collaborating organisations or a different one. The results would be the basis for a clear comparison as to the effectiveness of the templates' use in accessing the

SK. They would also highlight the adjustments that need to be made in order for the capture of all the necessary for the designers' knowledge in the templates.

3. *DR-SK tool:* The next step in complementing the developed DR-SK tool could be the addition of weights to the design requirements. Then, the designers would be able to rank them and make a comparison of the results with regards to the importance of each requirement and the knowledge types needed in every case.
4. *DF-SK tool:* Further interviews will be required for the creation of a comprehensive and detailed set of DF. It should be emphasised that this set could be used in specific cases, since the features, when detailed, can be applied only to specific products/components. The one formed by the author and used in the tool is generic, so that it can be valid regardless of the product.
5. *Database:* The author envisages its further development into a fully functional application that could be used by design and service personnel. Currently, its structure (tables) and the relationships, which exist among the tables, have already been created by the author. Also, three scenarios represented by the same number of forms exist within the database. The development of the database would encompass the creation of additional forms, through which the users will have the ability to access the SK. For this to be achieved interviews with the potential users need to be conducted and a developer should be engaged to build up the forms. Turning the existing database into a live application would be most likely useful in accessing the knowledge in a faster way and making comparisons and observing trends relating to a specific product, application or service facility.

9.8 Conclusions

This Section aims to show that the research study has achieved the objectives defined in Chapter 3 of this thesis.

The **first objective** was to understand the current practice in the design for service domain and identify terminologies used in practice to define a service. The review of the literature revealed that:

- There is a lack of research in capturing SK within a technical services context.
- It is crucial for designers to have access to service information; however, a small number of authors have explored this issue.
- The industrial investigation brought to light that the communication between the designers and the service personnel is an issue within the organisations; yet, invaluable for the enhancement of product design with the consideration of SK.
- As far as the terminologies used to describe services are concerned, there are several identified in the literature (Section 2.3.4), whereas the author attained the following types during the course of the industrial cases studies: planned maintenance, unplanned maintenance, service exchange, product repair and overhaul, retrofitting and upgrading, product installation, commissioning, and monitoring.

The **second objective** was to develop a representation for the SK that can be used by designers to improve product design. This was achieved by:

- Capturing the SK types within the boundaries of the research context.
- Classifying them in categories related to the product and the service organisation.
- Developing an ontology to represent SK which can be accessed by designers.

The **third objective** was to identify the SK required at the product design stage. To achieve this, the author divided the design into two stages: conceptual and detailed, and studied each one separately.

- At the conceptual design stage the focal point is the design requirements. Then, the author developed the DR-SK tool that both service and design personnel can use within the NPD team to define the relationships between SK types and DR, and also check whether the knowledge required is available within the organisation.

- At the detailed design stage the linkage between the two domains was accomplished with the use of features. In particular, two tools were developed; the first one (DF-SK) relates design features and service knowledge, and the second one (SF-SK) provides the service personnel with links between service feature and service knowledge.
- The author had envisaged a direct link between service and design features, but the different level of granularity between the two did not allow for the creation of such a link.

The **fourth objective** was to develop an effective methodology for SK re-use in product design. This was achieved by:

- Categorising the issues to the ones relating to the product and those associated with the service organisation. Issues in both categories can be represented by SK types, which the designers can re-use in order to make changes to a past product design or incorporate them in the design of a new product.
- Developing knowledge templates, where SK can be stored and accessed by the designers.
- Forming the structure of a database, which can be further developed as a fully functional application to enable the users to capture and re-use the knowledge, along with making comparisons and identifying trends related to a specific product or service facility.

The **fifth objective** was to validate the representation and the methodology using detailed case studies. The author achieved that through:

- The conduct of two case studies within the manufacturing sector. Both of them validated the SKaD methodology and framework via the usage of the knowledge templates and the developed tools.

- The feedback provided by the experts after each series of findings.

The author believes that the implementation of these research findings within an industrial environment will ease the re-use of service knowledge and therefore, enable the support of product design. Service knowledge integration in design can potentially lead to fewer future product failures; thus, better performing products.

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APPENDICES

Appendix A First set of interviews at Company 1 (Research Protocol)

A.1 Product-Service Systems

The developing paradigm of product service systems is pushing the need for closer integration of service design and deployment knowledge with product design and manufacturing engineering. Current research at Cranfield University has defined PSS: '***A Product Service System is an integrated product and service offering that delivers value in use***'. Getting the right knowledge applied at the right time during design is difficult. This project will try to help that process by finding out what knowledge design, manufacturing and service need, and when it is needed. A knowledge model will be developed, which we give to Company 1 once we have shown it is accurate and relevant.

A.2 Knowledge capture: aim

The aim of the knowledge capture exercise is to develop an initial framework describing service knowledge types. This represents the first stage in developing an integrated service, design and manufacturing knowledge model.

A.3 Knowledge capture: method

The participants should describe a situation from a current or recent project where they have encountered difficulty or overcome obstacles to come up with a solution. We would like to see what manufacturing knowledge designers need, or are missing, and what design knowledge manufacturing engineers need, or are missing. Through describing a critical task, knowledge that was required and applied during that task can be identified. The task should represent something which is important; a core knowledge component. This exercise should allow us to describe the knowledge requirement through modelling knowledge types.

A.4 Context: the research project

Collaborative product design, development, manufacture, and service is becoming increasingly important in globalised competitive manufacturing. The research challenge is to propose a set of methodologies to enable the use of appropriate knowledge across the Extended Enterprise, respecting the different intellectual property agreements and functional requirements.

In current technology, knowledge workers are not provided with context specific knowledge filters to present them with information appropriate to their professional work function. How much information they access and use depends on their individual perception and understanding on what they need for their tasks. The pre-requisite is to understand the knowledge requirement with respect to specific industrial applications and their needs.

The aim of this research is to develop a methodology to capture, represent, and re-use knowledge to support product development in a collaborative enterprise context. Core elements are: unified design knowledge, manufacturing capability knowledge, product service knowledge, and context specific knowledge management filters which ensure authorised access to the right knowledge for different work functions in the product development process.

Appendix B **Interview at Company 2 (Research Protocol)**

Research aim

Investigation of service issues in Company 2.

Research stage & current insight. Focus for exploration.

The aim of this research is to develop a service knowledge framework to support design. The current focus for exploration is to identify issues and problems in a service operation, service design and service issues in product design.

Subjects to be covered: variables and constructs

To identify and discuss issues in service operation and product / service design in Company 2.

Case description: company name, business unit

Company 2

Case justification: why this company? How does this company match the research aim? Why this business unit?

Company 2 represent a capital intensive, mature and complex aerospace domain, which is suited to a formal knowledge reuse methodology.

Questions to be covered in the interview

1.1.	How important is service to Company 2 as a business?
1.2.	Types of service carried out.
1.3.	What does PSS mean to Company 2?
1.4.	How is service taken into account into the design process?
1.5.	Feedback on the developed knowledge structure.

Any specific data required

No specific data is sought: this interview represents an investigative stage. A selection of the questions used in the detailed case studies are provided below as examples:	
1.1.	What criteria are used to assess quality of service?
1.2.	What are the major challenges of service delivery?
1.3.	How could manufacturing change to support the service process?
1.4.	What design aspects of the product could be modified to improve service?
1.5.	How do you feed back service concerns to design and manufacturing?
1.6.	How is the maintenance schedule developed?
1.7.	Does condition monitoring take place?
1.8.	What information is needed to support service design?
1.9.	What information is needed for the service operation?
1.10.	Describe typical defects found in the service process

Other methods (survey, observation, recording, notes)

Notes will be taken during the interview.

Analysis techniques & plan: type up notes/create cause and effect diagrams/create matrix/transcribe & code, etc.

A report will be created, describing the findings from the interview and comparing them with the findings from the other case studies and literature review.

Appendix C Service investigation at Company 1, US

Research aim

Capture of service knowledge in Company 1, Service hub, USA.

Research stage & current insight. Focus for exploration.

The aim of this research is to identify issues and problems in the service operation. This will support the development of a knowledge framework for use in design. The project is now capturing experience from people involved with service of the pump 1.

Objectives of these interviews include:

1. Recording issues faced during the service of pump 1

2. Identifying any relationship between service and design or manufacturing

3. Enriching the existing service knowledge types

4. Creating a report documenting the findings

The research will take place using semi-structured interviews.

Subjects to be covered: variables and constructs.

Service issues

The service problems and product defects will be identified and categorised. Design related issues are the main focus of the investigation, however all issues will be catalogued in order to assess the relative frequency and importance of the sources of service issues.

