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A PROTOTYPE METHOD AND TOOL TO FACILITATE KNOWLEDGE  
SHARING IN THE NEW PRODUCT DEVELOPMENT PROCESS

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A Prototype Method and Tool to Facilitate Knowledge Sharing in the New  
Product Development Process

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## **Abstract**

New Product Development (NPD) plays a critical role in the success of manufacturing firms. Activities in the product development process are dependent on the exchange of knowledge among NPD project team members. Increasingly, many organisations consider effective knowledge sharing to be a source of competitive advantage. However, the sharing of knowledge is often inhibited in various ways.

This doctoral research presents an exploratory case study conducted at a multinational physical goods manufacturer. This investigation uncovered three, empirically derived and theoretically informed, barriers to knowledge sharing. They have been articulated as the lack of an explicit definition of information about the knowledge used and generated in the product development process, and the absence of mechanisms to make this information accessible in a multilingual environment and to disseminate it to NPD project team members. Collectively, these barriers inhibit a shared understanding of product development process knowledge. Existing knowledge management methodologies have focused on the capture of knowledge, rather than providing information about the knowledge and have not explicitly addressed issues regarding knowledge sharing in a multilingual environment.

This thesis reports a prototype method and tool to facilitate knowledge sharing that addresses all three knowledge sharing barriers. Initially the research set out to identify and classify new product development process knowledge and then sought to determine what information about specific knowledge items is required by project teams. Based on the exploratory case findings, an ontology has been developed that formally defines information about this knowledge and allows it to be captured in a knowledge acquisition tool, thereby creating a knowledge base. A mechanism is provided to permit language labels to be attached to concepts and relations in the ontology, making it accessible to speakers of different languages. A dissemination tool allows the ontology and knowledge base to be viewed via a Web browser client. Essentially, the ontology and mechanisms facilitate a knowledge sharing capability. Some initial validation was conducted to better understand implementation issues and future deployment of the prototype method and tool in practice.

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## **Publications**

### **Journal Papers**

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### **Refereed Conference Papers**

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# **1 Introduction**

## **1.1 Trends and Challenges in Manufacturing Industry**

Manufacturing, or the production of finished goods for sale from raw materials using manual labour, was forged in the fires of the industrial revolution in the late eighteenth century (Mantoux, 1961). Spreading rapidly from Britain to Europe, North America and beyond, it drove the creation of wealth in those regions. In the early twentieth century, Henry Ford's innovative use of the assembly line in the automotive industry helped trigger the widespread adoption of mass production, which in turn led to a lower cost of production for many manufactured goods (Norcliffe, 1997). Products that were previously the preserve of the wealthy became accessible to the less well off and so demand for them grew. In this way, the cost of manufacturing products became a focus of competition for many manufacturers.

A report from the National Association of Manufacturers in the USA, claimed that more than three-quarters of global trade was in the form of manufactured goods in 2005 (National Association of Manufacturers, 2006). Manufacturing continues to play a significant role in the economic prosperity of Western economies. According to figures cited in the same publication, the United States of America remains the number one manufacturing nation and accounts for a quarter of global manufacturing output. The report also shows Germany, France, the United Kingdom, Italy and Belgium to be among the top nine leading exporters of manufactured goods.

However, the high labour costs in developed countries have encouraged a migration of manufacturing production to lower wage economies. This process has been supported by lower transport costs, the reduction or removal of trade tariffs and developments in communication technologies (Department of Trade and Industry, 2004). In order to address this challenge, governments of developed countries have advocated a shift towards the development of value-added products and innovation. The Department of Trade and Industry (DTI) in the United Kingdom published a strategy document for UK Manufacturing in 2002. This strategy identifies innovation as one of the seven 'pillars' required to build a successful manufacturing industry (Department of

Trade and Industry, 2002). A follow-up report states that innovation is crucial to the future of the UK manufacturing industry (Department of Trade and Industry, 2004).

## **1.2 Innovate or Stagnate**

Commercial organisations have sought to increase profits by investing resources in both the creation of new products and discovering new methods of manufacturing and delivering existing products (Trott, 2005). Such developments may be referred to as ‘innovations’. Alarming, there is evidence that the failure of an industry to produce product innovations, or new products, may contribute to its downfall. Hart (1996), citing Ughanwa and Baker (1989), provides the UK shipbuilding industry as a case in point. As the number of product innovations in the UK fell, so the industry declined. Between 1890 and 1974, the UK’s market share fell from eighty percent to under four percent. Meanwhile, Japan’s shipbuilding industry, which had presided over a rise in product innovations in the same period, saw its market share grow to around forty percent by 1969. This is was not merely symptomatic of some decline in Western industry however. Germany, which like Japan increased their output of product innovations, saw their industry command a twenty percent market share by 1970. Trott (2005) put it more succinctly, warning that ‘in order to increase profits, companies must innovate’.

It comes of little surprise then, that new product development (NPD) or ‘the overall process of strategy, organisation, concept generation, product and marketing plan creation and evaluation and commercialisation of a new product’ is of great interest to manufacturing firms (Kahn, 2005). A benchmarking study of firms in the United States of America from 2003 conducted by American Productivity and Control (APQC), reported that in the proceeding three years, new products had accounted for an average of almost twenty-eight percent of sales (Kahn, 2005). New products have emerged as a focus of competition for businesses (Brown and Eisenhardt, 1995). Furthermore, the process of product development is considered to be a ‘critical’ factor for the manufacturing businesses that aspire to prosper in competitive markets.

## **1.3 Role of the Product Development Process**

Unfortunately, merely engaging in the development of a new product is no guarantee that the project will be successful. For example, Crawford (1979) put the new product

failure rate at thirty-five percent. Moreover, Cooper, writing in the Product Development and Management Association (PDMA) Handbook of Product Development, cited a PDMA study of United States firms which revealed that roughly half of NPD projects were not delivered on time and a similar proportion did not meet their financial targets (Kahn, 2005).

NPD projects are effectively complex business processes involving individuals from different functions, which will typically include manufacturing, design and marketing (Ulrich and Eppinger, 2003). For some years scholars have maintained that project failures are in part caused by the lack of a systematic approach to these complex projects and have encouraged the use of formal process models to support managerial decision-making e.g. Jones and Stevens (1999), and Zirger and Maidique (1990) . Effectively, these systems serve as methodologies for the application of managerial rigour and discipline to the innovation process. Cooper (1994) defined the formal NPD process as ‘a formal blueprint, roadmap template or thought process for driving a new product from the idea stage through to market launch and beyond’.

A commonly used model today is the cross-functional stage-gate model, which Griffin (1997) indicates is employed by almost sixty percent of firms in the United States. This model divides the NPD process into discrete stages, each of which is followed by a review gate, as illustrated in Figure 1. Each stage can be broken down into a collection of predefined, cross-functional and concurrent tasks, which are executed by cross-functional teams. The importance of such a formal process model and its connection to best practice is well established in the literature (Griffin, 1997; Jones and Stevens, 1999; Cooper, 1994). Furthermore, Fredericks (2005) showed that cross-functional involvement in product development is dependent on a collective understanding of the tasks required at different phases of the NPD process.

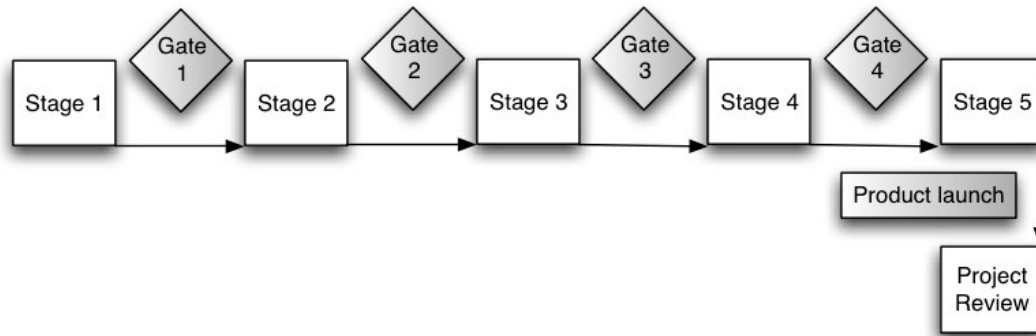


Figure 1: NPD stage-gate process model (adapted from Kahn (2005)).

#### 1.4 Emergence of Global Product Development

Recent decades have witnessed the emergence of the global product development (GPD) phenomenon. Respondents to a survey conducted by McDonough et al. (2001) predicted that a fifth of NPD teams in their firms would be global in nature by 2001. They characterised global product development team members as being geographically dispersed, speaking different languages and originating from different cultural backgrounds. This differentiates them from co-located teams who work in a single locale, such as region of a country or city, and share a common language.

Eppinger and Chitkara (2006) stressed that this use of global resources is not, as in previous years, to exploit low labour costs, but rather to exploit globally-distributed NPD expertise that cannot be obtained in one locale in order to achieve growth and innovation. McDonough et al. (2001) warned that global product development teams will become more prevalent and therefore research is required to develop methods of obtaining levels of performance from GPD teams that match those already available from their co-located counterparts.

#### 1.5 Managing Knowledge: Issues for Product Development

During the mid-1980s, Porter and Millar (1985) ventured the idea that information could be used to achieve a competitive advantage. By the 1990s, academics posited that knowledge, rather than capital would become the main source of wealth in the new economy (Quinn et al, 1996) and it would seem that this transition is indeed taking place. Stewart (1998) claimed that information represented three-quarters of value-

added in manufacturing. Nonaka (1991) opined that successful companies would be those that are able to create and disseminate knowledge rapidly and then transfer this knowledge into their new products. These ideas have contributed to an increasing interest in knowledge management. Söderquist (2006) commented that 'knowledge management is a subject at the top of the product development strategic agenda in large manufacturing firms'. Definitions of knowledge management are many. Recently, Ngai and Chan (2005) defined knowledge management as follows: 'knowledge management refers to the set process or practice of developing in an organisation the ability to create, capture, store, maintain and disseminate the organisation's knowledge'.

Writing in the Knowledge Management Handbook by Liebowitz (1999), Coleman argued that knowledge cannot really be managed and that knowledge management in fact serves as a blanket term for a number of functions. He listed these functions as knowledge creation, knowledge valuation and metrics, knowledge mapping and indexing, knowledge transport, storage and distribution, and lastly, knowledge sharing. It is the latter function that is of interest in this work.

## **1.6 Overview of Knowledge Sharing in Product Development**

Knowledge sharing, defined by Yang (2004) as the dissemination of information and knowledge within a community, is considered to play a crucial role in knowledge management ventures within the organisation (Liebowitz, 1999; Riege, 2005). Effective knowledge sharing drives organisational and individual learning, which in turn speeds up and improves the quality of product innovation (Riege, 2005).

As already alluded to, new products have become a focus of competition for many manufacturers, and the product development process has become increasingly important to these businesses. The product development process is comprised of 'a sequence of steps or activities which an enterprise employs to conceive, design, and commercialise a product' (Ulrich and Eppinger, 2003). These activities are linked by an exchange of information (Browning and Eppinger, 2002). Indeed, Eppinger (2001) urged that this exchange of information '... is the lifeblood of product development'.

Manufacturers are seeking to compete on issues like product quality and the time taken to introduce new products to the market. It has been argued by Gieskes and

Langenberg (2001), and Ramesh and Tiwana (1999), that such pressures have made the effective sharing of knowledge in the NPD process into a means of achieving a competitive advantage. Consequently, great attention has been focused in recent years on the application of knowledge management to new product development, a point emphasised by Zahay et al. (2004). Nonetheless, Hong et al. (2004) stressed that relatively little heed has been paid to knowledge sharing in the NPD domain.

However, the sharing of knowledge among individuals in an organisation is confounded by an abundance of obstacles. Obstacles to knowledge sharing common to large enterprises, or more specifically, large multinational companies, may concern the individuals working in the organisation or the environment in which these individuals function. For product development teams executing the kind of complex cross-functional product development business process referred to in section 1.3, it may reasonably be asserted that further knowledge sharing obstacles will be encountered. Indeed, even a cursory glance at the product development literature from the last decade, e.g. Court (1998), McDonough et al. (1999), Holland et al. (2000), McDermott and O'Dell (2001), and Akgün et al. (2006), lends credence to this assertion.

Such obstacles have been shown to be detrimental to product development performance. Hoopes and Postrel (1999) put forward evidence that gaps in shared knowledge could be directly responsible for costly mistakes made in the course of the product development process. Hong et al. (2004) conducted an empirical study into the efficacy of knowledge sharing in product development. They found that 'project teams working with high levels of shared knowledge in customers, suppliers and internal capabilities were significantly higher in their process performance outcomes than those teams with low levels of shared knowledge' (Hong et al., 2004). It is asserted then, that it is desirable to eliminate or reduce the impact of obstacles to knowledge sharing in a product development environment.

## **1.7 Aim and Objectives**

The aim of the research is:

To provide a prototype method and tool for facilitating knowledge sharing in early new product development.



The research objectives are to

1. Further explore the nature of knowledge and approaches to managing knowledge sharing in new product development;
2. Identify key barriers to knowledge sharing;
3. Empirically inform a conceptual model for improving knowledge sharing;
4. Develop a prototype method for reducing barriers to knowledge sharing in early new product development; and
5. Conduct an initial validation of the prototype method.

### **1.8 Sponsor Company**

The research project described in this document was conducted under the auspices of the Vaillant Group, a large, multinational manufacturer of domestic heating systems products. These products are predominantly electromechanical goods such as boilers. The project was executed in parallel with a product development knowledge management initiative being carried out at the business. The overall domain, aim, and objectives of the project were devised and refined in cooperation with the sponsor company.

### **1.9 Research Scope**

The scope of this investigation is confined to electromechanical goods in a global product development environment, using a formally defined NPD process based on the multifunctional stage-gate model. It will be limited to new product development projects that are derivations or incremental improvements to existing products and will focus on tasks performed by the Research and Development (R&D) functions in a single stage or 'phase' of the NPD process. However, the prototype method and tool is considered to be applicable to all the phases of the generic NPD stage-gate process model in a manufacturing context.

### **1.10 Overview of Research Approach**

A qualitative exploratory case study-based approach was adopted in this research. It began with a review of the literature pertaining to the current understanding of

knowledge as a concept and key knowledge issues relating to new product development. This review led to the formulation of the research objectives. An exploratory investigation of knowledge sharing barriers in NPD projects at a multinational manufacturing company was carried out. The key barriers identified in the exploratory investigation provided a framework for a literature review of salient methodologies for facilitating knowledge sharing in the NPD process. A prototype knowledge sharing tool was developed to address these barriers. This tool was then constructed and implemented for three sub-processes operating in the early phases of a new product development process. An evaluation of the perceived usefulness of the knowledge sharing tool as a means to facilitate knowledge sharing was subsequently conducted.

### **1.11 Thesis Structure**

Chapter 1 - Introduction: This chapter gives an introduction to the research domain and states the aim, objectives and scope of the research project.

Chapter 2 - Literature review: This chapter reviews the published literature relevant to knowledge sharing, generic knowledge sharing barriers in new product development, and methodologies and technologies to facilitate knowledge sharing. Areas for further research are also identified.

Chapter 3 - Research aim, objectives and process: This chapter outlines the research aim and objectives, the research programme and the structure of the remainder of the thesis.

Chapter 4 - Research methodology: This chapter reviews the available research methods and techniques and describes a research methodology to fulfil the research aim and objectives.

Chapter 5 - Empirical investigation: Here, the methods and findings of exploratory investigation of knowledge sharing barriers in the new product development process at a large, multinational heating systems manufacturer are described.

Chapter 6 – Conceptual design of knowledge sharing tool: This chapter outlines the work carried out to design a tool that tackles the knowledge sharing barriers identified in the empirical investigation documented in chapter five.

Chapter 7 - Development of prototype knowledge sharing tool: In this chapter, the development of a prototype knowledge sharing tool to facilitate knowledge sharing in the new product development process is described.

Chapter 8- Validation of prototype knowledge sharing tool: This chapter is divided into two parts. The first part presents a case study to implement the prototype knowledge sharing tool for the case of knowledge used in a real product development process, in order to illustrate its functionality. The second part describes a case study to evaluate the usefulness of the knowledge sharing tool by demonstrating it to NPD practitioners.

Chapter 9 –Discussion of research findings: A discussion of the findings of the research investigation.

Chapter 10 – Conclusions and Further Work: This final chapter states the conclusions of the research project and explores areas for further research.

## **2 Literature Review**

Based on the research aim, and under the auspices of the sponsor company, a review of the literature was carried out examining issues related to knowledge sharing in new product development (NPD). The review is broadly divided into two parts:

Part one discusses the current understanding of the nature of knowledge in the knowledge management domain, the types and content of knowledge used in NPD and examines models for knowledge sharing.

Part two provides an overview of the knowledge sharing issues in NPD. These issues include the barriers to knowledge sharing in organisations and cross-functional, geographically dispersed product development teams, as well as the general approaches to tackling knowledge sharing barriers and facilitating knowledge sharing.

## **2.1 Information and Knowledge**

In their paper 'The Eleven Deadliest Sins of Knowledge Management', Prusak and Fahey (1998) warned that the absence of a working definition of knowledge in a knowledge management project is a major error. They also lamented that knowledge management practitioners and researchers have often failed to make a distinction between data, information and knowledge. Indeed, Zeleny (1987) cautioned that this distinction is crucial. Wilson (2002) criticised the use of information and knowledge as synonyms in the literature. Similar criticism may be found in works discussing knowledge in the context of NPD, notably Court (1997) and Rodgers and Clarkson (1998b). Court (1997) also criticised the use of the terms information and data as synonyms. More recently however, Keane and Mason (2006) suggested that the distinction between information and knowledge should not be of concern to researchers involved with knowledge management systems. That is, that one should not be concentrated on at the expense of the other, since this increases the difficulty of managing knowledge.

This section of the review examines interpretations and definitions of data, information and knowledge in the knowledge management, information systems and engineering design literature. It goes on to consider a growing debate in the literature that questions the interpretation of these terms by various parties, which include researchers concerned with knowledge management systems. It concludes by providing a working definition of the terms for use in the remainder of the thesis. A great deal of research has been undertaken by the engineering design community into the nature and types of knowledge used in product development, and some of this literature is discussed later on in section 2.2.2. However, since knowledge sharing is considered here to be a function of knowledge management, this section will mainly focus on works in the knowledge management domain.

### **2.1.1 Definition of Data and Information**

As part of a broader study of the relationship between information and knowledge in new product development, Court (1997) reviewed definitions of data from the information science and library research domains. Wilson (1987), cited in Court (1997),

and writing in the context of information theory, offered the following definition of data: 'Data is the representation of information independent of meaning e.g., an integer number' (Wilson, 1987). Court (1997) commented that data is likely to be of little use without the ability or means to interpret it.

Information and its usage have been examined in a range of disciplines, which Toften and Olsen (2003) have identified as including management, marketing, organisational behaviour and social policy decision making. Other areas are knowledge management and new product development (NPD). In order to provide some focus, consideration of the term here will mainly concentrate on how it is perceived in the knowledge management and NPD literature.

From a knowledge management perspective, Nonaka (1994) defined information as a flow of messages. Court (1997), discussing information in the context of NPD, settled on describing information as a combination of raw data and meaning. Wilson (1987) provided a similar definition: 'information is the data plus the meaning connected with it'. Floridi (2005) noted that this latter notion of information as consisting of data with some level of meaning or contextual information attached has achieved wide acceptance in the information systems theory and information systems management domains.

### **2.1.2 Definitions of Knowledge**

The idea of knowledge has been a subject of philosophical debate since the age of the Ancient Greeks, a history of which was outlined by Polanyi (1962). Anderson (1989) has documented the philosophical origins of knowledge. Even within the confines of the knowledge management literature, there are many definitions of knowledge, possibly due to the wide range of intellectual antecedents that form the foundations of knowledge management. Among these subjects are economics, sociology, philosophy and psychology (Prusak, 2001). An industry-based case study by Zhang and Faerman (2004) suggested that initiatives to facilitate knowledge sharing could be rendered more effectual, where the nature of the knowledge to be shared is taken into consideration. The scope of this review will be confined to a discussion of the key ideas concerning the nature of knowledge and the identification of emerging trends pertinent to this research.

Baskerville and Dulipovici (2006) provided an overview of the development of the underlying theory of knowledge management, drawing on literature from 1995 to 2005. They argued that in order to understand the use of the term knowledge in the knowledge management literature, it should be distinguished from its use in two fields of information systems research: knowledge-base management in the expert systems field and organisational knowledge in the management field.

Examining knowledge in the context of expert systems, Zeleny (1987) asserted that 'Knowledge should refer to the observer's distinction of "objects" (wholes, unities) through which he brings forth from the background of experience a coherent and self-consistent set of coordinated actions'. It is also stated that 'knowledge refers to the process of active network configuration and reconfiguration of our human world of objects and their relations'. He went on to describe knowledge as the ability to make distinctions, choices and decisions. Significantly though, Zeleny warned that knowledge should not be perceived as a collection of explicitly defined objects that can easily be captured.

An important feature of knowledge is its relationship to information. In the words of Zeleny (1987), 'Data and information are parts and pieces of different levels of aggregation, but knowledge refers to the intended whole (which in itself can be a part of something).' Alavi and Leidner (1999), writing in the context of knowledge management systems, stated that knowledge is information contained in the mind of an individual. Similarly, Court (1997) posited that knowledge in NPD is 'more than just recorded information' and proceeded to define it as 'the mental state of ideas, concepts, data, techniques, etc, recorded in an individual's memory'. That is, knowledge cannot exist outside the mind of an individual. Rodgers and Clarkson (1998a) and (1998b), considered the use of information and knowledge in NPD. Like Court (1997), they characterised knowledge used by designers as being held in the memory of a person, while information is everything outside of the mind of the individual.

The effect of the personalised nature of knowledge on knowledge sharing will be discussed in later sections. However, the issue of concern here is with knowledge as it is used in a company. Davenport and Prusak (1998) proposed a working definition of

knowledge in the organisation, which is widely cited in the knowledge management literature:

Knowledge is 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 (Davenport and Prusak, 1998).

As Davenport and Prusak (1998) emphasised, this definition of knowledge highlights its non-trivial nature. Furthermore, it reflects the ideas of Alavi and Leidner (1999), Court (1997), and Rodgers and Clarkson (1998b), that knowledge is something more than information and can only exist in the mind of the individual. Outside of the mind, the knowledge becomes information, which may be found in various forms, including documents.

The definition provided by Davenport and Prusak will be adopted as the working definition of knowledge in this research project.

A slightly different definition of organisational knowledge was proffered by Tsoukas and Vladimirou (2001). They began by defining personal knowledge, that is, the knowledge of an individual: 'Our claim is that knowledge is the individual capability to draw distinctions, within a domain of action, based on appreciation of context or theory, or both.' They then evolved this definition to incorporate the notion that individuals in an organisation possess a shared understanding of certain concepts: 'Organisational knowledge is the capability members of an organisation have developed to draw distinctions in the process of carrying out their work, in particular concrete contexts, by enacting sets of generalizations whose application depends on historically evolved collective understandings'. The perspective of Tsoukas and Vladimirou (2001) departs from that of Davenport and Prusak (1998) in describing knowledge as a capability, rather than something that can be manifested in physical artefacts like documents.



### **2.1.3 The Notion of Knowledge ‘Types’ and Transfer**

Many works in the knowledge management domain draw on the ideas about the types and conversion of knowledge proposed by Nonaka (1991), and later Nonaka and Takeuchi (1995). Both of these works considered the role of knowledge in an organisation and they continue to be cited in the knowledge management literature e.g. Abdullah et al. (2006) and Kapič and Bernus (2006).

Nonaka (1991) proposed that there are two types of knowledge: explicit knowledge and tacit knowledge. Explicit knowledge is characterised as being formal and systematic in nature and is therefore easy to communicate and share. Nonaka suggested the specifications of a product as an example of explicit knowledge. In contrast, tacit knowledge is stated to be highly personal, difficult to formalize and consequently not easily articulated or communicated. He qualified this by citing the philosopher Polanyi’s comment ‘We know more than we can tell’ (Nonaka, 1991). He perceives tacit knowledge as being comprised of technical skills or ‘know-how’ and as having a cognitive dimension, that is, it incorporates beliefs and viewpoints. Based on this distinction between tacit and explicit knowledge, Nonaka (1991) outlined four modes of knowledge creation.

The first mode involves the creation of tacit knowledge from knowledge that is also of the tacit type, which is asserted to take place through social activities such as observation and practice. Nonaka (1991) called this process socialisation and observes that knowledge created in individuals in this way is difficult, although it should be noted not impossible, for a company to exploit. The second mode, which involves creating explicit knowledge from other explicit knowledge, effectively concerns the creation of new information, such as a business report, by using existing information in the company. The third mode is the creation of explicit knowledge from tacit knowledge, whereby the holder of the tacit knowledge attempts to articulate the knowledge in a way that allows it to be communicated and shared with their colleagues. The example provided by Nonaka alludes to a financial specialist in a company writing a formal method for a process, an activity that draws on their experience. Finally, the fourth mode is the creation of tacit knowledge from explicit knowledge. Here, knowledge in an explicit form is accessed by individuals in a company who use it to amend, or in Nonaka’s parlance ‘internalise’, their existing tacit knowledge. This approach of

categorising knowledge into explicit and tacit types was referred to by Hislop (2002) as the objectivist epistemology of knowledge.

#### **2.1.4 Post-Nonaka Views on Knowledge**

In the last few years however, several authors have criticised aspects of Nonaka's interpretation of Polanyi's work, including Wilson (2002), Tsoukas (2003), Blair (2002), Day (2005) and Keane and Mason (2006). They argued that problems with this interpretation have contributed to a wider misunderstanding of knowledge in the knowledge management field.

Wilson (2002) argued that the tacit knowledge discussed by Polanyi cannot be expressed and therefore cannot be captured. This view was echoed by Tsoukas (2003), who concluded that it is not possible to capture, translate or convert tacit knowledge to the explicit type. Wilson (2002) further argued that tacit knowledge may however be 'demonstrated', through knowledge that can be articulated or expressed, and through the deeds of individuals. He proposed that Nonaka (1991) and later Nonaka and Takeuchi (1995) had confused tacit knowledge with implicit knowledge, where 'implicit knowledge is that which we take for granted in our actions, and which may be shared by others through common experience or culture'. According to Wilson (2002), implicit knowledge is expressible knowledge, which is not normally expressed. If implicit knowledge is expressed, it becomes information.

Blair (2002) took a different approach, defining tacit knowledge more broadly as the knowledge of a practising expert. He proposed two types of tacit knowledge. One type is knowledge that is expressible, but has not yet been expressed. This was termed implicit knowledge by Wilson (2002). The other type is knowledge that cannot be expressed, which was referred to simply as tacit knowledge by Wilson (ibid.). Although the meanings of the terms may be distinguished by the degree to which the knowledge in each case is expressible, Day (2005) cautioned that they have been used synonymously in the knowledge management literature. Attempts by Expert System developers to capture this latter form of tacit knowledge were condemned by Blair (2002) as 'a saga of wasted time, effort and money'. Blair went on to cite the example of a success rate of one in three hundred for expert systems projects carried out by the United States Department of Defence. Lastly, Tsoukas (2003) advised that the attention

of knowledge management initiatives should instead be brought to bear on constant efforts alert one another to issues of interest, that is to say through social interaction. This theme of alerting individuals to knowledge items of interest will be pursued later on in this review in the discussion of metaknowledge (see section 2.6), albeit in a different context.

Keane and Mason (2006) criticised Nonaka's interpretation of explicit knowledge and tacit knowledge as 'types' of knowledge. They claim that tacit knowledge and explicit knowledge are more accurately described as dimensions of knowledge. Of fifty-nine knowledge management-themed journal articles and conference proceedings surveyed by these authors, almost ninety percent of articles treated tacit knowledge as a type of knowledge and only five percent referred to it as a dimension of knowledge. Hislop (2002) referred to this 'dimension' approach as the epistemology of practice perspective. Information represents the explicit dimension, while the tacit dimension concerns the interpretation and application of relevant knowledge. Day (2005) asserted that tacit knowledge could be labelled simply as 'knowledge' and that explicit knowledge is 'a sense of information'. Keane and Mason (2006) concluded that one consequence of considering explicit knowledge and tacit knowledge as types of knowledge was the proliferation of knowledge management systems that attempted to convert knowledge from one type to another. Indeed, they went as far as to claim that such knowledge management systems are 'incongruous with the aims of knowledge management'.

### **2.1.5 Findings**

A working definition of knowledge, that of Davenport and Prusak (1998), was provided in section 2.1.2. In this definition, knowledge not only exists in the minds of individuals, but may be embedded to some degree in documents, processes and procedures within an organisation. The remaining findings of this section of the review are as follows:

- The objectivist epistemology of knowledge, informed by the work of Nonaka, has been subject to growing criticism in the last few years. This epistemology has underpinned the development of knowledge management systems. An

alternative perspective on knowledge, the epistemology of practice, has been advanced in its place.

- In recent years researchers considering both epistemologies have suggested that tacit knowledge (in the objectivist epistemology) or the tacit dimension of knowledge (in the epistemology of practice) cannot be effectively captured in knowledge management systems.

## **2.2 Knowledge in New Product Development**

### **2.2.1 Introduction**

It was acknowledged in section 1.6 that information and knowledge play an important role in the NPD process. The diversity and complexity of NPD knowledge has inspired a significant body of work in the literature that attempts to describe its nature, usage, management and sources. Broens and de Vries (2003) claimed that classifications of knowledge help NPD practitioners such as engineers find knowledge more easily. In this way it might be said that classifications of knowledge can help to support knowledge sharing. This section of the literature review examines efforts to classify NPD knowledge, both in the broad context of new product development and the supporting NPD business process. Sources referenced include the engineering design and marketing literature.

### **2.2.2 NPD Knowledge Categorisation**

Many researchers have proposed classifications of knowledge used in the NPD domain. Among them are Eder (1989), Vincenti (1990), Rodgers and Clarkson (1998a) and (1998b), Broens and de Vries (2003), Donnellan and Fitzgerald (2004), and Zahay et al. (2004). Donnellan and Fitzgerald (2004) labelled such classifications practice-based knowledge typologies. Additionally, Eppler et al. (1999) presented a classification of business process knowledge.

Eder (1989), defining knowledge as a mixture of information and experience, examined the knowledge used by engineering designers. He offered a classification of knowledge used for design and knowledge about the design process itself. Two classes of knowledge were proposed. The first class is prescriptive knowledge or know-how,

which is comprised of knowledge related to the system being designed, and the second class is descriptive knowledge or theories, that is, theoretical knowledge.

Vincenti (1990), as cited in Court (1997), proposed six knowledge categories that should be made available to engineering designers: criteria and specifications, design instrumentalities, fundamental design concepts, practical considerations, quantitative data and theoretical tools. This study was based on an historical study of advances in aeronautical engineering.

Rodgers and Clarkson (1998a) reviewed the knowledge needs of designers in small-to-medium sized enterprises participating in NPD. They identified eight types of design knowledge regularly used by designers: explicit knowledge, tacit knowledge, operative knowledge, substantive knowledge, heuristic knowledge, algorithmic knowledge, deep knowledge and shallow knowledge. Deep knowledge entails 'causal explanation of reasoning', while shallow knowledge refers to 'a rule-of-thumb without explanation' (Rodgers and Clarkson, 1998a). In addition, eighteen knowledge areas used as sources of design knowledge were proposed: politics, safety, competition, market constraints, costings, packaging, standards, customer, environment, materials, reliability, patents, manufacturing processes, ergonomics, quality, performance, disposal and aesthetics.

Broens and de Vries (2003) set out to investigate whether mechanical engineers engaged in design activities preferred a particular taxonomy of technological knowledge, were it to be used a classification of knowledge in a knowledge management system. A selection of four technological knowledge taxonomies were presented to one hundred and ninety-nine employees of a design company involved in mechanical engineering roles, along with a questionnaire. The selection included an adaptation of the typology by Vincenti (1990). Two additional categories were added to the existing Vincenti classification: socio-technical understanding and collaborative design knowledge. These were appropriated from classifications by other authors. Forty-three percent of respondents to a survey question asking in which of the four classifications that they expected to find information most easily, selected the Vincenti classification. In this way, it emerged as the most popular classification.

What is important here is not the taxonomy itself. Broens and de Vries (2003) themselves conceded that the amended Vincenti classification was only a device to assess to what extent it was recognised by the surveyed engineers. The more significant result in the context of this research is that the engineers favoured a ‘functional’ classification of technological knowledge. In support of this idea, they cited the work of Newell (1982) ‘who claimed that knowledge in knowledge bases should be characterised functionally (‘what it does’) rather than structurally (‘verifying properties and relations’)’. They also claimed that the categories in the classification can be linked to stages of the design process. Broens and de Vries (2003) concluded the paper by recommending further study on the typology and classification of technological knowledge for design engineers and workers in other domains. The import of defining a purpose when designing a knowledge classification was also stressed.

Donnellan and Fitzgerald (2004) presented a typology of NPD knowledge that focuses on the critical knowledge used and generated at each stage-gate review in the formal new product development process. They claim that these reviews are important knowledge sharing events for NPD teams, which allow them to validate new knowledge. Further, the proposed typology is described as drawing on empirical data and previous NPD knowledge typologies in the literature, including some of those discussed in this section i.e. Eder (1989) and Rodgers and Clarkson (1998a and 1998b). The proposed typology features one engineering knowledge type for each of the five stages in the new product development process of a multi-national Integrated Circuit manufacturer. The stage gates, and associated engineering knowledge types are shown in Table 1, along with the corresponding stage gates in the generic product development process model by Ulrich and Eppinger (2003). As with the work of Eder (1989), this classification was devised based on the nature of the knowledge.

While these classifications address knowledge used in NPD and are therefore worthy of note in this review, they have not been devised for use by other functions involved in the NPD process, such as marketing or manufacturing.

In contrast to the knowledge typologies mentioned so far, which were focused on the knowledge used by design engineers, Zahay et al. (2004) examined the knowledge used by various roles in the NPD process. It was noted: ‘Product

development team success rests on sharing information regarding many different topics, including customer needs, market segments, firm capabilities, and competitor's strategies, obtained from many different sources.' The impetus of their study is attributed to their observation that existing information systems for managing information in product development had been designed in the absence of a comprehensive investigation into product development information needs.

<b>Stage gate title (from case study company business process)</b>	<b>Corresponding stage gate in Ulrich and Eppinger (2003)</b>	<b>Engineering knowledge type</b>
Business Review	Planning	Shallow
Feasibility	Concept Development	Fundamental Principles
Implementation	System-Level Design; Detail Design	Operative
Validation	Testing and Refinement	Procedural
Launch	Production Ramp-up	Causal

Table 1: Engineering knowledge typology from Donnellan and Fitzgerald (2004). Includes stage gate names from generic NPD process model proposed by Ulrich and Eppinger (2003).

A further distinction from the knowledge typologies discussed so far is the purpose of the classification. Instead of concentrating the nature of the knowledge itself, Zahay et al. (2004) were concerned with classifying knowledge in the context of information management needs in the new product development process. For this reason, this classification is of particular relevance to this research. It should be noted that the authors use the term 'data' in the title of the paper, and the term 'information', rather than 'knowledge', is employed throughout the body of the work. However, the scope of the study includes data, information and knowledge in the sense of the working definitions given at the beginning of this chapter in section 2.1.2. Information is viewed as having a spectrum of richness, from information with little richness like numerical data in a database to very rich information, such as information gained in face-to-face meetings with people.

Eight types of information and knowledge were described, which are further classified according whether they originated from internal sources (within the

company), external sources (outside the company) or both. Knowledge and information types originating from internal sources are strategic, financial and project management. Types from external sources are information about competitors and regulatory information. Finally, the types of information and knowledge identified as coming from both internal and external sources are information and knowledge about customers, customer needs and technical knowledge. Data was collected in interviews with fourteen NPD practitioners and six information management vendors. It was conceded that the scope of the study was confined to 'B2B physical goods and software industries', where B2B means business-to-business. These industries included pharmaceuticals, computer hardware and market research.

Although there has been a demonstrable interest in the classification of NPD knowledge for some years, relatively little attention has been paid to classifying knowledge in the context of the formal NPD process models, or NPD business processes. Eppler et al. (1999) examined business processes from a knowledge perspective. Their paper commences with a classification of business processes based on the intensity of their use of knowledge and their complexity. They considered the NPD process to be of high process complexity and high knowledge intensity compared to twenty-four other business processes they studied, including customer service, order fulfilment or even new business development. Among the attributes assigned to highly complex business processes was the involvement of many individuals. A trait linked to knowledge intensive processes was a high dependence on the experience of these individuals that allows them to apply creativity and innovation to problem solving. Based on these properties they then proceeded to determine which knowledge is crucial to the success of highly complex and knowledge intensive business processes.

Three types of critical knowledge were proposed by Eppler (1999): knowledge about the process, knowledge within the process and knowledge from the process. Knowledge about the process may be in both explicit form, such as flow maps showing the process stages, and implicit forms like the experience possessed by the process owners of managing the activities in that process. Knowledge within the process is that which is generated during the execution of the process e.g. test reports, business reports and the minutes of meetings. Lastly, the knowledge derived from a process is the experience that has been acquired from having carried out that process, e.g., lessons



learned, the experience accumulated by different people and improvements that could be implemented in future projects. All of these knowledge types are of interest to this study. However, the definition of knowledge within the process should not only include the generated knowledge, but also the input knowledge required to execute the business process.

### **2.2.3 Findings**

This section of the review has established the following findings:

- Classifications of knowledge can be used to help actors involved in product development to locate knowledge more easily.
- There is a dearth of research on the classification of knowledge used in the NPD process, both in the context of the business process and in a way that makes it pertinent to the NPD business process user, that is, the content of the knowledge.
- There is a paucity of literature classifying knowledge used by NPD functions in the NPD other than the design engineer, which would be necessary to encourage a shared understanding across the full range of users involved in cross-functional NPD process teams.

Further research is required into the classification of knowledge used in the new product development process from a content-based perspective, and which encompasses functional roles other than the design engineer.

## **2.3 Knowledge Sharing**

### **2.3.1 Two Views of Knowledge Sharing**

A succinct definition of knowledge sharing was provided by Yang (2004), namely that it is the dissemination of information and knowledge within a community. Having established a working definition of knowledge (see section 2.1.2), and considered the types of knowledge used in the NPD process (see section 2.2), it is now possible to consider the notion of knowledge sharing in more detail.

In simple terms, knowledge sharing refers to the transfer of knowledge between a knowledge source, or owner and a knowledge recipient, or reconstructor. (Hendriks,

1999; Baskerville and Dulipovici, 2006). Both Baskerville and Dulipovici (2006), and Hendriks (1999) noted that this process is also called knowledge dissemination or knowledge transfer. Hendriks (1999) emphasised that knowledge sharing is similar but distinct from both the communication and the distribution of information. Hislop (2002) identified two main perspectives on knowledge sharing in the knowledge management literature. The first is based on the objectivist epistemology of knowledge and the second builds on the epistemology of practice perspective, both of which have already been discussed. Each of these approaches will now be examined in greater depth.

Consider first the objectivist epistemology. As mentioned in section 2.1.3, in this perspective explicit and tacit knowledge are considered to be separate entities, see Figure 2.

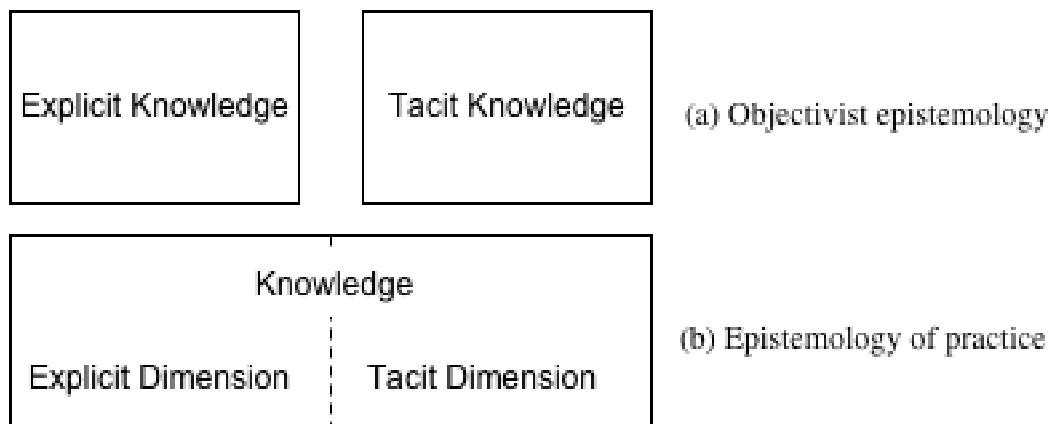


Figure 2: Epistemologies of knowledge.

Hislop (2002) presented the postal or transmitter-receiver model of knowledge sharing in which knowledge may be shared through the transfer of explicit knowledge, which has been codified, from a sender to a receiver. It is assumed that this process does not compromise the integrity of the knowledge and that the knowledge recipient will be able to understand and exploit this knowledge without any further assistance. This model is depicted in Figure 3.

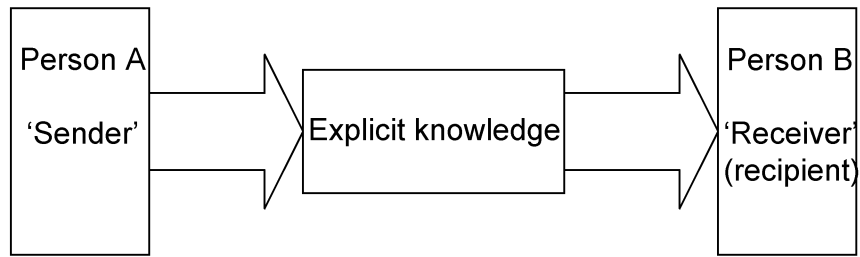


Figure 3: Transmitter-receiver model of knowledge sharing. Adapted from Hislop (2002).

However, the sharing of the tacit knowledge defined by Nonaka (1991) is more difficult. Properties of tacit knowledge that make it difficult to share include its personal nature and its inherently inexpressible nature (Hislop, 2002). Nonaka and Takeuchi (1995, p. 11), as cited in Keane and Mason (2006), proposed that the sharing of tacit knowledge could be achieved by transforming tacit knowledge into explicit knowledge. Hislop (2002) suggested that tacit knowledge can be shared through ‘direct communication among individuals’ and provides three examples from the literature as to how this may be achieved. These were language and stories, learning by observation of others and learning by doing within a community. These examples are not wholly convincing. As already proposed, if tacit knowledge can be articulated through language and stories, then it may be better described as implicit knowledge. However, learning by observation or doing essentially echoes the notion of sharing tacit knowledge by demonstration described by Wilson (2002).

According to Hislop (2002), information technology-based knowledge management systems are perceived as unsuitable for the transfer of tacit knowledge and their use is confined to that knowledge which can be rendered explicit by the sender.

Now consider the epistemology of practice. In this perspective, all knowledge has both explicit and tacit dimensions in line with the work of Keane and Mason (2006). As Hendriks (1999) commented, ‘Knowledge is not like a commodity that can be passed around freely, it is tied to a knowing subject’, that is to say, an individual such as an NPD project team member. Hislop (2002) pointed out that since from this perspective all knowledge has a tacit dimension, the transmitter-receiver model of knowledge sharing, which is applicable to explicit knowledge, is not valid. By extension, the use of information technology-based knowledge management systems

that rely on the capture of explicit knowledge is also rendered unsuitable. It was however conceded that in cases where knowledge has a significantly large explicit dimension and in a suitable social context, information technology may be exploited to support knowledge sharing.