Questions to be covered in the interview

1.	Can you talk us through a typical service of pump 1?
2.	What types of service take place for pump 1?

3.	What triggers a service (failure, time period, other indications)?
4.	What are the common causes for pump 1 failure?
4.1.	How could design be modified to reduce these failures?
5.	What criteria are used to assess quality of service?
6.	Are there any problems faced in servicing pump 1? If yes, give examples of the main ones.
7.	Is there any interaction between service and design or manufacturing? If yes, give examples.
8.	What is the frequency of the service activities?
9.	What equipment is used in the service process of pump 1?
10.	Who is involved in the service process of pump 1?
11.	What design aspects of the pump 1 cause difficulty?
12.	What aspects of the pump 1 design would you change, and why?
13.	Are there any aspects of the pump 1 design have been changed as a result of the service process?
14.	Could manufacturing change to support the service process?
15.	What are the major challenges of service delivery?

Analysis techniques & plan: type up notes / create cause and effect diagrams / create matrix / transcribe & code, etc.

A report will be created, describing the findings from the exercise. The report will focus on issues relevant to product 1.

Documenting the findings (and any solutions) using the knowledge structure developed. This development will contribute to the ongoing research project.

Appendix D Responses to the questions (as presented in Appendix C), Company 1, US

D.1 Indicators for pump 1 service

A service can be triggered due to two factors: failure and time period. Regarding failure, it can be caused by two main reasons: either by pump 'crash', in which a build-up of process material causes the pump to stop; or by a reduction in vacuum achieved due to wear to the pump internals caused by abrasive process material and aggressive cleaning chemicals. Company 1 recommends overhaul intervals based on the applications, where the pumps are used. For pump 1 the recommended interval is 3 years, between which the pump is designed to run without being maintained. The time period indicator for service is supported by embedded counters on the pump. There are 2 counters: one that records the total-run time (from the moment that the pump was manufactured) and another one that counts down until next service and it gives an indication to the customer (message alert) that the pump needs service and it gets reset after service.

D.2 Common causes for pump 1 failure

The customer returns a pump either because this is what is defined in his/her contract or because the pump does not achieve the targets illustrated in its specification. Most pumps (product 1) are returned due to accumulation of process material in them. Sometimes the customers use the pumps in harsher processes than the ones that are designed for or take the risk to run them beyond the 3-year recommended service interval (until they fail). Therefore, the pump stops and it needs servicing. A number of new pumps were returned due to electrical problems.

D.3 Criteria to assess the quality of service

All the interviewees mentioned that each service engineer follows the procedures that are described in the service manual (e.g. build or test the pump). Therefore, the service manual depicts the level of quality that they should achieve. Moreover, it has been mentioned that the skills of the inspector play an important role in the final performance of the serviced pump. Finally, the criteria defining quality of service are, in some cases, set by the customer that the pump needs to be returned to. For instance, when the customer is Intel, a higher level of detail is required and during the service process, Company 1 does a final inspection at the pump after testing it, a task that does not take place for other customers.

D.4 Problems faced in servicing pump 1

Two main problems were pinpointed by the interviewees. The first one was related with the availability of the spare parts; it has been stated that when they started the service of pump 1 it was taking quite long to receive the spare parts (e.g. 2-3 weeks to get stators or rotors). The second problem was related with the water lines, since their number was big and it was time-consuming for the service technicians to remove them. A design change, though, which was made to overcome problems with the water valves, resulted in the reduction of the water lines' number.

D.5 Frequency of the service activities

Based on the applications, Company 1 suggests overhaul intervals. For the majority of the applications in pump 1 the recommended time is three years. The pump is designed so that there is no need for maintenance between the 3-year intervals. For difficult applications, service is needed every one or two years and when the pump is used in light processes, it may need to be serviced after four or five years. It is worth mentioning that the 3-year service period is not yet up, and that all pumps that have been serviced so far have been failures caused by a harsher-than-specified application.

D.6 Equipment involved in the service process of pump 1

The service technicians use inspection, assembly and disassembly tools, TDS (Tool Drawing System) tools and the test is manual. They also use a hydraulic press for removing the shaft and another one to remove the rotors from the booster.

It should be noted that when the service of pump 1 started all service was done by one person due to very low volumes of pumps that required service. The division of the pump 1 service now includes three operations: DCI, build, test and if volume increases, the build operation may be further divided and set up on a conveyor line.

D.7 Design aspects that cause difficulty in service and changes that could be made or have already been made to facilitate it

Pump 1 is designed to be easily serviced. Therefore, there are only few design aspects that cause difficulty in service and they have been changed in order to smooth the service process. Generally, the product is compact and the more compact a product is, the more labour it requires for assembly and disassembly and sometimes the access to components is difficult. Specifically, the water system has been changed because the water valves were failing; this, consequently, resulted in the combination of the valves and, thus, their number was reduced. Subsequently, the number of the water lines was also decreased and this design change finally led to easier service, due to less time spent on the removal of the water lines. There were not any suggestions for additional changes to the design of the pump.

D.8 Major challenges of service delivery

It has been revealed from the interviews that one key challenge in service delivery is troubleshooting, as this pump is quite new for the service technicians and it is essential to identify faults in it. Apart from this, getting spare parts on time is of vital importance for service because they need to carry out the maintenance process according to the timeline specified. Also, the existence of a balance between service and production is needed with regards to spare parts allocation; so far, production was the priority but now it seems that they are both under the same umbrella. And last but not least, the fact that implementing the service operation of a product is not just the re-build of the pump should not be overlooked. This means that other aspects, such as who the person in charge is, who the decision maker is, the capacity of the service hubs and the time plan should be taken into consideration.

D.9 Interaction between service and design or/and manufacturing

It has been clear from the interviews that only the lead technician interacts with design and manufacturing up to an extent. Nevertheless, it should be further investigated if there are informal meetings and discussions among employees in different departments about issues arising in service and the help that could be provided by people in design or manufacturing.

Appendix E Service investigation at Company 1, Germany

Research stage & current insight. Focus for exploration.

The aim of this research is to identify issues and problems in the service operation, and to identify processes relating to product service and service implementation. This will support the development of a knowledge framework for use in design. The project is now capturing experience from people involved with service of pump 1.

The specific objectives of this research are:

1. Recording issues faced during the service of pump 1

2. Identifying any relationship between service and design or manufacturing

3. Enriching the existing service knowledge types

4. Creating a report documenting the findings

The research will take place using the critical incident technique, semi-structured interviews and observation.

Subjects to be covered: variables and constructs

Service issues

The service problems and defects will be identified and categorised. Issues will be catalogued in order to assess the relative frequency and importance of the sources of service issues.

Service methods

The service methods (processes, procedures) will be recorded.

Variables

Service engineers' skills

Training material and process

Availability of tools and spare parts

Right service procedures

Right implementation of service

Constructs

Communication between service and design and feedback Assembly and disassembly of the pump Components difficult to be accessed The testing procedure may reveal some design issues

Background knowledge

An initial investigation into service knowledge has been carried out with people involved in the NPD process for pump 1 in the UK. This has been used to develop an initial knowledge framework that can be used to structure and store knowledge. Five interviews have also been conducted with service people in a service hub, US.

Case description: company name, business unit

Company 1, European service operations Focus on pump 1, interviews with service engineers and the service site manager.

Case justification: why this company? How does this company match the research aim? Why this business unit?

Company 1 represent a capital intensive, mature and complex electro-mechanical design domain, which is suited to a formal knowledge reuse methodology.

Questions to be covered in the interview

1.	What specific knowledge is applied to the service design and operations for the selected product? Could you talk through a good and bad example of application of service knowledge for pump 1 design improvement?
2.	Can you talk us through a typical service of pump 1?
3.	How do you test pump 1?
4.	What triggers a service (failure, time period, other indications)?
5.	What are the common causes for pump 1 failure?

6.	What are the main problems faced in servicing pump 1?
7.	Is there any interaction between service and design or manufacturing?
8.	What is the frequency of service activities?
9.	Can you talk us through the introduction of pump 1 into the field service operation?
10.	What information is needed for the service operation?
11.	What equipment is used in the service process of pump 1?
12.	Who is involved in the service process of pump 1?
13.	What design aspects of pump 1 cause difficulty?
14.	Has pump 1 design changed as a result of the service process? Can you give some examples?
15.	How could manufacturing change to support the service process?
16.	What criteria are used to assess quality of service?
17.	What are the major challenges of service delivery?
18.	How could the performance of the service department be improved?
19.	How could customer satisfaction be improved? Are there any measurements or reports created regarding customer satisfaction?

Any specific data required

Service process methods: sequence of activities in the service operation

Overview of pump 1 field service implementation (Dresden view): information and knowledge required to implement pump 1 field service

Common causes of pump 1 product failure

Service related documentation

Other methods (survey, observation, recording, notes)

Semi-structured interviews will be the main method used in this visit.

Observation and recording will also take place.

Analysis techniques & plan: type up notes / create cause and effect diagrams / create matrix / transcribe & code, etc.

A report will be created, describing the findings from the exercise. The report will focus on issues relevant to the pump 1 project. Documenting the findings (and any solutions) using the knowledge structure developed. This development will contribute to the ongoing research project. A knowledge structure will be created Process models will be created to describe the various service operations

Appendix F Responses to the questions (as presented in Appendix E), Company 1, Germany

F.1 Indicators for pump 1 service

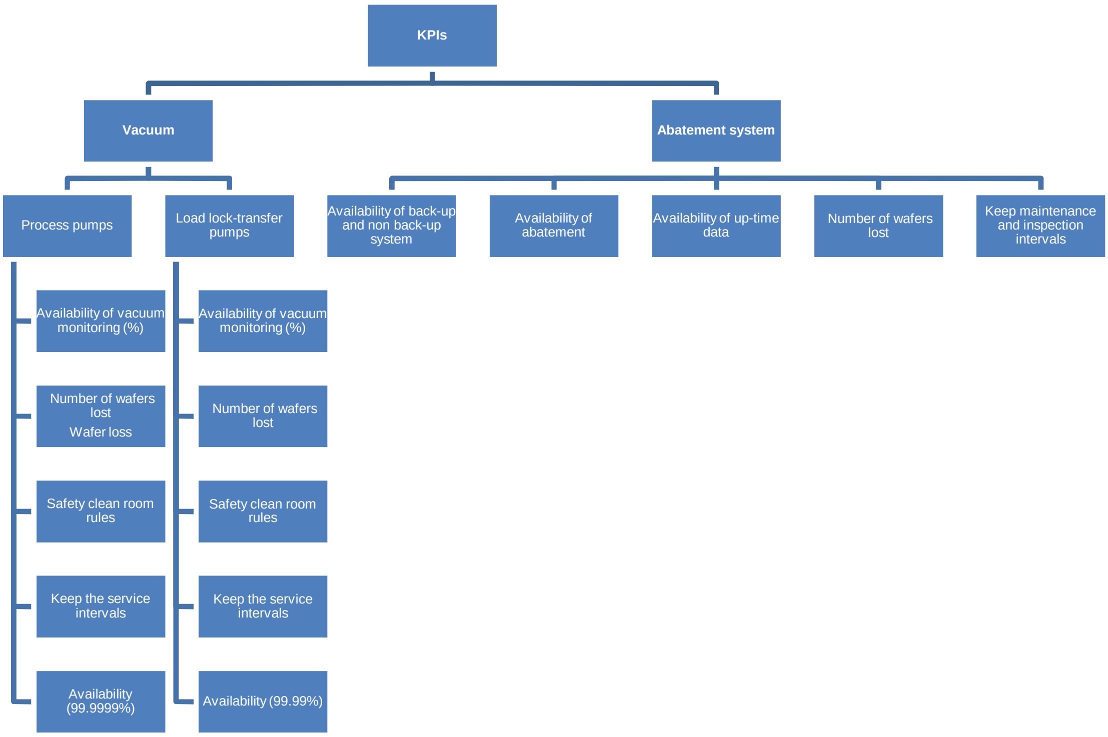
A service can be triggered due to two factors: failure and time period. Regarding failure, it can be caused by two main reasons: either by pump 'crash', in which a build-up of process material causes the pump to stop; or by a reduction in vacuum achieved due to wear to the pump internals caused by abrasive process material and aggressive cleaning chemicals. Company 1 recommends overhaul intervals based on the applications where the pumps are used. For pumps (type 1) at Infineon the recommended interval is either 2 or 3 years, between which the pump is designed to run without being maintained. The interval is set at either 2 or 3 years depending on the process where the customer uses the pump.

F.2 Common causes for pump 1 failure

The common cause of most pump 1 failures to date is accumulation of process material. Sometimes the customers use the pumps in harsher processes than specified. When the pump fails it needs to be removed and sent for repair. Various minor causes were also identified, including problems faced with the pump Ethernet interface, and faulty electrical connections.

F.3 Criteria to assess the quality of service

All interviewees mentioned that the criteria are set in the form of KPIs by the customer (Infineon) and there is a penalty in case Company 1 does not achieve them. The KPIs are as follows:



F.4 Problems faced in servicing pump 1

The problems identified in on-site service include:

- The customer installs the pumps very close one to each other, whereas the service technicians require a reasonable space between them so that they can access all of their sides and access the components that need to be replaced. As such, there is a conflict between the customer installation and the product access requirements for service. Moreover, sometimes they face problems with the fuses of the customers, who in their attempt to save money they install wrong fuses and afterwards they complain that the pump has problems.

- While pump 1 check valves are moving, there is a very small distance between them and the enclosure and sometimes the exhaust gets stuck.
- All the interviewees stated that they do not receive adequate number of pumps from the service hub (Czech Republic). Most refurbished pumps that are received are re-tested by Company 1 personnel in Dresden due to low confidence in the hub service operation. This happens because the hub service team there is now in its learning curve without previous substantial experience.
- The vibration and the noise level of the pump should be reduced to a minimum. The noise level can be reduced by the installation of a silencer; however, this process is quite expensive and the customer has to pay for it.

F.5 Frequency of service activities

Based on the applications, Company 1 suggests overhaul intervals. For the majority of the applications in pump 1 the recommended time is three years. The pump is designed so that there is no need for maintenance between the 3-year intervals. For harsher applications, service is recommended every two years. It is worth mentioning that at the Infineon site the 3-year service period is not yet up: all pumps that have been serviced so far have been failures caused by a harsher-than-specified application.

F.6 Equipment and people involved in the service process of pump 1

On-site service tasks include: troubleshooting, installation and pump swap on-site. Since there is no decontamination facility the pumps cannot be dismantled due to the chemicals used in the processes. They generally use commonly-used tools for removing the pump, in addition to a special adaptor to remove the pump 1 exhaust system.

It should be noted that Company 1 had low volumes of pumps at Infineon site, but currently they have 1,700 pumps (the number of pumps (type 1) is not confirmed). The people involved are 6 technicians for the pumps, 6 technicians for abatement and 5 people dealing with administration.

F.7 Design aspects that cause difficulty in service and changes that could be made or have been made to improve it

Pump 1 is designed to be easily serviced. Therefore, there are only a few design aspects that cause difficulty in service and they have been changed in order to smooth the service process. Pump 1 is a compact product, and in general terms compact products require more labour for assembly and disassembly. This is due to the limited space in the pump casing for electrical, electronic, nitrogen and coolant components. These components can make access to pump components difficult.

Pump 1 has only 3 wheels, so all 3 wheels are in contact with the surface and according to one of the interviewees, this is better than having 4 wheels.

A design change that was suggested during the interview was the reduction of the difficult parts of the pump. However, it was not stated which parts are perceived to be the difficult ones.

F.8 Performance of service people

At Infineon site, they use HR tools and they have a regular PDR (Personal Development Review). There are 4 team leaders, responsible for vacuum, abatement, administration and development. They use the KPIs given by the customer.

A bonus system is also established depending on:

1. Personal performance
2. Company’s performance

F.9 Customer satisfaction measurement

The customer is generally satisfied. The performance is judged by the customer according to the KPIs. Once a year Infineon has a supplier evaluation process and fortnightly they meet with Company 1 to discuss about problems that occurred and how quickly they were tackled.

Many issues arise in refurbished products, but not in new ones. This happens because in Czech Republic they are still in the learning curve. However, the customer cannot see all these issues, because they re-test in Dresden the pumps received from Czech Republic.

F.10 Interaction between service and design or/and manufacturing

It has been clear from the interviews that the project manager of the site and the operations site manager are the people that contact the design or manufacturing departments in the UK. Nevertheless, it has been mentioned that people from all over the world exchange knowledge and experience via e-mails or in meetings. There are also forums, where everybody can have access, but mainly because of the time pressure, people cannot report all the problems. Lastly, if there are serious problems, they report them in ECAR (Electronic Corrective Active Request). Also, when a new product is launched, some of the service technicians go to Crawley (UK) to get trained.

F.11 Service features

The interviewees were asked to define service features from their own perspective. The list below is the outcome of amalgamation of all the given answers:

- Relationship with OEMs
- Global presence with the same level of service provided everywhere in the world
- Quality (use original OEM parts, refurbished pumps are tested with the same standards as when they are new)
- Value-added features (features that differentiate them from their competitors)

- Detailed knowledge to quickly troubleshoot the problems
- Invisible (the customer does not want to notice their existence, just needs vacuum out of the pump) and comfortable (the customer wants quick informative answers)
- Time taken to swap out the pump
- Easy access to water, power, nitrogen
- Easy access to individual components that need to be replaced
- No maintenance activities between the overhaul intervals
- Manoeuvrability
- Minimum of 2 lifting points in each pump for safety reasons
- No special tooling required for the installation or the removal of the pumps
- Global availability of connectors, fuses and associated parts
- Worldwide consistency of the methods and procedures used.