Hislop (2002) ventured that a knowledge sharing model for the epistemology of practice ‘...involves two people actively inferring and constructing meaning from two different experiences’. This position is reflected in the model of knowledge sharing presented by Hendriks (1999); see Figure 4.

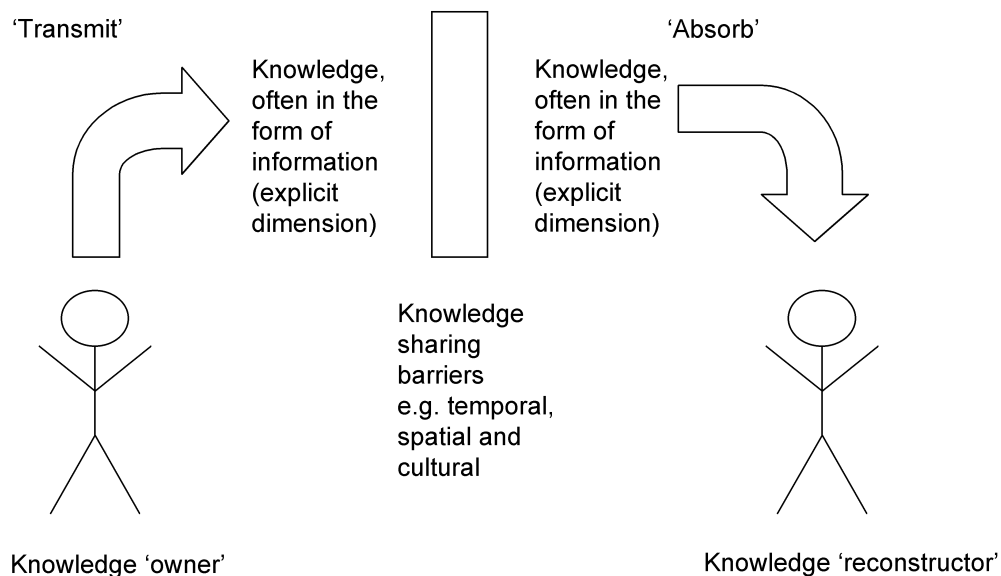


Figure 4: Knowledge sharing model; adapted from Hendriks (1999).

In order for individuals to share the tacit dimension of knowledge, a significant amount of social contact is desirable. Hislop maintained that in the course of this contact, the knowledge sender or knowledge owner, as described by Hendriks (1999), must construct the meaning of the knowledge. The knowledge receiver or Hendriks’ knowledge reconstructor must then deduce this meaning. Clearly, in geographically dispersed NPD teams, opportunities for social contact are likely to be fewer than for co-located teams.

Exploring a similar theme, Court (1997) posed the question ‘How is abstract knowledge communicated to other colleagues?’ In answering this question, Court

posited that it is not possible to create knowledge directly in the mind of an individual, as is proposed in the transmitter-receiver model discussed by Hislop (2002), without the use of a medium. Examples of mediums provided by Court are the reading of documents, participating in training sessions and engaging in dialogue at meetings. Court (1997) stated: 'Knowledge is created by mental activity and understanding, which is not controlled by machines or other individuals.' He proposed that the creation of knowledge in the mind of an individual can be encouraged by communicating information or 'stimuli' to them. These stimuli are in the form of messages. This notion is similar to the idea offered by Hislop (2002) of a knowledge sender synthesising the meaning of knowledge that they wish to share with another individual. The provision of contextual information about knowledge that acts as a kind of stimulus will be explored in later sections.

### **2.3.2 Findings**

Three key findings were made from this section of the literature review:

- The objectivist epistemology and the epistemology of practice each demand a different knowledge sharing model.
- Attempts to capture knowledge using information technology-based knowledge management systems are limited to explicit knowledge in the objectivist epistemology and to the explicit dimension of knowledge in the epistemology of practice. Although limiting in the former case, this is entirely unsatisfactory in the latter case, since what is being captured is essentially just information.
- By providing information that gives meaning or context to a given piece of information, the creation of knowledge in the mind of the individual can be encouraged.

## **2.4 Knowledge Sharing Barriers**

### **2.4.1 Knowledge Sharing Barriers Generic to Organisations**

Information and knowledge sharing is perceived to be a crucial part of knowledge management activities. Beckman, writing in Liebowitz (1999), described shared knowledge as integral to the success of an organisation. Riege (2005) claimed that the

efficient and focused sharing of pertinent knowledge results in faster learning for both the organisation and the individual. In this way, innovation can occur at a greater pace and better products can be introduced to a market in a shorter time. Unfortunately, the exchange of knowledge within organisations is subject to hindrance by various barriers. These knowledge sharing barriers are caused by social factors, technology issues and combinations of the two.

The range of knowledge sharing barriers related to social issues may be divided into two major categories: barriers attributable to the organisation and barriers attributable to the individual. Sourcing both the literature and field research, Disterer (2001), Riege (2005) and Ardichvili et al. (2006) have identified numerous barriers in both of these categories. A summary of these problems follows.

Knowledge barriers attributable to the organisation range from the physical layout of work areas an office to the hierarchical organisation structure, which thwarts knowledge transfer across functions and between hierarchical levels (Disterer, 2001; Riege, 2005). Some key examples of knowledge barriers involving individuals are: (1) The observation that explicit knowledge tends to be shared to a greater degree than tacit knowledge, inhibiting the spread of certain knowledge type, e.g. experience (Riege, 2005); (2) The view of knowledge, such as experience or expertise, as a source of power for the individual (Disterer, 2001; Ardichvili et al, 2006); (3) A lack of time in which to share knowledge with colleagues and to identify colleagues in need of knowledge (Riege, 2005); (4) Concerns relating to trust, such as the fear that colleagues may take credit for knowledge shared by an individual or that an item of knowledge may not be reliable or from a credible source (Riege, 2005); (5) Lack of a motivation to share knowledge, such as an understanding of the benefits it may bring (Disterer, 2001); and (6) Culture and background (Riege, 2005; Ardichvili et al, 2006), language differences (Disterer, 2001; Riege, 2005; Ardichvili et al, 2006), gender differences (Riege, 2005), and levels of education (Riege, 2005).

Barriers related to technology often involve the very technology intended to facilitate knowledge sharing. According to Riege (2005), such barriers include: poor integration of information technology (IT) systems and processes which compromise the workflow; incompatibility between different information systems; tardy

maintenance of systems that support communication and collaboration; and inadequate user training. Other problems are: IT systems that do not meet user requirements; the reticence of people to use systems with which they are unfamiliar; overzealous expectations of a technology; and lastly an absence of effort by an organisation to “sell” the benefits of the system to potential users.

#### **2.4.2 Knowledge Sharing Barriers in NPD**

Product development demands the cooperation of people from different parts of the organisation or functional areas, with different expertise and varying levels of experience. As a result, effective communication is required to manage the activities in the NPD process (Anderson and Button, 1993; Effendi et al., 2002). Indeed, in section 1.6 it was established that effective knowledge sharing is widely held to be crucial to the success of a product development project. Recent empirical research into the efficacy of knowledge sharing in product development projects, by Hong (2004), supports this claim.

Nonetheless, knowledge sharing in cross-functional, geographically dispersed product development teams may be thwarted by any or all of the generic barriers discussed in section 2.4. For example, a recent empirical study by Bakker et al. (2006) indicated an absence of trust as a barrier to knowledge sharing in product development projects. Knowledge sharing in such teams is also subject to other barriers. Sole and Applegate (2000), and latterly Malhotra and Majchrzak (2004) referred to numerous instances of such barriers described in the literature. The barriers can be broadly divided into two categories: those attributable to the range of functions involved in product development projects, and those aggravated by the physical distance between project team members.

For the former category, Sole and Applegate (2000) noted that the diversity of knowledge used by different functions is detrimental to knowledge sharing. This is because each function may have different vocabularies, targets, and ways of addressing problems that may make it difficult to achieve a shared understanding. Malhotra and Majchrzak (2004) highlighted research that suggested knowledge sharing among functions may be hindered because ‘there may be an unwillingness to share information or a lack of trust’.

The emergence of global product development has complicated this situation still further by introducing cultural and language differences, a point made previously by McDonough et al. (1999). Morelli et al. (1995) and McDermott and O'Dell (2001) cited cultural differences as a barrier to knowledge sharing. Developing the theme of culture further, Desouza and Evaristo (2003) provided the example of the differences in culture between North America and Western Europe, and Japan and Spain. They asserted that while the Spanish and Japanese are more inclined to exchange freely knowledge and do so using informal means, the North Americans and Western Europeans tend to exert a greater control over knowledge flow, and knowledge sharing is subject to more barriers. McDonough et al. (1999) found that different languages spoken by product development team members had an adverse affect on communication within the team and therefore on knowledge sharing.

Many other knowledge sharing barriers are attributable to the geographical dispersion of project team members. The first of these barriers is that knowledge may be concentrated in certain locales, but be unavailable in others. Malhotra and Majchrzak (2004) termed this phenomenon 'unevenly distributed knowledge'. Sole and Applegate (2000) warned that global distribution of project team members not only hinders face-to-face knowledge sharing, termed spontaneous knowledge sharing by Malhotra and Majchrzak (2004), but also makes it difficult for individuals from outside a community to share its 'collective knowledge' or 'implicit shared meanings'. This is because these shared meanings are linked to specific behaviours of that group. Another problem is that communication of information about the context of a task, which would normally be conducted by private communication, is less likely to take place where team members are not co-located. (Malhotra and Majchrzak, 2004).

This is not claimed to be an exhaustive review of knowledge sharing obstacles faced by geographically-dispersed, cross-functional product development teams. However, it does provide an insight into the array of barriers to knowledge sharing that they encounter.

### **2.4.3 Findings**

The key findings from this section of the review are as follows:



- Knowledge sharing among product development project team members may be hindered by many barriers, which are attributable to both social and technology-related issues.
- Cross-functional, geographically dispersed teams are subject to these and a further set of knowledge sharing barriers, such as knowledge diversity, the hindrance of informal knowledge exchange among team members due to lack of close physical proximity, trust, and culture and language differences.

## **2.5 Methodologies for the Facilitation of Knowledge Sharing**

Knowledge sharing barriers within an organisation may be tackled in two main ways. The first way is to introduce policies and procedures in the organisation that create a climate conducive to knowledge sharing. Selected examples of these policies and procedures include the nurturing of communities of practice (Martin et al, 2005), design of the organisation to promote ‘intra-organisational collaboration’ (Disterer, 2001), the encouragement of individuals to share knowledge about decision rationale (Malhotra and Majchrzak, 2004), and support for knowledge sharing from the senior management (Lin and Lee, 2006). Little detail is given about implementing these recommendations, partly because every organisation is unique in nature. They are also intended to influence behaviour, rather than to tackle specific knowledge sharing issues, and will not be considered any further here.

The second way is through the implementation of software-based methodologies and tools. These are supported by various information technologies. It is worth noting that some scepticism has been expressed about the effectiveness of information technology in support of knowledge sharing. Mc Dermott (1999) observed: ‘If a group of people don’t already share knowledge, don’t already understand what insights and information will be useful to each other, information technology is not likely to create it’. Latterly though, researchers have advocated that tools should be used as a knowledge sharing enabler and the emphasis is on people to carry out knowledge-related activities themselves (Tyndale, 2002). Key generic applications and methodologies are enterprise knowledge management systems, groupware, chat and video-conferencing clients, expert search software (Marwick, 2001), and Wikis (Wagner, 2004). Enterprise knowledge management systems tend to be based on

content management tools and various combinations of the applications discussed below. Many commercial vendors supply these tools, among them Autonomy Inc. (<http://www.autonomy.com>).

Groupware provides a software-based virtual environment in which individuals can share knowledge. This might take place by the exchange of documents, and the holding of Web-based, on-line meetings and presentations (Marwick, 2001). Lotus Notes by IBM is an example of such software. Chat and video-conferencing clients, such as Microsoft Net Meeting® and Skype® are Web-based applications that allow anybody with access to the Internet to talk on-line, regardless of their location. Intranets are private networks based around Internet technology for the dissemination of various media. They are the basis of modern groupware tools, usually contain Web-based content and their content and features are viewable and accessible via a Web browser client, such as Microsoft Internet Explorer® (Stoddart, 2001). Expertise location, or 'Yellow Pages' software, allows people who require knowledge on a subject to search for people in the organisation with the desired expertise. Current examples of commercial offerings are Autonomy®, Sopheon Accolade®, AskMe Enterprise® and KnowledgeMail® from Tacit Knowledge Systems®. None of these tools or methodologies is specifically targeted at addressing the knowledge sharing barriers encountered in an NPD environment.

Key supporting technologies for knowledge sharing are peer-to-peer networking or P2P (used in file sharing applications), intelligent agents, the World Wide Web (WWW) and ontologies. Zhang et al. (2004) noted that Web-based tools 'are desirable to adapt [sic] geographically distributed multidisciplinary product development teams and heterogeneous software and hardware environments'. Another approach is the ontology, a knowledge-sharing technology used by knowledge engineers. An ontology can be employed to facilitate a shared understanding of a knowledge domain that may be communicated among people (Pinto and Martins, 2004). Concepts in the ontology may be mapped to keywords in other languages, therefore providing a degree of multilingual support (Guyot et al., 2005). Similarly, knowledge maps may also be used to facilitate knowledge sharing among a group of individuals by contextualising information (Wexler, 2001).

### **2.5.1 Methodologies for the Facilitation of Knowledge Sharing in the NPD Environment**

In addition to the more generic information technology-based methodologies already discussed, there are several knowledge management methodologies specific to the NPD environment. All of these methodologies and tools claim to support knowledge sharing among project team members, to varying degrees. They include: the SHADE framework by Gruber et al. (1992), the SHARE methodology by Toye et al. (1994), the ConceptBase system by Ramesh and Tiwana (1999), the REMAP-based system by Tiwana and Ramesh (2001), the Product Innovation Portfolio Management application by Cormican and O’Sullivan (2003), the docK system by Donnellan and Fitzgerald (2003), an Agent-based system by Koyama et al. (2005), and the Distributed Knowledge Management Framework by Wang et al. (2005).

Making an assessment of the extent to which these methodologies are able to address knowledge sharing barriers in the NPD environment is difficult however, not least because of the many barriers that may be present. An effective review of these methodologies in the context of a multinational, geographically dispersed product development demands a focus on a smaller selection of knowledge sharing barriers

### **2.5.2 Findings**

The key findings from this section of the literature review are:

- Two main approaches to the facilitation of knowledge sharing in organisations are evident in the literature. One is the introduction of policies and procedures to influence the behaviour of individuals, and the other is the implementation of software technology based-methodologies and tools.
- Technology-based approaches cannot by themselves facilitate knowledge sharing, but they may be deployed as an effective enabler of knowledge sharing.
- Several information technology-based tools and methodologies have been proposed for managing knowledge in the NPD process, many of which address knowledge sharing barriers. However, given that there are a large number of possible knowledge sharing obstacles in a contemporary NPD environment, a

meaningful review of these methodologies and tools would necessitate a focus on a smaller selection of barriers.

## **2.6 Metaknowledge**

### **2.6.1 The Role of Metaknowledge in Knowledge Sharing**

In section 2.3, it was noted that providing contextual information about knowledge is a way to facilitate knowledge sharing. Following their critique of interpretations of Polanyi's tacit knowledge ideas in the literature, Keane and Mason (2006) advised that the designers of knowledge management systems (KMS) 'should focus on capturing information, the explicit representation of knowledge, and as much of the context of that information as possible'. They proposed that future research should focus on how to show information or explicit knowledge in a fashion that allows users to find and apply it in the required context.

Several authors in the knowledge engineering domain, notably Blanning (1987) and Menzies et al. (2000), and in the knowledge management domains, such as Davenport and Prusak (1998), Swanstrom (1999), Hendriks (1999), Menzies (2000), Donnellan and Fitzgerald (2003), and Wright (2005), have referred to this information about knowledge as metaknowledge.

Blanning (1987) considered how metaknowledge is used in expert systems and examined the implications of knowledge about the range of information sources available to a manager that might help them to decide on a solution to a given problem. In the scenario presented by Blanning, metaknowledge is defined as 'information about the content and structure of an expert system - for example, a description of the information contained in the system or an explanation of how the system works'. Blanning proposes that metaknowledge may be exploited by an organisation for the purpose of managing communication. Menzies et al. (2000) discussed the views of two groups of knowledge base researchers, one group focusing on the construction of knowledge bases, and the other group on the maintenance of knowledge bases. Both groups of researchers agreed that metaknowledge could be used to support communication tasks.

Neither Blanning (1987) nor Menzies et al. (2000) use metaknowledge in a scenario that is directly relevant here, since both were concerned about the use of metaknowledge to better understand knowledge base systems, rather than actual items of knowledge. Nonetheless, they both support the notion that metaknowledge may be employed to support the communication of knowledge. Next, the application of metaknowledge in the knowledge management domain will be examined.

Davenport and Prusak (1998) cited by Spinello (1998) limit the scope of application of metaknowledge to information, such as its format and type, for the automatic classification of knowledge in a knowledge base.

Swanstrom (1999) ventured a more sophisticated view of metaknowledge than Davenport and Prusak (1998) and presented a model to describe a way in which it can be applied to the management of knowledge. Two knowledge management roles are identified. The first role is that of the knowledge worker, who executes various knowledge processes, that is, the creation, development and exploitation of knowledge. In this case, the knowledge worker, whom Swanstrom suggests might be a product development team member, works with knowledge from a given domain. The second role is that of the knowledge manager, who actively seeks to manipulate the environment of the knowledge worker in order to influence these processes. In this case, the knowledge manager requires knowledge about the knowledge used by the knowledge worker.

Hendriks (1999) introduced the theme of knowledge sharing in a discussion of metaknowledge, describing metaknowledge as 'knowledge about the knowledge to be shared'. Metaknowledge is perceived as taking the form of either information about local information bases, such as their location, or information about the owners and users of knowledge. Examples of knowledge owners are colleagues who might possess knowledge needed by a knowledge worker, while knowledge users are people who require knowledge already possessed by a knowledge worker. Hendriks viewed metaknowledge as an aid to locating agents that possess, or are looking for, knowledge.

Donnellan and Fitzgerald (2003) advocated the exploitation of metaknowledge in their presentation of a knowledge management application to support knowledge dissemination among individuals within the NPD design engineering function. They

suggested that metaknowledge should answer questions such as where knowledge about a particular domain could be obtained. This echoes the work of Court (1997), which recommended that information systems used by design engineers should feature the ability to act as a reminder or “memory jogger” of where information may be found.

Wright (2005) claimed that early knowledge management efforts had focused on capturing knowledge for use as an organisational resource, while largely neglecting the way individuals work with knowledge. He argued that the more complex problem solving situations encountered by an individual demand the availability of extensive metaknowledge.

## **2.6.2 Findings**

This section of the literature review established the following findings:

- Metaknowledge can help individuals to locate relevant knowledge and apply it in the desired context. Research from the knowledge engineering and knowledge management domains has argued that metaknowledge supports the communication, dissemination and sharing of knowledge.
- Examples of metaknowledge espoused as useful for knowledge sharing include information about the location of knowledge and its format and type, as well as the human sources (those individuals who possess knowledge) and users of knowledge (those individuals seeking knowledge). There is a lack of research into the provision of contextual information about knowledge in new product development.

## **2.7 Prioritisation of Knowledge**

### **2.7.1 Prioritising Knowledge**

In the previous chapter (see section 1.5), reference was made to the role of knowledge in the creation of wealth, innovation and competitive advantage for companies. Van der Spek et al. (2004) observed that knowledge management initiatives in a business might not succeed if they are not consistent with the strategic priorities of that business.

Carayannis and Alexander (1999) posited that knowledge management demands the recognition that the knowledge assets within a company have varying degrees of importance according to their relevance to the core competencies of that business. Additionally, Preiss (2000) warned that important knowledge held by employees is at risk of being lost, should those employees leave the company. For these reasons, the aforementioned authors have advocated the prioritisation of organisational knowledge in line with business strategy and business objectives. Carayannis and Alexander (1999) stated: 'Knowledge must be prioritised in terms of business relevance.' Preiss (2000), referring to the potential loss of knowledge through the migration of employees, recommends the prioritisation of knowledge possessed by those employees. A further motivation for prioritising NPD knowledge is the sheer volume of knowledge associated with product development. Rodgers and Clarkson (1998a) noted that 'contemporary product development involves the application of huge amounts of knowledge, information and data'. It may be argued then that the prioritisation of knowledge, would help in the sharing of relevant knowledge.

To this end, efforts have been made to identify knowledge areas for prioritisation and link them to the goals of the organisation. It should be conceded though that these efforts originate from practitioners rather than academic researchers. For example, van der Spek et al. (2004), as cited by Helms and Buijsrogge (2005), provided a process to identify knowledge areas pertinent to a business objective and prioritise them. Furthermore, Plumley (2003) proposed the use of process-based knowledge mapping to prioritise knowledge in terms of its relevance to either business or knowledge management objectives.

An example of possible prioritisation criteria pertinent to a role in an NPD project team, albeit from an engineering design perspective, may be drawn from Rodgers and Clarkson (1998b), who considered the key knowledge needs of designers. These needs were stated to be cost, time, quality and environment. However it was noted that it is improbable that there is a set of knowledge needs that are generic to all designers. It is conceivable, then, that this is true for other roles involved in NPD, so prioritisation based on the overall strategic goals for new product development projects may be more appropriate.

### **2.7.2 Findings**

The key findings from this section are as follows:

- There is a body of research advocating the importance of prioritising knowledge assets according to their relevance to business strategy and business objectives. Methodologies have been proposed to identify knowledge areas for prioritisation.
- There is a lack of literature discussing the prioritisation of knowledge in the context of the new product development process. Therefore further research is required into this area.

### **2.8 Summary**

This chapter reviewed literature pertaining to the current understanding of the nature and types of knowledge discussed in the knowledge management and product development domain, the types and content of knowledge used in new product development, models for describing how knowledge is shared, and the barriers to knowledge sharing in both the organisation and in new product development teams. Lastly, it offered an overview of approaches to the facilitation of knowledge sharing.

There are numerous definitions of knowledge, even within the confines of the knowledge management domain literature. The definition proffered by Davenport and Prusak (1998) is to be used as the working definition of knowledge for this study. This definition is consistent with that used by other researchers considering knowledge in the context of NPD, in that it considers that knowledge exists in the mind of an individual, but that it can to some extent be externalised as information embedded in physical documents, as well as in various other forms.

The most commonly cited model for knowledge in knowledge management systems research is that of Nonaka (1991), who proposed that there were two ‘types’ of knowledge: explicit knowledge and tacit knowledge. Nonaka proposed that it is feasible to convert one type of knowledge to another. For instance, tacit knowledge might be converted to explicit knowledge. Over the last five years, a debate has been conducted in the literature as to whether this model is really valid. Some researchers have argued that tacit knowledge is by definition impossible or extremely difficult to



capture or convert. Keane and Mason (2006) rejected the Nonaka notion of knowledge types, and instead put forward the idea of knowledge having explicit and implicit dimensions, previously referred to as the epistemology of practice by Hislop (2002). As with the tacit knowledge type, the tacit dimension of knowledge cannot be easily shared. Regardless of which model is chosen though, the implication is that it is not possible to capture all kinds of knowledge.

This issue also impacts knowledge sharing, since the knowledge sharing models for the objectivist epistemology and the epistemology of practice involve the transmission and reception of explicit knowledge or the explicit dimension respectively. The sharing of tacit knowledge in the objectivist epistemology and the tacit dimension of knowledge in the epistemology of practice requires some degree of social interaction among individuals, which is likely to be highly restricted in global product development environments. The provision of contextual information that gives meaning or context to information can nurture the creation of knowledge in the minds of these individuals.

There is a consensus in the literature that effective knowledge sharing is crucial if a product development project is to be successfully executed. Nonetheless, although much attention has been focused on knowledge management in NPD, relatively little research has been carried out concerning knowledge sharing, a point supported by Hong (2004) (as referred to in chapter one, section 1.6). Knowledge sharing among cross-functional, geographically dispersed product development project team members may fall prey to many barriers. These include those social and technology-related barriers encountered in the wider organisation, as well as barriers more specific to NPD teams themselves, examples of which include the range of knowledge used in the product development process, the physical distance between team members, trust, culture and language.

Two main approaches to the facilitation of knowledge sharing in companies have been identified. Policies and procedures may be put into place to influence the behaviour of individuals. Otherwise, information technology-based tools and systems can be deployed. These tools cannot of themselves ensure that knowledge sharing takes place, but they can be exploited as an effective enabler of knowledge sharing. None of the commercial software tools and methodologies for the facilitation of knowledge

sharing specifically addresses knowledge sharing barriers in the context of new product development. Several knowledge management methodologies, which claim to facilitate knowledge sharing in NPD teams, have been presented in the literature. In view of the myriad of possible knowledge sharing barriers highlighted in this review, itself unlikely to be exhaustive, a meaningful examination of these methodologies is more likely to be obtained if it is conducted in the context of a smaller number of knowledge sharing barriers in an NPD environment.

According to researchers in both the knowledge engineering and knowledge management domains, another way in which knowledge sharing can be supported is through the provision of contextual information about knowledge, sometimes referred to as metaknowledge. This metaknowledge can be used by individuals to identify knowledge relevant to their current task. Notably though, there has been little research into providing such contextual information in the NPD environment.

Several taxonomies of the knowledge used in NPD activities have been devised. Most of these classifications are characterised by focusing on the knowledge used by the engineering designer functional role, and not the knowledge used by the many other functions involved in product development. Furthermore, the classifications tend to consider the nature, rather than the content of the knowledge. While of interest to academics, this is perhaps less useful to NPD practitioners looking for knowledge relevant to their current task. One proposed classification, that of Zahay (2004), categorised knowledge used in the NPD process based on its content. Interviews were conducted with individuals in roles such as project team leader or project manager, rather than design engineers. However, this study seemed to rely on a shallow study performed at many product development companies, rather than a deeper study involving many respondents at a single industry or company.

Given the knowledge intensive nature of the product development business process and the large range of knowledge used in its execution, it is argued that knowledge sharing could be facilitated by prioritising knowledge according to its strategic relevance to a given NPD project. Researchers have promoted the notion of prioritising knowledge assets according to their relevance to business strategy and business objectives. Practitioners have put forward methodologies to identify

knowledge areas for prioritisation, but there is a need for further research into the prioritisation of knowledge in the context of the new product development process.

### **3 Research Aim, Objectives and Process**

This chapter restates the research aim, sets out the research objectives and provides an overview of the research process adopted for this project. Each stage of the process is linked to the pertinent chapters in this thesis document.

#### **3.1 Research Aim and Objectives**

The aim of the research is:

To provide a prototype method and tool for facilitating knowledge sharing in early new product development.

The research objectives are to:

1. Further explore the nature of knowledge and approaches to managing knowledge sharing in new product development;
2. Identify key barriers to knowledge sharing;
3. Empirically inform a conceptual model for improving knowledge sharing;
4. Develop a prototype method for reducing barriers to knowledge sharing in early new product development; and
5. Conduct an initial validation of the prototype method.

#### **3.2 Research Process**

In order to meet the stated research objectives, a five-stage process was devised. These stages are described below. Figure 5 shows which thesis chapter corresponds to each stage of the research project. A detailed explanation of the research methodology for this process is given in chapter four. The process can be divided into four phases: a literature review, an industry-based empirical study of new product development process knowledge and key knowledge sharing barriers, the design and development of a tool to address these knowledge sharing barriers, and the validation of the knowledge sharing tool. Links between the stages and phases are illustrated in Figure 5.

### **3.2.1 Stage 1: Scoping Work**

Stage 1 of the research process involved conducting a review of the literature concerning knowledge sharing in the new product development environment, barriers to knowledge sharing, and approaches to the facilitation of knowledge sharing. The findings of this review were used to further define and refine the research objectives. This stage formed the scoping work phase of the research process.

### **3.2.2 Stage 2: Empirical Investigation in the Sponsor Company**

Reference to the literature revealed that various barriers to knowledge sharing are encountered in the course of executing the new product development process, and that there is a range of measures that may be applied to tackle them. An empirical study was executed at the sponsor company with the purpose of investigating knowledge sharing barriers in an NPD project environment and to provide a focus for the remainder of the research project. It was agreed with the sponsor that three of the identified knowledge sharing barriers should be investigated further.

An additional finding of the literature review, provided in chapter two, was that contextual information about knowledge can help facilitate knowledge sharing (see sections 2.2 and 2.6). Furthermore, there is a lack of a content-based classification of NPD process knowledge that considers all of the functions involved in NPD project teams. It has been proposed by researchers that classifications can help NPD practitioners find relevant knowledge sources and thereby support knowledge sharing (see section 2.2). The second part of this phase of the research programme concerned the identification of knowledge used and generated in the NPD business process of the sponsor company, and the classification of that knowledge based on its content. In addition, an investigation was carried out to ascertain what kind of information about knowledge NPD practitioners might require, and to determine what criteria they might use to prioritise this knowledge. Classification of the knowledge items identified was achieved by attempting to place all of the identified 'knowledge items' into an existing classification of NPD knowledge from the literature. The existing classification was modified to accommodate all of these knowledge items, leading to the creation of a new classification. Mind-maps were used as a supporting tool. The resulting classification

was to be used as a component of the NPD process knowledge ontology developed in stage 4.

Together, the investigation of knowledge sharing barriers and the study to identify and classify NPD process knowledge comprised the empirical study phase of the research project, as indicated in Figure 5.

### **3.2.3 Stage 3: Design of a Knowledge Sharing Tool**

This stage was divided into two parts. In the first part, a review of key methodologies for the facilitation of knowledge sharing in new product development environments was carried out. The purpose of this review was to assess to what extent they addressed the key knowledge sharing barriers identified in stage 2. This was followed by a review of knowledge sharing technologies intended to nurture a shared understanding of a knowledge domain. Again, the identified knowledge sharing barriers were used as a framework for the review. Based on the findings of this first part, it was proposed that a new tool was required to address the knowledge sharing barriers, and that this tool should be based on an ontology of information about knowledge in the NPD process.

In order to build the ontology of information about NPD process knowledge, an apposite ontology building methodology was required. The aim of the second part of stage 3 was to provide a methodology to construct an ontology of information about NPD process knowledge. This exercise commenced with a review of existing ontology building methodologies in the literature. An ontology-building methodology was then selected according to its suitability for use the context of this research project. Modifications were then made to the selected methodology to address any shortcomings and thereby render it fit for use in a real world context.

### **3.2.4 Stage 4: Development of a Knowledge Sharing Tool**

For stage 4 of the research process, a knowledge sharing tool was developed to support the sharing of knowledge in a product development environment by addressing the knowledge sharing barriers identified in the empirical study conducted in stage 2. As mentioned above, the ontology of information about NPD process knowledge at the heart of this tool was built using the methodology provided in stage 3 and featured the classification of knowledge devised in stage 2.

### **3.2.5 Stage 5: Refinement and Testing of Knowledge Sharing Tool**

Stage 5 of the research process was to implement, test and refine the knowledge sharing tool developed in stage 4. This exercise was carried out in two parts. In part one, the functionality of the tool was tested by implementing it and using it to capture information about knowledge used and generated in a selection of sub-processes in a single phase of the NPD business process at the sponsor company. This also allowed the knowledge classification developed in stage 2 to be assessed, by verifying that it could subsume all of the knowledge associated with the sub-processes. Part two was to assess the perceived usefulness of the aforementioned knowledge sharing tool by demonstrating it to NPD experts in the sponsor company and collecting their feedback.

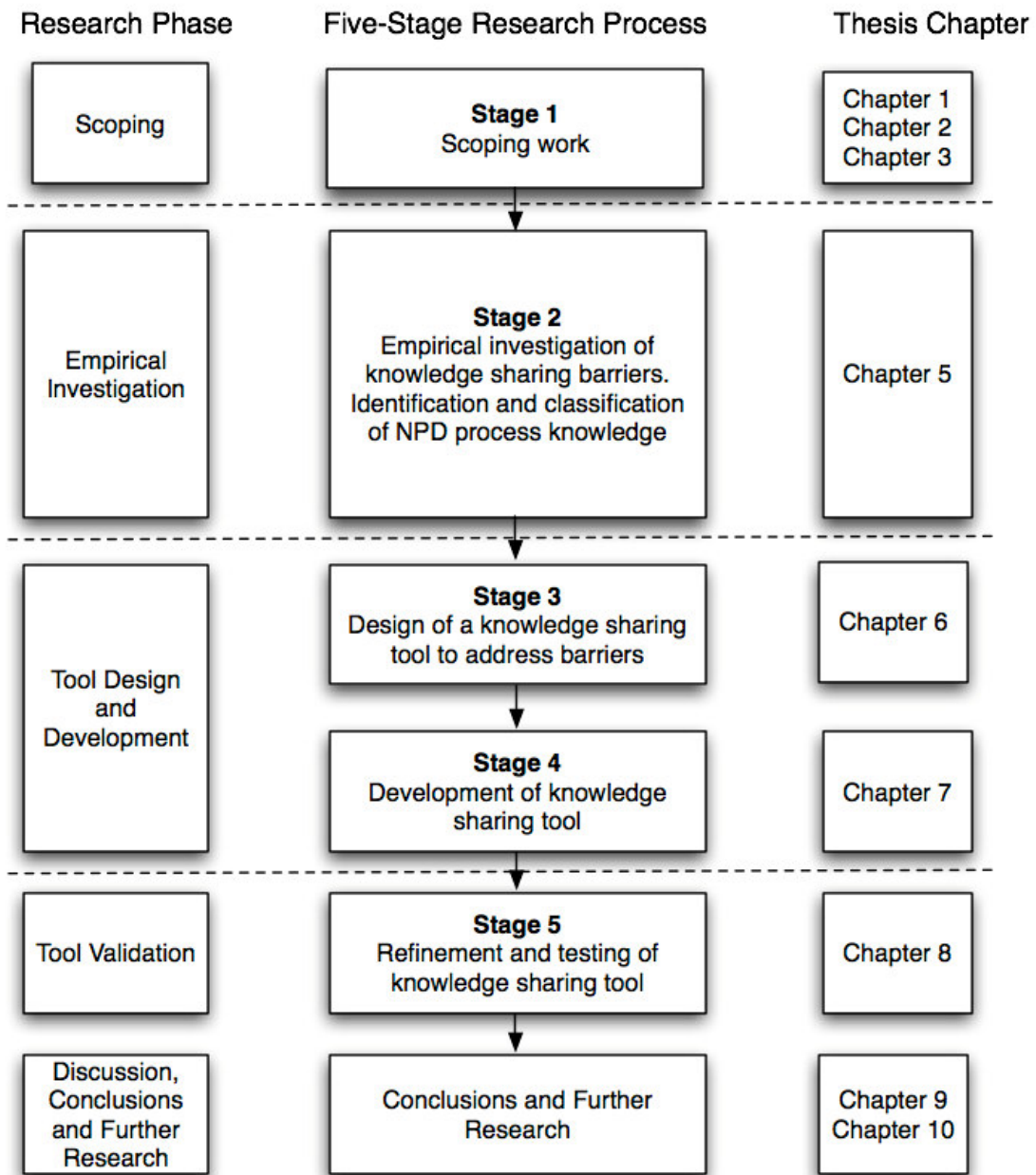


Figure 5: Five-stage research programme.



## **4 Research Methodology**

This chapter performs two main functions. Firstly, it reviews the different research approaches available to the researcher and identifies those employed to provide a methodology for this investigation. Secondly, it describes in detail a five-stage methodology to meet the research objectives and fulfil the research aim.

#### **4.1 Definition of Research**

Leedy (1989, p.5) described research as a procedure by which one attempts 'to find systematically, and with the support of demonstrable fact, the answer to a question or the resolution of a problem'.

Miller (1991, p.3-6) proffered the notion that organisational research focuses enquiries in three directions known as basic or pure, applied, and evaluation. As Miller would have it, investigators practicing pure research seek to 'advance knowledge' without concern for its short term utility. Their mission is 'to describe the world as it is, not to change it'. For applied researchers, on the other hand, the aim is 'to create knowledge that can be used to solve pressing social and organisational problems'. Similarly, Patton (1990, p.153) stated that the purpose of applied research is 'to contribute knowledge that will help people understand the nature of a problem so that human beings can more effectively control their environment'. Easterby-Smith et al. (2002, p.9) asserted that applied research should result in a solution to specific problems identified by a client. Lastly, evaluation research attempts to assess the outcomes of the treatment applied to given social problem or to assess the result of a current practice (Miller, 1991, p.4).

This investigation is concerned with providing solutions to problems in an organisation and therefore the applied research direction is indicated.

#### **4.2 Research Methodology**

A robust research methodology is widely acknowledged to be a crucial part of a research project. Irani et al. (1999) warned that 'any substantial research project must be based on a rigorous scientific methodology'. Definitions of a methodology are varied. In a survey of literature from the operations research and management science domains, Lehane and Vinton (1994) concluded that there were six categories of methodology:

- 1) 'The ways in which hypotheses become theories'.
- 2) 'The ways in which techniques are chosen to address a particular problem'.
- 3) 'The ways in which problems are chosen, which addresses the issue of sponsorship'.

- 4) 'Methods or techniques'.
- 5) 'The modelling process, which includes hard and soft systems approaches, and the ways in which the relevant variables are chosen for a model, and how reality is concomitantly simplified'.
- 6) 'The chronological planning of events - the research programme'.

Here, the discussion concerns a methodology for a research programme. Leedy (1989, p.88) defined the research methodology as 'merely an operational framework within which facts are placed so that their meaning may be seen more clearly'. That is, the research methodology is a way of obtaining some meaning from data.

#### **4.2.1 Research Strategy**

Irani et al. (1999) emphasised the important role of the research strategy in developing a research methodology: 'the underlying construct upon which any robust methodology is built is the research strategy. There are numerous strategies available to guide researchers around the phenomenon of interest.' Drawing on definitions from Galliers (1992) and Weick (1984), Irani et al. (1999) offered the following definition: 'A research strategy is considered to be a way of going about one's research, embodying a particular style and employing different research methods'. It is distinct from a research method, which 'is a way of collecting evidence that indicates the tools and techniques used during data collection'. Pursuing the same theme, Remenyi et al. (1998, p.256) highlighted the importance of outlining the philosophical approach adopted as the basis of the research programme, since it is this approach that determines the research strategy.

Remenyi et al. (1998) advanced a taxonomy containing two classes of research. These classes are theoretical research and empirical research. Theoretical research involves the study of academic literature and learned discourse of a subject, while generally refraining from observation of behaviour in the real world. Based on these studies, the research theorist will build a new view of this subject of interest, which might emerge as a theory, accompanied by conclusions that serve as a contribution to knowledge. Empirical research in contrast, involves studying observations made in the real world and the gathering of evidence. Conclusions are made based on this evidence

and it is this that is the potential contribution to knowledge. It is suggested that theoretical research demands the rigorous scrutiny of text-based sources, whereas empirical research will feature contact with people.

Empiricism is the underlying philosophy for positivist and phenomenological research. Some of the main assumptions of positivism summarised by Robson (2002, p.20) are that objective knowledge can be collected from observation, science is predominantly based on quantitative data and that the methods of natural science can be transferred to social science e.g. applied research. Phenomenology, in contrast rejects the notion of objective knowledge. It attempts to ‘capture people’s experience of the world’ and how they interpret it (Patton, 1990, p.71). In this way it takes a more subjective, qualitative stance. Remenyi et al. (1998) claimed that phenomenology is the prevailing philosophy in management settings. This is because it takes a holistic, subjective approach that is better suited to a complex social environment than the reductionist stance of positivism.

There follows an overview of research methodologies applicable to research in information systems, management and more general social science research projects.

#### 4.2.2 Overview of Research Approaches

Literature discussing research methodology would seem to indicate that there are at least two routes to the selection of a research methodology or approach. One is a data-driven approach, as advocated by Leedy (1989) and also found in Robson (2002), while the other is determined by the stated research problems or questions, as put forward by Yin (1994) and Remenyi et al. (1998). Other, more practical considerations may also affect the choice, as will be discussed.

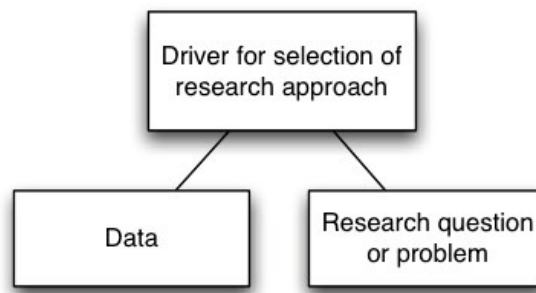


Figure 6: Drivers for the selection of a research approach or methodology.

Leedy (1989, p.88-89) argued that the research methodology selected for a research problem should be chosen with regard to the type of data likely to be gathered in the course of addressing that problem. He proposed that there only actually two types of data, writings and observations, which can in turn be subdivided into four categories, as listed in Table 2. A methodology or approach was assigned to each of these categories, also shown in Table 2.

<b>Methodology or Approach</b>	<b>Data type</b>	<b>Data Category</b>
Historical methods	Writings	Written records and accounts e.g. documents and literary sources
Descriptive or normative survey	Observations	Observation for whose transmission description is the best vehicle e.g. simple observational situations
Analytical survey		Observations that are quantified and exist in the form of numerical concepts
Experimental methods		Observations of certain differences and likenesses that arise from comparison or contrast of one set of observations with another set of similar observations

Table 2: Methodologies appropriate for different data types. Adapted from Leedy (1989, p.88-89).

It was determined that the data that was likely to be available in a product development company environment would be of a qualitative nature, or more specifically, written records and descriptive observations such as company reports or process documentation. Only a few approaches were supplied by Leedy (1989), which does not reflect the range of approaches that would appear to have become accepted research practice in the applied sciences over the last decade.

Yin (1994) proposed three conditions for selecting what he refers to as a research strategy. As with Remenyi et al. (1998), the first of these conditions is the type of research question to be addressed. The other conditions are the degree of control that

the investigator is able to exercise over behavioural events and the level of focus on contemporary events. Yin then proceeded to examine five social science research approaches or strategies in the context of these conditions (see Table 3).

<b>Strategy</b>	<b>Form of Research Question</b>	<b>Requires control over behavioural events</b>	<b>Focuses on contemporary events</b>
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival Analysis	Who, what, where, how many, how much	No	Yes/No
History	How, why	No	No
Case study	How, why	No	Yes

Table 3: Conditions for selecting a research strategy.

For Remenyi et al. (1998), the choice of a research approach should be influenced by four key issues: the research question or problem, the available financial resources, the available time, and the aptitude of the researcher. Building on work by Galliers (1992, p.150-151), a taxonomy of fourteen approaches to research is offered. These approaches are divided according to whether their philosophical foundations may be described as positivistic or phenomenological, and are listed in Table 4.

Remenyi et al. (1998) added focus groups, participant-observer and scenario discussion to the original taxonomy by Galliers. The work of Galliers considered research approaches employed in information systems research, which makes it relevant to the domain of this investigation. Bocij et al. (1999, p.27) defined an information system as ‘a group of interrelated components that work collectively to carry out input, processing, output, storage and control actions in order to convert data into information products that can be used to support forecasting, planning, control, coordination, decision making and operational activities in an organisation’.