Appendix G **Validation document, Company 1, Germany**

G.1 Introduction

This document includes findings from the interviews within Company 1 in Germany, which need to be validated from the key participants. The aim is that the researcher amends the content captured if necessary and depicts precisely the findings related to the company. Specifically, the knowledge types, and the KPIs, that were captured, are presented below.

G.2 Service knowledge types

The main knowledge types that were captured through the series of interviews conducted with Edwards are presented below. The researcher aims at verifying their validity and at ensuring that the issues mentioned in the interviews are well reflected in these knowledge types.

- Logistics

Shipping

  - Transport

- Product

Tooling

  - production
  - hub- TDS tools, inspection tools (for shafts, rotors, bearings, stator, motor), build tools, hydraulic press
  - field

Spares

  - definition
  - availability
  - cost
  - numbering

Serviceability

  - changes in product design
  - time

- o human resources

Manoeuvrability

Training

- o time
- o training material
- o skills of people involved

- Processes

Painting

- o customer dependent

Planned maintenance

- o overhaul intervals- time period, process material
- o H &S form- process material
- o No maintenance activities between the service intervals

Unplanned maintenance

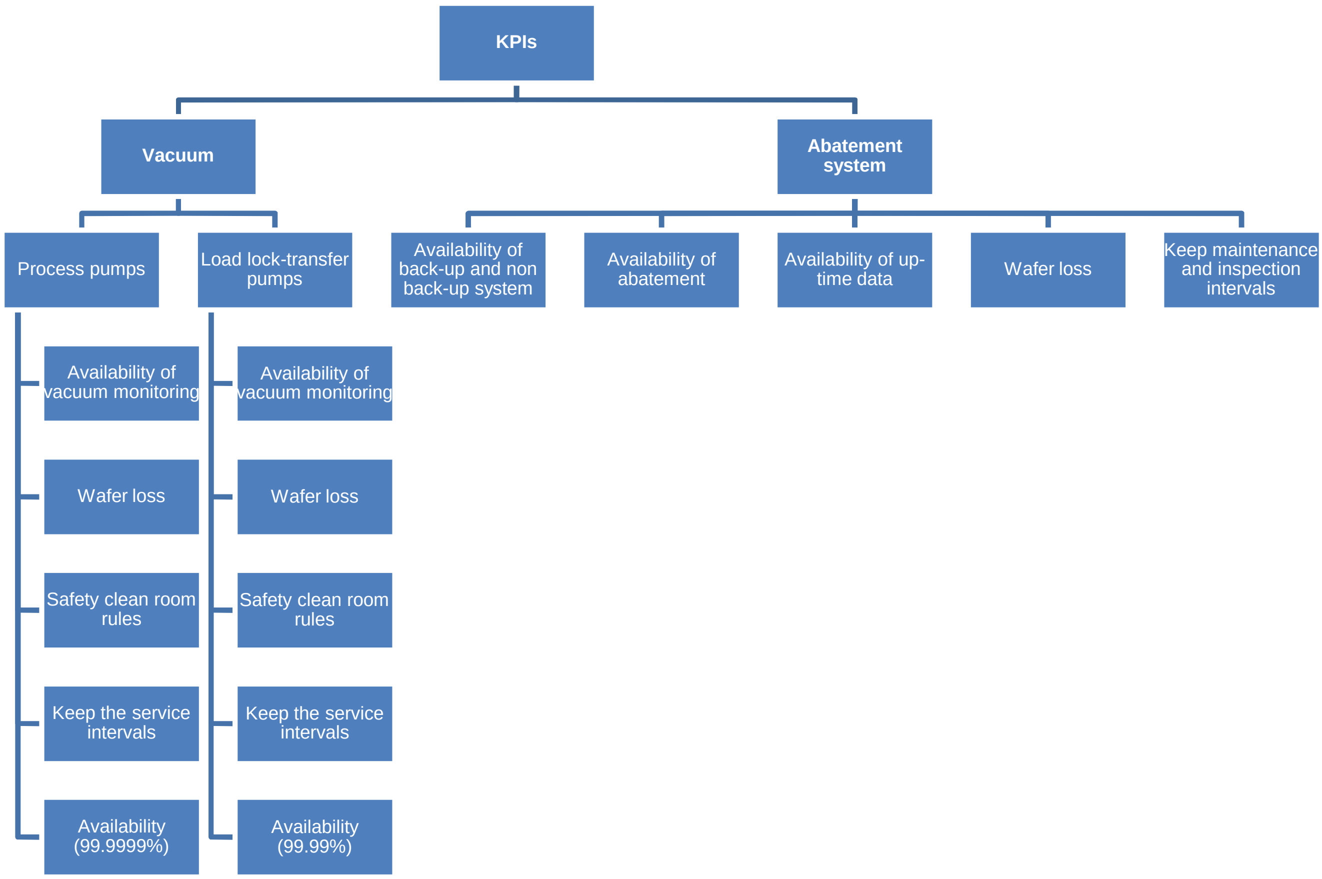
- o accumulation of process material
- o service failure codes
- o electrical problems
- o H & S form- process material
- o Processes out of specification

Packaging

- Service features
- o Global presence with the same level of service provided everywhere in the world
- o Quality
- o Value-added features (features that differentiate from the competitors)
- o Detailed knowledge to quickly troubleshoot the problems
- o Invisible
- o Comfortable
- o Worldwide consistency of the methods and procedures used
- o Swap out time
- o Availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up
- o Accessibility to: utilities, individual components that need to be replaced
- o Manoeuvrability
- o No special tooling required for the installation or removal of the pumps

G.3 KPIs

The KPIs below are the performance indicators that Company 1 is given by Infineon and needs to meet the requirements included in them. Therefore, the researcher needs to check if what captured is valid or not.



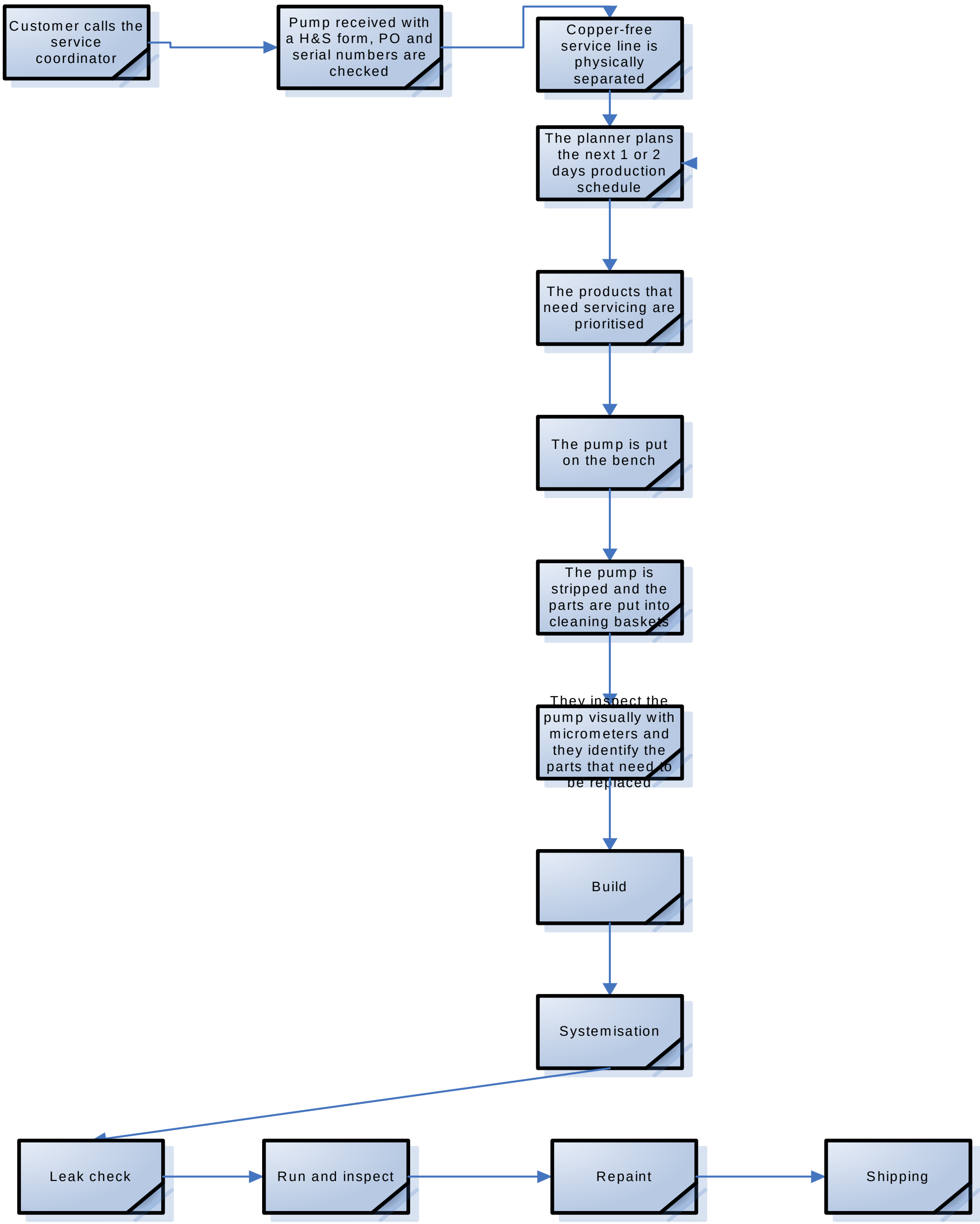
Appendix H **Validation document, Company 1, US**

H.1 Introduction

This document includes findings from interviews within Company 1 in the US, which need to be validated from the key participants. The aim is that the researcher amends the content captured if necessary and depicts precisely the findings related to the company. Specifically, the processes (service, DCI, build, and test process), and the knowledge types that are the outcome of the whole case study are presented below.