Each of these approaches will be considered in the context of their suitability for this research investigation. Earlier in this section, it was established that the likely data sources for the investigation would be qualitative in nature. It has also been alluded to that the phenomenological stance is better suited to research in a business environment. Therefore, those approaches that are only applicable within the positivist paradigm,

such as forecasting research, laboratory experiments, large-scale surveys, and simulation and stochastic modelling, will be dismissed immediately.

<b>Research Approach</b>	<b>Positivism</b>	<b>Phenomenology</b>
Action research		X
Case studies	X	X
Ethnographic		X
Field experiments	X	X
Focus groups		X
Forecasting	X	
Futures research	X	X
Game or role playing		X
In-depth surveys		X
Laboratory experiments	X	
Large scale surveys	X	
Participant-observer		X
Scenario discussions		X
Simulation and stochastic modelling	X	

Table 4: Fourteen research approaches

## **4.2.3 Exploration of Phenomenological Research Approaches**

### **4.2.3.1 Action research**

The purpose of action research is ‘to influence or change some aspect of whatever is the focus of the research’ (Robson, 2002, p.215). In this approach, the researcher will intervene in the environment or scenario being studied. Robson (2002, p.215) ventured that this intervention has three aims: to achieve an improvement in a practice, to gain an improved understanding of that practice by its practitioners, and to accomplish an improvement in the situation in which the practice is taking place. Remenyi et al. (1998, p.49-50) identified three main weaknesses to this approach. The first problem is that action research often requires long periods of time to observe the impact of an intervention. The second and more relevant problem is that the personal involvement of the researcher in the scenario being observed puts them at risk of compromising their ‘intellectual independence’. Of equal concern is the third problem, that of a perceived lack of research rigour in the approach. It is therefore cautioned that any use of this approach in a PhD research project must be conducted with great attention to rigour.

#### 4.2.3.2 Case studies

Yin (1994, p.13) defined a case study research strategy as ‘an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident’. Eisenhardt (1989) provided a similar definition: ‘a research strategy which focuses on understanding the dynamics present within single settings’. A setting is a single organisation or organisational grouping (Galliers, 1992, p.150).

Case studies may be used for descriptive or explanatory purposes, theory building, and theory testing (Darke et al, 1998; Eisenhardt, 1989). A case study provides deep understanding of a phenomenon and its context (Cavaye, 1996), and to a greater level of detail than is possible with approaches such as the survey (Remenyi et al., 1998). Irani et al. (1999) supported this claim by remarking that ‘a case study analysis goes much further than the superficial study of a survey, as it identifies theoretical constructs, variations in variables, reasons for their occurrence and the relative impact of each variable on the organisation’. The approach has been employed widely in information systems research (Orlikowski and Baroudi, 1991; Galliers, 1992; Darke et al, 1998). Darke et al. (1998) stated: ‘The case study research method is well suited to understanding the interactions between information technology (IT)-related innovations and organisational contexts’. Furthermore, case studies are an established research approach in doctoral research projects (Remenyi et al., 1998, p.51).

Yin (1994, p.13) identified two kinds of case study design: single case approaches and multiple case approaches.

In the single case design, one setting is analysed. This allows a rich analysis of a phenomenon to be carried out. There are three scenarios in which a single case study is appropriate (Yin, 1994, p.38-40). The first scenario is where the single case is a critical case ‘for testing a well-formulated theory’. The second scenario is where the case is an extreme or unique case. The third scenario is where the case is revelatory in some way, that is, it allows analysis or observation of a phenomenon previously inaccessible to scientific investigation. Although only setting is examined, it is nonetheless possible to embed more than one unit of analysis within the study (Yin, 1994; Irani et al, 1999).



A common criticism of the single case study approach is that the findings cannot be scientifically generalised, an issue mentioned by Yin (1994), Darke et al. (1998), Irani et al. (1999) and Bell (2005). Denscombe (2003) ventured, 'the extent to which findings from the case study can be generalised to other examples in the class depends on how far the case study example is similar to others of its type'. This remark reflects the notion put forward by Bassey (1981) concerning the relatability of the case under scrutiny. By this, it is meant that the details of a case should be adequate for others examining a similar situation to relate their decision making to that in the case study. Bassey (1981) stated: 'The relatability of a case study is more important than its generalisability'.

In a more recent work, Bassey (1999), cited in Bell (2005, p.12), described three different kinds of generalisation. One is the empirical generalisation sense referred to by physical scientists. This holds that a hypothesis can be generalised only if it cannot be refuted. This would seem to be an unlikely contingency if different organisations are being studied. Another kind is a statistical generalisation, a quantitative measure. That is, there is a chance 'x', that findings from a sample are also present throughout the population. Darke et al. (1998) warned that statistical generalisation to a population is not the aim of a case study and that cases are not sampling units.

The last kind is the fuzzy generalisation, a qualitative measure. This measure is applied to studies of singularities and it may be claimed that it is 'possible', 'likely' or 'unlikely' that the findings from this study will be encountered in similar situations. In addition, Irani et al. (1999) directed attention to the issue that no set of cases is likely to provide representative cases. Yin (1994) recommended that the findings of case studies should be generalised to theories and not to other case studies, in the way that scientists generalise experimental results to a theory.

The multiple case design offers the opportunity to compare evidence from different cases. Irani et al. (1999) identified two advantages of the multiple case design over the single case design. Firstly, 'it enables differences in context to be related to constants in process and outcome'. Secondly, research findings can be crosschecked following theory building. As a result it is considered to result in a more robust study, as argued by Herriot and Firestone (1983), cited in Irani et al. (1999). There is an

important disadvantage to this approach, which is that the researcher may not be able to obtain the same richness of data possible with a single case approach within the limited timeframe of a research project. Irani et al. (1999) suggested that there is little agreement in the literature on the number of cases that should be studied in the multiple case approaches, the recommended number varying between a minimum of four cases and a maximum of five or ten cases.

Unlike in-depth surveys, case studies rely on multiple sources of evidence (Yin, 1994). The significance of this is that it is possible to triangulate data sources and data collection methods, and reduce the effect of bias in the findings (Patton, 1990; Yin, 1994; Robson, 2002). Yin (1994, p.79) considered the strengths and weaknesses of six sources of evidence used in case studies: documentation, archival records, interview, direct observations, participant observation and physical artefacts, as shown in Appendix A. Bell (2005) observed that observations and interviews tend to be the most commonly used by researchers. Yin (1994) conceded that this list of six sources is far from complete, and he cites films, photographs, videotapes and life histories as just some examples of other possible sources.

Regardless of whether a single case or multiple case design is chosen, the overall case study approach has been subject to certain criticism. Galliers (1992, p.151) listed four weaknesses in the approach. The first is that the approach confines the study to one organisation. The second, which is particularly relevant to the case study approach, is the accusation that the findings of a case study may not be easily generalised. This is because of the difficulties of obtaining evidence from a sufficient number of cases. The third problem is the inability to control variables in a way that would be feasible in a laboratory-based experiment. The fourth weakness is that events in the case study setting may be interpreted in different ways by the parties involved in the investigation, or that 'selective reporting' may occur (Bell, 2005). Nevertheless, as Yin (1994, p.10) commented, such bias is not exclusive to the case study strategy and may also be found in experiments, surveys and historical research. Darke et al. (1998), building on the theme of data interpretation, pointed out that qualitative data analysis methods are not as well established as quantitative methods, and that processing large amounts of this type of data is time consuming. They concluded that these difficulties could be countered with a rigorous research design.

#### **4.2.3.3 Ethnographic**

Patton (1990, p.67) stated that ethnographic research is driven by the question ‘What is the culture of this group of people?’ Ethnographic research may well involve fieldwork in which the researcher is embedded in the culture under scrutiny. Creswell (1998, p.66) pointed out that an ethnography may be distinguished from a case study by the type of system that is being studied. He proposed that while ethnographies are concerned with a complete cultural or social system, cases studies are used to study more tightly bound systems such as programmes, activities or individuals and might investigate a range of subjects. Aside from the fact that this type of study cannot be replicated, it has three major drawbacks. Firstly, the subject of this research investigation is not a culture. Secondly, despite being a well-established and credible research approach in anthropology (Patton, 1990, p.67), it is not widely applied to business and management research (Remenyi et al., 1998, p.51). Thirdly, the duration of ethnographic studies may extend to many months or even years, which may prove to be beyond the scope of a PhD project, not least because it is often used alongside other approaches (Remenyi et al., 1998, p.52).

#### **4.2.3.4 Field experiments**

Field experimentalists seek to conduct experiments in a real world setting, rather than a laboratory, and field research has been employed in the business and management domain. Field experiments have been subject to considerable criticism, in part due to the effect that the knowledge that the experiment is taking place can have on the behaviour of the parties being investigated (Robson, 2002). Robson (2002) cautioned that the real world is not an environment where variables that may influence the outcome of the experiment can be readily controlled by the field researcher in the same way that they can be by the experimentalist in the laboratory. Remenyi et al. (1998) warned of three further problems. From a methodological point of view, field experiments are considered to be too artificial in the businesses domain. As a result, PhD researchers do not usually adopt this approach. Furthermore, it may prove difficult to convince a business to spend significant time and money implementing a change for the sake of allowing a researcher to study its impact. If it is not possible to persuade an organisation to initiate this change in a timetable suitable for the researcher, the researcher will have

to wait for the desired scenario to present itself in the natural course of events. This may not be practical within the timeframe of a PhD project. Together, these issues suggest that the field experiment approach is inappropriate for this investigation.

#### **4.2.3.5 Focus groups**

A focus group is a homogeneous group of selected well-informed or highly specialised individuals (Remenyi et al., 1998, p.53; Patton, 1990, p76). Groups usually consist of five to eight people. Evidence is collected from these groups using open interviews, which focus on carefully targeted subject areas (Remenyi et al., 1998, p.53; Patton, 1990, p.173, 335). Patton (1990, p.335) commented that an interview session might last from half an hour to two hours. Remenyi et al. (1998, p.53), noted that the focus group approach is typically employed in business and management research as one of many evidence collection techniques in a single project in doctoral research. It is, however, not included in the list of research approaches applicable to information systems research provided by Galliers (1992, p.149). Furthermore, it is posited that the focus group approach may be used at the start and end of a research project in order to support research questions derived from a literature review or to support findings respectively.

#### **4.2.3.6 Futures research**

According to Remenyi et al (1998, p.54), futures research is used for technology forecasting and business trend analysis, both of which are subjects with no direct relation to the domain of this research. Additionally, they argue that although the approach may be employed to support the findings of other approaches, it would not be considered adequate as the primary approach in a PhD research project. For these reasons, futures research was not considered to be a fitting approach in this study.

#### **4.2.3.7 Game or role-playing**

Remenyi et al. (1998, p.54-55) stated that game or role-playing is applied in the field of human relations and organisational behaviour. It may be viewed as the 'high-level simulation of interpersonal reactions, as well as group decision-making'. These issues are incongruous with those that must be addressed in this research investigation.

#### **4.2.3.8 In-depth surveys**

An in-depth survey approach seeks to elicit data from a small number of people by means of interviews (Remenyi et al., 1998, p.55). Interviews may be facilitated with an interview schedule or an interview protocol. Evidence is collected in the form of detailed notes or the interview is recorded and a transcript produced. The interview notes or transcript may be interpreted in a quantitative or qualitative fashion. For the former interpretation type, content analysis techniques may be applied to count the number of times an issue occurs. The frequency with which the issue appears is linked to the importance of that issue. For the latter interpretation type, the relevance attached to issues is based on the interpretation of the researcher, a technique known as grounded analysis. Given the subjective nature of this method, grounded analysis demands that the researcher ensures that the data collected is made available for analysis by other interested parties (Easterby-Smith et al., 2002). Remenyi et al. (1998) mentioned that the in-depth survey approach has been employed in new product development research.

Robson (2002, p.233) referred to in-depth surveys as ‘interview surveys’ and describes various disadvantages to the approach, all of which are attributable to the use of interviews. These include the risk of the interviewer unintentionally influencing the responses of the interviewee, cultural differences between the interviewer and the interviewee, and a reluctance of the interviewee to answer questions in a candid manner caused by a lack of anonymity.

#### **4.2.3.9 Participant-observer**

Although Yin (1994) described participant-observation as a source of data, other authors have described it as a research approach. In the participant-observer approach, ‘the researcher makes firsthand observations of activities and interactions, sometimes engaging personally in those activities as a ‘participant-observer’” (Remenyi et al., 1998). Patton (1990) suggested that this technique provides the researcher with a deeper insight into a programme than would be possible through interviews alone. He went on to comment that the participant-observer approach is really a method of ethnography. Since ethnographic approaches have already been deemed unsuitable for this study, the participant-observer approach will not be considered any further.

#### **4.2.3.10 Scenario discussions**

Scenario discussions concern the elicitation of evidence from a group of selected experts. In this way, the approach is similar to in-depth surveys. The group are called upon to discuss the implications of the occurrence of a hypothetical scenario (Remenyi et al., 1998, p.58). The comments and opinions of the group are collected by the researcher. Essentially, the scenario discussion is a qualitative approach to the quantitative futures research methodology already discussed, a point supported by Patton (1990, p.136). Since it is not within the scope of this investigation to anticipate future trends, it is argued that the scenario discussion approach is not appropriate for this investigation.

### **4.3 Previous Studies in the Domain**

Before proceeding to the choice of methodology, the research methodologies used in works addressing a similar domain will be considered. Donnellan and Fitzgerald (2003) used an action research approach to study the development and implementation of a knowledge management application to support knowledge sharing. Ramesh and Tiwana (1999) meanwhile, used the case study method for data collection and validation of a tool to manage and capture NPD process knowledge. Notably, they used an industry-based, single case study approach. Tiwana and Ramesh (2001) used an industry-based case study to illustrate the functionality of a design knowledge management system, although they provided little detail about the research methodology. Case studies were also used by Cormican and O'Sullivan (2003), and Wang et al. (2005) to implement and demonstrate knowledge management applications. Benbya (2006) used a case study approach for theory building in a study of the link between knowledge management systems and new product development.

### **4.4 Selected Approach**

A case study strategy was selected for the research investigation. This approach was chosen for the following reasons:

1. It provides a rich and deep understanding of the domain of interest.
2. It is suitable for application in a business environment.

3. It has sufficient academic credibility and rigour for use in a doctoral research investigation.
4. It may be used to carry out exploratory and theory testing research.
5. It allows the use of multiple sources of data and data collection methods. This has two advantages. The first is that at least three of these sources were likely to be available in a product development business environment. The second is that the issue of bias in the findings can be addressed using triangulation (refer to section 4.2.2).
6. It has been used in similar research projects published in international, peer-reviewed literature.

A single case design was selected, with multiple units of analysis embedded into the study. It was determined that the heating systems manufacturer sponsoring the research would act as the setting for the case studies. The close adherence of the cross-functional stage-gate process used by this company to generic models presented in the literature (see section 5.4.1), as well as the traits of the project teams that allow them to be described as global product development teams (see section 5.3), are features which lend the case reliability. Additionally, the relationship that the researcher (also referred to in the text as ‘the author’) was able to cultivate with the company in the course of an earlier industrial project, made it possible to gain access to confidential documentation and senior personnel that would otherwise be difficult to obtain.

#### **4.5 Selected Research Method**

As reported in chapters one and three, the research aim was to provide a prototype method and tool for facilitating knowledge sharing in early new product development. A summary of the five-stage research process used to fulfil the research aim was provided in chapter three, section 3.2. The process is reproduced in Figure 7. There now follows a more detailed description of the methods used at each stage of this process.

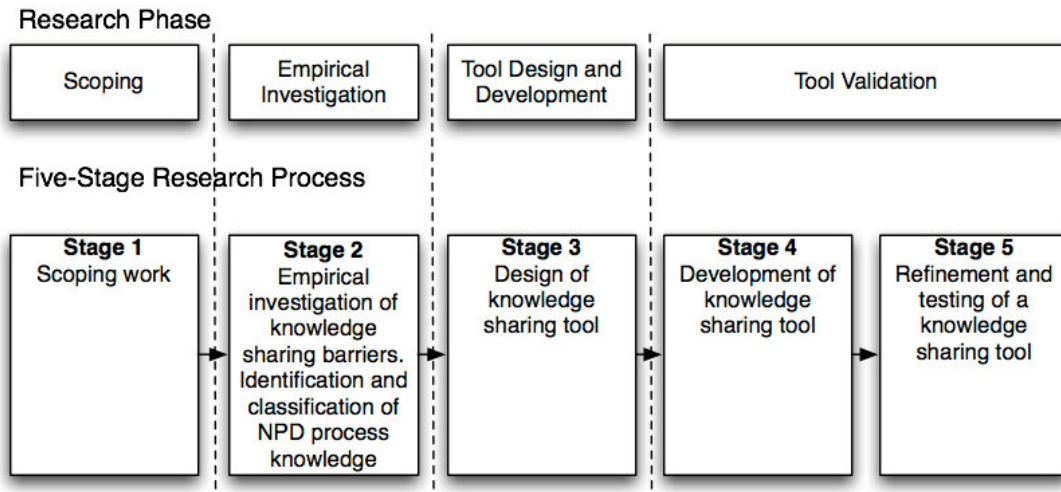


Figure 7: Five-stage research process, featuring process steps and research phases.

#### 4.5.1 Stage 1: Scoping Work

Formulation of the research objectives was based on a review of the literature. A wide-ranging review of key concepts concerning the nature of knowledge, knowledge sharing, and barriers to knowledge sharing in NPD environments was carried out, using literature mainly in the knowledge management and product development domains. The identification of salient publications and papers was facilitated using Internet-based search engines. This review occurred both prior to, and during, the empirical investigation at the sponsor company (see Stage 2).

#### 4.5.2 Stage 2: Empirical Investigation

Reference to the literature revealed that knowledge sharing in new product development is hindered by various obstacles or barriers, as discussed in section 2.4.2. It was also found that there is a lack of a content-based classification of NPD process knowledge used and generated by the different functional roles in an NPD project team 2.2.3. This prompted the execution of two empirical studies. One study was an investigation of key knowledge sharing barriers encountered by NPD practitioners, using the sponsor company as a case study environment. The other study sought to identify knowledge used in the NPD process at the same company, and then to classify it based on its content.



Since this stage of the research was largely exploratory in nature, the general approach adopted was to collect and develop ideas that could lead to the formulation of research hypotheses, an approach endorsed by Oppenheim (1992). Patton (1990, p.193 and p.244) cautioned that an over-reliance on a single data source within a study can threaten the validity and credibility of research findings. This is because it cannot be assumed that a given source of information offers a complete or unbiased view of a subject. Robson (2002, p.172) described three sources of bias, which he referred to as threats to validity. The first threat is reactivity, which concerns the influence a researcher may have on the environment in which their study is taking place. The second threat is respondent bias, which refers to scenarios in which a respondent either distorts their answers in order to please the researcher, or provides a more malicious misrepresentation of events if they dislike or feel threatened by the researcher. Lastly, the third threat is researcher bias, whereby the personal prejudices and beliefs of the researcher affects their choice of interviewees, interview questions and the data used for analysis.

One approach to tackling some of the threats to validity caused by bias is through triangulation of data sources, a strategy that is endorsed by many authors, among them Patton (1990, p.187), Robson (2002, p.174) and Yin (1994, p.90). Triangulation of qualitative data sources means using two or more different types of source within a study. According to Yin (p.79, 1994), sources of information include documentation, archival records, interviews, direct observations and participant observations. Additionally, Patton (1990, p.347) advised that 'practical, but creative data collection consists of using whatever resources are available to do the best job possible'. Consequently, and in line with methodological advice described above, the empirical studies in this stage drew on six data sources and three data source types: interviews, business process documents and screenshot artefacts. The six data sources are depicted in Figure 8.

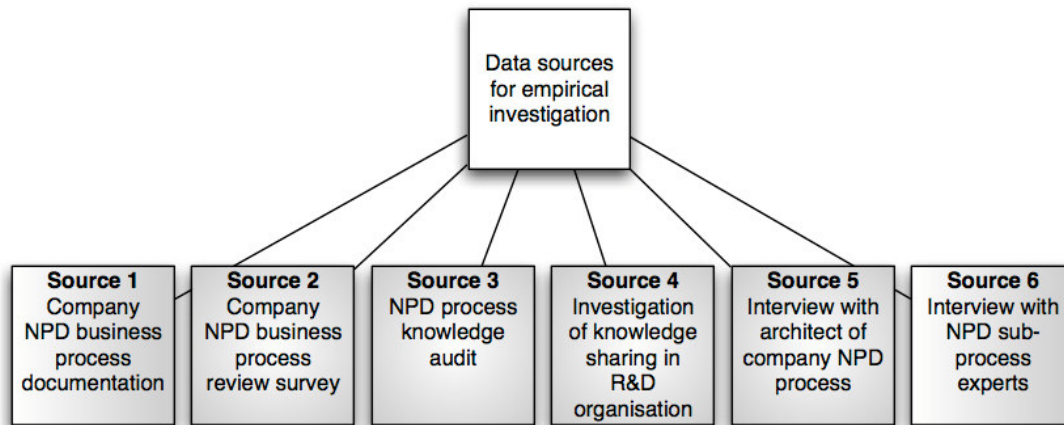


Figure 8: Data sources used in the empirical investigation.

Company documentation for the NPD business process represented the first source. This consisted of process flow maps and text-based summaries for every sub-process, including depictions of basic information and data flows. Although this data did not explicitly point to knowledge sharing problems, it provided a better understanding of where potential problems might occur and familiarised the author with terminology and acronyms peculiar to NPD process practitioners, and which might be encountered in the other data sources. The second source was company documentation containing results from an internal review of the new product development process at each of the three main sites. The third source was a knowledge audit of the new product development process. The fourth data source was an investigation of knowledge sharing problems among members of the R&D community at the company. An interview conducted with an architect of the new product development business process was the fifth source. Finally, the sixth source was an interview conducted with four sub-process experts concerning desired metaknowledge elements and knowledge prioritisation criteria.

There now follows a description of the data collection methods for each source, followed by a summary of the data analysis methods for each stage of the research process.

#### **4.5.2.1 Data Collection**

##### **Source one: Company NPD business process**

The complete documentation for the new product development business was secured, including business process flow maps for every sub-process (Vaillant Group, 2005a). The process flow maps included a breakdown of each sub-process into five to ten tasks. Each task was accompanied by a short description of the task aim and in some cases some of its data inputs and outputs were indicated. A digital, Web browser-viewable version of this documentation was obtained on a compact disc.

##### **Source two: NPD process review survey**

Firstly, an NPD Process Review workshop at the UK site of the sponsor company was attended and the proceedings observed. This workshop facilitated the presentation and discussion of the results of a corporate-wide NPD business process user feedback survey and included data from UK survey respondents, as well as the surveys conducted in company sites in France and Germany. The survey was carried out by the NPD business process development team at the sponsor company and involved survey-based interviews with sub process owners in Germany, France and the UK. Secondly, documentation summarising the main findings of the workshop was obtained via e-mail from the review organisers. This documentation summarised key findings from the survey and included extensive quotations from participants in the survey. The themes that comprised the main sources of the data in the NPD Process Review documentation were knowledge-related factors for a successful NPD business process, suggestions for optimising the process, and general statements about the process. In the case of this latter theme, a special category of language-related issues had been created by the company.

One criticism that may be levelled at the NPD process review data source is that the study that produced it was not designed by the author. Consequently, the details of its underlying methodology, and the rigour with which it was executed are not fully understood. However, the very fact that it was not undertaken by the author and that the respondents were able to submit their survey answers anonymously (aside from being

associated with a particular site) helps counter the potential criticisms of both respondent bias and reactivity.

### **Source three: NPD process knowledge audit**

A knowledge audit was conducted as part of a wider study of knowledge usage in the new product development process at the company. It was carried out using an adapted version of the methodology provided by Liebowitz et al. (2000), which was itself based on prior work by Debenham and Clark (1994). According to Debenham and Clark (1994), two of the objectives of a knowledge audit are to provide 'a high level view of the extent, nature and structure of knowledge in a specified section', in this case the NPD process, and 'to identify the relevant knowledge repositories within the organisation'.

Data collection involved interviews with eight company-appointed sub-process owners, each of whom represented a different sub-process. The company considered the process owner to possess the best understanding of that process. Collectively, the sub-processes represented all seven phases of the new product development process. As already discussed, interviews are one of the six sources of evidence proposed by Yin (1994). Each sub-process owner answered questions about the knowledge used and produced in a specific sub-process. The titles of the sub-processes and the phases of the NPD process in which they occur are listed in Table 5.

Given the complexity of the subject matter and the possibility of misunderstanding due to language differences, semi-structured interviews were selected. Additionally, as Robson (2002, p.277) ventured, the semi-structured interview 'allows respondents to react with richness and spontaneity'. The selection of semi-structured interviews differs from the postal questionnaire-type approach used in the industry-based knowledge audit case study conducted by Liebowitz et al. (2000). Indeed, Liebowitz et al. (2000) noted that the response rate to the questionnaire survey was low (about a third of the questionnaires were returned, representing less than three percent of employees in the organisation under scrutiny), and that follow-up interviews were required to elicit additional contextual information. The semi-structured interview allowed the researcher to follow the standardised interview protocol dictated by the knowledge audit, while allowing scope to provide further explanation of the background

to a question, should it be required by an interviewee. This advantage was lauded by Oppenheim (1992). It was considered that the risk of complicating the analysis of the data by any departure from the wording of the protocol was minimal, since the data collected was to be largely of a factual nature.

	NPD Process Phase in which Sub-Process Occurs								
	Product Strategy		Conception		Development		Industrialisation		Review
Title of Sub-Process	Status	Product	Requirements	Feasibility	Function	Detail	Process	Launch	
Analysis of Competitor Products	X								
Strategic 'Make or Buy' Evaluation		X							
House of Quality Part 1, Definition of Marketing Requirements / House of Quality Part 2 Definition of Technical Specification			X	X					
Risk Analysis Concept				X					
Definition of System at Component Level (Bill of Materials)					X				
Phase In/Phase Out Realisation							X		
Project Status Review			X	X	X	X	X	X	X
Target Costing and Cost Tracking			X	X	X	X	X	X	

Table 5: List of sub-processes represented by process owners interviewed in the knowledge audit and the NPD process phases in which they occur.

Many textbooks on research methodology, for example Patton (1990, p.247), Oppenheim (1992, p.67), and Robson (2002, p.290), strongly recommend that interviews are tape recorded, so that they may be subjected to further scrutiny at some later point in time. Nonetheless, during the early stages of the research the relationship with individuals in the company had not matured sufficiently to allow recording to take

place. In place of a tape recording and subsequent transcription, the answers of the interviewees were recorded on an interview protocol.

Interviews were conducted in the English language on a face-to-face basis, usually in the office of the interviewee, and lasted between forty and ninety minutes, depending on the verbosity of the interviewee. Two research students, one of whom was the author, were present at each interview. One student conducted the interview and wrote rough notes, while the other took detailed notes of the responses. The data was interpreted and written-up by the author. The changes made to the knowledge audit questionnaire protocol consisted of the removal of questions. This allowed more time to be spent on the issue of interest. The full knowledge audit interview protocol is included in Appendix B. Questions in the knowledge audit that elicited responses related to NPD process knowledge sharing barriers included 'what knowledge is missing to improve process goals?' and 'what would be the most effective method of delivering this knowledge?' The main output from the knowledge audit was a report that was written and compiled by the author of this research. Extracts from the knowledge audit report are given in Appendix C.

#### **Source four: Investigation of knowledge sharing in R&D organisation**

Source four was an investigation of knowledge sharing activities in the R&D function of the sponsor company (also referred to as the 'case study company'). This investigation was carried out at the behest of the sponsoring company for internal purposes.

Elicitation of evidence about knowledge and information sharing was achieved by conducting semi-structured interviews with nine individuals from R&D functions in the company. Oppenheim (1992, p.67) remarked: 'the purpose of the exploratory interview is essentially heuristic: to develop ideas and research hypotheses rather than to gather facts and statistics. It is concerned with trying to understand what ordinary people think and feel about the topics of concern to the research.' As with the knowledge audit, semi-structured interviews were adopted as the data collection technique for the same reasons of richness of response and flexibility. Data collection duties were shared with two other researchers acting as assistants. The design of the study, and the transcription and interpretation of the data were executed by the author.

Selection of personnel for the interviews was based on four criteria. The first criterion was that collectively, the interviewees must represent all of the competences that play a major role in the R&D function, namely Hydraulics, Electronics and Control, Thermal and Product Certification. The second criterion was that the interviewees must include the key roles involved in product development, such as managers, engineers and project leaders. The third criterion was that collectively, the interviewees must represent each of the sites where product development activities take place i.e. Germany, France and the UK. The final criterion, of a more practical nature, was that all of the candidates must be willing and available to be interviewed. A list of the roles held by the interviewees and their locations is provided in Table 6.

<b>Role</b>	<b>Location</b>
NPD Project Leader	UK
Engineer (Thermal Module Expert)	France
Boiler Project Manager	France
Project Leader, Electronics Development	Germany
Manager Floor Standing Boiler projects (Programme Manager, Centre of Competence for Hydraulics)	Germany
Manager Hydraulics expertise (Programme Manager, Hydraulics & Accessories)	Germany
Engineer, Boiler Project Manager	Germany
Project Manager Controls Expertise	Germany
Certifications Manager (Product Certification)	Germany

Table 6: Roles and locations of interviewees for the knowledge sharing investigation.

Interview questions were mostly open-ended to allow the interviewee to provide as rich and detailed a response as possible. This reasoning is supported by Oppenheim (1992) and Robson (2002). The interviews were conducted in the English language and on a face-to-face basis, with the exception of the parties in France where a telephone conference was arranged.

An interview protocol (see Appendix D) served as the main data collection tool, in line with the recommendations by Oppenheim (1992), Hague (1993), Stake (1995), Creswell (1998) and Yin (1994). A postal questionnaire may have provided data that was easier to process (Oppenheim, 1992), but the complexity of the subject matter meant that the questions could have been easily misunderstood or material overlooked.

Where permitted, the interviews were captured on a digital voice recorder for later reference, as advised by Patton (1990, p.347) and Robson (2002, p.289). Interviews lasted between fifty and ninety minutes. Questions posed in the interview relevant to the identification of knowledge addressed the types and format of knowledge used in the NPD process, and the storage of this knowledge.

The original purpose of the interviews was to help the company gain an improved understanding of knowledge sharing within the R&D function of the company. Questions posed in the interviews covered subjects including knowledge needs, sources of knowledge, and knowledge sharing. Much of the material pertinent to the identification of knowledge sharing barriers came from questions under the theme of searching for knowledge, specifically knowledge difficult to find (question six in the interview protocol, see Appendix D). Notably, the author was able to exploit the semi-structured approach and digress from the questions on the interview protocol in order to pursue any subjects that arose that were considered to be of relevance to this investigation. Given the commercially sensitive nature of some of the responses provided by the interviewees, the full set of completed interview protocols from the study could not be included. Instead, a selection of exemplar interview protocols is supplied in Appendix E.

An additional form of evidence collected about the storage of knowledge consisted of screenshots of the folder structure of the personal drive used by each interviewee to store their project data. In this way, an insight was gained onto the way that individuals involved in NPD projects prefer to classify explicit knowledge, as discussed in section 4.5.2.2.

#### **Source five: Interview with NPD business process architect**

A semi-structured, face-to-face interview was carried out with an architect of the NPD business process at the case study company. As, with sources three and four, a semi-structured approach was adopted as it 'allows respondents to react with richness and spontaneity' (Robson, 2002, p.277). It should be emphasised that this interview was neither devised, nor conducted by the author. These actions were carried out by another research student working with the sponsor company. Despite this, it represented a useful source of data and afforded some degree of triangulation to address issues of researcher



bias in the data collection process. An interview protocol, sent to the respondent by e-mail, was used to record the responses (see Appendix F). The full interview protocol is not included in its entirety due to the inclusion of the names of many individuals and commercially sensitive information, and in accordance with the wishes of the interviewee. Nonetheless, selected responses are quoted verbatim in chapter five.

#### **Source six: Interview with NPD sub-process experts**

Semi-structured, face-to-face interviews were conducted with four NPD sub-process experts. The experts were asked questions relating to three issues: (1) whether they felt any of the metaknowledge elements shown to them were unnecessary, and if so which ones, (2) whether any metaknowledge was missing, and if so, what, and (3) which criteria they would use to prioritise NPD knowledge. Open-ended questions were used following the advice of Robson (2002), who stated that they provide researcher with the chance 'to make a truer assessment of what the respondent really believes'. Their responses were recorded using a digital voice recorder. The interviews were both designed and conducted by the author.

#### **4.5.2.2 Data analysis**

This section is broken down into two parts. The first part describes the data analysis methods employed for the investigation of knowledge sharing barriers in an NPD environment. The remaining three parts outline the methods used for the identification and classification of NPD process knowledge. Table 7 indicates which data sources were used in each part of the empirical investigation.

#### **Empirical study of knowledge sharing barriers**

Four data sources were analysed to identify problems that could be described as knowledge sharing barriers. Knowledge sharing was taken to mean any activity involving the transfer, capture or deployment of information or knowledge, following the description of knowledge sharing by Bakker et al. (2006). Initially, those questions and themes that seemed pertinent to knowledge sharing were identified in the four data sources. These were the company NPD process review survey results, the interview protocols from the knowledge audit and the interview transcripts from the knowledge

sharing study. These questions and themes are shown in Table 8. In the case of the interview sources, their semi-structured nature meant that relevant responses might have been present elsewhere in the protocol or transcript, possibly as part of a digression from the current theme of the interview. Consequently, those parts that had remained unaddressed were also examined for material applicable to the theme of knowledge sharing barriers.

<b>Empirical Study</b>	<b>Data Sources</b>					
	<b>Source 1</b> Company NPD business process documentation	<b>Source 2</b> Company NPD process survey	<b>Source 3</b> NPD process knowledge audit	<b>Source 4</b> Investigation of knowledge sharing in R&D organisation	<b>Source 5</b> Interview with architect of company NPD process	<b>Source 6</b> Interview with NPD sub-process experts
<b>Part 1: Empirical Study of Knowledge Sharing Barriers</b>						
Empirical study of knowledge sharing barriers in NPD	No	Yes	Yes	Yes	Yes	No
<b>Part 2: Identification and Classification of NPD Knowledge</b>						
Identification of NPD process knowledge	Yes	No	Yes	Yes	No	No
Classification of NPD process knowledge	No	No	No	Yes	No	No
Identification of metaknowledge elements	No	No	No	No	No	Yes
Identification of prioritisation criteria	No	No	No	No	No	Yes

Table 7: Data sources used in empirical investigation.

Principal source(s) = Yellow

Significant supporting sources = Blue

Additional supporting sources = Pink

Once this exercise was complete, mind maps were employed to place the knowledge sharing barriers into broad categories, essentially creating what Patton (1990) referred to as an Analyst-constructed typology. This is an inductive research approach, whereby the researcher searches for categories and themes in data that can be used to generate findings. A similar technique is referred to by Creswell (1998, p.153-154) called categorical aggregation. Patton (1990) warned that the risk inherent in this approach is that the typologies devised by the researcher are not truly present in the data. To counteract this, it is recommended that the categories are presented back to the research subjects to verify that they are really present and lend verisimilitude to the findings. This was performed at several stages in the research by presenting the categories to senior management figures including the Group Innovation Manager, Group Project Manager and the Group R&D Manager. The commercially sensitive content of some elements of the data sources taken from the company meant that it was difficult to share them with other researchers. This meant that it was not practical to attempt validation of the categories by investigating whether other researchers produced the same categories after analysing the data sources.

<b>Data Source</b>	<b>Apposite Themes</b>	<b>Questions attached to that Theme</b>
NPD process review survey (Source 2)	'IP success factors'	Unknown
	'Suggestions for optimisation (success factors)'	Unknown
	'General statements'	Unknown
	'General statements – Translation'	Unknown
NPD process knowledge audit (Source 3)	'Missing knowledge' from NPD business process	'What knowledge is missing to improve process goals?'
	'Suggestions for improvement'	'What would be the most effective method of delivering this knowledge?'
Investigation of knowledge sharing in R&D organisation (Source 4)	'Searching for knowledge - Knowledge difficult to find'	'What kind of knowledge do you and your project team have problems finding?'
Interview with company NPD business process architect (Source 5)		'In your personal point of view, what would be the information flow bottlenecks occurring during the IP? What would your recommendations be to improve the group wide as well as local (in this case, Germany) knowledge sharing?'

Table 8: Relevant themes and questions in the sources used as a source of data for identifying knowledge sharing barriers.

## **Identification and classification of knowledge in the NPD process**

In the review of literature presented in chapter two, it was found that there was a lack of a classification of NPD knowledge that considered knowledge in the context of the NPD business process and that focused on the needs of all of the functions (Marketing, R&D etc.) involved in product development. It was later determined that a classification of knowledge was to be used in the NPD process knowledge ontology to be developed in Stage 3 (see section 4.5.4). Additionally, it was necessary to find out what metaknowledge was required by NPD practitioners in the case study company, and what criteria they might use to prioritise knowledge, in order to implement the knowledge sharing tool developed in Stage 4 (see section 4.5.5). This stage was divided into four parts: (a) identification of NPD knowledge, (b) classification of NPD knowledge, (c) determination of metaknowledge elements, and (d) determination of knowledge prioritisation criteria.

### *Identification of NPD process knowledge*

Information about the NPD process knowledge that was required to develop the NPD process knowledge classification was elicited from data sources one, three, and four. The primary source of data was source three, the knowledge audit study of eight sub-processes in the company new product development business process. Answers to questions in section 2 of the knowledge audit protocol (see Appendix B), entitled 'Knowledge Flow', provided the richest source of evidence about knowledge items.

Supporting this was source four, an investigation of knowledge sharing activities in the R&D functions of the organisation. It also provided useful evidence about knowledge used in the NPD process. Responses to questions 2 and 12 in the knowledge sharing investigation interview protocol (see Appendix D) were among the most pertinent to this study.

Source one, the company NPD process documentation provided two types of evidence. The first type of evidence was information about the NPD process itself, such as the sub-processes and tasks from which the process is composed, while the second type was an indication of the information inputs and outputs for some of the tasks in the sub-processes of the NPD business process.

### *Classification of NPD knowledge*

Classification of knowledge was carried out by mapping the knowledge items identified from the three data sources onto mind maps, in an approach similar to that exploited by Sure et al. (2002). An existing classification of NPD knowledge from the literature review was used as a starting point. The classification of explicit knowledge used by the interviewees for structuring their digital information and data, taken from source four, provided a practitioner perspective and was also taken into account. Since the standardised interview protocols had been used for the interviews and the information elicited was largely factual, it was possible, albeit time-consuming, to transfer information from the protocol to the mind map.

### *Determination of metaknowledge elements*

Determination of metaknowledge elements was achieved in three steps. In the first step, the five 'Ws and one 'H' (who, what, why, where, when and how) approach of journalistic enquiry was applied to determine the basic information a user may wish to know about a task or knowledge item. In the second step, this information about knowledge items was compared to the amended Dublin Core metadata element set proposed by Donnellan and Fitzgerald (2003), and a prototype metaknowledge element set created. In the third step, the prototype metaknowledge element set was placed on a mind-map and presented to four NPD process experts in the company (see data source 6). Following this the requested adjustments were made to the prototype metaknowledge set. A list of the roles held by the interviewees is given in Table 9.

<b>Role of Interviewee</b>	<b>Expert for Sub-Process</b>	<b>Location</b>
NPD Project Manager	Product Validation	Germany
Group Project Manager	Generate Product Proposal	Germany
Group R&D Manager	Project Performance	Germany
Group Project Manager	Project Performance	Germany

Table 9: Interviewees for determination of metaknowledge elements.

### *Determination of knowledge prioritisation criteria*

Determination of knowledge prioritisation criteria was achieved by asking the same four process experts approached in the exercise to determine the metaknowledge elements (see Table 9), which criteria they would use to prioritise knowledge used in the NPD process. It should be noted that these criteria were required for the purpose of illustrating the prioritisation mechanism and are not intended to be generalisable to the product development processes of other companies.

### **4.5.3 Stage 3: Design of Knowledge Sharing Tool**

Two exercises were undertaken to assist in the design of the knowledge sharing tool. These exercises were a review of methodologies and tools to facilitate knowledge sharing in the new product development environment, and the provision of an ontology-building methodology to construct an ontology of information about NPD process knowledge.

#### **4.5.3.1 Review of knowledge sharing methodologies and technologies for NPD**

A review of literature describing information technology-based methodologies for the facilitation of knowledge sharing in new product development activities was carried out. The knowledge sharing barriers identified in stage 2 were used as a framework for this review.

#### **4.5.3.2 Provision of a methodology to build an ontology of information about NPD knowledge**

A methodology to construct an ontology of information about NPD process knowledge was provided as follows. First a review of existing ontology building methodologies was carried out. An appropriate methodology was then selected according to two main criteria: (1) simplicity of execution, so that its application fell within the capability of the researcher, and (2) validation and use in previous literature that would support its application in a doctoral research project. Next, the selected methodology was examined to consider what changes might be required to apply it in the required real world context. In the final stage, the identified adaptations were made to this methodology

#### **4.5.4 Stage 4: Development of a Knowledge Sharing Tool**

Using the ontology developed in stage three, a knowledge sharing tool was developed to support the sharing of knowledge in a multilingual product development environment.

Mechanisms to support dissemination and multilingual language labels were developed in version 3.0 of the Protégé ontology editor and knowledge acquisition tool.

Development of the multilingual support mechanism drew on the findings of a literature review and practitioner experience captured in the Protégé user community Web forum.

Two approaches to development of the knowledge prioritisation mechanism were investigated. One used the frame-based version of the ontology tool and the other exploited the OWL (Web Ontology Language) version.

#### **4.5.5 Stage 5: Validation of Knowledge Sharing Tool**

As in the case of research objective three, this final stage was divided into two parts.

The objectives of part one were (a) to illustrate and test the functionality of the knowledge sharing tool resulting developed in stage 4 by implementing it for the case of knowledge used in a real NPD process, and (b) to test the knowledge classification in the ontology, upon which the tool is based. The aim of part two was to assess the perceived usefulness of the aforementioned knowledge sharing tool. In this second part, the case study is confirmatory rather than exploratory in nature and so a structured approach was adopted, as advised by Robson (2002).

##### **4.5.5.1 Part one: Implementation and testing of the knowledge sharing tool**

An NPD knowledge metaknowledge tool to facilitate knowledge sharing in NPD project teams was developed in stage 3 of the research process (see section 4.5.4). The developed prototype tool was tested using the knowledge associated with tasks from three sub-processes as a case study. All of the sub-processes came from the product conception phase of the company NPD process. In order to achieve this, a five-step method was employed: (1) selection of the three sub-processes, (2) elicitation of information about the tasks from which the sub process is comprised, (3) elicitation of information about the knowledge required for and generated by these tasks, (4) capture of this information or metaknowledge in the knowledge sharing tool and finally, (5) translation of the English language concepts and relationships that form the ontology

into German and addition of the multilingual labels. A more detailed explanation of each of these stages follows:

In step one, two main criteria were used for the selection of the candidate sub-processes. The first criterion was that the processes should involve the use of knowledge from a range of functional areas including Marketing, Research & Development, Product Testing and Validation, and Purchasing. This was intended to represent the broad spectrum of knowledge involved in new product development and provide a limited test of the knowledge classification in the ontology. The second criterion was that collectively the sub-processes should not be restricted to technical engineering processes and should include issues such as project management and the control of cost.