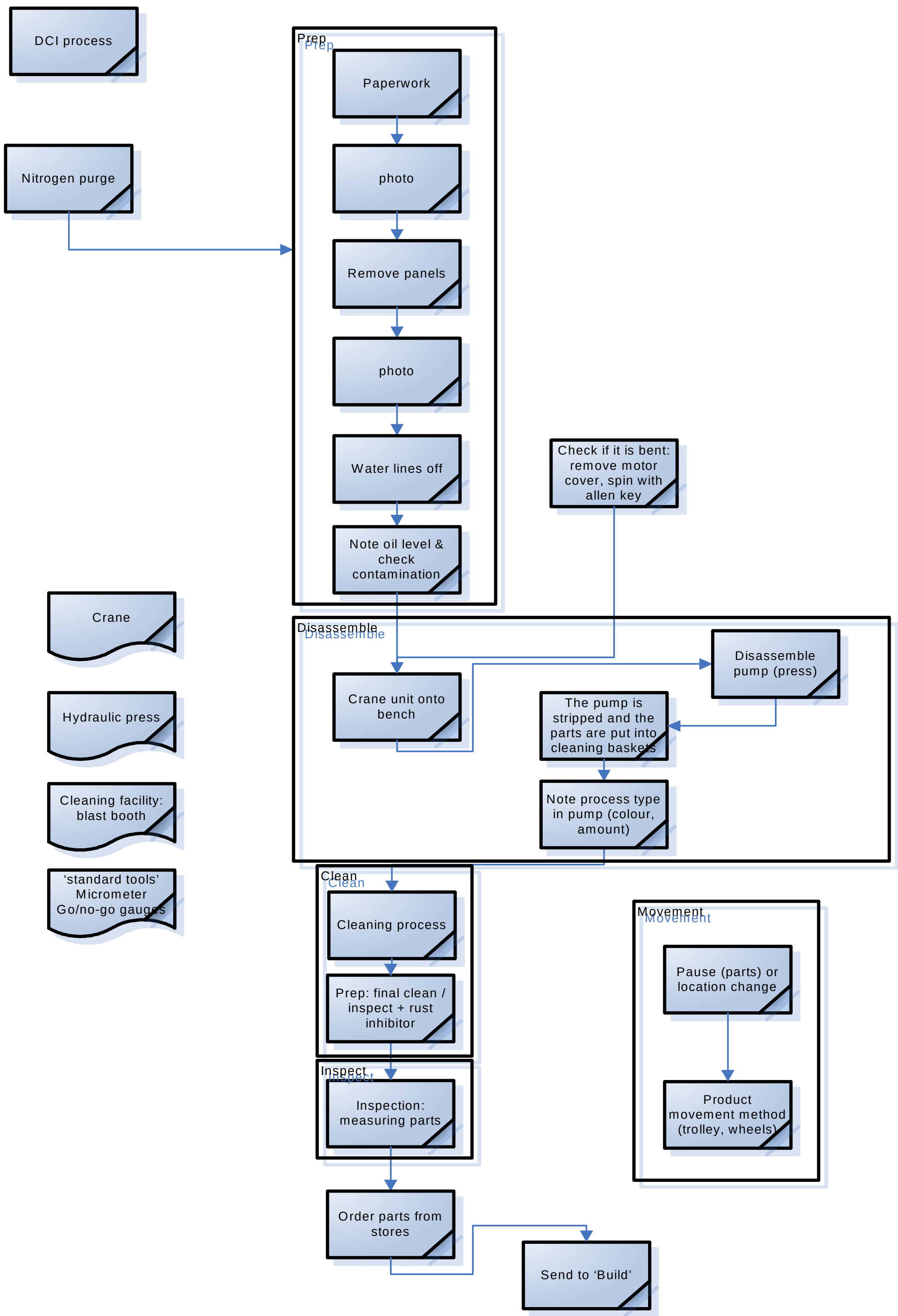
H.2 Processes

Service process

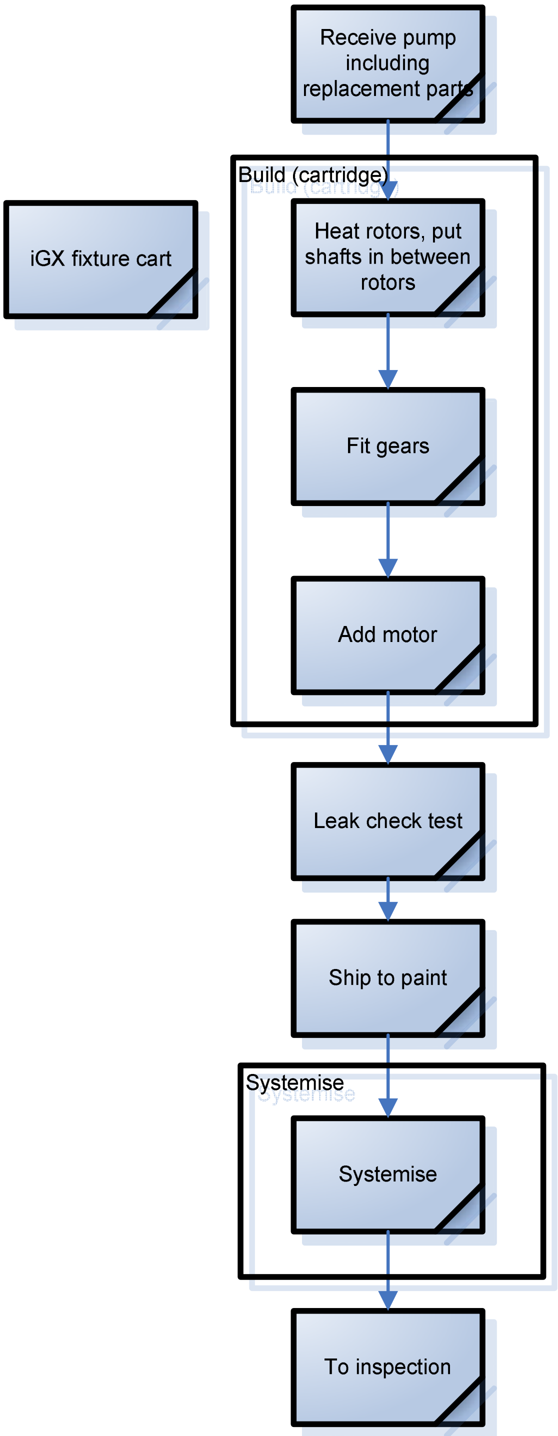


Customer calls the service coordinator
Pump received with a H&S form, PO and serial numbers are checked
Copper-free service line is physically separated
The planner plans the next 1 or 2 days production schedule
The products that need servicing are prioritised
The pump is put on the bench
The pump is stripped and the parts are put into cleaning baskets
They inspect the pump visually with micrometers and they identify the parts that need to be replaced
Build
Systemisation
Leak check
Run and inspect
Repaint
Shipping