Step two involved elicitation of information about the processes and tasks themselves, so that the NPD business process sub-process and task hierarchy could be modelled in the tool. This was achieved through analysis of the full NPD business process documentation, which had already been secured from the company.

For step three, information about the knowledge required for, and generated by the tasks in the three sub-processes was elicited from two sources. The first source was the aforementioned NPD business process documentation, which provides an indication of data and information inputs and outputs for some of the tasks. The second source was a semi-structured interview with the expert designated by the sponsor company for each process. As with the other interviews conducted in this study, it was intended that the semi-structured interview format, in conjunction with the use of open-ended questions would provide a much richer understanding of the different kinds of knowledge associated with each task. Table 9 lists the selected processes and interviewees.

Step four was executed out in two parts. The first part involved adding information about the sub-processes and tasks to the NPD process classification already implemented in the ontology. The second part involved creating the relevant knowledge items for each of the tasks created in the tool and then adding the metaknowledge for each of these knowledge items.

Finally, in step five, English and German language labels were added to the 'concepts' and 'relationships' in the ontology. Using this method, English and German versions of the tool interface were created. It should be noted that the translation is of a



'rough' nature and was conducted for illustrative purposes only. The NPD process documentation provided by the company served as an additional source of technical vocabulary.

#### **4.5.5.2 Part two: Evaluation of perceived usefulness of knowledge sharing tool**

A case study approach was used to assess of the usefulness of metaknowledge concept on which the knowledge sharing tool is based, as well as the perceived usefulness of the tool itself. Step one of the case study involved presenting the knowledge sharing tool created in part one to three NPD project team members representing two project development sites in the UK and Germany. Step two involved collecting feedback from the same three NPD practitioners. The data collection instrument was a questionnaire consisting of open-ended questions focusing on the degree to which respondents believe that the tool supports knowledge sharing and the usefulness of the tool itself. Open-ended questions were used for the reasons given in section 4.5.2.2. This technique generated qualitative data.

### **4.6 Threats to Validity**

It was posited by Robson (2002, p.170) that the validity of qualitative research is related to 'it being accurate, correct and true'. Robson (2002) also proposed that this validity is threatened by issues such as reactivity, researcher bias and respondent bias. One way of tackling all of these threats to validity is to use the triangulation strategy, an assertion found in Robson (2002) and Patton (1990). Indeed, Patton (1990, p.193) stated: 'Triangulation is a powerful solution to the problem of relying too much on any data source or method, thereby undermining the validity and credibility of findings because of the weakness of any single method'. That is, the shortcomings of one type of evidence are counterbalanced by the strengths of another. Robson (2002, p.174) opined that the use of multiple sources improves the rigour of the research.

In this investigation, data triangulation and observer triangulation strategies have been exploited to tackle bias in the data collection and interpretation. Triangulation of data sources was used in the investigation to identify knowledge sharing barriers, and in the study to identify knowledge in the NPD process, which relied on evidence taken from interviews and company documentation (see section 4.5.2.2). Patton (1990, p.233)

argued that documentation of this kind is a rich source of information. It is worth noting that the knowledge audit and knowledge sharing investigation were conducted a year apart and with a largely different group of respondents. Triangulation of methods was not employed in the testing of the prototype knowledge sharing tool. Interviews were used to collect the opinions of target tool users on the perceived usefulness of the metaknowledge concept and the tool, providing a highly subjective, qualitative response. One final kind of triangulation used was observer triangulation, also found in Robson (2002, p.174). In the knowledge audit and the knowledge sharing investigations described in section 4.5.2.2, more than one interviewer was involved in the collection of data.

#### **4.7 Limitations to Approach**

Care has been taken to design a research methodology that is both apposite to the resolution of the research problems and which falls within the temporal and financial constraints of the doctoral research project. However, it must be acknowledged that there are a number of weaknesses in the proposed methodology. Some of these weaknesses concern the research strategy and others are inherent to the research methods employed. A discussion of these weaknesses follows.

A major criticism of the methodology may be levelled at the choice of a single case study approach. It is argued that the selected case possesses important features that make it relatable to companies in similar circumstances. These features are the use of a stage-gate product development process that closely matches the generic models presented in the literature. Furthermore, the product development teams possess many of the traits attributed to global product development teams in the literature, as highlighted in chapter five (see section 5.4.1). Additionally, the focus on a single organisation for the entire duration of the research project allowed a level of trust to be established which meant that rich and confidential data could be obtained.

Another criticism is that the knowledge classification employed in the ontology was only tested using knowledge associated with the conception phase of the new product development process. Nonetheless, work by Zahay et al. (2004) has emphasised the diversity of knowledge used in this phase, and Ulrich and Eppinger (2003) stressed the importance of knowledge sharing in this stage of the product development process.

## 4.8 Summary

Following a review of the available research methodologies, a five-stage methodology was devised to fulfil the research objectives stated in chapters one and three.

Stage 1 involved conducting a literature review in order to establish the scope of the research project and to define the research objectives.

In stage 2 an investigation consisting of two empirical studies was carried out. The first study was to identify knowledge sharing barriers in the new product development process of the sponsor company, a leading, multinational heating systems manufacturer. For the second study, a single case study approach was adopted to identify and classify knowledge used and generated in the product development process of the aforementioned manufacturing company. Classification of the knowledge was facilitated by the use of mind maps.

Stage 3 involved two actions to assist in the design of a knowledge sharing tool to tackle the three knowledge sharing barriers identified in stage 2. The stage included a review of information-technology-based knowledge management methodologies for NPD environments that facilitate knowledge sharing, and a review of more generic information technology-based knowledge sharing facilitation technologies. Additionally an ontology-building methodology was provided which was deemed suitable for building an ontology of information about knowledge used and generated in the NPD process.

For stage 4, a knowledge sharing tool was developed using the ontology building methodology provided in stage 3, and featuring the classification of knowledge devised in stage 2.

Finally, stage 5 was comprised of two case studies. The first case study demonstrated the functionality of the knowledge sharing tool by showing how it could be used to capture information about knowledge for sub-processes in the new product development process of the sponsor company. The second case study evaluated the perceived usefulness of the knowledge sharing tool by presenting it to product development practitioners and collecting their feedback using a qualitative technique.

## **5 Empirical Investigation**

A finding of the literature review presented in chapter two was that there is a broad range of barriers to knowledge sharing in product development companies. In order to provide a focus for this research, it was determined that an empirical study of knowledge sharing barriers in an NPD project environment should be carried out. A further finding was that there is a lack of a content-based classification of knowledge used and generated in the NPD process that considers project team functional roles other than design engineers.

This chapter presents the method and findings of two empirical studies to address these issues. It is divided into four parts. The first part provides an overview of the sponsor company and its products. The second part introduces the formal product development process-model employed by the company. In the third part, an investigation of knowledge sharing barriers in the new product development (NPD) business process in the sponsor company is detailed. Crucially, these findings provided the basis for remaining stages of the research. Finally, the fourth part describes an investigation to identify and classify knowledge used and generated in the NPD process, also in the sponsor company. The classification process drew on the results of similar classification attempts presented in the literature, as well as informal classifications of knowledge used by NPD practitioners based in the company.

## **5.1 Overview of the Company**

Vaillant Group is a privately held manufacturing company engaged in the design and manufacture of two types of physical goods. The first product type is heating systems appliances and the second type is household goods in the form of aluminium ladders and platforms. It is the development of the former product type that will provide the focus for this study.

The present incarnation of the Vaillant Group was formed in 2001 as a result of the acquisition of Hepworth plc by Vaillant GmbH. Both of these groups had a long history of boiler manufacture dating back to the late nineteenth century. During 2002, the newly established Vaillant Group, hereafter referred to as 'the company' or 'the sponsor company', introduced a new organisational structure that served to integrate the two groups. The company owns a series of European boiler brands including Glow-worm in the UK, Saunier Duval in France, AWB in the Netherlands, Protherm in the Czech Republic, Bongianni in Italy, and Vaillant in Germany.

At the close of 2005, the company had over 8500 employees and generated a turnover of 1.791 billion Euros in 2005. Heating systems technology is the main focus of the company, accounting for over ninety-eight per cent of this turnover from the sales of 2.7 million appliances (Vaillant Group, 2005b). The main heating systems products produced by the company are gas-fired wall-hung boilers for domestic central heating systems. Currently, the company has a share of around twenty-seven per cent of the wall-hung boiler market in Europe (Vaillant Group, 2007). Boilers are sold in markets in Europe, Iran and China via local sales offices, which also provide various customer and end-user support services. Customers are not the product end-users (householders), but rather the product installers, such as construction firms or plumbers.

## **5.2 Type of New Product Project**

New products manufactured by the company are predominantly new product platforms to be used as a basis for existing brands, and changes to existing products. Boilers comprise four functional modules, namely hydraulics, thermal, electronics and casing. Product platforms are customised for each market, drawing on local sales and marketing offices and maintenance engineers for an understanding of product requirements in

those markets. New product development is driven by factors like changes in environmental legislation and the demands of installers in each market, such as boiler dimensions and end user preferences for control systems and performance.

### **5.3 Company NPD Project Teams**

Heating appliance production is undertaken at fourteen sites in seven European countries. However, only four of these sites, Nantes in France, Belper in the UK, Remscheid in Germany and Skalica in Slovakia, have research and development (R&D) capabilities. The first three sites have the largest and longest-established R&D operations and at present, most new product development projects are undertaken by personnel from these sites working in cross-functional teams. The company's NPD projects and project teams exhibit many of the traits that literature suggests differentiate global product development projects and teams from their conventional, co-located counterparts. Table 10 provides a summary of the main characteristics of Global Product Development (GPD) teams taken from works by Subramaniam et al. (1998), McDonough et al. (2001), and Eppinger and Chitkara (2006).

Not all of these properties are exhibited by the NPD process and project teams under investigation here. For example, the teams do not use an exclusively digital product development process, although the utilisation of digital tools, such as Internet-enabled Computer-Aided Design (CAD) tools and Enterprise Resource Planning (ERP) applications, is increasing. In addition, the exploitation of engineering resources in multiple locations is concentrated on what Eppinger and Chitkara (2006) termed 'captive off-shoring', as opposed to 'global outsourcing'. Captive off-shoring involves the establishment of a production development operation in a country where a company wishes to develop new business. Crucially, that company retains ownership and control of that operation. The principal purpose of this venture is to make use of experience, training and market knowledge peculiar to that region. In this instance, the sponsor company is establishing this kind of operation in Eastern Europe and China. Global outsourcing, on the other hand, involves the subcontracting of engineering tasks to suppliers in other countries, without actually taking ownership of that supplier or its resources. This second form of global product development has not been adopted to any significant extent by the company considered in this study.

<b>Properties of Global Product Development Processes and Teams</b>			
<b>Properties of NPD Project Teams in Company</b>	<b>Properties of GPD Teams Identified in Literature</b>		
	Subramaniam et al. (1998)	McDonough et al. (2001)	Eppinger and Chitkara (2006)
Teams comprised of members from the UK, France, Germany; Slovakia is to follow.	Cross-national teams	Teams are comprised of 'individuals who work and live in different countries and are culturally diverse'	'Globally distributed teams'
Mostly exploiting high-cost R&D and production resources at present. Local production and R&D to be established in Skalica and China.			'Takes advantage of engineering in multiple geographic locations, including low-, medium- and high-cost regions.'
Use Internet-based design tools and ERP systems. Documents on file systems available via the Internet.			'Uses an entirely digital PD process to facilitate distributed collaborative engineering.'*
Local brands contribute to product conception and testing. New product platforms are shared among brands.	Overseas subsidiaries act as sources of new product concepts		

Table 10: A comparison of the characteristics of the company product development activities and teams with the characteristics of GPD processes and teams identified in the literature (\*PD=Product Development).

#### **5.4 Company NPD Business Process**

The full business process documentation was secured, as described in section 4.5. This was in the form of business process flow maps in an electronic format. A high-level view of the business process may be found in Figure 9. The process consists of seven phases: 'product strategy', 'conception', 'functional development', 'detail development', 'industrialisation – process', 'industrialisation – launch' and 'review'. A description of the activities in each of these stages may be found in Appendix G.

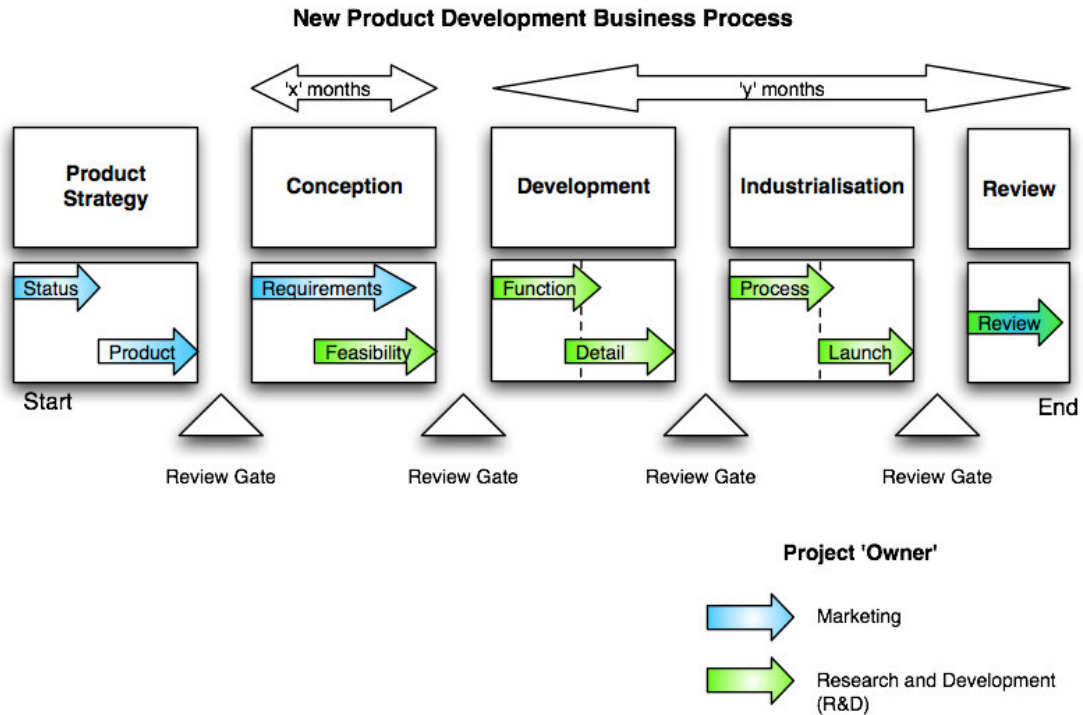


Figure 9: High-level view of the company NPD process model. Source: The Vaillant Group.

#### 5.4.1 Comparison to Generic NPD Process Models

The company NPD process model closely adheres to the so-called generic NPD process models encountered in the literature. This may be seen in a comparison of the activities and stages in the company model with the generic product development process model by Ulrich and Eppinger (2003) and the stage-gate model by Cooper in Kahn (2005), as summarised in Table 11. A more detailed breakdown of each process is presented in Appendix G. In general form, the company NPD process model is better matched by Cooper's stage-gate model, since it incorporates a post-product launch review stage. This stage occurs during the commercialisation of the product and results in the termination of the NPD project. During the review, issues such as the performance of the product and NPD project are evaluated, probably by the use of metrics like costs, timing and so on (Cooper, 1990).

An important similarity to both the models is the presence of a review after each stage of the process. In the Ulrich and Eppinger (p.23, 2003) model, there is a review after each stage from the end of the concept development phase, to the end of the testing



and refinement phase. There is also a project ‘mission approval’ session between the planning and concept development stages. For the Cooper stage-gate process model, there is a review between each stage, acting as a ‘quality control checkpoint’. At each review gate, a cross-functional ‘gatekeeper’ team will review the progress made in the preceding stage. Cooper (1990) described this as involving an assessment of the stage deliverables and a business-centric evaluation of the quality of the project. If the project is economically viable, it may continue, otherwise it may be revised, put on hold or even terminated. Should the project be approved, a plan is devised for the following stage and appropriate resources are made available.

	<b>Stage Title Ulrich and Eppinger (2003) Model</b>	<b>Corresponding Stage Title in Kahn (2005)</b>	<b>Corresponding Stage Title in Company NPD process; Vaillant (2005)</b>
1	‘Planning’	‘Scoping’	‘Product Strategy’
2	‘Concept development’	‘Build the Business case’	‘Conception’
3	‘System-level design’	‘Development’	‘Development (Function)’
4	‘Detail design’		‘Development (Detail)’
5	‘Testing and refinement’	‘Testing and validation’ and ‘Launch’ (some overlap)	‘Industrialisation – Process’
6	‘Production Ramp-up’	‘Launch’	‘Industrialisation – Launch’
7		‘Post launch review’	‘Review’

Table 11: A high-level comparison of the company process model with two generic process models. Stages are arranged in chronological order with number 1 the earliest and number 7 the latest.

It would seem unlikely that the stage-gate product development process used by any two manufacturing companies will be identical, a point supported by the work of Phillips et al. (1999). In a study comparing the stage-gate product development processes of six manufacturing companies, Phillips et al. (1999) found variation in the detail of each process. They concluded that all of the processes followed the basic doctrine of the stage-gate approach to product development devised by Cooper, as presented in Cooper (1994) and Kahn (2005). However, it may be said that the NPD process of the company under scrutiny here is an exemplar of both the Cooper stage-

gate model and the Ulrich and Eppinger's generic product development process model. This has an important impact on the degree to which of the findings of this investigation can be generalised.

## 5.5 An Empirical Exploration of Knowledge Sharing Barriers

### 5.5.1 Method of Investigation

Four main sources of evidence were used in the investigation of knowledge sharing barriers. These were the NPD business process survey carried out by the sponsor company at each of the three main manufacturing sites, an interview with the NPD business process architect, the NPD process knowledge audit, and the investigation of knowledge sharing practices in the R&D organisation. A description of the data collection and data analysis methods for each data source may be found in section 4.5.2. The findings of the investigation follow in section 5.5.2.

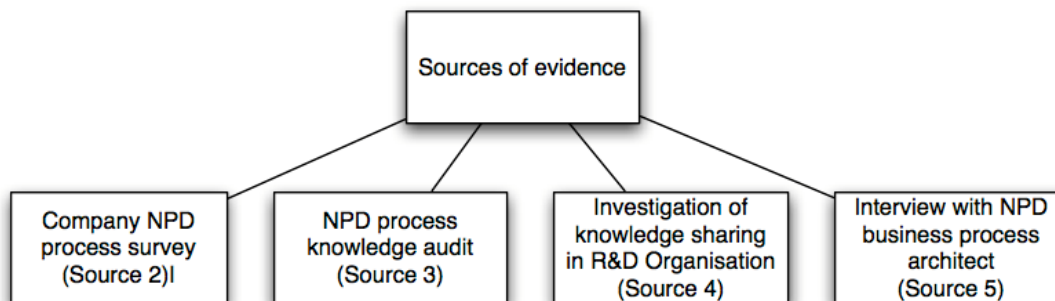


Figure 10: Sources of evidence used in investigation of knowledge sharing barriers  
Source numbers correspond to those shown in Figure 8.

### 5.5.2 Key Findings of the Investigation

Three key knowledge sharing barriers that emerged from the investigation will be focused on in this study, although it should be noted that other knowledge sharing barriers were found. The three barriers were:

- Barrier A: Lack of an explicit definition of information about knowledge used in the NPD process
- Barrier B: Lack of support for a multilingual NPD environment
- Barrier C: Lack of a means to disseminate information about NPD process knowledge among geographically dispersed project team members

A discussion of these barriers follows in section 5.5.3, along with supporting quotations where permission was obtained from the sponsor company to use them. Otherwise, notes taken by the author and extracts from the knowledge audit report are used. Further exemplar quotations for each barrier are included in Table 12. As Patton (1990, p.347) noted, ideally, quotations should be the ‘raw data’ from an interview.

<b>Barrier</b>	<b>Supporting Exemplar Quotations</b>
A. Lack of information about knowledge used in the NPD process	<p>(i) “The biggest bit of knowledge that we need is, it sounds stupid, but a knowledge of what knowledge there already is. Because nine times out of ten, when we start something, you get halfway through it thinking you’re starting from scratch, and then you find out that somebody’s already done it somewhere else six months ago. ... But again it’s just knowing what’s available. And that’s the biggest thing that I’ve come up with. ” (Source: NPD Project Leader, UK)</p> <p>(ii) “The knowledge we have problems finding? It’s the same as I said at the start. It’s trying to find out what’s available. Once you’ve found out what’s available, you can generally find it. But it’s finding out that there is something there to find. It might sound silly, but...” (Source: NPD Project Leader, UK)</p> <p>(iii) In response to the question: ‘what kinds of knowledge do you and your project team have problems finding?’</p> <p>“To find the relevant person, to be sure that they have right knowledge for your project, your question, so this is also a big problem here.” (Source: Manager, Controls Expertise, Germany)</p>

	<p>(iv) ‘It was proposed that a definition of “who knows what” is needed, so that experts with the required knowledge may be identified quickly. Furthermore it was suggested that information, such as that contained in e-mails should be better organised so that it is easier to find. Finally the interviewee posited that it might be possible to model the [NPD business process] in a way that better illustrated the knowledge links between processes.’ (Source: Extract from knowledge audit report on interview with ‘Risk analysis concept’ sub-process owner)</p> <p>(v) In response to the question ‘what frustrates you and your team about searching for knowledge?’ an interviewee highlighted the problems of the informal, implicit nature of the understanding of project knowledge in the company:</p> <p>“In general I think each site... has made decisions in the past. And each company or brand has its own history. And it’s very difficult to understand the history and get the information out of this history, because at the end you have to stay several years in a company and have to feel the spirit of the company or the brand. And it’s different and it’s okay. But this is the point. For example, some informal things that are clear for everybody in Germany and clear for everybody in France, but the link is difficult.” (Source: Programme Manager, Hydraulics and Accessories, Germany)</p>
<p>B. Lack of support for a multilingual environment</p>	<p>(i) In response to the question, ‘how important is sharing this knowledge among the sites? Would you describe it as mandatory?’</p> <p>“I think knowledge sharing across the group is a brilliant idea because there is so much out there, but your biggest problem is going to be language. Language was the biggest problem we had with the [NPD business process] in the first place. It was all set up; it was all done in German. And the reason it didn’t get adopted properly in the UK and implemented and driven through the business is because bits were translated into Pidgin English, it just didn’t make sense and was too</p>

difficult to work your way through” (Source: NPD Project Leader, UK)

(ii) In response to the question, ‘what kind of knowledge do you and your project team have problems finding?’

“The new format for specifications is dual language. It’s written in German and English. It’s written paragraph-by-paragraph in two languages. But the problem we have... it’s easier, the Germans will write that and they’ll write it in German and English, but when it comes to us, we’ll ignore the German part and just write the English part because we don’t have the language skills to do it. We can’t translate back. That’s something that is a problem.” (Source: NPD Project Leader, UK)

(iii) Speaking in reference to an Excel spreadsheet that stores all information pertaining to the design of the electronics module of the boiler, an interviewee commented:

“At the moment it’s still in German, but for the new platform we have a different file which is already translated, so that it’s to use in [France] as well, so they have some problems, not speaking German.” (Source: Project Leader, Electronics Development, Germany)

(iv) In response to the question, ‘is there any functionality you feel could improve the process of searching for knowledge on the Intranet?’

“One common Intranet for all the brands, English language, because sometimes we are searching also for very easy information about functionalities of applications which are only sold by [company brand in France], [company brand in UK] and something else. Okay and it’s very difficult to go then on a [company brand in France] Intranet page and to search inside this page.” (Source: Project Manager, Controls Expertise, Germany)

(v) ‘The interviewee also commented that while competitor benchmarking works well, the reports from the team performing this work are always in the German language, which limits the sharing of any knowledge they contain.’ (Source: Extract from knowledge audit report)

	<p>(vi) “We have a common Intranet, but okay, sometimes you find the information is French and so it’s not always translated... There is also another point, which is at the end difficult. If a project team is mostly for example located in Germany, then it’s clear that the language is German. To transfer everything in English... then it’s difficult to get all the things together and find it out. The question is what is the right balance?” (Source: Programme Manager, Hydraulics and Accessories, Germany)</p>
<p>C. Lack of a means to disseminate information about knowledge</p>	<ul style="list-style-type: none"> <li>• Key theme: Importance of sharing knowledge used in NPD projects among different sites</li> </ul> <p>(i) “Yes, it's very, very important to share this knowledge. More and more we are developing some components for all the sites and we need to profit from the experience of each site. In fact my colleagues on the other sites and I, we are on the same team and centre of competence and I'm working at the centre of competence, so it's very, very important for us to share all our knowledge, yes it's clear.” (Source: Thermal Module Expert, France)</p> <p>It was found in the knowledge audit and knowledge sharing investigation that there was no information system that formally defines information about knowledge used and generated in the NPD business process. A number of quotations showed the need for avoid the ‘localisation’ of this information and a lack of awareness about knowledge at other sites.</p> <ul style="list-style-type: none"> <li>• Key theme: Importance of an awareness of knowledge available at each site</li> </ul> <p>(ii) “The interviewee commented that [the company] brands have the same competitors in all markets, so the knowledge about them is reusable across the brands.” (Source: Extract from knowledge audit report, House of Quality sub-processes)</p> <ul style="list-style-type: none"> <li>• Key theme: Lack of awareness of knowledge across the company</li> </ul> <p>(iii) “What we also have is an informal network. This is the Hydraulics</p>

	<p>function. There we had each four weeks a meeting together for two days and discussing topics and there at the end there is an informal network and you could ask for informations there, or if you have a problem you could ask [France], [UK] and so on to give you some informations... There is a tradition. We have a brand [at a site in a different country] and there it is very difficult for me to ask get several people to give me information and so on.” (Source: Programme Manager, Hydraulics and Accessories, Germany)</p> <p>(iv) In response to the question ‘Do you and your project team search for knowledge locally (at your site), or is the search extended to the whole Group’s knowledge, or even outside of the Vaillant Group?’:</p> <p>“Depends on the projects. In [the site in France], seventy-five percent [of the knowledge], in accordance with my estimation, is in [the site in France].” (Source: Boiler Project Manager, France)</p> <ul style="list-style-type: none"> <li>• Key theme: Consequences of a lack of awareness of knowledge</li> </ul> <p>(v) “We are often buying a competitor’s boiler two to three times, rather than just once because different brand units [in different countries] do not share their knowledge.” (Source: Extract from knowledge audit report, House of Quality sub-processes)</p> <p>(vi) A project leader in the UK made the following comment about not knowing about a large materials testing laboratory on the German site, “Again nobody knew it was there, the big materials testing laboratory...” (Source: NPD Project Leader, UK).</p> <p>This meant the UK site was deprived of important test data, meaning that they risked repeating tests that had already been conducted.</p>
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Table 12: Knowledge sharing barriers and supporting quotations.

### 5.5.3 Key Knowledge Sharing Barriers: Discussion

Knowledge sharing barrier A was the lack of an explicit definition of information about knowledge in the new product development process. This information includes the tasks for which a given knowledge item is an input or output, the location of the knowledge, and the experts with knowledge relevant to the task.

In response to question ‘what kind of knowledge do you and you project team have problems finding’, an interviewee opined that it was difficult to find “knowledge about what knowledge is available”. More specific examples of this knowledge about knowledge were found. In a response by the boiler project manager to the question ‘is there any knowledge you consider missing’, it was suggested that information should be provided that links stages in the NPD business process to knowledge items. Similarly, the Risk Analysis Concept sub-process owner, interviewed in the knowledge audit investigation, highlighted the “links between [knowledge] inputs/outputs in the [NPD business process]” as missing knowledge.

As already alluded to, another example of knowledge about knowledge is information about knowledge residing in human repositories. In answer to a question about what knowledge was required but unavailable, the expert for the Risk Analysis Concept sub process in the knowledge audit ventured that a definition of “who knows what” was required. Turning once again to the knowledge sharing investigation, a key knowledge searching problem was “finding the relevant person with the right knowledge” for a particular task in the NPD process. In the absence of information about knowledge residing in people from say, previous projects, the Risk Analysis Concept process owner interview in knowledge audit) complained that they were left to ponder: “Is a knowledge source the ‘right’ expert?”

A further complaint by respondents to the NPD business process review survey (data source 2) was the surfeit of available information in certain areas and the dearth of information in others. For example, a product maintenance expert complained, “there does [sic] appear [to be] too many documents, again not user friendly and too detailed for use in Product Maintenance projects”. At the same time, another respondent bemoaned a ‘chronic lack of historic information, reference information, design detail, quality records generally’. This indicates that some form of knowledge prioritisation



may be necessary and so information about knowledge should indicate the priority of the knowledge in the context of specific project.

The lack of explicitly defined information about knowledge seemed to accentuate the time spent searching for information or knowledge pertinent to a given activity. One participant in the knowledge audit explained that establishing “who knows what” is facilitated by making telephone calls through a network of contacts until the appropriate person is found. Clearly, in a geographically dispersed product development environment, this process will be all the more arduous if the knowledge requestor is not working at the same site as the knowledge supplier. The knowledge audit protocol featured a question about whether the respondent felt that they spent a significant amount of time searching for knowledge (see ‘Background’ section of protocol in Appendix B). Four of the interviewees provided an estimate of this time. It ranged from a few hours a week for the ‘Target costing and cost tracking’ sub-process owner, through to ten percent of the working time for ‘Risk analysis concept’ and ‘Phase in / Phase out’ sub-process experts, and up to a week in certain project phases for the owner of the ‘Project status review’ sub-process.

Although these estimates are from a small sample size, they reflect figures given in more statistically robust studies found in the literature. A survey by Jacobson and Prusak (2006) of two hundred workers in four organisations, one of which was the drug manufacturer Novartis, found that knowledge workers spent about ten percent of their time searching for relevant knowledge. Court (1997) cited research suggesting that an engineering designer uses up to thirty percent of their time finding and availing themselves of engineering design information. Rodgers and Clarkson (1998a) suggested that engineers spent up to forty percent of their time seeking out appropriate knowledge. In a subsequent study, Court (1998), again citing work by other researchers, puts the proportion of working time spent by engineers searching for, and dealing with the latest information at up to seventy percent.

Court (1997) asserted that the large amount of time spent searching for knowledge has led to a lack of ‘information awareness’ among engineering designers, causing them to rely on personal knowledge, rather than exploiting sources further afield. The potentially expensive consequences of this awareness deficit were

highlighted by a comment from the House of Quality sub-process owner, in the context of a discussion about the analysis of competitor products. The owner remarked, “We are often buying a competitor’s boiler two to three times, rather than just once because different brand units do not share their knowledge.” More often than not, this is because one brand unit does not realise that another has already analysed a competitor’s appliance.

By extension, the same argument can be made for the other roles involved in product development. Donnellan and Fitzgerald (2004) stressed the importance of understanding the knowledge required at each stage of the NPD process: ‘in today’s competitive and turbulent environment, companies need to have a sophisticated understanding of the types of knowledge critical to the [sic] each phase of the NPD process’.

Knowledge sharing barrier B highlights the knowledge sharing challenges presented by a multilingual environment. Respondents to the NPD process review survey (data source 2) conducted at the case study company complained that NPD process documentation in languages other than their own, served to inhibit their understanding of it. NPD practitioners at one site complained that the NPD business process documentation was “not in the local language” and was therefore unusable. In reply to the assertion that the French and English translations of this documentation were “incomprehensible”, another practitioner remarked that they “fully agree, needs sorting to ensure that all have the same understanding”. Another remarked that it was “poorly translated” and that it “leaves doubt as to understanding”. A further revelatory comment was offered by the new product develop business process architect (data source 5), in an answer to a question about what he thought the information flow bottlenecks in the NPD process were (see interview protocol in Appendix F). He opined that, “in some cases, language is also the reason of [sic] misunderstandings and redundant work”. This illustrates the significance of language differences as a knowledge sharing barrier among NPD project team members. Any effort to address knowledge sharing barrier A should also incorporate support for a multilingual environment.

In the knowledge management literature, Disterer (2001), Riege (2005) and Ardichivili (2006) drew attention to the role of language differences as an obstacle to knowledge sharing in organisations (see section 2.4.1). This challenge has also been identified in research carried out in the NPD domain by Holland et al. (2000), and in the requirements engineering domain by Effendi et al. (2002) and Kerr et al. (2004). The knowledge sharing barrier caused by language differences prevents NPD project team members from achieving what Kleinsmann and Valkenburg (2005) referred to as a shared viewpoint. There is a lack of a mechanism to make information about knowledge accessible to process users within a multilingual environment.

Lastly, knowledge sharing barrier C concerned the lack of a mechanism to disseminate information about NPD process knowledge. The author observed that information about knowledge was not made available users via the NPD business process flow maps. Indeed, the representation of information required for, and generated by, tasks on the Intranet-based implementation of the process used by all employees was limited to providing links to a narrow range of documents, e.g. templates and spreadsheets. A recommendation from the knowledge audit (data source 3), approved by the company on presentation to senior managers was that NPD knowledge should be ‘pushed’ to process users. Since one kind of knowledge is ‘information about knowledge’ (see section 5.6.3.2), it follows that it should also be disseminated in this fashion.

The quotations provided in Table 12 indicate a desire by NPD practitioners in the company to share knowledge among the product development sites, but also a lack of awareness of the knowledge available at these sites, and with it a reluctance to search for this knowledge. Furthermore they suggest that this lack of awareness may have potentially damaging consequences, causing duplication of effort and unnecessary expense. Therefore it is argued that a mechanism is required that makes information about knowledge available to all sites with product development activities.

In this way, the level of knowledge awareness among NPD team members could be increased. As a result, the risk of duplicating work in different locations, such as the purchasing of the same model of competitive boiler by multiple brand units, could be reduced.

Dissemination means the distribution and sharing of knowledge in organisation via formal or informal means, after the definition by Akgün et al. (2006). Examples of formal communication media mentioned by Akgün et al. (2006) are memos, reports and face-to-face meetings. Informal means might take the form of coffee breaks, informal meetings and so on. In the environment under consideration in this study, team members may perform different functional roles and be based in various locations around the world. McDonough et al. (2001) proposed that NPD project management difficulties are made worse as the physical distance between project team members increases. It would appear that informal means of dissemination are less suitable in this case, since geographical dispersion of project team members makes face-to-face meetings more difficult to achieve. Therefore a formal means of dissemination is indicated. Song et al. (2007) asserted that information technology (IT) can be employed as a facilitator of knowledge dissemination in product development projects. A mechanism is required that can disseminate this kind of information about knowledge.

Collectively, the three knowledge sharing barriers prevent global NPD project teams from achieving a shared or common understanding of the knowledge used and generated in the formal product development process. This in turn has a detrimental effect on NPD performance. For this reason, the barriers need to be reduced.

#### **5.5.3.1 Limitations**

Restricting the scope of the investigation to a single company means that it suffered from all of the shortcomings of a single case study approach, as explored in chapter four (section 4.7). Nonetheless, conducting the research in the environment of the sponsor company allowed access to a rich and varied body of evidence. The author was involved in the data collection for the knowledge audit and knowledge sharing investigation, and devised the knowledge sharing investigation protocol. It should be cautioned though that none of the three interview-based sources of evidence was originally designed specifically to identify knowledge sharing barriers. That is, only some of the questions posed elicited answers that were relevant to this study.

Despite these limitations, it was found that the three key knowledge sharing barriers identified, or the consequences of these barriers, are referred to in the knowledge management and product development literature. For this reason it can be

argued that these barriers are likely to be present in other product development companies engaging in global product development-type activities.

#### **5.5.4 Summary of Findings**

An exploratory investigation was carried out at large, multinational heating systems manufacturer. The company develops two types of new product: new product platforms and variations on existing products. Product innovation is strongly driven by external factors, which include environmental legislation in local markets, local market tastes and installation requirements. A formal, cross-functional stage-gate-type product development process is employed by the company for all new product projects. Comparison of this process with generic NPD process models in the literature has revealed that it matches them very closely, in both form (the key phases) and in the detail of the description of the activities that take place. In chapter one, it was noted that literature-based research is available which claims a large proportion of manufacturing companies have adopted a cross-functional stage-gate model.

Another important observation is that product development activities and product development teams possess many of the characteristics of global product development proposed in the literature, including geographically dispersed product teams, cultural diversity and the use of engineering resources in different regions. These observations suggest that the company is a useful exemplar for the examination of knowledge sharing problems in the NPD process of firms experiencing the challenges of moving towards a global product development model. The findings may be generalised to companies with similar product development practices and environments.

Through examination of four data sources, three main knowledge sharing barriers were identified:

- Knowledge sharing barrier A was the lack of an explicit definition of information about knowledge in the new product development process;
  - Knowledge sharing barrier B was the lack of a mechanism to make information about knowledge accessible to process users within a multilingual environment;
- and

- Knowledge sharing barrier C concerned the lack of a mechanism to disseminate information about NPD process knowledge.

In concert, these barriers serve to inhibit the achievement of a shared understanding of NPD knowledge in a multinational, multilingual product development environment. They will serve as the focus for the research in the remainder of this investigation.

## **5.6 Identification and Classification of NPD Knowledge**

### **5.6.1 Background**

This section is divided into two parts. The first part details the investigations used as sources of evidence for identifying the knowledge used in the NPD process of the sponsoring company. In the second part, the process and methods employed to classify this knowledge are described and the resulting taxonomy of NPD knowledge is presented. Recognising that the properties of this knowledge were likely to be of interest in later parts of this investigation, the findings regarding the media, sources, and storage of this knowledge are also described.

It should be reiterated that the term knowledge refers to a ‘fluid mix of framed experience, values, contextual information, and expert insight’ and is manifested in documents, processes and the minds of individuals, as defined by Davenport and Prusak (1998). This definition was discussed in the literature review; see section 2.1.2.

### **5.6.2 Identification of NPD Knowledge**

In section 2.2.2 of the literature review, it was stated that Eppler et al. (1999) posited three types of knowledge associated with a knowledge-intensive process such as new product development. These types are knowledge about the process, knowledge generated in the course of executing the process, and knowledge derived from the process. Instances of these knowledge types are given in Table 13.

Eppler et al. (1999) proposed that knowledge about the process is typically found in business process documentation such as flow maps. Knowledge generated during the process and knowledge derived from the process resides in documents and in the minds of individuals involved in carrying the process out.

Process Knowledge Type	Exemplars
Knowledge about the process	Quality manuals, process design handbooks, charts, and the experience of process owners and users
Knowledge within the process	Tests, written analyses and meeting minutes
Knowledge derived from the process	Lessons learned (e.g. mistakes made, drivers and barriers to success) and insights from the process

Table 13: Three types of process knowledge and exemplars (adapted from Eppler et al. (1999)).

Taking this into consideration, three sources of evidence were exploited to identify the knowledge used in the new product development process, as described in section 4.5.2.2. The first source was a knowledge audit focusing on the NPD business process at the sponsor company, the second was the company business process documentation, and the third source was a knowledge sharing investigation, also conducted under the auspices of the sponsor company.

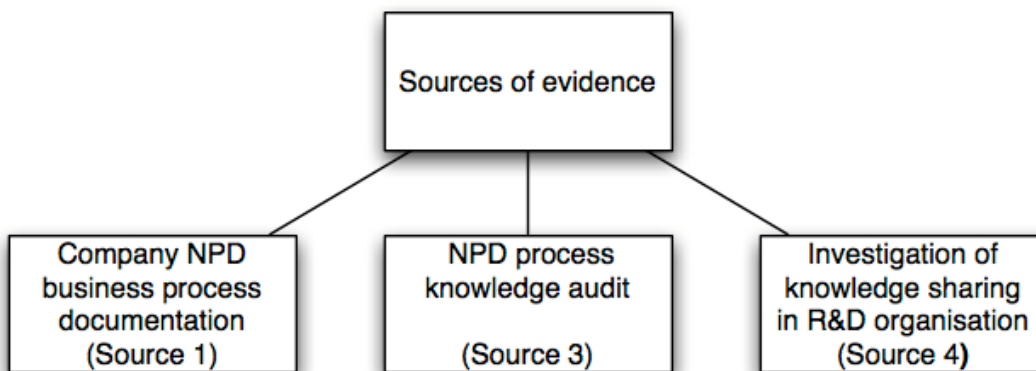


Figure 11: Sources of evidence used to identify knowledge used in the NPD process. Source numbers correspond to those shown in Figure 8.

### **5.6.2.1 Knowledge Audit (Source 3 in Figure 8)**

As part of a wider knowledge management initiative undertaken by the sponsoring company, an audit of the knowledge used in the NPD business process was executed. The purpose of the original investigation was to provide an approximate view of the extent and state of knowledge in the new product development business process of the sponsoring company.

Debenham and Clark (1994) stated that the aim of a knowledge audit is ‘to give a deliberately approximate view of the extent of specified sections of knowledge in an organisation’. They also stated that three of its objectives are:

- ‘to give a high-level view of ‘the extent, nature and structure of the knowledge’ in a specified part of the organisation;
- ‘to identify the relevant knowledge repositories within the organisation’; and
- ‘to provide a statement of the qualitative characteristics of the chunks of knowledge within a particular knowledge repository’.

Further, they ventured that the output of a knowledge audit is the knowledge audit report. The knowledge audit report documents the main findings of the audit and provides a high-level description of the knowledge in a limited part of an organisation. It also describes the knowledge ‘chunks’, hereafter known as knowledge items, within this area.

Since the object of this investigation was to identify the knowledge items used in the new product development process, it is argued that the execution of knowledge audit was an apposite approach to meeting this objective. Additionally, reference to the literature reveals that the knowledge audit has been used in a number of previous studies to better understand the knowledge used in companies. For example, Liebowitz et al. (2000) conducted a knowledge audit to identify knowledge assets in an organisation, using a health care organisation as a case study. Schwikkard and du Toit (2004) presented the findings of a knowledge audit to ascertain the knowledge requirements of a large service-based company. Burnett et al. (2004) outlined the process, methods and results of a knowledge audit in the tax department of a multinational oil exploration and production firm. From these examples, it may be seen that the knowledge audit is



regarded in the literature as sufficiently rigorous to be used as a research technique. The data collection methods employed in each of these studies may be found in Table 14.

<b>Reference</b>	<b>Focus of Knowledge Audit</b>	<b>Data Collection Method(s) Employed</b>
Liebowitz et al. (2000)	Determination of what knowledge is required, available, missing, applied and contained	Questionnaires and follow-up interviews
Schwikkard and du Toit (2004)	Determination of the knowledge requirements of an organisation	Interviews and workshops
Burnett et al. (2004)	Determination of where knowledge exists, knowledge types and transfer methods, how knowledge is applied. Development of best practice benchmarks and a knowledge management strategy	Semi-structured interviews

Table 14: Data collection methods employed in previous knowledge audit studies.

The work of Liebowitz et al. (2000) was considered to be of particular relevance to this investigation for two reasons. Firstly, it concerned the identification of knowledge assets or knowledge items, and secondly the knowledge audit methodology described included a questionnaire for eliciting the required evidence from individuals in the company of concern.

An adapted version of this methodology was used in the knowledge audit conducted at the case study company. In order to meet the requirements of the scenario to be studied, three changes were made:

- 1) Semi-structured interviews were used rather than the questionnaire-based survey approach taken by Liebowitz et al. (2000). It was considered that given the complexity of the subject matter, semi-structured interviews would make it possible to provide further explanation of the questions to the interviewee, should it be required. A more detailed explanation of the reasoning behind this decision is given in section 4.5.3 of the research methodology. The questionnaire was retained in the form of an interview protocol as a guide for the interviewer.

- 2) Some questions were removed from the questionnaire provided by Liebowitz et al. (2000). This was done because these questions fell outside of the scope of the investigation required by the company, and also to reduce the time required to conduct each interview.
- 3) The formulation of some of the questions was changed. This was done either to simplify the language so that they could be more easily understood by interviewees who were not native speakers of English, or so that the questions more specifically addressed the issue under study.

All changes to the questionnaire are documented in Appendix H. It should be noted that the scope of this investigation is narrower still, since it was confined to identifying the knowledge used by and generated in the NPD process and did not consider issues such as what would help individuals to use knowledge more effectively. Evidence used in the identification of knowledge used and generated in the NPD process came from the answers to the questions listed in Table 15.

<b>Questionnaire Section in Liebowitz et al. (2000)</b>	<b>Question</b>
2	Please describe any methods you use to codify (store) knowledge (databases, rule books, who knows what maps, repository of customer problems etc.)
2	What mechanisms exist to transfer knowledge from experts to non-experts? (NB These might include training, informal discussion and so on)?
2	Do you require knowledge from external sources in order to complete the process successfully?
2	To whom or what do you transfer knowledge generated by the process (e.g. pass on to? (Make a map of Topics, People, Documents, Ideas and Links for process)
2	What areas does the knowledge you need to complete this process come from? (E.g. machine capability-material suitability)
2	From which sources do you obtain this knowledge?
2	Which departments/people/sites contact you for information?
2	List reports you make available for groups outside your unit. (Recipient, format, frequency)
2	Who are the experts in Vaillant Group for this/this type of knowledge?
4	How do you use training to enhance knowledge and skills?

Table 15: Questions from the knowledge audit source that yielded answers pertinent to the identification of knowledge in the NPD process.

The data collection methods used in the knowledge audit study are documented in detail in section 4.5.2.1 of the research methodology. Briefly summarised, the

knowledge audit concentrated on the knowledge used in, and generated by eight sub-processes in the NPD process. Collectively, the selected sub-processes represented every phase in this process. An interview was conducted with the owner for each sub-process using questions from the amended knowledge audit questionnaire, as reproduced in Appendix B. Notably, the sub-process owner had been nominated by the company as the individual with the greatest level of relevant expertise. Responses from the interviewees were recorded on interview protocols and it was these that served as the focus of analysis. A separate interview protocol was used for each sub-process.

Analysis of the interview protocols consisted of four steps. Firstly, the responses to the questions shown in Table 15 were extracted. Next, a mind map was created onto which the responses were mapped. Initially, the data was sorted according to the interview question with which it was associated. Once this exercise was complete, data on the mind maps was compiled into a single map for further examination, as described in section 5.6.3. The mind map, featuring all of the knowledge items arranged by knowledge class (see section 5.6.3) may be found in Appendix I. Over ninety individual knowledge items were identified.

#### **5.6.2.2 NPD Business Process Documentation (Source 1 in Figure 8)**

Unlike the knowledge audit (source 3) and knowledge sharing investigation (source 4), the NPD business process documentation was employed as a supporting source of evidence. Some data flows are indicated on the business process flow maps in this documentation, and the digital version of the process described many of the documents and spreadsheet tools that are inputs and outputs to process tasks. Generally, this source was used to substantiate claims made by the interviewees in the investigations that provided the evidence for sources 3 and 4.

#### **5.6.2.3 Knowledge Sharing Investigation (Source 4 in Figure 8)**

This third source of evidence was an investigation of knowledge sharing issues carried out under the auspices of the case study company.

The main aims of this study were: (1) to identify the information and knowledge shared among members of the Research and Development (R&D) organisation and the challenges these members encountered finding and accessing this knowledge, and (2) to

recommend improvements to current knowledge sharing practices to improve the capitalisation of knowledge within the company. Of these, it is the findings related to the first aim that are of interest here.

Like the knowledge audit, the knowledge sharing investigation identified knowledge used and generated in new product development. However it differed from the knowledge audit in three important ways. The first difference is the scope of the investigation. Rather than examining the sub-processes representing different phases of the NPD business process, the knowledge used in the new product development project as a whole was considered. The second difference is that the sources of data were a mixture of NPD project leaders, managers and senior engineers. The third difference was the investigation explicitly sought to discover information about the properties of the knowledge used in the NPD process. These properties included the format of the knowledge and the repository in which it is stored.

The project leaders at the company come from different parts of the organisation. They possess a good general awareness of all the knowledge used in the NPD process, since they are responsible for decisions taken in the project at each stage gate review, from early in the conception phase until the sign-off to production. They remain involved in the project until its termination at the end of the project review stage (see section 5.4). All of the project leaders interviewed had experience of working on NPD projects in marketing or engineering roles. The certification manager possessed special knowledge of legislation and standards in the product markets. The senior engineers provided an insight into the technical knowledge required for developing a product.

Only a cursory account of the data collection methods will be provided here. Once again, a more detailed description is available in section 4.5.2.2. Elicitation of information about knowledge and information sharing was achieved by conducting semi-constructed interviews with personnel from the R&D functions of the organisation. The interviewees were also asked to provide screenshots of the folder structures used to store data in recent NPD projects. The purpose of this was to provide an understanding of the way that practitioners prefer to classify information used in an NPD project.

Selection of personnel for the interviews was based on four criteria. The first criterion was that collectively, the interviewees must represent all of the competencies that play a major role in the R&D function. These competencies were Hydraulics, Electronics and Control, Thermodynamics, and Certification. The second criterion was that the interviewees must include the key roles involved in product development: Project Managers, Project Leaders, and Engineers. The third criterion was that collectively, the interviewees must represent each of the sites where product development activities take place, i.e. Germany, France, and the UK. The final criterion was that all of the candidates must be willing and available to be interviewed. Table 6 in chapter four lists the interviewees and their location.

An interview protocol served as the data collection tool and a separate interview protocol was used for each interview session. Interview questions were devised by the author and those relevant to the identification of knowledge addressed the following issues: the types and format of knowledge used in the NPD process, the storage of this knowledge, and the process of searching for knowledge. The specific questions of interest are listed in Table 16.

<b>Interview Protocol Question No.</b>	<b>Question</b>
2	What kind of information/knowledge do you and your project team need in the course of a project?
3	What is the format of this knowledge?
4(a)	Where do you and members of your project team look for knowledge?
4(b)	Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group's knowledge, or even outside of the Vaillant Group?
6	What (kind of) knowledge do you and your project team have problems finding?
8	In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?
10	Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?
12(a)	What kind of information or knowledge do you and your project team generate?
12(b)	Do you and your team currently collect and organise this information somewhere? If so, where?

Table 16: Questions from the knowledge sharing investigation source that yielded answers pertinent to the identification of knowledge in the NPD process.

In a similar fashion to the analysis of data collected for the knowledge audit, the responses recorded on the interview protocol were transferred, albeit in an abbreviated form, to a series of mind maps. One map was created for each process. The contents of these mind maps were then collated onto a single map. The knowledge items are depicted in Appendix J. In this way, the data was made ready for classification, as described in section 5.6.3. Over fifty individual knowledge items were identified.

### **5.6.3 Classification of Knowledge**

This section describes the techniques used to classify the knowledge identified from the sources referred to in section 5.6.2. It concludes by proposing a classification of knowledge used and generated in the NPD process based on its content, also referred to here as its domain.

#### **5.6.3.1 Method Used to Classify Knowledge**

As already alluded to, the knowledge identified in section 5.6.2 acted as the principal source of evidence used to devise the knowledge classification.

In order to guide the classification process, two additional sources of information were referred to. These were: the project folder screenshots from the NPD project leaders, project managers and engineers which provided an insight into the way NPD practitioners organise their explicit knowledge, and the typology of NPD information proposed by Zahay et al. (2004), which provided a literature-based perspective. This latter investigation sought to answer the question ‘what information is relevant to developing new products for B2B firms?’

A convincing and robust typology of knowledge types must be able to accommodate all of the knowledge items identified in section 5.6.2 and would be expected to incorporate the knowledge types identified in previous research. Therefore, the typology provided by Zahay et al. (2004) was used as a starting point for the classification. The information types from this classification were placed on a mind map. Then, starting with the knowledge items identified from the knowledge audit, an attempt was made to place each item under its relevant category on the map. Those knowledge items that did not fit under the existing categories were set aside. Once the available knowledge items had been exhausted, proposals were made for new categories

to subsume the knowledge items that been set aside, or for changes to the boundaries of the existing categories. Using the modified classification as a starting point, the exercise was repeated for the knowledge items identified in the knowledge sharing investigation. This process is illustrated in Figure 12. When a typology had been reached that included the knowledge items identified from both sources, the process was terminated.

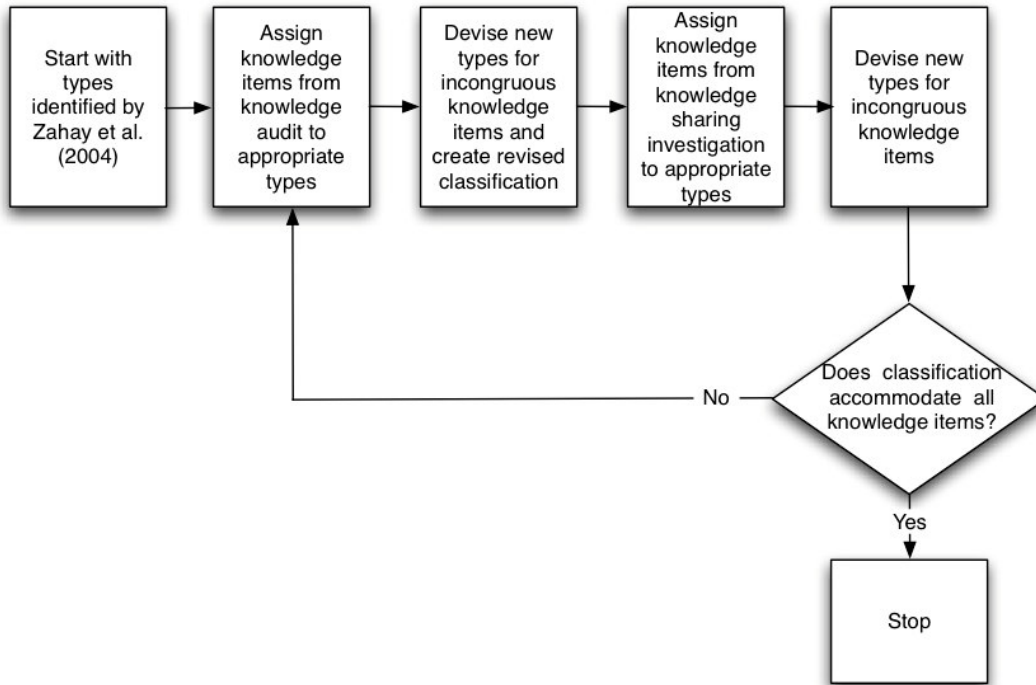


Figure 12: Steps for the development of the NPD knowledge classification.

### 5.6.3.2 Resulting Classification

Twelve classes of knowledge were identified. These were (1) project management and performance, (2) computer-based tools and applications, (3) strategic, (4) quality (product, process and suppliers), (5) NPD process, (6) NPD project experience, (7) regulatory, (8) technical design, (9) financial, (10) information about competitors (11) customer requirements knowledge, and (12) information about the knowledge itself.

The knowledge classes or categories and the knowledge items from the knowledge audit and knowledge sharing investigation that fit into these categories may be seen in

Appendix I and Appendix J respectively. An explanation of each of these knowledge categories follows.

**‘Project management and performance’** refers to information mostly used by the project leader to plan and track the progress of the project. Examples of this information drawn from the knowledge sharing investigation (source 4) include the overall ‘project plan’, the project ‘test plan’ which dictates what tests must be carried out for the product to be sold in its markets, and a project ‘milestone checklist’ (see Appendix J). Instances taken from the knowledge audit (source 3) are the ‘pre-launch report’, ‘balanced scorecard’ report and the ‘key performance indicators’ report for the project (see Appendix I). Most of the project management and performance knowledge then is mostly explicit in nature and is in the form of information or data. The project leaders interviewed in the knowledge sharing investigation stored such information on their network drive folders under titles including ‘project control’ and the ‘project cockpit’.

A plethora of information systems technology tools are needed in the course of an NPD project. **‘Computer-based tools and applications’** encompasses the knowledge required to use these tools. For instance, specialist knowledge is needed to use quality management systems and computer-aided design packages. Specific examples of these from the knowledge audit source include ‘APIS’ a database of ‘Failure Mode and Effect Analysis’ reports from the ‘Risk analysis concept’ sub-process interview, ProEngineer, a computer-aided design (CAD) package, and the ‘test database’ a system containing product test protocols and test data. The latter two were mentioned in the ‘Definition of system on component level’ interview.

This knowledge is experiential and more tacit in nature. It is gained from training and repeated and regular use of a software tool.

**‘Strategic’** knowledge covers knowledge such as ‘brand identity’, company ‘sales strategy’ and ‘market share’ data, all of which are examples taken from the knowledge audit. Other knowledge items from this source that fell into this category were definitions of ‘global strategy for the brand’, and manufacturing strategy knowledge like ‘availability of parts from the supplier’, and ‘flexibility and capability’ of the supplier’. One further type of strategic knowledge, ‘predictions about future



technologies’, was revealed in the knowledge sharing investigation. This concerns knowledge about existing and emerging technologies that could be applied in new products. An example is the application of wireless communications technology to boiler control systems, as discussed in the exemplar interview transcript in Appendix E.

As may be ascertained, strategic knowledge mostly originates from the senior management, marketing and sales functions, and may be either quantitative or qualitative in nature. Since even in its qualitative form it is communicated in documents, it may be argued that it is largely explicit. This is a broader category than its counterpart type in Zahay et al. (2004).

**‘Quality’** encompasses all knowledge required for, or generated by, quality initiatives in the course of NPD process. The category covers issues relating to the quality of the physical product itself, the quality of suppliers of components and parts (i.e. how capable are they are of supplying parts to the desired specification), and process quality (i.e. whether the business processes been executed according to specification). It is asserted that quality knowledge is an important category of knowledge for product development projects using a stage-gate process. Ulrich and Eppinger (2003) noted that a benefit of a well-defined product development process is to assure the quality of the final product. This is achieved in part through the use of judiciously specified quality stage-gate reviews. The knowledge required for, and generated in these reviews may be classified as knowledge related to quality.

Examples of quality knowledge related to the product are the ‘part line-reject and field-reject report’, failure ‘risk analysis report’, ‘test report’ and ‘Failure Mode and Effect Analysis (FMEA) report’, all extracted from the knowledge audit source. Test reports include product field trials, combustion testing, endurance tests, and function and wear tests. Supplier ranking by product quality, as exemplified by the ‘Top 80 Supplier list’ and ‘Quarterly supplier ranking’, and ‘qualification of supplier analysis report’ items from the knowledge audit, is a sub-category of quality knowledge related to suppliers of components. Quality process knowledge is manifested in highly qualitative forms such as the training received by a knowledge auditor, or the rationale behind a decision taken in a stage-gate review. This last sub-category encompasses the knowledge items ‘Quality management planning knowledge’, ‘Audit training’,

‘Rationale behind decisions taken at stage-gates’, and lastly ‘Project Quality Engineer-type background’. This latter item refers to the professional experience that an individual should possess in order to carry out the NPD project auditor role. Again, all of the aforementioned items come from the knowledge audit source.

‘**NPD process**’ knowledge refers to information about the NPD business process itself. This knowledge acts as a guide to project team members as to what tasks must be completed at different stages in an NPD project. It also indicated what the expected output from each of these tasks would be. This knowledge is mostly explicit and was found in the business process documentation (source 1 in Table 7), specifically in business process flow charts and training presentations included with the process on the compact disc. Although not necessarily attributable to organisations other than the case study company, it is worth noting that project team members are obliged to attend a training programme intended to acquaint them with the NPD business process. This highlights the perceived importance of NPD process knowledge at the firm. In a firm using a formal NPD process, an understanding of the business process provides project team members with important contextual information about the tasks they carry out.

‘**NPD project experience**’ addresses knowledge that an individual gains from the act of being involved in an NPD project. This knowledge could take a number of forms. It may be used in subsequent projects to assist in decision making, especially where expert judgement is required. This might occur during an NPD project audit in a stage-gate review, or at point in a process where no historical data or information is available to guide the individual or team taking the decision.

A specific instance is the knowledge gained by a cost analyst when they perform a cost analysis. The cost analysis is highly experiential and there is no explicitly documented way to carry out the action. This point is illustrated by the following extract from the ‘Target costing and cost tracking’ sub-process interview report in the knowledge audit source: ‘Analysis knowledge is about experience, rather than tangible, explicit knowledge. Cost controllers tend to exist “in their own world”. They have their own rules and their own language. These rules and language are very difficult to understand if one does not work within this “bubble”’.

Another instance of knowledge in this category is knowledge about which individuals in the company executed given roles in an NPD project, an issue raised by the Germany-based boiler project manager in the knowledge sharing investigation. Their answer to the question ‘What kind of information/knowledge do you and your project team need in the course of a project?’ included the statement, ‘Responsibilities in former projects; who was the project leader?’

A final example is the personal checklist devised by project team members to ensure that they have assembled all of the information required to complete a process. Consider this extract from the ‘Phase in / phase out realisation’ sub-process interview report in the knowledge audit: ‘Judgements were made by process users based on experience. Process users developed their own checks to ensure that the necessary knowledge has been gathered.’ The knowledge in the ‘NPD project experience’ category is mostly tacit or implicit in nature.

**‘Regulatory’** knowledge concerns information about regulations, laws and legislation in place in the product markets that constrain or otherwise influence the product design. ‘Patents’, ‘contracts’ with customers and suppliers, ‘technical standards’, product ‘distribution networks’, ‘European Commission directives pertaining to emissions and energy saving’, European ‘Quality marks’ and ‘local directives in country where boiler is to be sold’ are all examples of regulatory knowledge found in the knowledge sharing investigation. Generally, regulatory knowledge is mostly explicit and is captured in documents.

**‘Technical design’** knowledge is a broad category that covers all knowledge related to the design and manufacture of the product. Design knowledge might be product ‘design rules’ or testing expertise. Predominantly explicit design knowledge items are ‘materials data’, ‘bill of materials’, functional and performance ‘calculations’, conceptual drawings, and digital product models. All of these examples were taken from the knowledge audit and knowledge sharing investigation sources. An awareness of technology trends, mentioned in the knowledge sharing investigation, is also important for engineers, but here the emphasis is on the technology itself, rather than its strategic role in the product market. Manufacturing-related knowledge, also taken from the knowledge audit and knowledge sharing investigations, features ‘machining rates’,

‘machining routines’, and the tooling required to fabricate and assemble different parts of the product. Knowledge in the technical design category then, is mostly explicit. Many other examples of knowledge items placed in this category may be found in Appendix I and Appendix J.

The **‘Financial’** class includes various finance and cost information and data. ‘Price positioning’ of a product in the market, ‘machining costs’, ‘prices for standard components’ used in the product, the impact of project plan changes on profit and loss and cash flow, sales figures, and other cost calculations are all knowledge items that fall into this category. Project target cost tracking activities are presented in ‘cost analysis reports’ and an ‘Absolute Cost Control report’. Financial knowledge is also embedded to varying degrees of richness in a collection of templates and tools. Absolute Cost Control (ACC) activities are supported by the ACC tracking tool and a template was developed for creating project business plans. All of these knowledge items were identified in the knowledge audit. This knowledge is generally quantitative and manifested in an explicit form.

Knowledge in the **‘competitor knowledge’** category concerns the products and organisational traits of market competitors. Knowledge about competitor products is sourced from product brochures, data sheets, and actual appliances. This latter source provides knowledge about the product functions and about the impression of quality that it conveys. This knowledge is disseminated in the form of photographs, presentations and reports.

Examples of knowledge items pertinent to competitor products are ‘product function’, that is the functional capabilities of the product, ‘quality impression’ or the perceived quality of a product, and ‘competition context’, which concerns the markets that competitors are attempting to capture with their current product range. Assessment of the perceived quality of a product is largely based on visual cues and handling of an actual appliance, or examination of photographs, as mentioned above. Geographical location of manufacturing facilities and the level of supply chain integration are knowledge items about a competitor’s organisation. All of these knowledge items are taken from the ‘Analysis of competitor products’ and ‘Risk analysis concept’ sub-

processes in the knowledge audit. Knowledge in this category can be either mainly tacit or mainly explicit.

**‘Customer requirements’** knowledge is gathered by the marketing function. It may be in a qualitative form such as description of desired functionalities of a product, or in a quantitative form indicating the number of customers or markets desiring a particular product feature (see Appendix I and Appendix J). Customer requirements are explicitly defined as far as possible in a matrix containing the desired technical functionality and performance, appearance, and price and handling properties. This exercise is carried out by the Marketing function and the document is subsequently handed over to Research and Development (R&D) function, who use it to develop a product concept that is ideally both technically feasible and desirable to the customer, as part of the ‘House of Quality’ sub-processes. This evidence was sourced from the knowledge audit. At the product strategy phase, the knowledge gathered from markets is in a variety of formats, including sales data and product ‘impressions’. In the product conception and development phases though, this knowledge is usually found in documentation, and so it can be said to be mostly explicit.

Finally, **‘Information about knowledge’** concerns information that an individual or information system can provide about other knowledge items used in the execution of the NPD process. Some data inputs and outputs are defined in the process flow maps that make up the NPD business process documentation (source in Table 7). These inputs and outputs refer to specific documents or data that may be required for, or generated by, a process, as well as links to relevant document templates. Nonetheless, the evidence from the knowledge audit and knowledge sharing investigation showed that a far wider spectrum of knowledge is used than is described in the data flows. Indeed, knowledge is in many formats and may be distributed across organisational functions and geographical locations. A project manager in Germany interviewed in the knowledge sharing investigation remarked that “... information must be compiled from a wide range of sources and tools.” The UK project leader participating in the same investigation commented that “The biggest bit of knowledge that we would need is, a knowledge of, it sounds stupid, but a knowledge of what knowledge is there already.”

An important knowledge item in this category is information about human sources of knowledge. Discussing their understanding of the term knowledge, the thermal engineering expert in France noted: “For example, often a person who has lots of experience inside the company is able to have this synthesis of information. So for me for example, something quite important, a way to get a quickly an information is to know the good person.” Asked what knowledge they used in the course of an NPD project, a project manager in Germany stated that one kind of knowledge was information about “... responsibilities in former projects – who was the project leader? This is important in order to exchange experience.”

Information about knowledge is by definition explicit knowledge. However, it can refer to both explicit knowledge like reports, and implicit knowledge, such as knowledge residing in the mind of a person.

### **5.6.3.3 Comparison of proposed classification with literature and practitioner-based sources**

A comparison of the proposed classification with that provided by Zahay et al. (2004) may be found in Table 17. Examples of the project folders used by the eight project leaders and engineering experts at the company is also included to illustrate parallels between the classification and the categories used by practitioners to organise and find the explicit knowledge they use and generate in the NPD process.

As might be expected, there is a significant overlap with the work of Zahay et al. (2004). However, the proposed classification abandons one category and adds five new ones. The category present in the work of Zahay et al., but missing from the proposed classification is Information about the customer. This knowledge from this category is incorporated into the ‘strategic’ category in the new classification. The five new categories are ‘Quality’, ‘NPD project experience’, ‘Information about knowledge’, ‘Computer-based tools and applications’ and ‘NPD business process’.

The differences between the findings of the two studies are not entirely surprising. Although both studies considered the question of what knowledge is pertinent to NPD projects in business-to-business firms, there are some salient differences. The first is that Zahay et al. (2004) looked at companies from a range of

different industries, rather than performing an in-depth study on a single company and using multiple sources of evidence. A second difference is that this research investigation placed a greater emphasis on examining knowledge in the context of the actual NPD business process than Zahay et al. (2004). A third, but less obvious point of difference is the definition of information and knowledge used in the studies (see section 2.2.2).

Zahay et al. (2004)	Classification proposed by this Investigation	Project Folders (from screenshots of NPD practitioner drives)
Strategic	Strategic	
Financial	Financial data and information	Purchasing
Project management	Project management and performance	Project reporting cockpit Business plan Project milestones Project Control
Customer	Customer requirements knowledge	Marketing and Service
Needs	Technical product	Technical Drawings and Technical Specifications Spare Parts Hardware Documentation
Technical	Competitor	Competitor Products
Competitor	Regulations and Standards	Approvals and Certification Patents Quality
Regulatory	Quality	
	NPD Project Experience	
	Information about Knowledge / Metaknowledge*	
	Computer-based tools and applications	
	NPD Business process	Comment: The majority of project documentation arranged according to the sub-process that uses or requires it. Each sub-process is allocated a folder inside the project folder on the network drive.

Table 17: Comparison of the proposed classification with that of Zahay et al. (2004).

As an appendix to the classification of knowledge discussed above, the attention of this study will now be turned to the sources, media and repositories of this knowledge.

Knowledge required to execute tasks in the NPD process is taken from a broad range of internal sources (within the company) and external sources (outside the company). The main internal sources used by the R&D engineering specialists were reports, including product, part and material test reports. Other reports included quality reports (such as Failure Mode and Effect Analysis (FMEA) reports), summaries of environmental legislation, safety laws, and norms relevant to the design of a product. Company NPD business process documentation was also consulted to obtain information about the required outputs from process tasks. In instances where knowledge cannot be found in reports or documents, colleagues may be contacted to find a source of the required expert advice. Project leaders and managers exploited the same sources as the engineering specialists, with the addition of business reports from finance functions to understand product and project cost requirements. Reports, presentations and advice from the marketing functions were used to communicate and explain customer requirements.

External sources consisted of technology exhibitions, university research departments and newsletters from part suppliers. The newsletters are used to gain knowledge of new technologies, which may be incorporated into product design. Additionally, the Web sites of market competitors are examined to gain product information. Actual products are purchased from competitors for testing by research engineers and assessment by cost analysts. Examples of sources for knowledge concerning product certification in different markets included personal contacts on legislative committees (e.g. the European Commission), the relevant notified bodies, and certification organisations for each country. Occasionally, direct contact with competitors is established to discuss changes that affect the industry as whole. An example of such an issue might be a significant change in environmental legislation.

Media used to store and deliver knowledge in the new product development process consisted of paper-based or 'hard copy' documents, digital documents, digital data files generated by software tools and verbal discourse. Some examples of the knowledge items available in each medium are given in Table 18.



<b>Knowledge Medium</b>	<b>Example drawn from interviews</b>
Paper-based document	Brochures and data sheets Journals and periodicals
Digital document	Project documentation, business reports, test reports (Microsoft Office file formats, Portable Document Format (PDF)) E-mails exchanged among project team members Business process documentation
Digital data files generated by special software tools	Simulation software (simulation data from previous projects and simulation histories) Drawings (Mentor Graphics® files) Data and Information in SAP Company Intranet Portal External Internet 'Web sites'
Databases	Various specialist databases: Quality, Certification and Regulation
Verbal discourse	Advice from experienced colleagues <ul style="list-style-type: none"> <li>• Telephone calls</li> <li>• Face-to-face contact in meetings</li> </ul>

Table 18: Media used to deliver knowledge in the NPD process.

Knowledge generated during the product development process was stored in four types of repository, as listed in Table 19. The first type encompasses folders on a network drive accessible to product development project team members. One example was a folder accessible to all personnel involved in the product development process. This folder stores all information pertaining to the NPD business process itself, such as project audit documentation and project reports. Another example was a project folder on a network server shared by personnel in the R&D function. Knowledge and information stored on this drive includes various technical reports and design data generated during the development process. The structures of these folders varied between sites and projects. The second type is a collection of knowledge and information management systems (including product quality management knowledge), databases (containing product drawings) and Enterprise Resource Planning (ERP) applications, such as SAP® (containing data about parts, suppliers and financial data). The third type is an archive of paper documents stored on each site. An example of this is information relating to the conformance of a product to various regulations, such as test reports. Information is kept in this format for each product so that it may be quickly handed over to a regulatory body, should it be requested. Finally, the fourth type of repository is the personnel in the NPD teams. These team members retain knowledge

that cannot be, or is not encoded in, any of the documentation. An example of such knowledge is the context in which a decision was taken or the reasoning behind it.

<b>Repository</b>	<b>Example of knowledge</b>
Project folder on network drive for all NPD project team members Project folder on network drive shared by personnel in the R&D function	Project reports, project presentations, test reports, quality reports, presentations from marketing function
Knowledge and information management systems	Finance data in SAP, information and data relevant to product quality
Paper document archive	Standards and certification reports; and legacy project documentation
NPD project team personnel	Rationale behind decisions and NPD project experience

Table 19: Repositories for NPD knowledge.

#### **5.6.3.4 Limitations**

Aside from the methodological weaknesses of a single case study approach discussed in chapter four (section 4.7), certain other limitations should be acknowledged. A key limitation is that the study is mainly based on data extracted from eight interviews in the case of the knowledge audit study and nine interviews in the case of the knowledge sharing investigation. Griffin and Hauser (1993), recently cited in Fredericks (2005), suggested that twenty to thirty interviews are required to gain a comprehensive understanding of a subject area. Nonetheless, it is countered that the use of the screenshot artefacts and company process documentation in the identification and classification of NPD process knowledge provided a richer and more varied range of data sources than interviews alone. Furthermore, it was possible to compare the findings to a similar, more general study from the literature

#### **5.6.3.5 Summary**

An investigation to identify and classify knowledge used and generated by the new product development process at the case study company has been carried out. The identification of NPD process knowledge drew on three sources of evidence, including company NPD process documentation, an NPD process knowledge audit, and a knowledge sharing investigation in the R&D function of the company. The latter two sources were based on a total of seventeen interviews with NPD practitioners occupying

a variety of functional roles. These roles included NPD sub-process owners, project managers, NPD project leaders and specialist engineers. The NPD business process documentation was employed to provide the researcher with an awareness of the data and information inputs and outputs in the process. Over ninety knowledge items were identified from the knowledge audit source and more than forty knowledge items from the knowledge sharing investigation.

Classification of knowledge was conducted using an iterative process and facilitated by the use of mind maps. An existing classification of NPD knowledge from the literature, and screenshots of the folder structures used by NPD practitioners in the company to organise information contained in digital media, were employed to guide and inform the classification. Ultimately, twelve categories of knowledge were identified that accommodated all of the knowledge items identified in the empirical investigation at the company. This classification subsumes the knowledge categories contained within the classification of NPD information types found in the literature, but differs from it by adding five new categories and abandoning one. It was suggested that the differences between the two classifications may be attributable in part to the use of an in-depth study of a single organisation, rather than the broad-based investigation of multiple companies used as a source of evidence for the previous classification.

A final outcome from the study was the determination of the sources of the identified knowledge, the media used to transfer it, and the repositories used to store it. Knowledge sources were of two types, internal and external. The principle internal sources were reports, expert advice and presentations. Technology exhibitions, university departments, part suppliers and certification organisations were examples of external sources. Five main types of media were found, ranging from paper documents through to specialist software tools and verbal discourse. Project folders on company network servers, knowledge management systems, paper documents archives, and NPD project personnel represent the four categories of knowledge repository.

## **6 Conceptual Design of Knowledge Sharing Tool**

This chapter describes the work conducted to support the design of a prototype tool to facilitate knowledge sharing in the new product development (NPD) process by addressing the three key knowledge sharing barriers identified in chapter five. The development of this knowledge sharing tool is described in chapter seven. Conceptual design of the tool was split into two parts:

- The identification of requirements for a knowledge sharing tool based on a review of existing methodologies for the facilitation of knowledge sharing.
- The provision of an ontology-building methodology to build an ontology of information about NPD knowledge (stage 3 of the research process; see chapter three).

The chapter commences with a review of knowledge management methodologies specifically designed for the NPD context that claim to support the facilitation of knowledge sharing to some degree. After this, information technology-based approaches that are intended to support knowledge sharing are reviewed. Finally, the process and results of a study to provide a methodology to build an ontology of information about NPD process knowledge are detailed.

## **6.1 Review of Knowledge Sharing Facilitation Technologies and Methodologies for NPD**

### **6.1.1 Methodologies for the Facilitation of Knowledge Sharing in the NPD Process**

This first part of the review identifies existing technology-based methodologies that seek in some way to facilitate knowledge sharing in the product development environment and examines the extent to which they address the three key knowledge sharing barriers. Briefly reiterated, the barriers were:

- Barrier A: No explicit definition of the process knowledge
- Barrier B: Lack of a mechanism to support multilingual knowledge environment
- Barrier C: Lack of a mechanism to disseminate the knowledge

An overview of each research effort is provided, including its purpose, the forms of information and knowledge it deals with, the ways in which it claims to facilitate knowledge sharing, and its intended audience. The methodologies are considered in the context of their ability to address the three barriers. Sources drawn upon included internationally peer-reviewed journal and conference papers.

International research efforts that specifically address knowledge sharing and broader knowledge management issues surrounding the NPD process emerged in the early 1990s, possibly driven by advances in collaborative technologies related to the Internet. The most relevant of these efforts will be discussed below.

#### **6.1.1.1 SHADE Framework by Gruber et al. (1992)**

Gruber et al. (1992) asserted that the range of information systems employed by the different functional roles involved in product development may inhibit information sharing among these systems and also the people that use them. They argue that this is because information does not leave the confines of a given tool. Team members performing other functions must manually add data or information to other tools. As information technology-based tools are often specific to a particular product development function, this means that information generated by these tools is not shared

with other functions. Additionally, they state that the rationale behind design decisions is rarely captured.

A framework called SHADE was proposed that was intended to support communication among people and applications by means of a knowledge medium. According to the authors, a knowledge medium is an information technology environment where people and applications communicate using an explicit representation of knowledge. The core of SHADE is an ontology of design knowledge, which was designed to support the capture of design knowledge, the announcement of changes to a design and design dependency management. However, no ontology was actually implemented by the authors.

In the intervening years, many of the problems raised by Gruber et al. (1992) have been addressed at least in part by the evolution of enterprise resource planning software, such as SAP®, and the emergence of Internet and Web technologies including XML, and Web Services. Nevertheless, the application of an ontology to facilitate knowledge sharing was novel and this makes the work noteworthy. None of the knowledge sharing barriers is addressed by SHADE.

#### **6.1.1.2 SHARE Methodology by Toye et al. (1994)**

Toye et al. (1994) described SHARE, a methodology for collaborative product development to enable NPD project engineers, or more specifically design engineers, to work on a distributed team using their own tools and databases. In short, the system attempts to provide the means to capture the structured digital information (such as reports) and unstructured digital information (such as e-mail, video clips or sketches) used and generated within a design project. It was proposed that this is to be done by means of a digital design notebook, which is stored in a file on a computer. Parts or the whole of this notebook can be shared among engineers. Information, such as reports or text from an e-mail, is electronically ‘copied’ and then ‘pasted’ into the notebook. Templates containing a number of fields and tags allow engineers to assign metadata, including a priority tag, to information they add to the notebook. The metadata is intended to enrich the information with context and meaning and thereby assist the user in conducting any subsequent analysis of this information.

Notably, the project correctly anticipated the use of digital tools and the Internet to facilitate collaboration. A further useful insight was the proposal of the use of a loosely-coupled application environment and a system-architecture based on agents. The agents, which represent applications directly or indirectly employed by the engineer, perform tasks such as making requests for information from other agents or informing other agents of changes to a design. Unsurprisingly the tools deployed in the study are now redundant or superseded. More importantly, the methodology does not consider knowledge sharing in the context of the formal NPD process and for this reason it will not be considered any further here.

### **6.1.1.3 ConceptBase System by Ramesh and Tiwana (1999)**

Ramesh and Tiwana (1999) identified a number of problems in the new product development process. These problems were taken from the literature and their own observations from a study at a manufacturer of personal digital assistants. One of the problems was the lack of a shared understanding in NPD teams caused by the ‘diversity of expertise needed in the process’. Consequently, the work has some similarity with this research project. Another problem they identified was a bias towards the exchange of explicit, rather than tacit, knowledge.

To tackle these problems they proposed a prototype system to capture and manage NPD process knowledge, which allows users from different disciplines to map and communicate their views of a design problem or concept. Concepts, which are intended to represent knowledge components, might be questions that must be answered in order to take a decision, possible answers to these questions, evidence to support or challenge each of these answers, or the basic assumptions that lie behind a concept itself.

Users are expected to construct metamodels of the knowledge components using a dedicated modelling tool called ConceptBase, including the relationships between these concepts and metadata. Once the metamodel is complete, the concepts may be linked to the information sources, such as text-based documents, images, audio clips and video clips. The resulting knowledge base is stored on a server and can be accessed and edited by NPD team members using a client Graphical User Interface (GUI). The

authors of the paper claim that this functionality allows users to engage in conversations, and so facilitates the exchange of different views and perspectives.

The system offers a more sophisticated approach than the SHARE methodology proposed by Toye et al. (1994). For example, it offers a way of capturing information about the rationale and context behind design decisions, rather than just the information contained in various media, like reports. However, it does not provide information about human sources of knowledge. Moreover, the construction of knowledge component metamodels relies on the investment of much time and effort by individuals. Scalability must also be a concern, since hundreds of design decisions may be taken in the course of a product development project.

Barrier A is not fully addressed, as knowledge is defined in the context of decisions made during the design process, rather than in the context of tasks or sub-processes in the new product development business process. Barrier B, the language issues presented by a multilingual environment, is not also not addressed or within the scope of the project. Barrier C, the dissemination of information about knowledge, is achieved using by allowing users access to the knowledge base via a browser client. Additionally, documents and media may be linked to documents and other media via a Web gateway.

#### **6.1.1.4 REMAP-based System by Tiwana and Ramesh (2001)**

The authors of the ConceptBase System subsequently proposed a knowledge management system (KMS) to support collaborative information product development through knowledge capture (Tiwana and Ramesh, 2001). One of the knowledge sharing problems that they attempted to address was the lack of a shared understanding of critical design factors among NPD members from different functional areas and specialist roles. It was suggested that differences in vocabulary and domain knowledge contribute to this lack of understanding.

The system takes a similar approach to that adopted in the previous research by the authors (Ramesh and Tiwana, 1999) and employs concept maps to model process knowledge, and link it to 'artefacts' or informal and formal media. Metadata may be linked to informal media such as video clips to provide users with contextual



information. Also similar is the ability to author and annotate, that is to say edit, the process knowledge and concept maps over a network so that the knowledge can be used in a distributed product development environment. In this case though, the supporting software tool used is called REMAP. This software enables a user to copy information from popular tools including Microsoft Office and Microsoft Outlook and transfer it to a knowledge base. The software provides the means to link this knowledge to other knowledge so that a design 'conversation' may be constructed.

In the context of the three knowledge sharing barriers of interest in this study, the knowledge management system suffers the same shortcomings as its predecessor. Knowledge is defined in the context of decisions made during the design process and not in the context of tasks or sub-processes in the new product development business process, so barrier A is not addressed. Although an interdisciplinary aspect of the language sharing problems in barrier B is discussed by the authors, the issue is not explicitly addressed by the tool. The main multilingual issue in barrier B is also not addressed at all. Dissemination of the information provided by the concept maps is achieved through the REMAP client, the functionality of which can be used via a Web browser client. Therefore barrier C is addressed.

#### **6.1.1.5 Product Innovation Portfolio Management by Cormican and O'Sullivan. (2003)**

Cormican et al. (2003) outlined a knowledge management application to help product managers to manage a portfolio of product innovation projects in a distributed environment. Although this application addresses knowledge sharing issues in the product innovation process, it is aimed at the management of product innovation projects, rather than the addressing the knowledge used and generated during an NPD project. For this reason, it will not be examined in any more detail.

#### **6.1.1.6 docK System by Donnellan and Fitzgerald (2003)**

Donnellan and Fitzgerald (2003) posited that learning within a NPD design engineering team is dependent on a mechanism with which the NPD project team members can identify both the knowledge being produced by the wider NPD community and the creators of this knowledge. They termed such information metaknowledge. A

knowledge management system application, 'docK', that is intended to meet this need was described. It was claimed that the application provides its users with metaknowledge, and so makes it easier for individuals engaged in technical functions to find various forms of documentation and share knowledge.

The proposed system comprises resource discovery tools and a resource description schema. Resource discovery tools consist of a Structured Query Language (SQL) database to store documents, a Web server which captures metadata about the documents and indexes this metadata in a search engine, and a Web browser-based client that allows users to view and edit the metadata and access information contained in the repository. Resources are described using a metadata schema based on the Dublin Core Element Set (Dublin Core Metadata Initiative, 2004). The set contains elements for information such as title, creator, contributor, format, source, language and filename.

A novel aspect of the approach taken by 'docK' is that it set out to avoid demanding the level of effort required by users to capture knowledge in the system, encountered, for example, in the work by Tiwana and Ramesh (2001), while attempting to provide enough information about the captured knowledge or metaknowledge for the system to be useful to its users. Donnellan and Fitzgerald (2003) highlighted the importance of people as a source of knowledge, but the system is restricted to capturing so-called explicit knowledge contained in documents. That is, the system does not include information about people and the knowledge that they may possess. The authors suggested that future developments of the application would incorporate some form of expert search functionality, but they do not enter into any further detail.

Despite the use of metaknowledge to provide information about product development process knowledge, the knowledge is not defined in the context of tasks in the formal new product business process. Nor does the application afford the opportunity to assign a priority to knowledge items. Therefore it can be argued that barrier A is not addressed. In addition, the problems caused by differences in language were not within the scope of the 'docK' project and so barrier B is not tackled either. Dissemination of information about the knowledge is achieved through the Web-based client and so barrier C is addressed.

#### **6.1.1.7 Agent-based System by Koyama et al. (2005)**

Koyama et al. (2005) asserted that in a distributed engineering environment, the composition of product development teams could be an enabler of knowledge sharing and innovation. They went on to argue that at the start of an NPD project, team members may not have worked together before and a given member may not be aware of the skills, experience and competencies of their colleagues. It is claimed that existing expert search tools are of limited use in many companies, because privacy rules prevent the storage of data about the skills and project experience of an employee from being made public. A proposal was made for a system that will recommend candidates with profiles that match the required expertise. It achieves this by examining documents stored in the personal workspaces or hard disk drives of employees.

An ontology was employed to represent a conceptual model that relates candidate profiles to their specialist knowledge domain. Agents were used to represent each candidate for a project team and analyse documents on their personal hard drive to devise a candidate profile. This same agent sends queries based on this profile to look for collaborators with similar expertise to a second type of agent. The second type of agent is used to look for similar profiles and produce a list of recommended candidates. Although the use of an ontology to facilitate knowledge sharing in the context of the new product development process makes this work worthy of note, its application domain is not relevant to the problems considered in this research project. Therefore it will not be examined in any more detail.

#### **6.1.1.8 Distributed Knowledge Management Framework by Wang et al. (2005)**

Finally, Wang et al. (2005) suggested that previous studies, including that by Ramesh and Tiwana (1999), did not support collaborative engineering activities in a genuine knowledge management context and so should not really be applied to engineering knowledge. They proffered a methodology and system framework to manage knowledge in allied concurrent engineering. Allied concurrent engineering is defined as a unification of the virtual enterprise and concurrent engineering concepts. It is considered here because the authors stressed that successful concurrent engineering depends on the understanding and effective sharing of process knowledge and a similar claim has been made in this study for new product development.