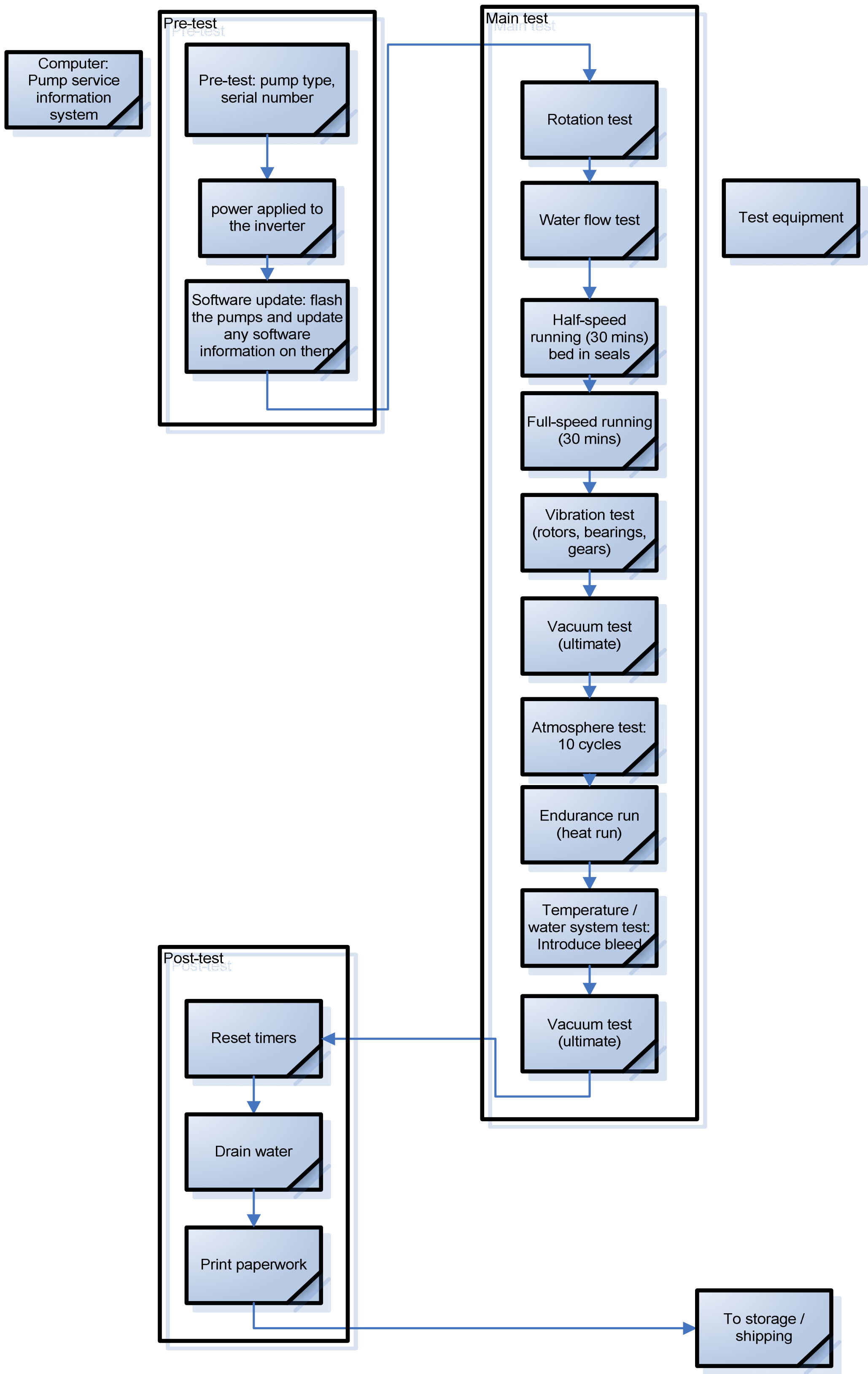
DCI process


DCI process
Nitrogen purge
Prep
Paperwork
photo
Remove panels
photo
Water lines off
Note oil level & check contamination
Check if it is bent: remove motor cover, spin with allen key
Disassemble
Disassemble pump (press)
Crane unit onto bench
The pump is stripped and the parts are put into cleaning baskets
Note process type in pump (colour, amount)
Crane
Hydraulic press
Cleaning facility: blast booth
'standard tools' Micrometer Go/no-go gauges
Clean
Cleaning process
Prep: final clean / inspect + rust inhibitor
Inspect
Inspection: measuring parts
Movement
Pause (parts) or location change
Product movement method (trolley, wheels)
Order parts from stores
Send to 'Build'

Build process



Test process



H.3 Service knowledge types

- Logistics
- Shipping
    - Transport
- Product
- Tooling
    - production
    - hub- TDS tools, inspection tools (for shafts, rotors, bearings, stator, motor), build tools, hydraulic press
    - field
- Spares
    - definition
    - availability
    - cost
    - numbering
- Serviceability
    - changes in product design
    - time
    - human resources
- Manoeuvrability
- Training
    - time
    - training material
    - skills of people involved
- Processes
- Painting
    - customer dependent
- Planned maintenance
    - overhaul intervals- time period, process material
    - H &S form- process material
    - No maintenance activities between the service intervals
- Unplanned maintenance

- accumulation of process material
    - service failure codes
    - electrical problems
    - H & S form- process material
    - Processes out of specification
- Packaging
- Service features
    - Global presence with the same level of service provided everywhere in the world
    - Quality
    - Value-added features (features that differentiate from the competitors)
    - Detailed knowledge to quickly troubleshoot the problems
    - Invisible
    - Comfortable
    - Worldwide consistency of the methods and procedures used
    - Swap out time
    - Availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up
    - Accessibility to: utilities, individual components that need to be replaced
    - No special tooling required for the installation or removal of the pumps

Appendix I Knowledge templates related to product failure

I.1 'General info' template

Knowledge types	Instances
Product type	
Painting method	
Packaging (materials used, recyclable or not)	
Location of the customer vs service facility	
Safety record (accidents/ near misses)	
Password protection (yes/ no, issues)	

I.2 'Issues faced' template

Knowledge types	Instances
Painting issues (specify component or subsystem if poss)	
Shipping issues	
Manoeuvrability issues (specify component or subsystem if poss)	
Serviceability issues (specify component or subsystem if poss)	
Maintainability issues (specify component or subsystem if poss)	
Tooling issues	
Accessibility issues	
Spares issues	
Other issues (please specify)	

I.3 'Failure' template

Knowledge types	Instances
Failure type (specify component or subsystem if poss)	
Actions taken after failure	
Number of components used	
Component ID	
Recyclability of materials used	

I.4 'Installation environment' template

Knowledge types	Instances
Installation environment- floor space required	
Installation environment- humidity	
Installation environment- temperature	
Installation environment- utilities required	

I.5 'Application' template

Knowledge types	Instances
Installation environment- floor space required	
Installation environment- humidity	
Installation environment- temperature	
Installation environment- utilities required	

Appendix J Development of SF list

J.1 Company 1

List of 18 features:

1. Global presence with the same level of service provided everywhere in the world
2. Quality
3. Value-added features (features that differentiate from the competitors)
4. Detailed knowledge to quickly troubleshoot the problems
5. Invisible
6. Comfortable
7. Worldwide consistency of the methods and procedures used
8. Swap out time
9. Availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up
10. Accessibility to: utilities, individual components that need to be replaced
11. No maintenance activities between the service intervals
12. Manoeuvrability
13. No special tooling required for the installation or removal of the pumps
14. Spares availability and cost
15. Shipping
16. Painting
17. Packaging
18. Training

11 became part of maintenance strategy.

14 became a slot of the 'spares' class.

15 became a subclass of the 'logistics' class.

16 and 17 became subclasses of the 'product attribute' class.

18 became a class of the 'service organization' main class.

List of 12 features:

1. Global presence with the same level of service provided everywhere in the world
2. Quality
3. Value-added features (features that differentiate from the competitors)
4. Detailed knowledge to quickly troubleshoot the problems
5. Invisible
6. Comfortable
7. Worldwide consistency of the methods and procedures used
8. Swap out time
9. Availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up
10. Accessibility to: utilities, individual components that need to be replaced
11. Manoeuvrability
12. No special tooling required for the installation or removal of the pumps

Add 'continuous improvement' of the value-added features (after the two validation sessions).

8 became a slot in the 'pump swap out' subclass (of 'on-site service process' subclass of 'service process' class).

10 became a subclass of the 'installation environment' subclass (of 'service facility' class)

11 became subclass of the 'product attribute' class.

12 is included in the 'tooling' class.

Final list of 8 features:

1. Global presence with the same level of service provided everywhere in the world
2. Quality
3. Value-added features (features that differentiate from the competitors) and continuous improvement of them
4. Detailed knowledge to quickly troubleshoot the problems
5. Invisible
6. Comfortable
7. Worldwide consistency of the methods and procedures used
8. Availability of: the product, vacuum monitoring, up-time data, abatement, back-up and non back-up

J.2 Company 3

List of 11 features

1. Machines' uptime (achieve minimum downtime)
2. Offer of cheap service packages to the customers so that they can afford
3. Speed in response (customer as well)
4. Ability of engineers (well-trained and informed engineers arrive punctually with the correct parts) (customer as well)
5. Attitude of the engineers and all the people that the customer is in contact with (honesty, politeness)
6. Availability of spare parts
7. Prompt delivery of spare parts
8. Professionalism of the service personnel (customer as well)
9. Provision of the necessary documentation
10. Tidiness
11. Quality

6 became a slot of the 'spares' class.