The methodology includes a knowledge management life cycle model and a 'distributed knowledge management framework'. An example system was implemented in a virtual concurrent engineering environment at a University-based research laboratory. The system framework consists of two knowledge repository types, one for personal knowledge and the other for project team knowledge. Agents are used to perform various knowledge management functions. It is envisaged that engineering product data created during a project will be captured at the end of the project in a knowledge repository. The intended users of the system would seem to be product development project teams and individual team members.

Wang et al. (2005) set out to identify, characterise and model knowledge in the context of the activities that make up tasks in the virtual concurrent engineering process. They emphasised that it is important to manage knowledge 'in association with engineering processes' and characterised engineering knowledge management as being process dependent. Knowledge is classified into knowledge items that relate to activities or tasks in the NPD process. Knowledge modelling is exploited to represent the attributes and semantic properties of a knowledge item, in part to facilitate knowledge sharing. It was claimed that attributes assist users in searching for knowledge items, while semantics provide system users with a better understanding of the context and meaning of a knowledge item. The attributes and semantic information is to be entered by the user into a template form when the knowledge item is checked into a system repository.

A number of criticisms may be made about this 'abstraction' approach however. The first is that all knowledge items checked into the system are apparently physical items, even if they are fragments of information representing the tacit knowledge of engineers. It does not seem to consider people as repositories of knowledge, probably because personal knowledge cannot be 'checked out'. A second problem is that of the classification. Knowledge is classified from a knowledge management perspective, but not from the functional domain or knowledge 'content' perspective that might be preferred by a user such as an engineer. Finally, no attempt seems to have been made to provide a knowledge prioritisation mechanism. As a result, barrier A may be said to have been only partially addressed by this methodology and system.

Knowledge sharing barriers related to differences in the language of team members are not considered and no mechanism is present in the proposed system to tackle this issue. Barrier B is therefore not addressed. A client-server architecture allows any team member with access to the network client software to access and manipulate the knowledge items and the accompanying attributes and semantic data. Additionally, a knowledge map is employed to assist systems users with navigation of the knowledge. Mechanisms are present that help disseminate the knowledge among users, and so barrier C is tackled. Nonetheless, the absence of any mention of a Web-based client makes this a less flexible solution than some of the methodologies and tools discussed earlier.

#### **6.1.1.9 Findings**

A review of literature related to information technology-based methodologies for the facilitation of knowledge sharing, in the context of the three knowledge sharing barriers, has established the following findings:

- No single methodology addresses all three knowledge sharing barriers. For this reason, it may be asserted that a new methodology or tool is required to tackle these barriers.
- None of the previous research efforts address the issue of the multilingual environment. This means that Barrier B has not been tackled by any of the methodologies considered here.
- Web-based tools are the predominant technology for dissemination of information featured by existing NPD knowledge management tools.

Additional findings are that:

- Previous methodologies efforts have mainly focused on the role of the design engineer, but have neglected other NPD team roles e.g. project leader or manager.
- Previously proposed systems demand the installation of significant systems infrastructure e.g. knowledge repositories. This seems to be due in part to an insistence on attempting to ‘capture’ knowledge.

- The emphasis on capturing knowledge seems to have led to a lack of attention on knowledge residing in people, i.e. people-based knowledge repositories.

### **6.1.2 Review of Information Technology-Based Knowledge Sharing Approaches**

It was established in section 6.1.1 that a new method and tool was required that would address the three knowledge sharing barriers identified in chapter five. In order to determine what kind of approach might form the basis of such a tool, a review of information technology-based approaches for the facilitation of knowledge was carried out.

In this second part of the review then, two key knowledge sharing facilitation approaches described in the recent literature are examined. An overview is provided of each approach, as well as an exploration of the ways in which it might be used to address the knowledge sharing barriers. Notably, the scope of the review was confined to those approaches that explicitly claim to support the development of a shared understanding of a knowledge domain among people. The knowledge sharing approaches considered are knowledge maps and ontologies. Consequently, communication and dissemination technologies, such as the Internet and the World Wide Web, are excluded from this review.

#### **6.1.2.1 Knowledge Maps**

Knowledge maps have been applied to problems in research domains as diverse as Economics, for example Howard (1989), and Education, as reported in McCagg and Dansereau (1991). More recently, the knowledge management literature has identified the knowledge map as a key tool for understanding knowledge flows and communicating knowledge within a business (Hansen and Kautz, 2004; Burnett et al, 2004). Eppler (2001) discussed how knowledge maps might be used to improve knowledge-intensive processes such as product development by contextualising information and connecting it with pertinent sources of expertise and experience. According to Wexler (2001), in this way the information is made 'actionable', creating knowledge in the minds of the map users. Moreover Wexler (2001) claimed that knowledge maps are an effective means for organisations to capture, disseminate and share knowledge.

A widely cited definition of a knowledge map in the context of knowledge management was provided by Vail (1999): ‘A knowledge map is the visual display of captured information and relationships, which enables the communication and learning of knowledge by observers with differing backgrounds at multiple levels of detail.’ Davenport and Prusak (1998) commented that knowledge maps do not actually hold the knowledge they represent, but rather they provide pointers to the knowledge. Crucially, this level of abstraction allows knowledge maps not only to point to sources of information like documents, but also to direct attention to the knowledge possessed by people, an assertion supported by Vail (1999).

Knowledge map is really a blanket term for several different types of map found in the literature. Wexler (2001) identified five types of knowledge map: competency maps, strategy maps, causal maps, cognitive maps and concept maps. Carnot et al. (2001) commented that concept maps are distinct from knowledge maps in that although they represent concepts connected by labelled links, they are mostly hierarchical in construction and contain concepts with single labels. Eppler (2001) in contrast, viewed both concept maps and ‘cause’ maps as knowledge mapping techniques and proposed five types of knowledge map that might be used in a corporate environment. These were knowledge source maps, knowledge asset maps, knowledge development maps, knowledge structure maps and knowledge application maps. Of these types, knowledge application maps are perhaps the most relevant to this research, since they illustrate the type of knowledge required at a given phase of a business process and provide information about specific knowledge, such as its source. Eppler (2001) observed that this type of map is employed by individuals engaged in knowledge intensive processes like product development

Two important enabling technologies for the application of knowledge maps in a collaborative product development environment are the Internet and the World Wide Web. These allow a knowledge map to be constructed and then presented as a ‘clickable map’ on a corporate Intranet (Eppler, 2001), in a form similar to the concept map browser tool introduced by Cañas et al. (2004). Additionally they afford access to the knowledge map for anybody within the company able to use a Web browser client.

Nevertheless, knowledge maps present certain disadvantages to both map creators and map users, as highlighted by Eppler (2001) and Wexler (2001). From the map creator's perspective, Eppler (2001) suggested that there is a risk of providing too much information on a map in situations where the knowledge domain represents many elements. That is, concept maps are constrained by the richness of information that they can effectively convey. Given that a product development process could involve hundreds of tasks and many hundreds of knowledge items, each of which must be described with various pieces of information, a knowledge map is likely to become extremely cluttered. Eppler (2001) listed high production costs, the complexity of designing an ergonomic visualisation paradigm, and the diminution of complicated ideas to symbols, thereby risking misinterpretation by users, as challenges to the designer.

Further problems can occur if map creators and map users do not share a common language, as emphasised by Wexler (2001). This last issue is likely to be of particular concern in the multilingual environment considered in this research. As a result, the knowledge map approach would seem ill-suited to addressing all of the knowledge sharing barriers.

### **6.1.2.2 Ontology**

Wielinga et al. (1997) asserted that knowledge management 'requires knowledge of ways to describe, develop and maintain knowledge'. They argue that tools, methods and techniques developed for knowledge engineering may be applied to knowledge management to help meet this need. One example of this is the application of ontologies to facilitate the sharing and communication of knowledge among people in a company (Gruber et al., 1992; Studer et al, 1998).

Ontologies can be used to nurture a 'common' or shared understanding among human workers (Jasper and Uschold, 1999). More specifically, ontologies may be employed to facilitate a shared understanding of a knowledge domain that may be communicated among people or software agents, an assertion which has long been echoed in the literature (Gruber, 1993; Corcho et al, 2003; Pinto and Martins, 2004). For this reason, ontologies are of relevance to the knowledge sharing problems of concern in this research.



The origins of the term ontology lie in philosophy, where it refers to a branch of metaphysics describing the nature of being (Pearsall, 1999). In the early 1990s, the term was adopted by the Artificial Intelligence research community to refer to what can be computationally represented of a world (Studer et al, 1998; Guarino and Welty, 2002), or in more specific language, a given knowledge domain. Ontologies of this type have been applied to knowledge sharing problems in areas as diverse as Medical Informatics and Bioinformatics (Musen, 1992; Lambrix et al, 2003), the Semantic Web (Fensel, 2002), linguistics (Ruiz-Casado et al, 2007) and Manufacturing (Schlenoff et al., 1998). Liao (2005) outlined some additional application domains.

Studer et al. (1998), using a previous definition by Gruber (1993) as a model, defined an ontology as ‘a formal, explicit specification of a shared conceptualisation’. A conceptualisation is an abstract, simplified view of the world that needs to be represented for some purpose, as defined by Gruber (1993). This simplified view is expressed in terms of a model consisting of relevant concepts in a knowledge domain. The concepts in the model and the constraints governing their application are explicitly defined, hence the use of the term explicit (Studer et al, 1998). There are many other definitions of the term in the ontology literature, but as Corcho et al. (2003) pointed out, they do not vary greatly and there seem to be no significant disagreements about its meaning within the research community.

Certain parallels can be drawn between knowledge maps and ontologies. For example, the concepts in an ontology are linked together by relationships, much as they would be in a concept map, a point already highlighted by Preece et al. (2001). Indeed, Benjamins et al. (1998) noted that an ontology used in the context of an organisation could be referred to as an enterprise knowledge map. However the scope of application of an ontology is far wider than that of a knowledge map. Ontologies can be applied to the modelling not only of static domain knowledge, but also dynamic reasoning knowledge (Studer et al, 1998). Furthermore, unlike knowledge maps they feature definitions of concepts that can be interpreted by a computer (Noy and McGuinness, 2001), hence the use of the term formal in the definition of ontology by Studer et al. (1998).

Ontologies also resemble taxonomies in that both feature a taxonomic hierarchy of classes representing concepts (Ciocoiu et al, 2001). Distinctions may also be made between an ontology and a taxonomy. Studer et al. (1998) stated that there are two differences between an ontology and a taxonomy. The first is the greater richness of the internal structure of the ontology and the second is that an ontology represents a shared understanding or consensus among its users. Corcho et al. (2003), on the other hand, reported that some research has labelled taxonomies as ontologies, since they represent a shared conceptualization of a given knowledge domain. They further expounded that in order to deal with this, the research community has devised the terms lightweight ontology and heavyweight ontology. Lightweight ontologies are comprised of concepts and concept taxonomies, concept properties, and relationships between concepts. Heavyweight ontologies possess all of the traits of lightweight concepts and also feature axioms and constraints.

### **Classes of ontology**

Fensel (2003) identified six classes of ontology from the ontology literature: generic ontologies, metadata ontologies, representational ontologies, method ontologies, task ontologies and domain ontologies. van Heijst et al. (1997) discussed one additional class, the application ontology.

Generic ontologies, also known as general, core, reference or upper level ontologies, capture general knowledge such as high level concepts that could be valid across many domains (Noy and Hafner, 1997; Stevens et al, 2000). Metadata ontologies feature a vocabulary for describing data and representational ontologies do not represent a domain per se, but make available entities that can be used to represent knowledge (Fensel, 2003). Tasks are problems that may be solved using problem-solving methods and task ontologies specify the terminology associated with a task (Motta et al., 1999). According to Tu et al. (1995), a method ontology is a definition of the vocabulary that describes the operations of which a problem solving method is composed. Domain ontologies represent the knowledge specific to a given application domain (Gennari et al, 2003). Lastly, Heijst et al. (1997) described application ontologies as containing the concepts which are necessary to model the knowledge needed for a given application.

## **Applications of ontologies in manufacturing and product development**

Ontologies have already been applied to various knowledge sharing problems in manufacturing and the NPD process. So far the application of ontology to manufacturing knowledge management has been mainly focused on the sharing of information between various kinds of manufacturing software applications. Ciocoiu et al. (2001) reviewed research projects that aimed to integrate the different software applications used by engineers by utilising an ontology. The ontologies discussed facilitate interoperability among software applications by mapping the terminology used by one application to the terminology used by another. They described two approaches to achieve this. One approach is to provide a single ontology to represent information used by every application, which Ciocoiu et al. (2001) called a standardisation approach. Examples of projects using this approach are TOVE (Fox et al., 1993) and the Enterprise Ontology (Uschold et al, 1998). Another approach is to provide a different ontology for each application, along with mediating software to translate information between them. Ciocoiu et al. (2001) called this kind of ontology ‘interlingua’ and cited the Process Interchange Format (PIF) (Lee et al, 1998) and Process Specification Language (PSL) (Schlenoff et al, 1999) as examples of interlingua projects.

Metaxiotis et al (2001) presented a methodology to build ontologies for production scheduling information systems used in manufacturing and production planning. They set out to provide the information system designer with the important parameters in production scheduling problems and knowledge of production planning theory. More recently, a knowledge-based requirements management tool featuring an ontology of product knowledge for the specification of a car seat was proposed by Kerr et al. (2004). The ontology formed the foundation of a knowledge-based tool. The aim of the tool was to bring about a shared understanding of automotive seat product requirements between the automobile manufacturer and the suppliers of the modular systems from which a seat is comprised.

In the NPD domain, ontologies were applied by Moore et al. (1999), to aid in NPD process management, and by Rezayat (2000), to develop information sharing protocols for translating customer needs into product specifications. Szykman et al. (2001) proffered an ontology-based knowledge representation to facilitate the exchange of design information among heterogeneous tools in a product development scenario.

The SHARE project proposed using an ontology for the classification and organisation of various types of design information that could be captured electronically (Toye et al, 1994). The latter project will be discussed in more detail later on in this review.

It would seem that most applications of ontologies in new product development have so far focused on providing interoperability among software applications, rather than among people. The scope of these ontologies seems to have been limited to knowledge used by design engineers and not the broader range of functional roles in the NPD process.

### **Application to three knowledge sharing barriers**

Ontologies then, provide a way to formally define information about knowledge associated with the NPD process and to classify it. In doing so, they could be used to encourage a shared understanding of NPD process knowledge among NPD project team members. They do not though alone offer a method to identify this knowledge. Consequently, problem category A could be partially addressed by ontology-based technology.

Problem category B demands a mechanism to make information about knowledge accessible to NPD process users in a multilingual environment. The application of an ontology to provide a shared understanding of knowledge in a domain, in interdisciplinary scenarios analogous to those encountered in NPD teams, has been described by Metaxiotis et al. (2001) and Kerr et al. (2004). In the case of Metaxiotis et al. (2001), the purpose of the ontology was to give an information systems designer an understanding of relevant issues in the manufacturing production scheduling domain. Kerr et al. (2004) used an ontology to tackle the lack of a common understanding between an people with potentially different viewpoints and disciplinary backgrounds, namely an original equipment manufacturer and its suppliers.

In recent years, researchers have examined ways to use ontologies to support a multilingual environment. The literature contains two approaches to the issue, a view supported by Bonino et al. (2004). One approach is to model the domain concepts in a single language ontology and then to map word keywords from the required languages to the same concept in the ontology. Lauser et al. (2002) used this approach to create a

prototype biosecurity ontology, and Jarrar et al. (2003) adopted it in their proposal for the construction of an ontology of knowledge in the complaints management domain. Valarakos et al. (2003) included it in their proposed methodology for the enrichment of a multilingual domain ontology by machine learning.

Lauser et al. (2002) proposed that a portal might then be constructed to retrieve the same information from the ontology, regardless of the language of the user. This mapping approach is applicable to both the issue of sharing the ontology among users who speak different languages, and to the issue of semantic differences in vocabularies used by different functions or those with different views of design. Jarrar et al. (2003) commented that ontologies represent concepts and not terms, and so they are abstract from natural language, or as Bonino et al. (2004) stated, an ontology is 'language independent'. Jarrar et al. (2003) further argued that an ontology is intended to represent a particular knowledge domain, which is consented to by, and can be shared among, its users. Therefore the lexicalisation of a concept, by which they mean devising a natural language expression to describe that concept, is intended to render the ontology more usable.

Guyot et al. (2005) defined a multilingual ontology as one that includes a set of dictionaries for each of the languages required by its users. Similarly, Vouros et al. (2005) described multilingual ontologies simply as 'multilingual terminological knowledge bases'. Essentially, this is a database of natural language terms, each of which lexicalizes a concept in an ontology.

Jarrar et al. (2003) provided a different perspective on the multilingual ontology. They suggested that in the case of ontologies used in natural language processing, developing a multilingual ontology involves developing an ontology for each language required, along with an alignment layer to map one ontology to another. It is this definition that forms the basis of the second approach, which is suitable for natural language processing applications (Jarrar et al., 2003). Bonino et al. (2004) identified several disadvantages to this type of approach. These disadvantages include the significant time and labour resources needed to map the ontologies, the redundant work that may result from creating concepts for each language, which are common to all three

languages, and lastly the possibility of yielding an unwieldy product which is difficult to update and maintain.

Addressing problem barrier C concerned providing a mechanism to disseminate information about knowledge to NPD project team members who could be distributed across the globe. An ontology does not in itself provide a means to disseminate NPD knowledge in this way. However, some ontology building software tools include features that allow ontologies to be visualised, navigated and viewed over the Internet via Web browsers. Two such tools are the KAON portal tool which features in the KAON ontology management infrastructure (KAON, 2005b), as deployed by Maedche et al. (2003) and the WebProtégé plug-in included with the Protégé ontology editor (Gennari et al, 2003), which was deployed by Hale et al. (Pre-print).

### **6.1.2.3 Findings**

The following findings have been made in this section of the review:

- Ontologies have been applied to nurture a shared understating of a knowledge domain in multidisciplinary environments.
- Ontologies may be used to support knowledge sharing in multilingual environments.
- Technology is available to disseminate the information contained in an ontology via the Internet using a Web browser client.
- There is a lack of research into the use of ontologies or ontology-based applications to facilitate knowledge sharing among humans in the NPD domain.

### **6.1.3 Discussion and Summary of Findings**

The findings of the review of technology-based NPD knowledge management methodologies in the literature indicated that further research is required into the development of tools to facilitate knowledge sharing in the new product development process by tackling the three knowledge sharing barriers.

In section 5.5.2 of the empirical investigation of knowledge sharing barriers in industry, it was stated that the three barriers identified prevent NPD teams from

achieving a shared or common understanding of the knowledge used and generated in the NPD process. A review was conducted of knowledge sharing technologies that are intended to encourage a shared understanding of a knowledge domain, as presented in section 6.1.2. Two approaches were considered: knowledge maps and ontologies. The findings of this review suggested that an ontology might be employed as part of a knowledge sharing facilitation tool for an NPD environment. The ontology would allow the formal, explicit definition of information about NPD process knowledge. However, mechanisms would be required to make the ontology accessible to multilingual, geographically dispersed NPD project teams.

## **6.2 Provision of an Ontology–Building Methodology**

### **6.2.1 Background**

The aim of this section is to present the methods and findings of a study to provide a methodology to build an ontology of information about knowledge used and generated in the new product development process. It begins by explaining the purpose of an ontology building methodology and briefly summarises the evolution of such methodologies in the ontology engineering literature. It continues by explaining the typical activities involved in the development lifecycle of an ontology. Following this, seven criteria for a methodology suitable for use in this research project are defined. These criteria act as a framework for reviewing the ontology methodologies.

The formal, mature, ontology-building methodologies from the literature are reviewed in the context of this framework and the most suitable candidate selected. Then any necessary adaptations that need to be made to the selected methodology, in order that it should meet the aforementioned criteria, are identified and explained. Finally, a methodology for building an ontology of information about NPD process knowledge is provided.

### **6.2.2 Ontology Building Methodologies**

The first major published work on ontologies appeared in the early 1990s, as described in section 6.1.2.2. By the mid-1990s Uschold and King (1995) noted that while there had been many hints and guidelines for building ontologies, there was a lack of general

methodologies to assist in this purpose. Some years later Jones et al. (1998) lamented that even ontologies built for similar purposes were significantly varied in nature. Indeed they reflected: ‘At present the construction of ontologies is very much an art rather than a science.’ This position was also taken by Fernández-López and Gómez-Pérez (2002).

These problems led to efforts to provide formal methodologies to develop ontologies, many of which were published in the latter half of the 1990s, e.g. the skeletal ontology building methodology by Uschold and King (1995), the TOVE methodology (Grüninger and Fox, 1995) and METHONTOLOGY (Fernández-López et al., 1997). A more detailed history of ontology building methodologies was provided by Fernández-López (1999), which was updated by Fernández-López and Gómez-Pérez (2002).

Pinto and Martins (2004) defined ontology building as ‘a process that aims at producing an ontology’. Fernández-López et al. (1997) used the phrase ‘ontology development process’ to refer to ‘what activities you need to carry out when building your ontologies’. As the term methodology is often used rather loosely, for the purposes of this exercise a methodology is defined as ‘a comprehensive, integrated series of techniques or methods creating a general systems theory of how a class of thought-intensive work ought to be performed’ (IEEE, 1995). This definition was deemed appropriate in the context of ontology building by Fernández-López and Gómez-Pérez (2002).

### **6.2.3 Basic Ontology Lifecycle**

In their review of ontology sharing methodologies, Pinto and Martins (2004) defined an ontology development life cycle as ‘the usually described stages through which an ontology is built’. The stages in this lifecycle are: specification, conceptualisation, formalisation, implementation and maintenance.

In the specification stage, the purpose and scope of the ontology is identified. Conceptualisation concerns devising a conceptual model of the required ontology that meets the aforementioned specification. This model is formed from concepts that describe the domain and the relationships among these concepts. Formalisation involves



converting the conceptual model into a formal model, using axioms to define the concepts and a hierarchy to organise these concepts. Implementation entails encoding the formal model using a formal representation language. Maintenance of the ontology principally means updating the ontology to reflect changes in the domain.

Three additional activities are also included, which Pinto and Martins (2004) indicated should be undertaken throughout the lifecycle of the ontology. The first activity is knowledge acquisition. Here, knowledge is acquired about the subject of the ontology by means of a variety of elicitation techniques. The second activity is evaluation; this activity entails making a technical judgement about the quality of the ontology. The third activity is documentation. The methods used to build the ontology, and the rationale behind the decisions made in the process, are recorded by the ontology developers. Pinto and Martins (2004) placed great emphasis on documenting the terms represented in the ontology.

Not all of the stages and activities in this lifecycle are of paramount relevance to the ontology to be developed for this investigation. This is because the ontology is to be provided mainly for illustrative purposes and is not intended for long term use in the real world. Based on this reasoning, the maintenance stage is abandoned and issues connected to it will not play a significant role in the selection of the methodology discussed in the following section.

#### **6.2.4 Selection of a Methodology**

Pinto and Martins asserted that there are two approaches to constructing an ontology (2004). One approach is to reuse an existing ontology and the other is to build it 'from scratch'. Pursuing the former approach involves the ontology engineer searching various ontology resources for an ontology or ontologies that address or closely match the domain of interest. These resources might be ontologies published in the literature, or more likely Web-based directories of ontologies, also called ontology libraries. Pinto and Martins (2004) proposed that there are two main approaches to reuse, which are fusion and composition. Fusion is building an ontology on one subject by reusing one or more ontologies addressing that same subject. The ontologies are merged into a single new one. In the composition approach, a new ontology is created by assembling

ontologies from different subject areas. Composition may require that minor changes are made to the source ontologies.

#### **6.2.4.1 Criteria used in literature**

The literature provides some guidance about the issues to be considered when selecting an ontology building methodology. Corcho et al. (2003) proffered the following questions for this purpose:

1. ‘Which methods and methodologies can I use for building ontologies, either from scratch, or reusing other ontologies already available on ontology servers?’
2. ‘Which activities are performed when building ontologies with a methodology?’
3. ‘Does any methodology support building ontologies cooperatively?’
4. ‘What is the life-cycle of an ontology that is developed with a specific methodology?’

Since in this case it was envisaged that the author would be building the ontology, question 3 was ignored. Questions 1, 2 and 4 though, are worthy of further consideration. The question of whether building a new ontology or reusing an existing ontology or ontologies is more appropriate has been incorporated into certain ontology building methodologies e.g. Noy and McGuinness (2001). As methodologies are available that are specifically designed for either building ontologies from scratch, or for ontology reuse, the issue was tackled prior to any further consideration of the methodologies, as will be seen below.

#### **6.2.4.2 Process for selecting a methodology**

Selection of an apposite methodology was achieved by following a six-stage process, as illustrated in Figure 13. A description of the activities involved in each step follows.

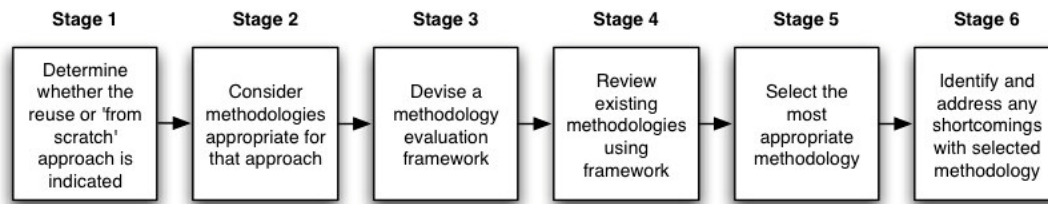


Figure 13: Six-stage process for the selection of an ontology building methodology.

### **Stage 1: Adoption of reuse or ‘from scratch’ approach**

The choice of whether to use or adapt an existing ontology, or to build a new ontology is largely dictated by whether an ontology appropriate to the domain is available in the published resources. To determine this, two categories of resources were investigated: the knowledge engineering literature and the sources of published ontologies available on the World Wide Web. Eight sources were examined, as described in Appendix K.

The search focused on finding an ontology of information about knowledge used in the new product development process or of a closely-related domain. Each source featured either a Web-based search engine or a downloadable Adobe Portable Document Format (PDF) file that was text string searchable. Searching was carried out firstly using phrases, such as ‘product development’, and then single words like ‘product’, ‘development’ or ‘knowledge’. As of March 2007, none of the ontologies in the sources listed in Appendix K explicitly addressed the scope of ontology required in this investigation. Of course, it may be argued that the composition-type reuse approach might be adopted. However, an additional problem is the lack of methodologies for reuse for either the fusion or composition approaches. Pinto and Martins (2004) emphasised that methodologies for this purpose remain a research issue. Consequently it was decided that a methodology suitable for building an ontology from scratch was required.

## Stage 2: Identify methodologies suitable for ‘from scratch’ approach

Having established that the ‘reuse’ ontology building strategy was inappropriate, it was then possible to identify ontology building methodologies suitable for building a new ontology.

Latterly, major reviews of ontology building methodologies have emerged in the literature, most notably those by Jones et al. (1998), Fernández-López (1999) (subsequently extended in Fernández-López and Gómez-Pérez (2002), Corcho et al. (2003), and Pinto and Martins (2004). Their work will not be reproduced here. However the key methodologies they identified from the literature are shown in Table 20. One widely cited methodology absent from all three works has been added to the list, namely the ontology building guidelines devised by Noy and McGuinness (2001).

Methodology	Key References	Suitable for development approach
Cyc	Lenat et al. (1990)	‘From scratch’
Uschold and King (Enterprise)	Uschold and King (1995)	‘From scratch’
Grüninger and Fox (TOVE)	Grüninger and Fox (1995)	‘From scratch’
KACTUS	Bernaras (1996)	‘Reuse’
METHONTOLOGY	López et al. (1999)	‘From scratch’
SENSUS	Swartout et al. (1996)	‘Reuse’
On-To-Knowledge – See Corcho et al. (2003)	Staab et al. (2001)	‘From scratch’ and/or ‘reuse’
KBSI IDEF 5	Benjamin et al. (1994)	‘From scratch’
Noy and McGuinness	Noy and McGuinness (2001)	‘From scratch’ and/or ‘reuse’

Table 20: Methodologies for building ontologies.

Pinto and Martins (2004) identified three methodologies suitable for a building ontologies from scratch. These methodologies were TOVE, Enterprise and METHONTOLOGY; they did not analyse any of the other methodologies in any great detail. These and the other methodologies in Table 20 were examined to see what approach they best suited. Some of the methodologies were found to accommodate both approaches. On-to-Knowledge (Staab et al, 2001) features a stage in which available ontologies should be studied and considered for reuse. Noy and McGuinness (2001) includes a step recommending the consideration of the reuse of existing ontologies. Nonetheless, neither methodology describes this reuse stage in detail.

The findings of this study are indicated in the third column of Table 20, and those methodologies deemed as suitable for the ‘from scratch’ approach will be those reviewed in stage 4 of the ontology-building methodology selection process.

### **Stage 3: A framework for selecting an ontology building methodology**

A framework to assist in the selection of an ontology building methodology was devised based on a number of selection criteria. The selection criteria were compiled using the reviews of methodologies presented in the literature and by considering the specific needs of this investigation.

In the review carried out by Fernández-López (1999), nine criteria were used to analyse the methodologies. Fernández-López based these criteria on the IEEE software development standard (IEEE, 1996a). The criteria are reproduced in Appendix L. Some of these were considered to be of relevance to this investigation, specifically the level of detail included in the methodology, the strategy for building ontologies, the strategy for identifying concepts, recommended techniques for performing the activities in the methodology, and whether there were any ontologies developed using the methodology.

Pinto and Martins (2004) distinguished their work from that of Fernández-López (1999) by defining the activities involved in a sort of generic ontology building process and using these activities as a framework for comparing the methodologies. They argued that this was a superior approach, because ‘it follows the actual ontology building process’. The activities were defined as specification, conceptualisation, formalisation, implementation, maintenance, knowledge acquisition, evaluation and documentation. However, beyond establishing the completeness of a given methodology against this process, it does not provide any insight into criteria for the selection of a methodology for this investigation.

Seven criteria for selecting an appropriate methodology were ventured. The methodology should possess the following traits:

1. It should be suitable for constructing a domain ontology, that is, for defining the concepts within that domain.
2. It provides a detailed description of the activities involved in each stage of the process.

3. It should be appropriate for application by practitioners who potentially have no background in ontological engineering and knowledge engineering e.g. the author and any practitioners who may wish to use the ontology. The constraints on the time available for this investigation, and the lack of experience in ontology engineering possessed by the researcher, make this an important practical criterion.
4. There are applications of the methodology available in the literature. This demonstrates that it is possible to apply the methodology to a real world case and lends it a degree of academic credibility and robustness.
5. It should be appropriate to the application domain.
6. Ideally, the methodology will be supported by tools that assist in the implementation of the ontology. Corcho et al. (2003) pointed out that many such tools have emerged in the last few years.
7. It will exhibit maturity. For Fernández-López (1999), Fernández-López and Gómez-Pérez (2002), and Corcho et al. (2003), maturity refers to the degree to which the methodologies are comparable to software engineering and knowledge engineering methodologies. In this case, maturity has the aforementioned meaning, and also demands that the methodology is built on previous research into ontology-building methodology development.

#### **Stage 4: Review of existing methodologies**

There now follows a review of the methodologies suitable for building a ontology from scratch, in order to select the one that is best suited to this investigation. The review is based on the framework of criteria described in stage 3 and considers the following methodologies: Cyc (Lenat et al, 1990; Lenat and Guha, 1990), Uschold and King's Enterprise (Uschold and King, 1995), Grüninger and Fox (1995), METHONTOLOGY (Fernández-López et al., 1997), On-To-Knowledge (Staab et al, 2001), KBSI IDEF 5 (Benjamin et al, 1994), and Noy and McGuinness (2001).

#### **Cyc Methodology**

The Cyc methodology was presented as part of the Cyc project, an artificial intelligence project that seeks to compile a knowledge base of commonsense knowledge. One

component of this knowledge base is an ontology (Lenat et al, 1990). This methodology is independent of the uses to which the ontology may be applied in knowledge based applications, according to Fernández-López and Gómez-Pérez (2002). The methodology consists of three phases (Lenat and Guha, 1990): manual extraction of common sense knowledge, computer-aided extraction of common sense knowledge and computer managed extraction of common sense knowledge. In their review of ontology building methodologies, Fernández-López and Gómez-Pérez (2002) noted that these phases are ‘described in a general way’ and concluded that ‘the concrete techniques for building Cyc are not detailed in the book’, where the book is Lenat and Guha (1990). A lack of supporting ontology-building tools and the use of a custom implementation language, CycL, will increase the difficulty of applying the methodology. Additionally, the methodology does not seem to have been used in domains other than the Cyc Knowledge Base.

### **Uschold and King (Enterprise)**

Uschold and King (1995) presented a methodology developed from their activities building the Enterprise ontology. This ontology was designed for the purpose of modelling enterprise processes. The methodology is comprised of four stages: identification of purpose, building of the ontology (including capture, coding and integration of existing ontologies), evaluation and documentation. Each of the stages is outlined in Uschold and King (1995).

Uschold and Grüninger (1996), later cited in Fernández-López and Gómez-Pérez (2002), asserted that these stages could not be referred to as a methodology. They noted: ‘Every methodology should also included [sic] a set of techniques, methods and principles for each of the above four stages and they should indicate what relationships exists [sic] between the stages’. Developing on this theme, Jones et al. (1998) observed that ‘as the use of existing knowledge acquisition techniques is recommended for this informal stage, no advice is given on how to identify ontological concepts’. It may be said then, that this methodology does not provide a detailed description of each stage in the process.

Nonetheless, considerable praise has been lavished on the ease of use of the methodology relative to its counterparts. Pinto and Martins (2004), comparing the

methodology with that of Grüninger and Fox (1995) and with METHONTOLOGY (Fernández-López et al., 1997), described it as ‘a good compromise between guidance provided and freedom of what/how to represent the domain’. Concepts in a domain are defined in natural language rather than in a formal ontology language. As a result, Pinto and Martins (2004) reasoned that domain experts without knowledge engineering skills can use the methodology to build an informal ontology. A major drawback of the methodology though, is the absence of a link to a supporting ontology-engineering tool. This means that ontology engineering-expertise is needed to formalise this informal ontology.

Corcho et al. (2003) considered the methodology to be immature in comparison with software engineering methodologies. The fact that this was one of the earliest attempts to produce a formal methodology means that it does not feature some of the refinements encountered in later works.

### **Grüninger and Fox (TOVE)**

Grüninger and Fox (1995) proffered a methodology that was developed based on the practices used to build business processes and activities modelling ontologies as part of the TOVE project.

The six stages in the process are: establish and describe the motivating scenario, formulate competency questions (these are the questions that the ontology must be able to answer and they are expressed informally, in natural language), specify the terminology of the ontology in first-order logic (FOL), formally define the competency questions in FOL, specify the axioms to be used in the ontology in FOL, and define the set of conditions under which the solutions to the competency questions are complete.

Ontologies developed for the TOVE project include Enterprise Design Ontology, Project Ontology, Scheduling Ontology and Service Ontology, as documented in Fernández-López and Gómez-Pérez (2002). From these examples it can be seen that the scope of application has been restricted to the business domain.

Like the Uschold and King (1995) methodology described above, the TOVE methodology has been criticised for not providing a sufficiently detailed explanation of each stage in the ontology building process. For instance, Fernández (1999) implied that the techniques and activities required for performing ontology development were



missing from this methodology. In support of this point, Fernández-López and Gómez-Pérez (2002) criticised this methodology for only describing a small number of techniques. Lastly, Pinto and Martins (2004), comparing the methodology with the basic ontology lifecycle described in section 6.2.2, raised the issue of the lack of a knowledge acquisition activity.

The Grüninger and Fox methodology suggested that the First-Order Logic should be used as the knowledge representation language. This will result a formal, machine readable ontology. This high degree of formality is considered a strength by Fernández-López and Gómez-Pérez (2002). However, it demands that the domain experts building the ontology have the appropriate knowledge representation background. Pinto and Martins (2004) proposed that ontology designers attempting to use the methodology without this background will find it 'in general too vague and too difficult to use.' It is further stated that for naïve ontology builders, little guidance is provided on how the activities in the methodology should be carried out. There is also no ontology building tool dedicated to supporting this methodology.

## **METHONTOLOGY**

METHONTOLOGY is described by Fernández-López et al. (1997) as a well-structured methodology to build ontologies from scratch. Drawing on the experiences of its authors in developing an ontology of chemicals, the methodology features an ontology development process with ten activities: plan, specify, acquire knowledge, conceptualise, formalise, integrate, implement, evaluate, document, and maintain. It may be used to build domain ontologies. Fernández-López and Gómez-Pérez (2002) listed some of the ontologies that have been built using METHONTOLOGY. The domains of these ontologies include chemical elements and crystalline structures, monoatomic ions, environmental pollutants, silicates, hardware and software, knowledge about the scientific community and knowledge about ontologies themselves.

Two of the major strengths of METHONTOLOGY (Fernández-López et al., 1997) are the detailed explanation of the stages of the ontology building process contained in the methodology and its relative ease of use for users without a significant knowledge engineering background. An example of the detail provided in the methodology is the provision of four knowledge elicitation techniques that could be

used in the knowledge acquisition stage: non-structured interviews, informal text analysis, formal text analysis and structured interviews. Factors contributing to its ease of use were highlighted by Pinto and Martins (2004). They pointed to the inclusion of a relatively high level of guidance beneficial to inexperienced ontology builders, and the proposal that ontology building is done at the knowledge level (conceptualisation), rather than at the formalisation level or implementation level, at which greater knowledge engineering skills are necessary. They further reported that based on their own experience and the feedback they had obtained from ontology developers, inexperienced ontology builders selected METHONTOLOGY because 'it gave them more concrete guidelines as to what they must do in each stage'. Nonetheless, Pinto and Martins (2004) warned that the methodology might encourage a novice to give too much attention to the knowledge acquisition stages.

In a review comparing METHONTOLOGY with methodologies including Cyc, Uschold and King, Grüninger and Fox, and On-To-Knowledge, Corcho and Martins (2003) claimed that METHONTOLOGY was the most mature methodology in terms of its adherence to software engineering methodologies e.g. IEEE (IEEE, 1996b). They referred to a recommendation by the Foundation for Intelligent Physical Agents (FIPA) as evidence for this. A more compelling endorsement though, comes from its use in significant previous research in the domain, like that of Uschold and Grüninger (1996).

The METHONTOLOGY methodology is supported by the Web ODE tool for developing ontologies and integrating them into applications. WebODE was described by Arpirez et al. (2003). Other tools may also be used to support the ontology though, an assertion supported by Corcho et al. (2003).

### **On-To-Knowledge Methodology**

The On-To-Knowledge methodology was created for the development of ontology-based knowledge management systems (Staab et al, 2001). Consequently, the methodology is application dependent. That is, the process used to construct the ontology may be affected by the system in which it is to be used (Corcho et al, 2003).

Previous applications of the methodology are limited to CHAR, a knowledge management system for tracking and optimising corporate business histories. The

specific domain of this ontology was business strategy in the chemical industry (Staab et al, 2001).

A five-step ontology development process is ventured. The steps in this process are a feasibility study, a kick-off phase, refinement, evaluation and maintenance. Only an overview is provided of these steps. For the feasibility study, they recommend the approach taken in the CommonKADS methodology (Schreiber et al., 2000). Learning this formal methodology may well be challenging for novice ontology builders. However beyond this, little detail pertaining to the execution of the ontology development process is included.

On-To-Knowledge is supported by the OntoEdit tool (Sure et al., 2002) and so this should assist in the building of the ontology.

### **KBSI IDEF5 Method**

In the IDEF5 Method Report by Knowledge Based Systems, Inc., a section is included describing the IDEF5 ontology development procedure (Benjamin et al, 1994). The process consists of five activities: organising and scoping, data collection, data analysis, initial ontology development, and ontology refinement and validation.

It is advised in this report that ‘it is not prudent to adopt a “cookbook” approach to ontology development’. Therefore, rather than a set of step-by-step instructions, ‘a general procedure along with a set of useful guidelines’ is provided (Benjamin et al., 1994). In this sense then, the IDEF5 method is not entirely what is required here. It does however provide a tool for describing the purpose, viewpoint and context of the ontology, as well as summarising the documents used for recording the ontology. Advice is also given about what information elicitation techniques could be employed in the data collection activity. No data could be found about the ease of use of this process or specific ontologies built using the methodology. There is also no formal link to a particular ontology building tool.

### **Noy and McGuinness Methodology**

Noy and McGuinness (2001) described what they refer to as a ‘simple’ knowledge-engineering methodology for developing ontologies to model domains. The guidelines feature a process that consists of seven steps: determination of the domain and scope of

the ontology using competency questions, as in Grüninger and Fox (1995), the consideration of the reuse of existing ontologies, enumeration of important terms in the ontology, definition of classes and the class hierarchy, definition of the properties of classes, definition of the facets, where facets are the allowed values of the class properties, and lastly, the creation of instances.

The methodology has been utilised for the construction of ontologies in a variety of domains. Two recent examples are Sathiamurthy et al. (2005) and Kerr et al. (2004). Sathiamurthy et al. (2005) cited the methodology in the development of an ontology of immune epitopes, which was applied to a database of immune activities. In a domain closer to that of this research, Kerr et al. (2004) applied the methodology to the development of an ontology for an automotive car seat specification. This ontology was used as part of a knowledge-based requirements management tool.

Being among the most recent of the methodologies, this methodology builds on previous work in the domain. It exploits competency questions to determine the scope of the ontology after the methodology by Grüninger and Fox (1995). Additionally, it refers to the work of Uschold and Grüninger (1996) in advising on a suitable approach to develop a class hierarchy, e.g. as a top-down, bottom-up or combination approach.

The methods and techniques needed to carry out each step are described in some detail, albeit using examples that specifically refer to the Protégé ontology editing tool. This tool is a project developed by Stanford Medical Informatics, to which the authors of the methodology are affiliated. No guidance is provided on what methods and techniques might be used in the knowledge acquisition stages, e.g. the enumeration of important terms in the ontology.

Ontology development is carried out at the knowledge level, so that natural language terms can be employed to model the concepts in the domain of interest. Although a good deal of ontological engineering terminology is used, the difficulty this might cause a novice ontology builder is tempered by the provision of examples from an example ontology to help explain what these terms mean. Indeed, the methodology is presented in the style of a tutorial for ontology engineering novices.

As already mentioned, the Protégé Ontology editing tool may be used to support the methodology. One criticism of this methodology is that the ontology building

guidelines refer to specific features of the Protégé tool. Noy and McGuinness asserted that the methodology is designed for ontology development systems featuring a frame-based data model. Conceivably then, it could be applied using other frame-based tools such as Onto-Edit (Sure et al., 2002), Ontolingua (Farquhar et al, 1997) and Chimaera (McGuinness et al., 2000).

### **Stage 5: Selection of ontology building methodology**

None of the methodologies reviewed fulfil all of the criteria specified in section 6.2.2. While the methodologies have some common features, each approach is different. Corcho et al. (2003) attributed these differences to a lack of collaboration among the research groups developing ontologies and ontology building methodologies. Noy and McGuinness (2001) stated: ‘there is no single correct ontology for any domain’. They also remarked: ‘The potential applications of the ontology and the designer’s understanding and view of the domain will undoubtedly affect ontology design choices.’