7 became a slot of the 'spares' class.

List of 9 features

1. Machines' uptime (achieve minimum downtime)
2. Offer of cheap service packages to the customers so that they can afford
3. Speed in response (customer as well)
4. Ability of engineers (well-trained and informed engineers arrive punctually with the correct parts) (customer as well)
5. Attitude of the engineers and all the people that the customer is in contact with (honesty, politeness)
6. Professionalism of the service personnel (customer as well)
7. Provision of the necessary documentation
8. Tidiness
9. Quality

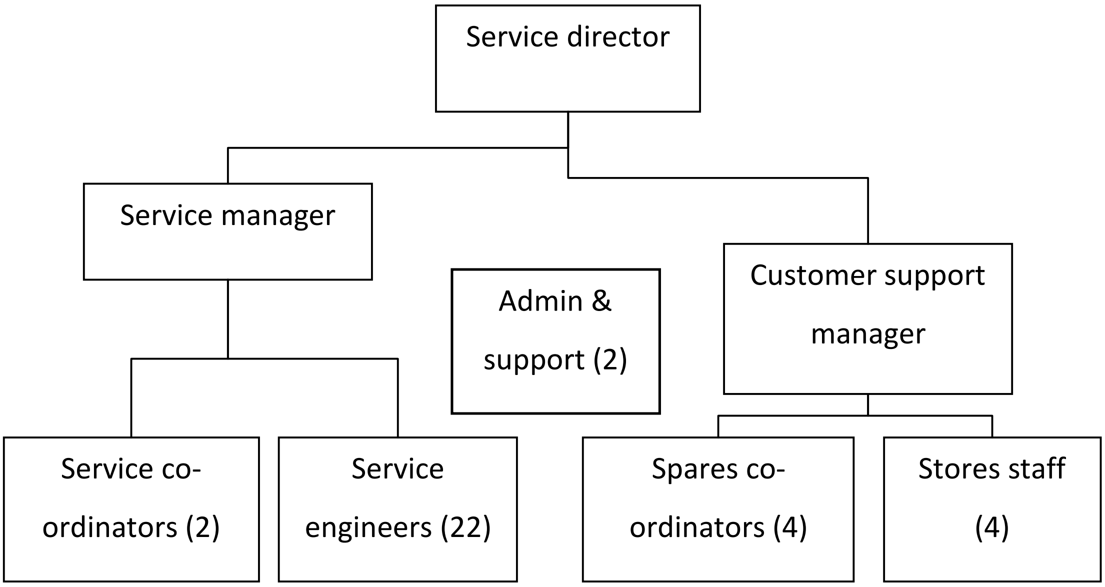
5, 6 and 8 combined.

List of 7 features

1. Machines' uptime (achieve minimum downtime)
2. Offer of cheap service packages to the customers so that they can afford
3. Speed in response (customer as well)
4. Ability of engineers (well-trained and informed engineers arrive punctually with the correct parts) (customer as well)
5. Attitude of the engineers and all the people that the customer is in contact with (honesty, politeness, tidiness, professionalism)
6. Provision of the necessary documentation
7. Quality

Appendix K **Results from research at Company 3**

K.1 The service organisation



K.2 Research method

The researcher conducted interviews with members of the service group. 13 people from a variety of roles in spares, service and applications were interviewed. 3 customers were also interviewed.

Notes were taken during the interviews, and these were used during the preparation of the report.

K.3 Findings

K.3.1 Service value

The people interviewed were asked their view on service value: "what aspects of service deliver value to the customer"? The author got a variety of responses, including:

- Speed of response to the customer
- Ability of engineers (well-trained and informed engineers)

- Attitude of the engineers (honesty, politeness, professionalism, punctuality)
- Minimum machine downtime
- Attitude of all the people that the customer is in contact with (honesty, politeness, professionalism)
- Tidiness of the engineer whilst working – and the condition they leave the machine
- Prompt delivery of spare parts
- Provision of any necessary documentation

The customers were also asked to identify service value: the main question addressed to them was 'what is the most important aspect of service'. In every case, **response** stood out as the main component of service value. The key attributes of service value according to the customers are:

- Response
- Professionalism
- Capability of the engineer

K.3.2 Service performance

Very early on, the interviewees mentioned that 'it's all about logistics'. At the end of the study, this stands out as the primary aim of the service group:

Deliver the right parts and the right engineer to the customer at the right time.

The company is not currently achieving this to the high standards expected.

Within the company, people were asked how their performance is measured. In almost every case, there are no performance measures. The only way to determine how well you are performing is 'how many complaints have I received'. There are no positive indicators.

K.4 Customer view on what matters in service: value vs. Delivery

Response, response, response.

The customer perspective is mixed. Company 3 have some very good engineers who customers are happy to pay the high prices for (and Company 3 engineers *are* expensive), however the spares backup is not good enough.

Service provision appears to be about giving the customer assurance that they can begin production again: taking away the uncertainty that a breakdown creates. Production managers are generally working on tight schedules with very little room for error. When a machine goes down, part of the stress factor is the lost production, and part of it is the uncertainty it creates. When can I get running again – how late will this make me – will I miss my deadlines – what is this going to cost? All of these questions remain unanswered until a service engineer arrives on site and gives a full diagnosis of the problem along with an estimate of when the machine can be repaired. Ideally, the repair takes place at the same time.

Assigning a service engineer to visit the customer site is only part of the issue. Company 3 appear to perform well in this area, and the customers interviewed were generally satisfied with the response time.

Assigning the right engineer to the customer is crucially important. If an engineer arrives and asks 'how do I turn this on' the customer is not reassured. Service is about reassuring the customer that production can start again. An engineer with no experience of a machine creates more stress for the customer and leaves them questioning their decision to buy that machine. Due to the high variation in the product range at Company 3, there is an issue with engineer skills: not all engineers can service all machines. A skill-based strategy for training and service management should be developed.

The main problem in service is the delivery of parts. An uncensored view on parts provision from a customer with some negative experiences: “your parts’ people are jokers”.

This refers to a feeling that the people working in the spares department do not have good product knowledge, regularly deliver the wrong items, forget to deliver parts, fail to deliver on the agreed day, send parts to the wrong address, and are not up-front and honest with the customer about the process. In one case, the customer questioned whether a part order had been placed with Company X. They were told that it had been done, however the customer knew that the USA was not open for business that early in the day.

Sales, in every case, depend not only on the product specification but on a continued high level of service provision throughout the life of that machine. As described earlier, a production manager making a decision on what machine to buy wants to know that it will be reliable. Because they expect occasional breakdowns, machine reliability includes service performance. This was identified as a key decision not only with large customers, but also with small customers who may only buy one machine. They are likely to ask other Company 3 users “will they deliver the same level of service to me”.

Very good service is remembered for a long time, and customers recognise when you go the extra mile. That memory soon fades when bad service is delivered. At that time they start considering new machine tool suppliers.

A good reputation is hard won and easily lost.

A personal relationship with suppliers is important. This helps in cases where a repair is really urgent – if they know you, the communication about when you have an issue that can wait a little while and when you have a desperately urgent problem works better. There is some give and take expected here – ‘help me out quickly when I am really desperate and I will not be too upset when you ask whether you can come in 2 days time’.

Appendix L Research protocol- detailed design stage, Company 4

L.1 SF- Resources

The table below describes the resources that are necessary so that every service feature is realised. The ultimate aim is that the resources are used in such a way, that the service provided by the company meets the customer requirements.

Service feature	Resources
Reliability (the ability to deliver the promised service)	▪ Service manager: he/ she is the main responsible person of the service facility ▪ Service engineers: they are the people delivering the service ▪ Spare parts department: they need to be punctual ▪ Supplier: needs to provide the spare parts on time ▪ People that are in contact with the customer: extract the correct information from the customer and convey it precisely and on time to the company's responsible team
Assurance (service engineers' behaviour and knowledge)	▪ Service engineers: need to be polite, professional and knowledgeable ▪ Employees who provide the training so that the service engineers know their job well
Tangibles (documentation + tidiness)	▪ Documentation: team responsible for the creation of the documentation (the latter needs to be comprehensive; attention needs to be paid on the language used within a multinational company ▪ Tidiness: Service engineers,

	company's policy
Empathy (attributes that differentiate from the competitor)	▪ Benchmarking team ▪ Product itself ▪ NPI team: they need to define the requirements for the next generation of products
Responsiveness (speed in response + global presence)	▪ Speed in response: People who define the service policy, service engineers, people who are in contact with the customer ▪ Global presence: service management team
Service price	▪ Service management team who define the policy ▪ Benchmarking team
Perceived impact of service (invisible + comfortable)	▪ Service engineers ▪ Service management team
Machine uptime	▪ Product itself ▪ Service team that sets the correct service intervals ▪ Service engineers: they have to provide the needed service on time when a failure occurs.

1. Is there anything missing?
2. Do you think that the links are valid?
3. Do you believe that by taking the resources needed into account for the realisation of the service features will make their realisation easier?

L.2 SF-SK

Each organisation needs to meet its customer requirements in order to survive in today's worldwide market. One of the aspects that need to be fulfilled is the service provision; thus, there are several service features, which have to be taken into account when designing the service that will be provided to the customers. These features should be linked with the relevant service knowledge types in order for the former to be achieved and delivered to the customer.

1. Reliability:
    - Logistics
    - Training
    - Service personnel
    - Planned and unplanned maintenance
    - Spares
    - Product reliability
2. Assurance:
    - Ability: Training
Service personnel
Spares
Tooling
Equipment
    - Attitude: Training
Service personnel
3. Tangibles:
    - Documentation: Training
Service personnel
Planned and unplanned maintenance
Processes
    - Tidiness: Service personnel
4. Empathy:
    - Product
    - Painting
    - Packaging
    - Machine uptime
    - Service price
    - Product reliability
5. Responsiveness:
    - Speed in response: Logistics
Service personnel
    - Global presence: Logistics
Processes
Painting

Planned and unplanned maintenance
Packaging
Service price
Tooling
Equipment
Spares

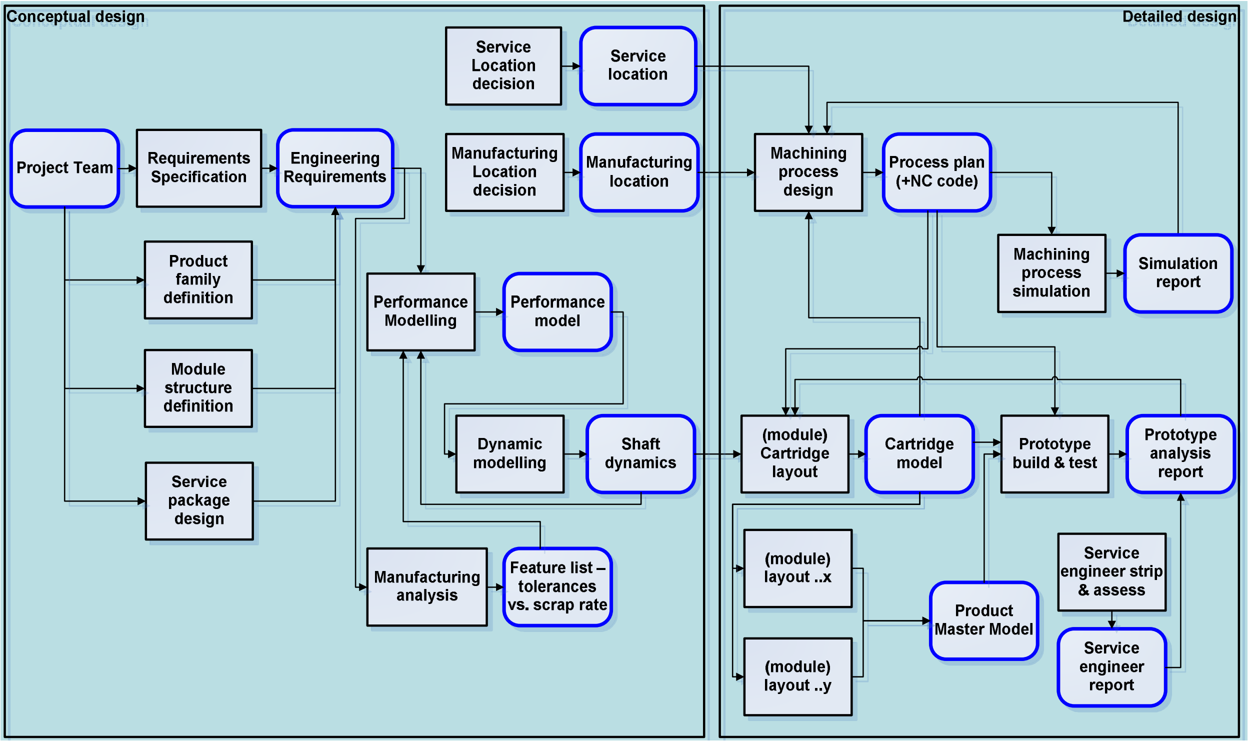
6. Service price
7. Perceived impact of service:
   - Invisible: Logistics
     Training
     Service personnel
     Planned and unplanned maintenance
   - Comfortable: Training
     Installation environment
     Service personnel
     Serviceability
     Manoeuvrability
     Processes
     Planned and unplanned maintenance
8. Machine uptime:
   - Service personnel
   - Product
   - Planned and unplanned maintenance
   - Spares

Questions:

1. Are these links valid?
2. Do you find this linking beneficial? Will it make any difference in your daily activities?

L.3 Detailed design stage information

This document presents the information needed in each activity of the detailed design stage, as described within the collaborating company.



The detailed design stage is situated in the right half of the figure. It consists of five activities, which are as follows:

1. Machining process design
2. Module X layout
3. Machining process simulation
4. Prototype build and test
5. Service engineer strip and assess

The information, which is needed in each of the activities, is described below.

Detailed design activities	Information needed	Information needed ***from service***
Machining process design	Manufacturing location Cartridge model Simulation report	Service location (distance from the customer)

Module X layout	Process plan + NC code Prototype analysis report Shaft dynamics	Past issues and failures recorded (manoeuvrability, serviceability, maintainability, accessibility)
Machining process simulation	Process plan + NC code	
Prototype build and test	Process plan + NC code Product Master Model Cartridge model	Past issues and failures recorded (painting, spares, tooling, serviceability, manoeuvrability)
Service engineer strip and assess		Past issues and failures recorded (tooling, serviceability, accessibility, maintainability)

Appendix M **Excel sheet DF-SK**

Design features/ service knowledge types	Product type	Issues faced	Resources needed	Failure type	Actions after failure	Planned/ unplanned maintenance	Difference between actual and expected life	Paint	Number of components used	Component ID	Accessibility	Training	Location (customer / service facility)	Recyclability of materials used	Serviceability	Maintainability	Safety record	Password protection	Installation environment (temperature, humidity)	Application used in	Application specified for
Cleanable																					
Cost																					
Ergonomics handling																					
Manoeuvrability																					
Manufacturability																					
Serviceability																					
Surface finish																					
Thermal control																					
Traceability (parts ID, machining data)																					
Weight and dimensions																					
Packaging																					
Maintainability																					
Life																					
Safety																					
Error proofing																					
Material type																					

Appendix N DR-SK tool final validation questionnaire

Research aim

Validation of the DR-SK tool.

Research stage & current insight. Focus for exploration.

The aim of this research is to develop a service knowledge framework to support design. The current focus for exploration is to validate the DR-SK tool, which was developed by the researcher.

Case description: company name, business unit

Company 1

Case justification: why this company? How does this company match the research aim? Why this business unit?

Company 1 represent a capital intensive, mature and complex electro-mechanical design domain, which is suited to a formal knowledge reuse methodology.

Questions to be covered in the interview

1.1.	Is the structure of the tool comprehensive?
1.2.	Would you suggest any changes to the SK types and/ or the design requirements?
1.3.	What are the advantages and disadvantages of the tool?
1.4.	Any suggestions for further improvement?

Other methods (survey, observation, recording, notes)

Notes will be taken during the interview.

Analysis techniques & plan: type up notes / create cause and effect diagrams / create matrix / transcribe & code, etc.

A report will be created, describing the findings from the interview and necessary amendments will be made to the tool.

Appendix O Ontology final validation questionnaire

Research aim

Validation of the ontology.

Research stage & current insight. Focus for exploration.

The aim of this research is to develop a service knowledge framework to support design. The current focus for exploration is to validate the ontology, which was developed by the researcher.

Case description: company name, business unit

Company 1

Case justification: why this company? How does this company match the research aim? Why this business unit?

Company 1 represent a capital intensive, mature and complex electro-mechanical design domain, which is suited to a formal knowledge reuse methodology.

Questions to be covered in the interview

1.1.	Is the structure of the ontology comprehensive?
1.2.	What are the advantages and disadvantages of the ontology?
1.3.	Which are the challenges for its industrial implementation?

Other methods (survey, observation, recording, notes)

Notes will be taken during the interview.

Analysis techniques & plan: type up notes / create cause and effect diagrams / create matrix / transcribe & code, etc.

A report will be created, describing the findings from the interview and necessary amendments will be made to the ontology.