With this in mind, the selection of a method will concentrate on the criteria relevant to the practicalities of this investigation, namely the detail with which the ontology is described, its ease of use and supporting tools, and its application to the building of other ontologies published in the literature.

The Cyc methodology is hampered by a lack of detail and is not supported by an ontology building tool. Similar criticisms may be levelled at the methodologies of Uschold and King, the IDEF method, Grüninger and Fox and Onto-Knowledge, although it is conceded that the latter two are supported by ontology building tools. METHONTOLOGY would seem to satisfy most of the requirements well, but warnings have been issued about the risk of it causing an inexperienced ontology developer to invest too much time in the knowledge acquisition phase of the ontology building process. Noy and McGuinness (2001) provided detailed, practical guidelines for the development of an ontology that are presented in a format and style aimed at ontology builders that do not possess a deep knowledge of ontology engineering. Moreover, it is supported by an ontology engineering tool and has been adopted by other researchers to build ontologies. The results of these efforts have been published in internationally peer-reviewed literature. Therefore, the Noy and McGuinness methodology was selected as the basis of the ontology building methodology for this investigation.

### **Stage 6: Identification and resolution of shortcomings in selected methodology**

A key shortcoming of the Noy and McGuinness methodology is the lack of a detailed description of the methods and techniques of the knowledge acquisition stage of the ontology lifecycle. This is also true of the other methodologies, with the exception of METHONTOLOGY and the IDEF 5 method. These methodologies propose what methods and techniques might be employed to elicit information from domain experts. What is missing from all of the methodologies is a formal method that offers an explicit definition of the information elicitation techniques and tools suitable for application in a firm practicing new product development.

In order to address this and other shortcomings, two adaptations to the generic methodology provided by Noy and McGuinness were required.

1. The second step of the Noy and McGuinness methodology ‘Consider reusing existing ontologies’ was removed. This is because the decision to build an ontology from scratch had already been taken (see Stage 1 earlier in this section).
2. More significantly, it was proposed that a modified version of the methods used in the investigation to identify knowledge in the new product development process, as detailed in section 5.6.2, should comprise the missing knowledge acquisition stage. The modifications to the investigation consist of the removal of questions in the questionnaire, as shown in Appendix H.

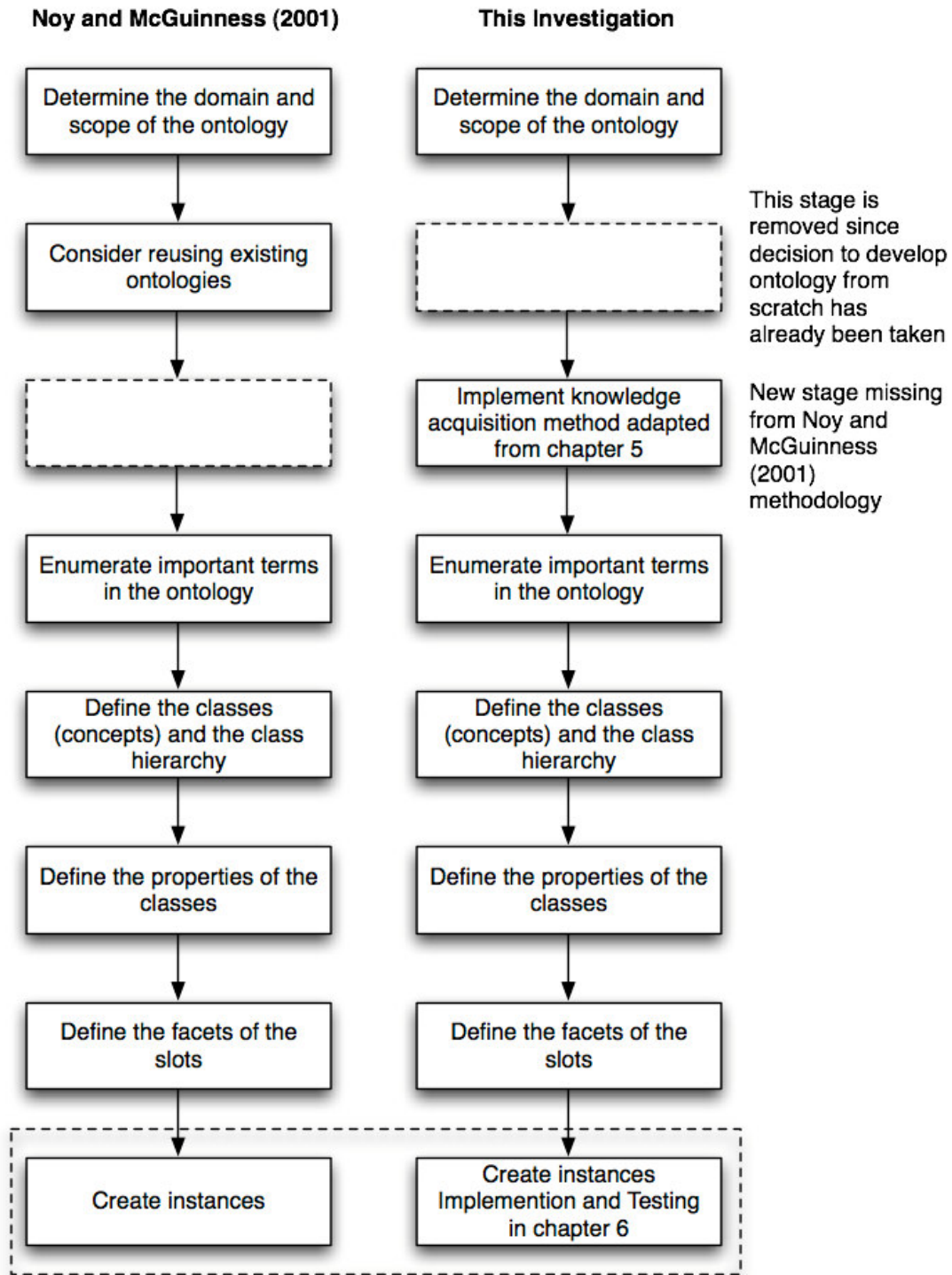


Figure 14: Comparison of the stages in the Noy and McGuinness (2001) ontology building methodology with those in the methodology provided for this investigation.

### **6.3 Summary**

A review was carried out of literature describing information technology-based knowledge management methodologies for NPD environments that in some way claim to facilitate knowledge sharing. It was found that none of the methodologies addressed all of the knowledge sharing barriers identified in chapter five. Subsequently, a review was conducted of information technology-based knowledge sharing technologies intended to provide an improved shared understanding of a knowledge domain. It revealed that an ontology-based tool approach could be adopted as the basis of a knowledge sharing tool that addressed the three knowledge sharing barriers. The ontology would be used to explicitly define information about NPD process knowledge.

An ontology-building methodology has been provided to build the aforementioned ontology. The methodology is an adapted version of that developed by Noy and McGuinness (2001). In doing so, it was identified that existing ontology-building methodologies all feature descriptions of knowledge acquisition stages that were either non-existent or that confined themselves to providing advice on which information elicitation techniques might be exploited. In the Noy and McGuinness (2001) methodology, this knowledge acquisition stage was entirely absent. Therefore, a refined version of the methodology used in the main empirical investigation for identifying NPD process knowledge, as described in chapter five, was proffered to address this shortcoming.

The findings presented in this chapter partially meet research objective four, as stated in chapters one and three.



## **7 Development of Prototype Knowledge Sharing Tool**

One objective of this research investigation was to develop a prototype method for reducing barriers to knowledge sharing in new product development (NPD). In chapter six, it was proposed that an ontology-based tool could be used to achieve this end. This ontology-based tool is essentially a knowledge base. Stanford Medical Informatics defined a knowledge base as a set of instances which may be used by Problem Solving Methods (Stanford Medical Informatics, 2000). In turn, a Problems Solving Method is ‘a computer program used in conjunction with a knowledge base to answer questions or solve problems’ (Stanford Medical Informatics, 2000). Here though, the knowledge base is not intended for use by computers, but rather by people, in order to answer questions they may have about NPD process knowledge.

Before proceeding any further, it is worth noting that when ‘knowledge’ is referred to in the context of a knowledge base, it is defined differently to knowledge in the sense of ‘NPD process knowledge’. Schrieber et al. (2000, p.85), remarked: ‘From a systems engineering point of view, knowledge is probably best seen a special type of information, namely “information about information’. They also stated, ‘A simple form of knowledge is incorporated in class hierarchies, which have become a common tool in data modelling’.

The knowledge sharing tool is made up of three modules. These modules are:

- (i) An ontology building and editing tool to construct and maintain the ontology and knowledge base.
- (ii) A knowledge base based on an ontology of NPD process metaknowledge, and mechanisms to support a multilingual environment and the prioritisation of NPD knowledge items.
- (iii) A mechanism to disseminate the ontology and knowledge base to geographically dispersed NPD project team members.

This chapter presents the development of these tool modules. It commences by describing the process used to select an ontology building tool. Following this, the method used to develop an ontology of NPD knowledge metaknowledge and

mechanisms to support a multilingual environment, assign a priority to knowledge items and disseminate the knowledge base to geographically dispersed NPD project team members, are described.

### **7.1 Selection of Ontology Editing Tool**

In the OntoWeb Consortium's survey on Ontology Tools, ontology development tools are defined as 'tools, environments and suites that can be used for building an ontology from scratch or reusing existing ontologies' (OntoWeb, 2002). Such tools may also, but do not necessarily, support other ontology lifecycle activities. These activities include ontology merging and integration, evaluation, annotation, storage and query, and ontology learning. Within this study, the terms ontology development tool and ontology building tool are both to be interpreted using the above definition.

In a recent survey, Denny (2004) identified ninety-four ontology-editing tools available for use by ontology builders. Analysing and testing all of these tools first-hand would be an arduous and time-consuming task. Over the last decade, several attempts have been made to review ontology-building tools using various criteria. Examples of such attempts include the comparative study of ontological engineering tools by Duineveld et al. (2000), the survey on ontology tools by the OntoWeb consortium (OntoWeb, 2002), a review of Ontology building tools by Corcho et al. (2003), an evaluation of ontology development tools for the bioinformatics domain by Lambrix et al. (2003), and the aforementioned survey by Denny (2004). Despite containing useful advice on these tools, these works are of limited use here for two reasons. Firstly, many of the tools covered have been updated in the intervening years, rendering the material pertaining to these tools out of date. Secondly, the criteria used to evaluate the tools are not necessarily relevant to this investigation.

Taking this into account, a four-step process was devised and followed to select an appropriate ontology-building tool. Step one was to use the published reviews and surveys to identify the tools recognised in the literature which appeared to be most suitable for the required application, thereby producing a shortlist of tools. Step two was to devise a set of selection criteria in order to provide a framework for evaluating the shortlist of tools. With the criteria in place, the tools could be evaluated and a final tool chosen; these activities were steps three and four respectively.

### 7.1.1 Tool Shortlist

Corcho et al. (2003) provided the most recent review of ontology building tools found in the literature, the work by Denny (2004) being both a Web-based article and a survey, rather than a review. Reviewing what they considered to be the eight 'relevant' ontology-building tools, Corcho et al. (2003) found that they could be broadly grouped into three categories of tools. The first category was the original generation of ontology building tools, which includes Ontolingua Server (Farquhar et al, 1997), Ontosaurus (Swartout et al., 1996) and WebOnto (Domingue, 1998). These tools are characterised as being 'isolated tools that did not require many extensibility facilities'. The generation of tools in the second category was developed to facilitate the integration of ontologies in information systems. Tools included in this category were Protégé 2000, now called Protégé (Gennari et al, 2003), Web ODE (Arpirez et al, 2003) and OntoEdit (Sure et al., 2002). Lastly, the third category featured tools for the development of ontologies for Semantic Web applications. OILEd (Bechhofer et al., 2001), which at the time of writing is longer maintained, and DUET (Kogut et al, 2002) were the tools included in this group.

Given that it was intended that the ontology would be used as the basis for a computer information system application, it was the tools listed in the second group that were selected for evaluation. The notion that these tools are key ontology development tools is reflected in the literature-based reviews of ontology building tools. Lambrix et al. (2003) regarded Protégé as a well-established tool, and the survey by OntoWeb included OntoEdit, Protégé and WebODE (OntoWeb, 2002). The earlier review by Duineveld et al. (2000) included both ODE (the predecessor to WebODE) (López et al, 1999) and Protégé. This would suggest that ontology builders have considered the tools in the shortlist to be significant tools for many years. Elements of OntoEdit have been incorporated into the KAON Ontology Framework (KAON) (Corcho et al, 2003; KAON, 2005b), while the OntoEdit tool itself has been superseded by the OntoStudio application (Ontoprise, 2007). Both KAON and OntoStudio were included in the tool shortlist in place of OntoEdit. All of these tools are suitable for developing a domain ontology.

### 7.1.2 Criteria for Selection of Ontology Building Tool

The criteria used to select an appropriate tool consisted of those used in the evaluation frameworks of previous reviews and surveys, as well as criteria specific to this particular study. Indeed, Denny (2004) remarked that an objective in selecting an ontology editor is ‘to maximise the match between its potential output (as ontology content and structure) and the character and dynamics of the particular domain problem space that your ontology is intended to address’.

Eight criteria were identified, which can be broadly divided into technical and pragmatic requirements. Technical requirements concerned those issues related to the development of the ontology itself, such as methodological issues and functionalities that might assist in the development of the various mechanisms. Pragmatic requirements referred to all those issues related to the practical constraints of the project e.g. the knowledge engineering expertise of the researcher, time and budget limitations, and the environments in which the tool must be developed and potentially used. Not all of the criteria were deemed to be of equal significance to the investigation and so they were divided into those of primary importance and those of secondary importance. The criteria are listed in Table 21, where they are sorted by type of requirement and importance. Requirements of primary importance were those that had to be met by the selected tool. Requirements of secondary importance addressed features that would be of great benefit in the context of the investigation, but were not essential. An explanation of each criterion follows.

**Support for an ontology building methodology:** In chapter five, section 6.2.4, it was mentioned that some ontology-tool building methodologies are formally supported by tools. A formal link between an ontology building tool and the selected methodology should ease the process of developing the ontology.

**Usability** was a key factor in the choice of ontology building tool. This was principally because the researcher had no experience of ontology building and wished to avoid spending a great deal of time learning how to use a new tool. Additionally, if the methodology used to build the tool were to be applied by domain experts, in this case NPD practitioners, it is unlikely that they would have a great knowledge of ontology engineering.

Importance	Requirements	
	Technical/Academic	Pragmatic
Primary	1. Support for Noy and McGuinness (2001) Methodology  2. Features to support the development of the mechanisms (extensibility)	4. Usability - Interface features - Perceived ease of use for non-experts 5. Hardware and software requirements  6. Support - Support from a community and developers - Tool upgrades - User documentation  7. Maturity and Stability
Secondary	3. Support for Ontology standards e.g. export to OWL and RDFS	8. Cost to obtain tool and license type

Table 21: Criteria for evaluating the ontology building tools.

As part of the survey conducted by Denny (2004), respondents were asked ‘What advancement in existing tools do you believe is needed most to improve our ability to build useful ontologies?’ The survey reportedly achieved a fifty-six percent response rate, but it was not stated explicitly that the developers of the ninety-four tools mentioned in the work were the survey respondents. It was found that the most desired feature was a higher-level abstraction of an ontology language construct. One reason given for this was that it facilitates the use of more intuitive knowledge expressions. The second most desired feature was that the tool affords easy navigation of the ontology, possibly exploiting a visual navigation interface.

Another aspect of usability considered here was the perceived ease of use by tool users, particularly those with little or no knowledge of ontology building. This might be enhanced by the tool user interface design or the provision of example ontologies. Duineveld et al. (2000), OntoWeb (2002), Lambrix et al. (2003), and Corcho et al. (2003) addressed aspects of usability in their evaluation framework.

**User Support:** For reasons similar to those given in the explanation of the usability criterion, the provision of support for the tool user was considered to be of great importance. Support in this context refers mainly to technical support either from the tool vendor, the tool developers, or the tool using community. However, it may also come from tool user manuals and other associated documentation.

**Support for Standards:** In recent years, a number of standard ontology languages have emerged, in part driven by the use of ontologies in Semantic Web applications. The World Wide Web Consortium (W3C), a major body in the development of Web standards, has advanced OWL as a formal language for representing ontologies (McGuinness and van Harmelen, 2004), alongside RDF and RDF Schema (RDFS) (Brickley et al., 2004).

Support for such languages is not considered to be crucial, as the intended output was an illustrative prototype tool, and not just the ontology. Any reuse of the ontology in subsequent applications though, would be assisted through the ability to export it to the standard ontology languages. The reviews of tools by Duineveld et al. (2000), OntoWeb (2002), and Corcho et al. (2003) included consideration of the ontology languages that the tools can import from and export to.

**Features to support development of mechanisms:** In section 7.1.1, it was mentioned that the shortlist of tools was drawn from a generation of ontology building tools intended to provide support for the integration of ontologies in information systems. Any features in the tools that might assist in the development of the multilingual support, knowledge prioritisation or dissemination mechanisms were considered to be highly influential in the choice of the tool. Such features might take the form of extensions and plug-ins for the tool, provided either by the tool developers or by third-party developers. Tool extensibility was an issue considered by OntoWeb (2002), Lambrix et al. (2003), and Corcho et al. (2003).

**Cost:** Given the limited financial resources available to the researcher, a limitation in selecting a tool was the financial cost of obtaining a license. Furthermore, although it was intended that the ontology and mechanisms should be built as an illustrative prototype, rather than for deployment in a real world environment, any subsequent use of the tool by the sponsoring company would be considered commercial

use by the tool vendor. This may necessitate the purchase of a commercial license. Avoidance of the costs associated with such a license would be favourable to both the researcher and the company. Nonetheless, this criterion was not considered to be of great importance. The pricing policy adopted by the vendor of each tool was included in the review by Corcho et al. (2003).

**Maturity and stability:** A stable development environment should help ease the ontology development process. Such behaviour is often, although not exclusively, exhibited by tools that have been in development for some years.

**Hardware and operating system support:** Only Microsoft Windows®, Apple Mac OS X® and Linux-based operating system environments were available to the researcher. Therefore the chosen ontology tool had to be compatible with one or more of these operating systems. Microsoft Windows XP® was used by the sponsor company.

### 7.1.3 Evaluation of ontology building tools

There follows an evaluation of the WebODE, Protégé, OntoStudio and KAON ontology building tools using the framework of selection criteria discussed above.

#### *WebODE*

WebODE is an environment intended to support the design, development and management of ontologies. It features an ontology editor (Arpirez et al, 2003) and uses a frame-based ontology model. The most recent stable edition of WebODE is version 2.09, which was released in November 2003. At the time of writing, no indication is provided of whether updates to the tool are in development.

Rather than being installed as a local client, WebODE is based on a Web server and is accessible via a Web interface. In the user manual available at the WebODE Web site, the developers specify Microsoft Internet Explorer® version 5.0 and the Java Web browser plug-in version 1.2.x as software requirements (Technical University of Madrid, 2003). Access to WebODE via the Web is free of charge (Technical University of Madrid, 2003). Ontologies developed in WebODE may be exported to RDFS, OIL, DAML+OIL, OWL, and UML, among others.

WebODE formally supports the METHONTOLOGY methodology, but may be used with other methodologies (Corcho et al, 2003).

Ontologies are represented in a form-based graphical user interface similar to Protégé, and modelled at the knowledge level, as opposed to being modelled in a formal language. All of these features should serve to enhance the usability of the tool, although no empirical evidence was found about the usability of WebODE. Support would appear to be limited to e-mail contact with the tool developers and documentation downloadable from the tool Web site in the form of a user manual. The user manual has not been updated since the year 2000. No example ontologies could be downloaded from the tool website, but references to ontologies developed using the tool are provided.

The Web-based nature of ontologies developed in WebODE mean that they could easily be disseminated via a Web browser. There do not appear to be any features to assist in the development of a multilingual support mechanism or a prioritisation mechanism.

### *Protégé*

Protégé provides a set of tools for the construction of ontology-based domain models and knowledge-based applications (Gennari et al, 2003; Stanford Medical Informatics, 2007c). It provides two models for developing ontologies; one is the Protégé-OWL editor tool (Knublauch et al., 2004; Stanford Medical Informatics, 2007f) and the other is the Protégé frame-editor tool (Stanford Medical Informatics, 2007e). The current stable edition of Protégé is version 3.2.1, released in December 2006, which is available for Microsoft Windows XP®, Apple Mac OS X® and Linux-based platforms. The Protégé client is installed locally. Protégé is covered by an open source-type licence and is free to download. Ontologies can supposedly be exported to RDF, RDFS, DAML+OIL, OWL, CLIPS and UML formats.

The documentation for Protégé (Stanford Medical Informatics, 2007b) does not formally link it with any of the ontology building methodologies. Nonetheless the Noy and McGuinness methodology, which was adapted for use in this investigation (see section 6.2.4), explicitly and exclusively refers to the Protégé editor in all the examples



it provides for implementing the methodology (Noy and McGuinness, 2001). Moreover, Noy has been involved in the development of the Protégé tool as an affiliate of Stanford Medical Informatics.

Lambrix et al. (2003) noted that Protégé has been designed ‘as an easy to use tool for knowledge extraction’. An evaluation of the tool was carried out by Lambrix et al., (ibid) which addressed usability issues such as tools to visualise the ontology and the complexity of the user interface. They praised the graphical, tabbed pane interface approach adopted by the Protégé tool. Indeed they noted: ‘This approach gives the user a good overview and feeling of control’ and the tool was ‘easy to learn’. It was criticised for the use of symbols incongruous with those found in the Microsoft Windows® user interface. Despite this it was concluded that the user interface was a notable strength of the tool.

Upon installation of a current version of the tool, a few years newer than that examined by Lambrix et al. (2003), it was established by the author that the interface had been further refined, but that some of the interface quirks remained. The use of the Protégé data model in both the frame-based and OWL tool interface provides a useful level of abstraction, although it is hardly trivial to learn.

Protégé remains in development. A user guide, in-tool help system and active support forums visited by the Protégé developers and users would seem to provide a prodigious level of support. It was found by Lambrix et al. (2003) that the example ontologies provided with the tool were considered to provide useful insights into the tool functionality.

No direct support is provided for multilingual ontologies. However, reference to the Protégé user support forums (Stanford Medical Informatics, 2007a) indicated that a level of multilingual support may be achieved by attaching natural language labels to concepts and relationships in the ontology. This applies to ontologies built in both the frame-based and OWL ontology language tools. The full version of the Protégé includes an application to display Protégé knowledge bases over a Web browser. In this way a foundation was available for the development of a dissemination mechanism.

### *OntoStudio/OntoEdit*

OntoStudio, developed by Ontoprise, is the current implementation of the OntoEdit tool and is intended for ontology building and the development of Semantic Web applications. Unlike the other tools in this survey, OntoStudio is a commercial product, although at the time of writing a three-month trial download is available for non-commercial use (Escórcio and Cardoso, 2007). Ontostudio uses a frame-based data modelling language called OXML to model ontologies.

The version of OntoStudio considered here (version 1.6, trial edition) runs on Microsoft Windows 2000® or XP®, and requires Java version 1.5.0 or better. Ontologies developed in OntoStudio can be exported in OWL, RDF, F-Logic and OXML. OntoEdit has been under development since 1999 (Sure et al., 2002), so it may be argued that the tool is relatively mature. No evidence could be found in the literature about the stability of OntoStudio, although no problems were experienced during the brief testing of the tool by the author.

OntoEdit supports the On-to-Knowledge methodology, as described by Staab et al. (2001). Notably though, there is no explicit mention of this methodology in the documentation accompanying OntoStudio. The OntoStudio user interface provides a hierarchical view of the ontology class structure, as well as the relations and attributes in the ontology. However, in the view of the author, the interface would prove to be complicated for a user with no background in ontology engineering.

User support is supplied in the form of two tutorials included with the tool. These provide a good overview of the tool interface as well as many of its more advanced functionalities, such as the F-Logic language used for reasoning. There appeared to be no links to user forums available on the vendor's Web site (<http://www.ontoprise.de>). Further professional support for OntoStudio is available from the vendor, but at a financial cost.

Like Protégé, OntoEdit features an extensible architecture that can make use of plug-ins. As Escórcio and Cardoso (2007) would have it, these plug-ins mainly provide functionality for Semantic Web applications. Further, none of the plug-ins seemed relevant to the development of the knowledge sharing mechanisms to be included as components of a knowledge sharing tool.

## *KAON*

KAON, the Karlsruhe Ontology and Semantic Web Tool Suite, is a collection of tools for ontology creation and management (KAON, 2005b). As the full length title of the tool suite would suggest, KAON is principally aimed at developing ontologies for Semantic Web applications. The main tool in the KAON suite for editing and building ontologies is OI-Modeler (Maedche and Staab, 2003).

KAON was superseded by KAON2 in 2005. The decision of what ontology development tool to use was taken prior to the release of KAON2. However, it would appear that the only notable difference between the two versions is that while KAON used a proprietary extension of RDFS as the ontology implementation language, KAON2 employs OWL-DL and F-Logic (KAON2, 2007).

The version of KAON considered here is version 1.2.9, released in November 2005 (KAON, 2005a). At the time of writing in 2007, there has been no activity in either the mailing lists or the forums on the tool download site (KAON, 2005a). KAON can be downloaded at no cost and in a version that runs on the Microsoft Windows® operating system. It is released under the GNU Lesser General Public License (LGPL) and requires the installation of Java version 1.4.0 or higher (KAON, 2005b).

No explicit connection is made to any ontology building methodology, despite the connection between OntoEdit and KAON.

No studies could be found in the literature that evaluated the usability of the tool, so the KAON suite was downloaded and installed for testing by the author. The OI-Modeler tool included with KAON allows the concepts, relationships and instances in an ontology to be viewed in the form of a tree-like graphic, achieved using the TouchGraph library (University of Karlsruhe, 2002; TouchGraph, 2007). It was the experience of the author that this graphical interface paradigm made it easy to navigate the ontology. In general though, the tool interface seemed complicated, compared to, say, the Protégé editor, and better suited to more experienced ontology developers than novices.

The main source of support for KAON is the documentation, which is comprised of manuals and handbooks. These provide useful guidance on learning the basic functionality of the OI-Modeler tool, but have not been updated since 2005. There

appear to be no links to user-community forums or mailing lists on the KAON website. The forum on the KAON download site at Sourceforge has had no new activity for some years (KAON, 2005a).

Possibly the most attractive aspect of KAON in the context of this investigation are features that would facilitate the development of the multilingual support mechanism and the dissemination mechanism. The lexical layer feature described in the OI-Modeler manual allows lexical entries, in this case language labels, to be created (University of Karlsruhe, 2002). For example, English, German and French labels could be assigned to a concept in the ontology. In this way a multilingual tool interface could be built. A component of the KAON suite called KAON portal, described by Bozsak et al. (2002), is a tool designed to allow the creation of multilingual Web site portals, which could assist in the development of a dissemination mechanism.

#### **7.1.4 Selected Ontology Building Tool**

Ultimately, both Protégé and KAON included functionality that appeared to be useful in the development of an ontology and knowledge sharing tool. However, KAON was hampered by a complicated user interface and more crucially, a lack of support beyond the tool documentation. Therefore, Protégé was chosen as the tool for building the ontology and ontology-based tool. Its main strengths were its link to the Noy and McGuinness (2001) ontology building methodology, its apparent ease of use and vibrant support community, and features that could be exploited to develop the multilingual environment support and dissemination mechanisms. In addition the software is available for use under an open source-type license as a free download and has software requirements appropriate to the application considered in this investigation. Having selected the ontology building tool component, the remaining components of the knowledge sharing tool could be addressed. These components will be described in the remaining sections of the chapter.

## **7.2 NPD Process Knowledge Metaknowledge Ontology and Knowledge Base**

This section describes the concepts used in the design of the ontology to be used as the foundation for a knowledge base. In section 7.1.3, it was established that the selected ontology building tool, Protégé, supported two approaches to modelling an ontology.

The first approach, Protégé-Frames, supports the building of frames-based domain ontologies (Stanford Medical Informatics, 2007e). It implements a knowledge model compatible with the Open Knowledge Base Connectivity (OKBC) protocol, as outlined by Noy et al. (2000). Briefly summarised, the OKBC protocol facilitates access to knowledge bases in knowledge representation systems (Stanford Medical Informatics, 2007b). Ontologies created according to the Protégé knowledge model are comprised of ‘a set of classes organised in a subsumption hierarchy to represent a domain’s salient concepts, a set of slots associated to classes to describe their properties and relationships, and a set of instances of those classes - individual exemplars of the concepts that hold specific values for their properties’ (Stanford Medical Informatics, 2007e).

Stanford Medical Informatics (2007b) listed steps that lead from the construction of an ontology, through to the establishment of a knowledge acquisition tool, the creation of a knowledge base, and the execution of applications. These steps are depicted in Figure 15 and mentioned at the start of this chapter. All of these steps can be executed via the Protégé-Frames tool interface.

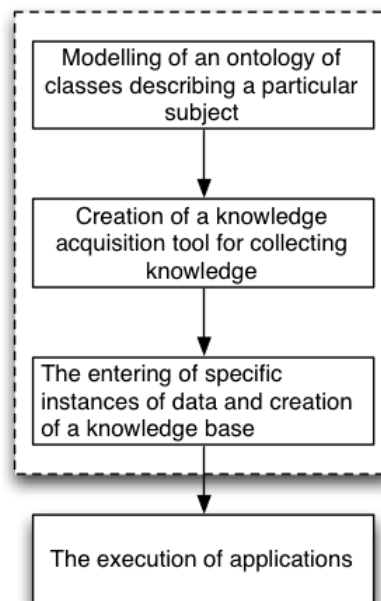


Figure 15: Process for the development of a knowledge base (enclosed by dotted line). Based on steps described by Stanford Medical Informatics (2007b).

The second ontology-modelling approach is made possible by the Protégé OWL editor. This is an extension of the Protégé tool that supports the Web Ontology Language (OWL), a standard ontology language promoted by the WC3 for use in the Semantic Web (McGuinness and van Harmelen, 2004). To this end, Knublauch et al. (2004) stated that the aim of the extension was to provide features for the development of Semantic Web applications.

Like Protégé Frames, ontologies built in OWL are composed of classes, properties (analogous to slots) and instances. Unlike Protégé-Frames though, the Protégé-OWL extension is not frame-based and instead uses Description Logic, a formalism for representing knowledge described by Baader et al. (2003), as cited in Knublauch et al. (2004). An example of a difference between the two models is the representation of the relationship between classes, as identified by Knublauch et al. (2004). Classes in the Protégé model are linked by hierarchical superclass and subclass relationships. Classes in the OWL model are related by two kinds of conditions: 'necessary' and 'necessary and sufficient'. Horridge et al. (2004) gave an explanation of both of these conditions. A necessary condition stipulates that for an individual to be a member of a given class, it has to satisfy that condition, although that satisfying that condition alone may not be sufficient for it to actually be a member. If a condition is defined as necessary and sufficient for membership of a class, then any individual that satisfies that condition must be a member of that class.

As is the case with its Protégé-Frames counterpart, Protégé-OWL includes a graphical user interface to edit ontologies. However, Knublauch et al (2004) highlighted that it also provides access to description logic (DL) reasoners. Reasoners can be used to assess whether one class in the ontology is a subclass of another and thereby infer new class hierarchies, as detailed by Horridge et al. (2004). This issue will be pursued further in the discussion of the prioritisation mechanism in section 7.3.2.

It will be seen that the Protégé-Frames and Protégé OWL approaches each enable the use of different functionalities, and it was not clear prior to the design and development of the multilingual support and prioritisation mechanisms which approach would be employed here. As a result, the final decision on whether to model the

ontology as a frame-based ontology or an OWL ontology will be given following the discussion of the various mechanisms (see section 7.3).

### **7.2.1 Development of the Ontology**

Development of the ontology was carried out using version 3.11 of the Protégé tool. At the time of writing this is no longer the current version of Protégé tool, but the ontology has been successfully loaded in more recent versions of the tool, i.e. Protégé 3.2.

Previous versions of the tool are available at the Protégé download Web site. The Protégé-Frames editor was selected to build the initial version of the ontology. This was because the examples provided in the Noy and McGuinness (2001) guidelines adapted for building the ontology are based on this version of the tool. The tool provides facilities to export Frame-based ontologies to the OWL format. This meant that even after building the initial ontology it would still be possible to exploit the special features of OWL, should they have been required in the development of the multilingual support and prioritisation mechanisms.

#### **7.2.1.1 Determination of the domain and scope of the ontology**

Noy and McGuinness (2001) ventured four questions that must be answered when setting out to build an ontology:

- ‘What is the domain that the ontology will cover?’
- ‘For what are we going to use the ontology?’
- ‘Who will use and maintain the ontology?’
- ‘For what types of questions will the information in the ontology provide answers?’

The first three of these questions can be answered immediately. The domain of the ontology is information about NPD process knowledge. Its purpose is to serve as the foundation of a knowledge base that will answer questions that globally dispersed NPD project team members might have about NPD process knowledge. Potential users of the ontology are the members of NPD project teams, including project leaders, engineers and other project roles. Beyond this, users may also include any parties with an interest in NPD process knowledge management. The maintenance of the ontology is a more

contentious issue. Domain experts, such as project leaders and sub-process owners, in combination with information technology (IT) experts, are proffered as the best choice of roles to maintain the ontology and to add instances to, or edit instances in, the knowledge base. While the latter two tasks are likely to be within the aptitude of these experts, if not their available time, the former maintenance task would require some understanding of ontology engineering.

In section 5.5.2, examples were provided of the explicit information about knowledge or metaknowledge that may be unavailable to NPD process practitioners. Examples included the (a) knowledge inputs and outputs for NPD process tasks, (b) the location of knowledge, and (c) information about experts with knowledge pertinent to a given task. These were used to assist in the formulation of competency questions, which are required to address the fourth question posed by Noy and McGuinness (2001). Possible competency questions to provide the aforementioned items of information about knowledge are:

- a. What are the knowledge inputs and outputs for a given task?
- b. Where is a piece of knowledge (a knowledge item) located?
- c. Who possesses expert knowledge for a task?

Acknowledging that these questions alone were unlikely to account for all of competency questions that an NPD process user might ask, an investigation was undertaken to provide a more comprehensive set of competency questions. Rather than attempting to directly formulate competency questions, the investigation focused on gaining a more detailed understanding of what metaknowledge was of interest to NPD practitioners.

This was achieved in three stages. In the first stage, the five 'W's and one 'H' (who, what, where, why, when and how) approach of journalistic enquiry was applied, in order to determine the basic information a user may wish to know about a knowledge item. In the second stage, the information for a knowledge item was compared to the metadata element set proposed by the Dublin Core Metadata Initiative (2004), as well as a version of this set proposed by Donnellan and Fitzgerald (2003), to create a prototype set. The Dublin Core Metadata Element Set is a vocabulary of fifteen properties for use in resource description and is intended to be applicable to describing a broad range of



resources. Donnellan and Fitzgerald (2003) provided an adapted version of the Dublin Core Metadata Element set for use in an NPD knowledge management application.

In the third stage, the prototype metaknowledge element set was placed on a mind-map and presented to four NPD project leaders in the company. The project leaders were asked two questions: (1) whether they felt any of the metaknowledge elements were unnecessary, and (2) what metaknowledge was missing. Following this the requested adjustments were made to the prototype metaknowledge set. The resulting list of metaknowledge elements and the corresponding competency questions for knowledge items are included in Table 22.

<b>Description of Metaknowledge for Knowledge Items</b>	<b>Corresponding competency question</b>
Languages in which item is available	In what language is the knowledge item?
Is an output from task	What task generated the knowledge item?
Knowledge contributions from previous projects	What contribution was made to this knowledge item in a previous project?
Functional domain to which knowledge item belongs	To what domain does the knowledge item belong?
Knowledge item medium	In what medium is the knowledge item? E.g. Excel spreadsheet, verbal communication.
Other versions of knowledge item	What other versions of the knowledge item are there? E.g. other revisions of the document
Owner of knowledge item	Who is the owner of the knowledge item?
Repository in which knowledge is stored	In what repository is the knowledge item stored?
Description of knowledge item	What is a brief description of the knowledge item?
Format of knowledge item	What format is the knowledge item? E.g. report, meeting minutes, advice
Location of knowledge item	Where is the knowledge item located? E.g. country, manufacturing site
Title of knowledge item	What is the title of the knowledge item
Is an input for task	For what tasks is the knowledge item an input?

Table 22: Metaknowledge elements and competency questions for knowledge items.

### 7.2.1.2 Enumeration of important terms in the ontology

Enumeration of the important terms in the ontology entails capturing the terms related to the domain of interest that must be explained to the ontology user. No attempt was made at this stage either to classify the terms or to determine the relationships among them. The aim, as dictated by Noy and McGuinness (2001), is to obtain ‘a comprehensive list of terms’. Terms were mainly elicited from the metaknowledge set, the competency questions, and through brainstorming, as recommended by Uschold and Grüninger (1996). A selection of the terms may be found in Figure 16.

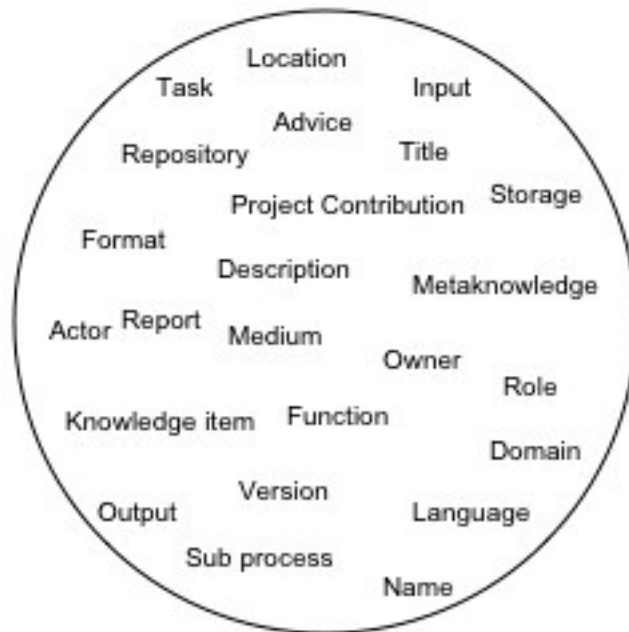


Figure 16: Some terms related to information about NPD knowledge.

The list of terms serves a starting point for the subsequent steps involving the definition of classes and class hierarchy, and definition of the class properties. Noy and McGuinness (2001) warned that these next steps are difficult to perform separately. Indeed, this was the experience of the researcher, and it was found that the steps form an iterative loop that could only be considered closed when all the competency questions could be answered.

### 7.2.1.3 Definition of the classes and the class hierarchy

Uschold and Grüninger (1996) described three approaches to defining classes and a class hierarchy: bottom-up, top-down and middle out. Bottom-up means starting by defining the most specific terms in a domain and moving towards more abstract terms. They identified three problems with this method. Firstly, it involves a good deal of effort, secondly, it can obscure commonality between related concepts, and thirdly it increases the chance of a lack of consistency in the ontology, which means rework would be required. Top-down, in contrast, involves moving from abstract terms to increasingly specific terms. In this approach Uschold and Grüninger (1996) warned that a danger is that high-level terms are defined on an arbitrary basis, contributing to a lack of stability in the resulting model. Again, effort must be applied to fix these problems. For the middle-out approach, termed ‘combination’ by Noy and McGuinness (2001), the fundamental terms for a given subject are defined, followed by the more specific and more abstract terms. Since the specific concepts are derived from these fundamental terms, less work is required than with the bottom-up approach. Similarly, the more abstract, higher-level concepts are defined in terms of these fundamental terms, so the risk of instability inherent in the top-down approach is reduced. The middle-out development process was recommended by Uschold and Grüninger (1996) and was adopted in this work. The NPD knowledge metaknowledge domain concepts resulting from executing this process were divided into four groups.

**Group one** is the knowledge generated or required by NPD process tasks, which are represented by the ‘knowledge item’ concept. In line with the definition of knowledge provided by Davenport and Prusak, knowledge might be embedded in items such as documents, processes or practices (Davenport and Prusak, 1998).

**Group two** contains various metaknowledge concepts, e.g. the format of the knowledge item (a report or perhaps advice from a colleague) or the repository in which it is stored (information system or human).

**Group three** encompasses concepts that relate to information about the NPD business process itself, that is, the tasks and sub-processes that make up the process. It will be seen later on that this last group forms an important reference point for users of the tool.

Finally, **group four** contains concepts that are related to the metaknowledge concepts, but cannot by themselves be described as knowledge item metaknowledge. Examples include the ‘Actor’ class, which describes people or computer information systems acting as knowledge item brokers. Instances of this class might be linked to instances of the ‘Knowledge Item’ class, in the capacity of ‘knowledge item owners’, or to the ‘Location’ class, to explain where the Actor is located.

A high-level view of the taxonomy devised for the NPD process knowledge metaknowledge ontology is depicted in Figure 17. A description of every class in the ontology is provided in Appendix M.

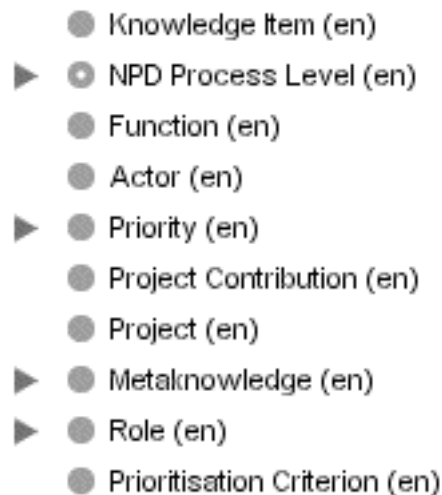


Figure 17: The taxonomy used as the basis of the NPD process knowledge metaknowledge ontology. Note that the ‘(en)’ suffix indicates that the class labels are in the English language. The full taxonomy of classes is given in Appendix M.

#### 7.2.1.4 Definition of class properties - slots

Class properties, known as slots in the Protégé knowledge model (Noy et al., 2000), were created for each of the classes described in Appendix M. Properties used were predominantly of two types: ‘extrinsic’ and ‘relationships to other individuals’, as defined by Noy and McGuinness (2001). Examples of an extrinsic slot are the description of a knowledge item or the title of a task. Relationships to other individuals

are those that link a class to other classes or instances of other classes. In practice, this meant that a 'relationship' must be created in the ontology for each element of metaknowledge and assigned to the 'Knowledge Item' and 'NPD Process Task' concepts. The relationships created for each class along with a description of their purpose are listed in Appendix N.

It should be noted that the definition of the classes and class hierarchy, and the definition of slots, collectively make up the conceptualisation stage of the ontology development lifecycle described by Pinto and Martins (2004) (see section 6.2.3). Since these activities were both carried out solely by the author, the resulting conceptualisation is not a 'shared' one. This means that the resulting ontology does not strictly conform to the definition of ontology provided by Studer et al., (1998) discussed in section 6.1.2.2.

#### **7.2.1.5 Definition of the facets of the slots**

Once the slots had been determined, the slot facets were defined. Slot facets set the allowed values and the value types of a slot. So an extrinsic slot such as the title of a task would have a slot type 'string' to allow text to be entered. A relationship between a class and the instances of another class, say the 'has\_input\_knowledge\_item' slot between the NPD process task class and the knowledge item class, would be set to the type 'instance'. The cardinality or number value of this slot was set to multiple, since a task might require many input knowledge items. Again, the slot type and values for each slot are specified in Appendix N.

#### **7.2.1.6 Create instances**

In order to use the ontology as the foundation for a knowledge base, instances of the classes must be created. For example, an instance of the 'knowledge item' class might be the 'how and whys' of a decision taken in a stage-gate review meeting. Through the creation of class instances, knowledge used in the NPD process and information about that knowledge can be added to the knowledge base, providing answers to the kinds of questions posed earlier in this section. This principle is illustrated in Figure 18. In the Protégé ontology editor tool, creating an instance of a class results in the creation of a form that includes the slots assigned to that class. The values for these slots must then

be chosen; slots assigned to the knowledge item class would point to the instances of the ‘NPD Process Task’ class and to instances of the various metaknowledge classes.

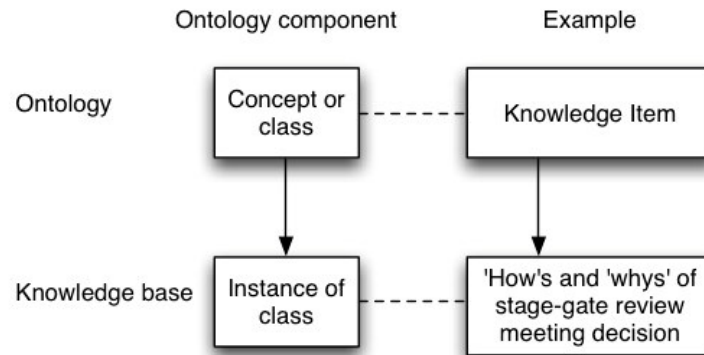


Figure 18: The relationship between classes and instances, accompanied by illustrative examples.

At this stage, not all of the instances could be added, since information had not been collected about the knowledge items required for, and generated, by specific tasks in the NPD process. However, certain types of instance could be added immediately. These were instances of classes for which evidence had already had been gathered, which included the ‘Knowledge Repository’, ‘Knowledge Domain’, ‘Knowledge Item Format’, ‘Language’ and ‘Knowledge Medium’ classes.

Instances, for example tasks and knowledge items, were added in the validation stage of the research presented in chapter eight, thereby creating a knowledge base.

### 7.2.2 Overview of Resulting Knowledge Acquisition Tool

The interface of the resulting ontology-based knowledge acquisition tool in the Protégé Editor is shown in Figure 19. The left-hand pane of the application window displays the ontology class hierarchy. This hierarchy serves as the first point of reference for exploring the ontology.

Once instances of real NPD tasks and knowledge items had been added to the tool to create a knowledge base, it was envisaged that a process user would navigate the instances of tasks relevant to their role in order to discover information about pertinent knowledge items. The NPD business process provides a common reference point

because it is used by all the functions participating in an NPD project. Indeed, the class hierarchy representing the NPD process itself constitutes the backbone to the tool. A project team leader or project manager on the other hand, may wish to understand the significance of a given knowledge item within the process and seek information such as what tasks require or generate that knowledge. In this case, they may search for a knowledge item directly and see which tasks contribute to the creation of that item, and which tasks are dependent on it. The tool interface, including the ways in which it could be used to answer the ontology competency questions referred to in section 7.2.1, is discussed in greater detail in chapter eight.

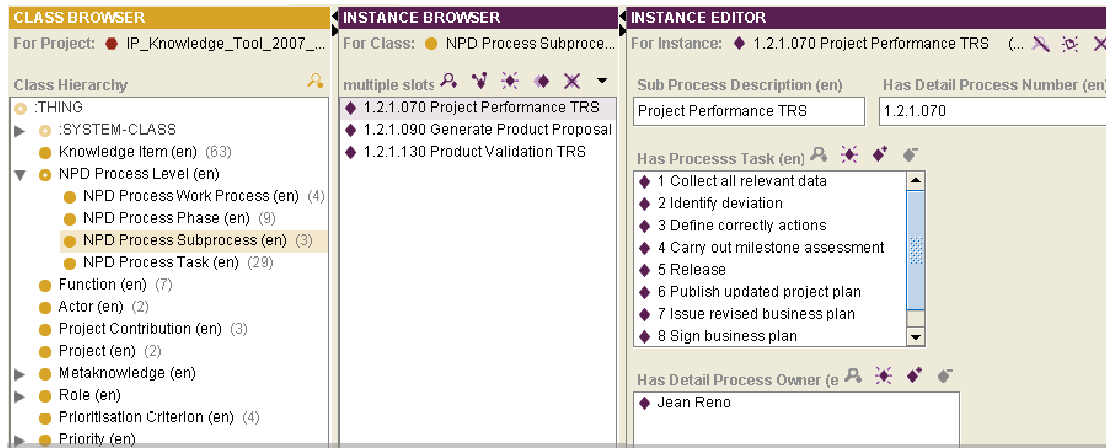


Figure 19: Knowledge acquisition tool interface in Protégé Editor.

### 7.2.3 Degree to which Ontology May Be Considered Generic

It is maintained that certain components of the ontology are generic to manufacturing firms conforming to the following requirements:

- The NPD business process conforms to the generic stage-gate-type NPD models found in the literature; and
- Products developed using the process are new product platforms or modifications to existing platforms.

All of the super-level classes are considered to be generic, since they are not specific to the case study company. The same goes for the subclasses of the 'Metaknowledge' superclass. This claim cannot be made for the subclasses of the NPD Process Level class. This because they reflect the sub-process hierarchy of the case study company NPD business process.

As might be anticipated, a lesser claim can be made for genericity at the instance level, since this is the most specific level of the ontology. Instances of the 'Knowledge Item' class are specific to a given NPD process. The same goes for instances of the 'NPD Process Task' class, 'Function' class, 'Actor' class, 'Project Contribution' class, 'Role' class and 'Location' class. The situation is not so clear for instances of the 'Metaknowledge' class subclasses. It is argued that instances of the 'Knowledge Domain', 'Knowledge Item Format', 'Knowledge Repository', 'Knowledge Item Medium' and 'Language' classes may well be valid in other product development processes, but it cannot be claimed that they are comprehensive. That is, some instances may need to be added to meet the specific needs of different NPD environments.

### **7.3 Provision of Multilingual Support, Prioritisation and Dissemination Mechanisms**

This section describes the methods used to provide support mechanisms to address three knowledge sharing issues:

- A mechanism for supporting multilingual NPD project teams
- A mechanism for prioritising knowledge used in the NPD process
- A mechanism to support the dissemination of information about knowledge, or metaknowledge, used in the NPD process

#### **7.3.1 Method for the Development of a Multilingual Support Mechanism**

In section 6.1.2.2, it was established that the literature describes two ways of using an ontology to support a multilingual environment. One technique is to model the domain concepts in a single language ontology and then to map key words from the required languages to the appropriate concept in the ontology. The other technique is to develop an ontology for each language required, along with an alignment layer to map one ontology on to another. It was also noted that there are several disadvantages to this



second technique, among them the significant time and labour require to map the ontologies, and the possibility of creating a product that is difficult to update and maintain. Furthermore, it is intended for use in natural language processing applications, which is not the domain of interest in this investigation. Therefore, the first technique was adopted for the development of a multilingual support mechanism.

Two approaches were investigated for the development of this mechanism, one using features of the Protégé-Frames knowledge model, and the other using the Protégé-OWL model.

### **7.3.1.1 Approach 1 – Protégé-Frames**

An important feature of the Protégé knowledge model is its use of metaclasses. Noy et al. (2000) described a metaclass as ‘a template for classes that are its instances’. That is, it determines the ‘own slots’ a class will have. Own slots are properties of that class, as opposed to properties of the instances of that class. Classes in Protégé are instances of a metaclass called ‘STANDARD CLASS’, which contains slots such as the name of the class and documentation for the class. When a class is created, the slots of the metaclass become ‘own slots’ for this class.

In the tool user interface, the name displayed by default for each class is the ‘:NAME’ own slot for that class. Similarly, the display name for slots themselves is assigned to a slot called ‘:NAME’, which is attached to the ‘:STANDARD-SLOT’ metaclass. Protégé provides the facility to create a subclass of a metaclass, to which new slots can be added. These new slots become own slots for classes created as instances of such a subclass. It will be seen that that this is the functionality that will be exploited to build a multilingual support mechanism.

It has already been mentioned that one way of adding multilingual support to an ontology is to map word keywords from the desired languages to concepts in an existing single language ontology. There is little literature describing formal methodologies for the development of such ontologies using ontology building software tools. However, Noy (2005) proposed informal guidelines for adding natural language labels to concepts in ontologies built using the Protégé ontology editor. It is these guidelines that formed the basis of the method described below.

The method for adding multilingual support to the tool consisted of four main steps, as shown in Figure 20. There now follows a detailed description of each of these steps, which were carried out using the frame-based version of the Protégé ontology editor.

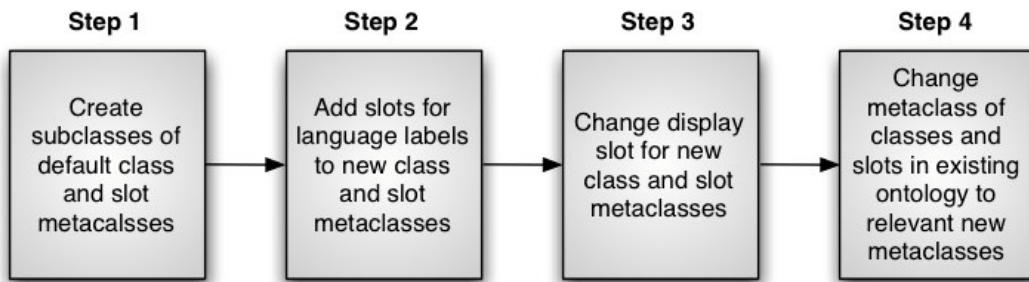


Figure 20: Method for the addition of multilingual labels to an ontology, based on Noy (2005).

**Step one** involved the creation of a new subclass of the ‘:STANDARD-CLASS’ metaclass and of the ‘:STANDARD-SLOT’ metaclass. This new subclass would act as a template to which new slots could be added.

**Step two** consisted of adding a slot to the new metaclasses for each of the required languages. The slot type was set to ‘string’, so that the appropriate language label could be added to classes or slots that are instances of their respective metaclass. Each slot was named so as to indicate which language label it should contain, as shown in Figure 21. Slots were also added for synonyms, in order to support potential variations in vocabulary among the different disciplines involved in NPD project teams, although this was not the principle purpose of the mechanism.

Template Slots		
Name	Cardinality	
english_label	single	String
english_synonym_label	multiple	String
german_label	single	String
german_synonym_label	multiple	String

Figure 21: Language slots featured in the for newly created metaclass form.

The aim of **step three** was to change the text displayed in the tool interface for classes and slots to the desired language. This was achieved by selecting each of the new metaclasses in turn and using the Protégé Form Editor tool to remove the 'NAME' slot, which is displayed by default. Following this, the required language label slot was selected in the 'Display Slot' list; see Figure 22.

**Step four** consisted of selecting each class and slot in the ontology and changing the assigned metaclass from the standard class to the respective new class and slot metaclasses created in step one. This was done using the 'Change Metaclass' function.

The test of the proposed method indicated that it could be successfully implemented to create a mechanism that allows the ontology-based knowledge-sharing tool to support a multilingual environment. However, the method has two important limitations.

Firstly, while new metaclasses featuring slots for language labels can be created using the default class and slot metaclasses, the same approach cannot be applied to instances created from classes. For certain classes in the ontology, such as the 'Actor' class, an instance of which might be the name of an individual, this issue is unimportant. Other classes though, like the 'knowledge item' class, have instances with descriptive phrases that are not language agnostic. One approach to tackling this problem would be to add description slots directly to classes, but this would require the user to manually browse the knowledge items or process tasks. Secondly, adding labels to all of the classes and slots is time intensive, although much of this work is a one-off task, since it is not anticipated that the core ontology will be subject to frequent change on a large scale. Any changes that do occur are more likely to be minor, such as the addition of new instances of knowledge items or process tasks.

It should also be acknowledged that the tool may not support languages that are not incorporated into the Unicode character set (Unicode, 2007).

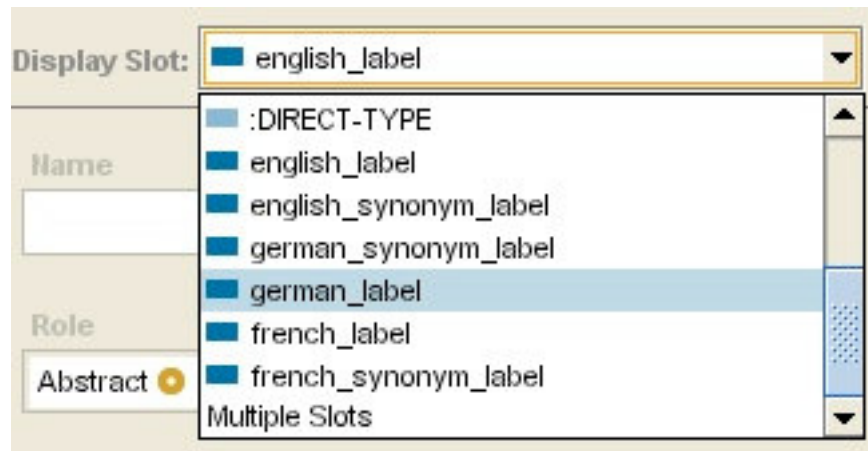


Figure 22: Selection of required language label slot in the Protégé Form Editor.

### 7.3.1.2 Approach 2: Multilingual labels in OWL

An approach analogous to that used in Protégé-Frames is feasible in Protégé OWL. As with Approach 1, the Protégé metamodel is exploited. This metamodel was extended by the Protégé developers to deal with OWL, as documented by Knublauch et al. (2004). There are three versions of OWL, which are OWL Lite, OWL DL and OWL Full (McGuinness and van Harmelen, 2004). Of the three, only OWL Full includes metaclass support and so ontologies developed in OWL that make use of metaclasses are of the OWL-Full type. OWL extends RDF Schema or RDFS which itself contains metamodel classes and properties. A property from RDFS of particular interest to this study is the 'rdfs:label' property, which the W3C defined as providing a human readable version of a resource name (Brickley et al., 2004).

Once again, practitioner guidelines were adopted to provide a method for adding natural language labels to the classes and relationships in the ontology, this time based on guidelines for hiding identifiers of classes and relations outlined by Dameron (2006).

A four-stage process was followed to add language labels to classes and relationships in an OWL version of the NPD process knowledge ontology. In this case, the ontology was a simplified version of that used in the previous approach, since at this point it was only required for illustrative purposes. Adding labels to all of the classes

and properties in the ontology had proved to be a lengthy task. The process steps are illustrated in Figure 23. Each of the steps in the process will now be described.

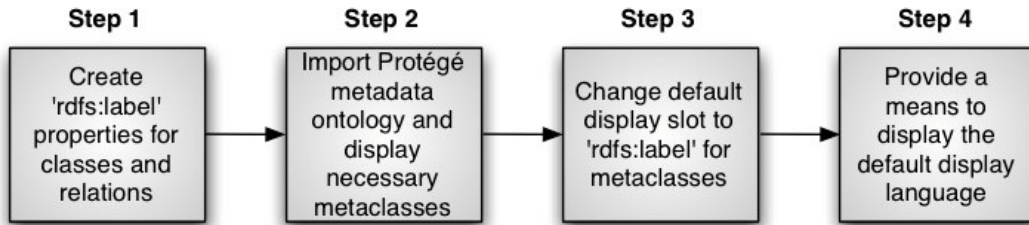


Figure 23: Method for the addition of multilingual labels in Protégé OWL, based on Dameron (2006).

**Step one** was to create an annotation property of the type ‘rdfs: label’ for every class and relation in the ontology, as depicted in Figure 24 and Figure 25. A separate annotation property was created for each language required. The value of a given property was filled in with an appropriate natural language label for its class or relation, and the language ‘lang’ attribute was set to the appropriate language, e.g. ‘en’ for English and ‘de’ for German.

Property	Value	Lang
<input checked="" type="checkbox"/> rdfs:label	Knowledge Item (en)	en
<input checked="" type="checkbox"/> rdfs:label	Wissenslement (de)	de

Figure 24: Annotation properties for the ‘Knowledge Item’ class, representing English and German language labels (‘en’ and ‘de’ respectively).

Property	Value	Lang
<input type="checkbox"/> rdfs:label	is knowledge item for	en
<input type="checkbox"/> rdfs:label	ist Wissensenelement für	de

Figure 25: Annotation Properties for the ‘isknowledgeitemfor’ slot, representing English and German language labels (‘en’ and ‘de’ respectively).

In **step two**, the Protégé metadata ontology was imported into the test ontology. As its name suggests, this metadata ontology enables the creation of ontology metadata, as is required here. A more detailed explanation of the metadata ontology was offered by Supekar (2005). Following this, the ‘owl:Class’ and ‘rdf:Property’ metaclasses were made visible in the Protégé-OWL interface using the OWL plug-in preferences tool, exactly as specified by Dameron (2006).

**Step three** consisted of ensuring that one of the newly created language labels was displayed rather than the default concept name ‘:NAME’; see Figure 26. As in Approach 1, the forms editor, this time in the Protégé-OWL plug-in, was utilised to change the displayed slot for the ‘owl:Class’ and ‘rdf:Property’ metaclasses from ‘:NAME’ to ‘rdfs:label’.

The aim of **step four** was to provide a means to set which of the language labels is displayed in the interface. Closely following Dameron’s process, a new annotation property of the type ‘protege:defaultLanguage’ was created in the OWL plug-in metadata tool, as illustrated in Figure 27. The value of this property should then be filled in with desired language label for the classes and relations displayed in the tool interface, e.g. ‘en’ for English, ‘de’ for German, or ‘fr’ for French.

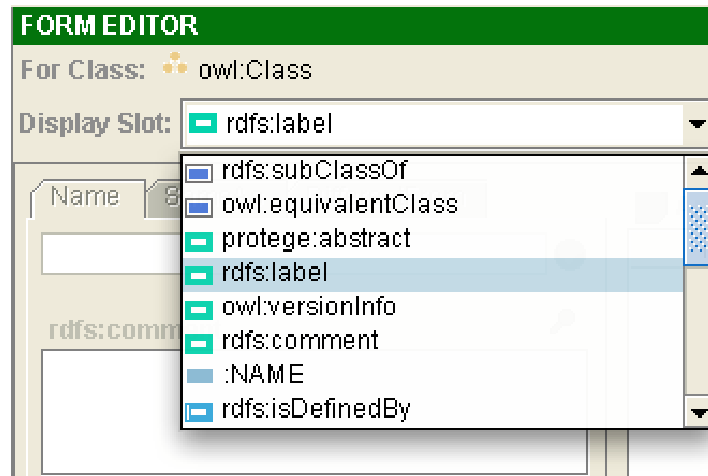


Figure 26: Selection of rdfs:label as display slot for owl:Class meta-class in Form Editor.

Property	Value	Lang
protege:defaultLanguage	de	

Figure 27: Creation of the protege:defaultLanguage annotation property in the metadata tool. In this example, German, 'de', has been selected as the default language.

The limitations for this approach are identical to those of Approach 1. Firstly, the labels can only be used with classes and relations, and not with instances. Secondly, it is time consuming to add properties to every class and relation. Thirdly, the tool may not fully support languages that do not use the Latin or Roman alphabet. Nonetheless, it arguably provides a more elegant solution than the Protégé-Frames approach.

Both approaches appeared to provide an effective mechanism for presenting the classes and slots (or relations) in different languages. However, the final choice of mechanism was reserved until the investigation of methods for the development of a prioritisation mechanism had been carried out, as outlined in section 7.3.2.

### 7.3.2 Prioritisation Mechanism

The aims of the prioritisation mechanism were firstly to provide a means of indicating the priority of a given knowledge item and secondly to provide a way to assign criteria to each priority level. For example, it might be decided by a company that their main strategic goal was to focus on product quality. In this case, it may be desirable to assign a 'high' priority to all knowledge related to Quality matters and indicate this to NPD project team members. Two different approaches, one executed in Protégé Frames and the other in Protégé-OWL, were investigated.

#### 7.3.2.1 Approach 1: Protégé-Frames

This method involved four key stages. Stage one involved the creation of a class named 'Priority', with subclasses representing the desired 'priority levels', as shown in Figure 28. Here, three priority levels were created: low, medium and high. A symbol was assigned to each level using a slot of the string type, to quickly indicate the knowledge item priority to users. Low priority items were assigned a single star ('\*'), medium priority knowledge items with two stars ('\*\*') and high priority items were indicated with three stars ('\*\*\*').

Stage two consisted of creating a new class to represent the criteria by which the knowledge items are to be prioritised. This class was named 'Prioritisation Criterion'. In this example, four criteria were created as instances of the 'Prioritisation Criterion': class: function, time, cost and quality (see Figure 29). A slot was created to link these instances to the desired priority level.

Finally, stage three involved opening the form for a given knowledge item and selecting the criterion that best describes that knowledge item. The form editor was used to ensure that the symbol for the appropriate priority was displayed next to the criterion, as illustrated in Figure 28.

The classes and slots that make up the Protégé- Frames knowledge prioritisation mechanism are listed in Table 23.



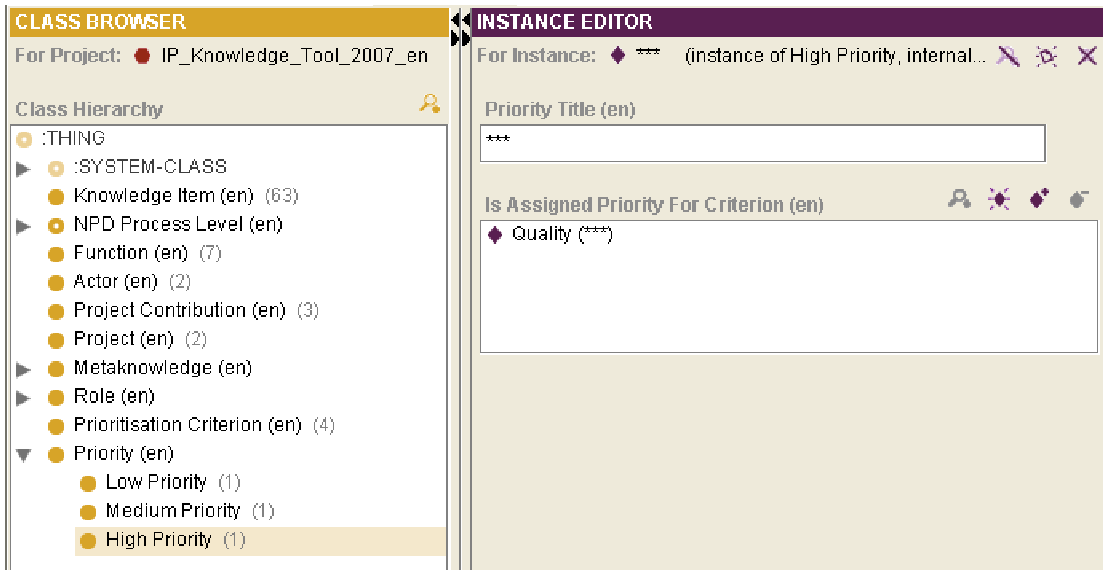


Figure 28: The 'priority' class with low, medium, and high priority level concepts as subclasses.

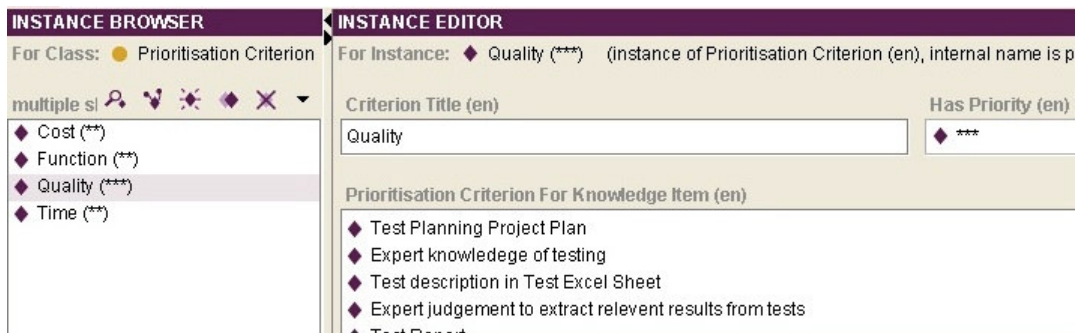


Figure 29: Extract of the form for the Prioritisation Criterion class. A priority can be assigned to each prioritisation criterion. Listed below the criterion title (right-hand side) are the knowledge items to which it has been assigned.

Class	Subclasses	Slots	Slot Type/Value
Prioritisation Criterion	-	criterion_title	String
		has_priority	Instance of 'Priority' class
		prioritisation_criterion_for_knowledge_item	Instance of 'Knowledge Item' class
Priority	Low Medium High	is_assigned_priority_for_criterion	Instance of 'Prioritisation Criterion' class
		priority_title	String
Knowledge Item		has_prioritisation_criterion	Instance of 'Prioritisation Criterion' class

Table 23: Classes and slots in the knowledge prioritisation mechanism.

### 7.3.2.2 Approach 2: Protégé-OWL

In the second approach, features peculiar to OWL were exploited, namely the ability to exploit a reasoner or classifier to compute an inferred class hierarchy, as outlined by Horridge et al. (2004) and discussed earlier on in this chapter. The basic idea was to create classes representing different priorities that could be assigned to a knowledge item. For example, it might be decided that there are three priorities: low priority knowledge items, medium priority knowledge items and high priority knowledge items. Conditions would then be assigned to these priority classes that assert that members of those classes must be members of a knowledge item class with a property linking them to an appropriate criterion domain such as 'Quality'.

Domain experts adding new knowledge items would only have to decide which of a pre-determined selection of knowledge domains was most relevant to a given knowledge item. The prioritisation would be achieved by running a reasoner to classify the ontology, which would produce a new inferred classification, as described in Horridge et al. (2004). In this classification, knowledge items would be placed under the low, medium or high priority knowledge item classes, depending on the knowledge domain to which they had been assigned.

Upon initial testing it became clear that there were some major obstacles to the execution of this approach. The first and most critical obstacle was that a reasoner could only be used with the OWL-DL form of OWL. If an OWL ontology were to be used,

the multilingual support mechanism demands the use of metaclasses, which are only available in OWL Full. This issue has been documented in the Protégé-OWL FAQ (Stanford Medical Informatics, 2007d) and by Horrocks et al. (2003). A second problem is that any changes required to the initial set-up of the prioritisation mechanism, for instance the priorities assigned to knowledge domains, would require some knowledge of ontological engineering from the domain experts involved. Additionally, the recommended OWL reasoner software plug-in for Protégé, 'RacerPro' by Racer Systems GmbH, is commercial software, although a free trial version is available to academic researchers (Racer Systems GmbH, 2007).

### **7.3.3 Dissemination Mechanism**

The Protégé ontology software tool used to develop the ontology includes a number of built-in features and plug-ins that allow an ontology to be visualised and browsed. However, the use of these features or plug-ins demands that the Protégé tool is installed locally on a user's computer. This situation may restrict access to the tool in a business environment.

In the literature review in section 6.1.2, it was found that Web-based tools were a prevalent technology for the dissemination of information. A survey conducted in 2005 by the European Union's statistics office showed that ninety-nine percent of large enterprises (those with 250 or more employees) in twenty-five European Union member states had Internet access. The results of this survey were reported by Ottens (2006). Ninety-two percent of enterprises in the same group had broadband access. One software tool that is already accessible to all the NPD business process users in the case study company is the Microsoft Internet Explorer® Web browser client.

Consequently, it was decided to develop a Web-based mechanism for the dissemination of information about NPD knowledge. The main requirements for this mechanism were that:

- it would allow both the Protégé-Frames and Protégé-Frames ontologies to be displayed;
- it should be compatible with the Microsoft Internet Explorer® Web browser tool; and

- ideally, it should be free of charge in order to meet the funding constraints of the research project.

Earlier in this chapter, it was established that Protégé included an application to display Protégé knowledge bases via a Web browser client. This application, known as Protégé Web Browser, meets all of the requirements listed above. Protégé Web Browser, also known as WebProtege, is a Java-based application. It is designed to be deployed from a JavaServer Pages (JSP)-enabled server. JSP and Java were developed by Sun Microsystems Inc. (Sun Microsystems, 2007). The Protégé developers noted that Protégé Web Browser allows users to ‘share, browse and so some basic editing of Protégé knowledge bases via the World Wide Web’ (Ahsan, 2006).

Alongside the ability to view and browse ontologies, WebProtégé offers two other features that may well prove to be useful in the application setting. The first of these features is a search facility, which allows text-based searches of Protégé knowledge bases to be executed, including classes, slots and instances (Ahsan, 2006). The second feature is the ability to create password-protected user accounts for accessing the tool, and to determine which of these users is allowed to edit the ontology, as documented in the Protégé Web browser FAQ (Stanford Medical Informatics, 2006). This latter feature will not be explored any further here.

### **7.3.3.1 Method for Development of Dissemination Mechanism**

The Protégé Web Browser tool is included with the full installation of the Protégé editor (version 3.1) used to develop the ontology of information about NPD process knowledge. Installation of the Protégé Web browser tool was carried out according to the instructions provided in the Protégé Wiki (Stanford Medical Informatics, 2005). The installation process consisted of four steps:

1. Installation of Sun Java 1.4.2 and Apache Tomcat (version 5.0), a JSP Engine on a computer running the Microsoft Windows XP® operating system.
2. Copying of the Web Protégé application directory to the Web application directory (‘webapps’) in the Apache Tomcat installation.
3. Copying of all Protégé plug-in files to the directory specified in the Protégé Web Browser installation documentation. These plug-ins included the OWL-

plug-in required for the display of OWL ontologies. Without the plug-in, only Protégé-Frames ontologies are supported.

4. Execution of Tomcat and navigation to the Protégé Web Browser Uniform Resource Locator (URL) address. For the purposes of testing, this was a local address on the same computer as the Web browser client.

### 7.3.3.2 Dissemination Mechanism Architecture

A simplified view of the dissemination architecture is given in Figure 30. The server side consists of the WebProtégé application, which contains the ontology, and the Apache Tomcat Java application server (version 5.0.28). On the client side, a Web browser such as Microsoft Internet Explorer® is employed to visualise the ontology.

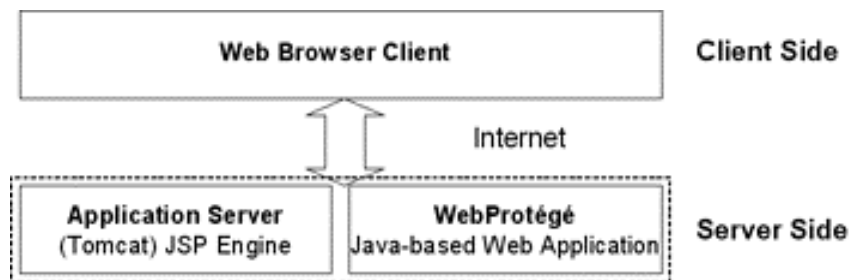


Figure 30: Dissemination mechanism architecture.

### 7.3.3.3 Resulting Dissemination Mechanism User Interface

The forms created in the Protégé editor that constitute the knowledge-acquisition tool and knowledge base, are reproduced in the Web browser client window. As in the Protégé editor interface, users are able to navigate their way around the ontology using the familiar 'point and click' paradigm. Illustrative screenshots of the Protégé-Frames and Protégé-OWL ontologies are provided in Figure 31 and Figure 32. It should be noted that the Protégé-OWL interface is rather clumsy in comparison to its Protégé-Frames counterpart.

Figure 31: Protégé-Frames Ontology in Web Protégé Interface.

Figure 32: Protégé-OWL prototype ontology in Web Protégé interface.

By entering words or phrases in the search box at the top right of the Protégé Web Browser window, a user can find classes or instances of interest that cannot be located quickly by browsing the classes manually. Furthermore, while synonym labels cannot be displayed in the same manner as the multilingual labels, they can be used as search terms in the search tool to find their corresponding slots or classes. An example of such a search is shown in Figure 33.

1 Search Results found for "milestone"

Display Graph Instance Column

Frame	Direct Type	Matched Slot	Matched Value
<a href="#">12 Milestone TRS meeting with product validation planning for the following change</a>	<a href="#">NPD Process Task (en)</a>	<a href="#">task title (en)</a>	Milestone TRS meeting with product validation planning for the following change

Figure 33: Search function in Web Protégé interface.

There are certain limitations to this approach. Making major changes to the ontology, such as changing the default language label slots displayed in the forms must be done via the Protégé editor, or by directly editing the text-based files in which the ontology is saved. Either way, the ontology Web server must be restarted following these changes. Consequently, it would be more convenient to save a separate version of the ontology for each desired language. In order to avoid multiple versions of the ontology being created by users of each language version, adding or deleting instances in the ontology, and editing of the ontology, would have to be restricted to nominated ontology maintainers. In this scenario, users would not make changes directly using the Protégé Web Browser tool. Instead, proposed changes to the ontology would be submitted to the parties responsible for its maintenance.

## **7.4 Selection of Ontology Model and Mechanisms**

In section 7.2, it was stated that the final decision on whether to use a frame-based (developed in Protégé-Frames) ontology or an OWL (developed in Protégé-OWL) ontology would be made after the discussion of methods for developing the multilingual support, knowledge prioritisation, and dissemination mechanisms.

Methods were devised and successfully tested for the development of all three mechanisms for both the Protégé-Frames and Protégé-OWL versions of the ontology, with one exception. This was the prioritisation mechanism proposed for the Protégé OWL ontology and knowledge base.

Ultimately the Protégé Frames version of the ontology was chosen. This meant that the Protégé-Frames versions of the multilingual support and prioritisation mechanisms were selected. There were two main reasons for this decision.

Firstly, the Protégé OWL tool interface is less user-friendly than the Protégé-Frames version. This is due to the differences in paradigms of the frame-based language used in the Protégé –Frames editor and the Description Logic-based OWL used in Protégé-OWL, as well as the extra functions in the Protégé-OWL interface to support the OWL language (Stanford Medical Informatics, 2007d). Unlike its Protégé Frames counterpart, the Protégé-OWL editor was not principally intended to produce knowledge-acquisition tools and knowledge bases that could be used by domain experts. Its goal is to provide an infrastructure for the development of Semantic Web applications. Secondly, the proposed OWL prioritisation mechanism (Approach 2) cannot be used in conjunction with the metaclass-based multilingual support mechanism, as explained in section 7.3.2.

## **7.5 Overview of Knowledge Sharing Tool**

The framework formed by the components of the proposed knowledge sharing tool is represented in Figure 34.



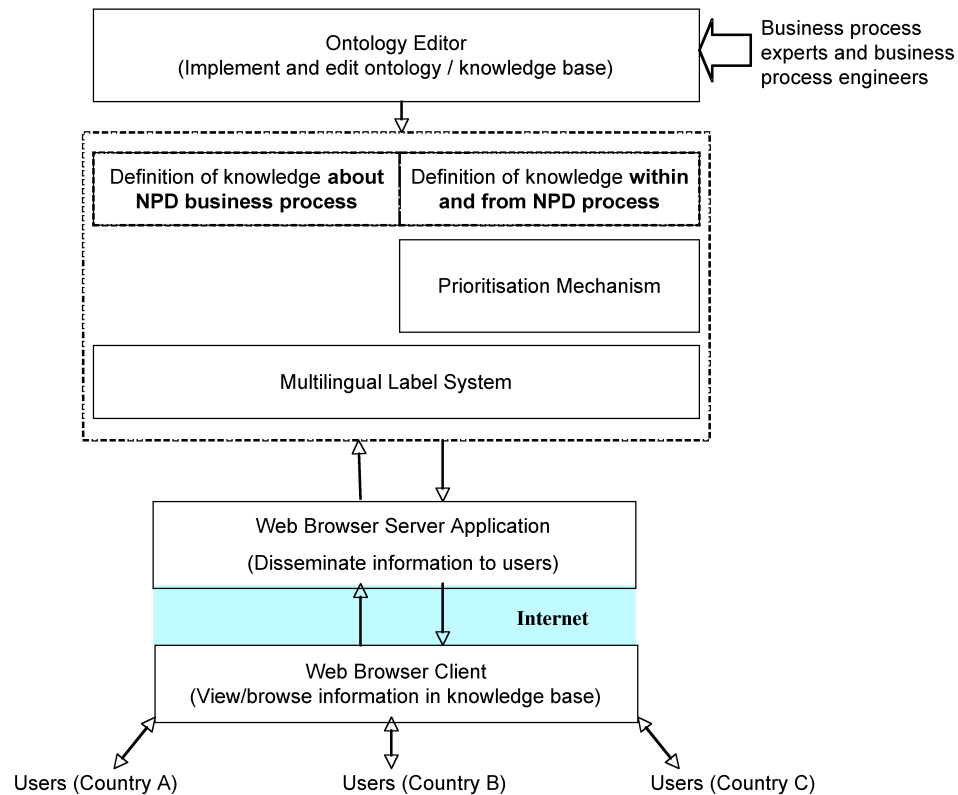


Figure 34: Knowledge sharing tool components.

Editing of the ontology is to be carried out in the Protégé ontology editor and knowledge-acquisition tool. It is envisaged that this will involve NPD process domain experts such as NPD process and sub-process owners, and NPD project leaders, as well as the information technology specialist charged with maintaining the tool. The ontology forms the basis of a knowledge-acquisition tool. The addition of instances to this tool, e.g. process tasks and knowledge items, creates a knowledge base. Features of the Protégé-Frames ontology model allowed the implementation of a mechanism to support a multilingual environment and a mechanism to indicate the priority of knowledge according to its domain or content. In combination, the knowledge base and mechanisms form a knowledge sharing tool. Finally, the Web browser tool allows the ontology to be disseminated to NPD project team members throughout the organisation, irrespective of their geographical location.

## **7.6 Summary**

A method to develop a knowledge sharing tool for facilitating knowledge sharing among NPD team members by reducing the three knowledge sharing barriers identified in chapter five has been presented. The tool consists of three main modules: (1) an ontology editing tool, (2) a knowledge base based on the ontology of NPD process metaknowledge and mechanisms to support a multilingual environment and the prioritisation of NPD process knowledge items, and (3) a mechanism to disseminate the ontology and knowledge base to geographically dispersed NPD project team members. In doing so, research objective four has been met.

## 8 Validation of Prototype Knowledge Sharing Tool

This chapter describes a case study to implement and test the prototype knowledge sharing tool presented in chapter seven. The objectives of this exercise were:

- to illustrate the functionality of the tool, by using it to capture information about knowledge used and generated in the activities of a real new product development (NPD) business process;
- to determine what changes to the knowledge acquisition tool component of the knowledge sharing tool might be required as a result of capturing this information about knowledge.
- to evaluate how useful potential users of the tool consider it to be as a device for the facilitation of knowledge sharing in the execution of the product development process; and
- to obtain feedback from potential users on the shortcomings of the tool.

Implementation involved demonstrating the functionality of the knowledge sharing tool, and providing a test of the knowledge content classification used in the ontology. This was carried out by using the knowledge acquisition tool component to capture information about knowledge used and generated by tasks in the NPD business process of the case study company, thereby creating a knowledge base.

Further testing of the tool was conducted in two phases. The first phase involved presenting and demonstrating the knowledge sharing tool, including the aforementioned knowledge base, to NPD practitioners in the same company. In the second phase, feedback about its perceived usefulness and deficiencies was elicited from NPD practitioners using a questionnaire.

## **8.1 Implementation of the Knowledge Sharing Tool Using Case Studies**

### **8.1.1 Approach**

An industry-based case study was undertaken in order to illustrate the functionality of the knowledge sharing tool by using it capture information about knowledge used in a real new product development (NPD) process, and to provide an albeit limited test of the knowledge domain classification in the ontology, as documented in Appendix M. Case studies have also been used for the testing of NPD knowledge management systems in studies by Ramesh and Tiwana (1999), and Donnellan and Fitzgerald (2003).

The setting for the study was the same heating systems manufacturing company used in the earlier stages of this research and it was conducted under the auspices of this company. In chapter five, it was established that the company uses a multifunctional stage-gate-type business process model to support its new product development projects. The model consists of seven stages or phases: strategy, conception, function development, detail development, industrialisation process, industrialisation launch, and project review. Each of these stages is broken down into sub-processes, which are further broken down into activities, henceforth to be referred to as 'tasks'. The hierarchy of phases, sub-processes and tasks is illustrated in Figure 35, in which each titled box represents a phase at the phase level, a sub-process at the sub-process level and a task at the task level.

The activities involved at the phase level of the NPD process are described in Appendix G. Between two and twenty-eight sub-processes are present in each phase. In turn, each sub-process typically contains anywhere from five to twelve tasks.

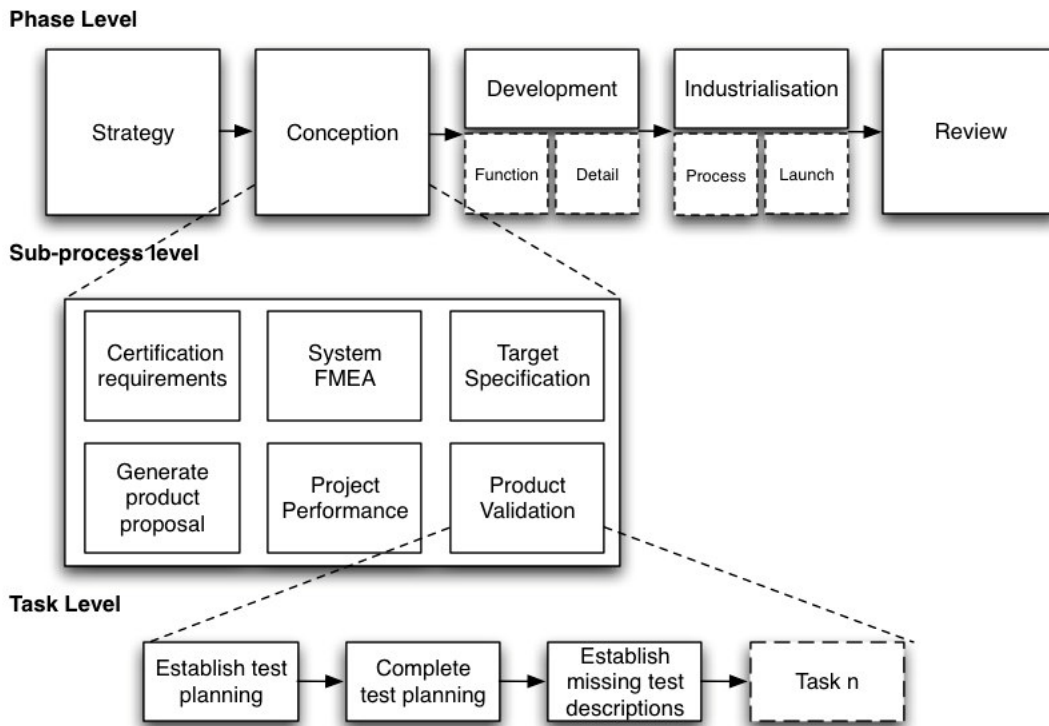


Figure 35: Hierarchy of phases, sub-processes and tasks in the case study company NPD process.

Since these tasks were the lowest and most detailed level of activity described in the NPD process documentation and available to NPD process users, it was this level of the process hierarchy that was chosen for analysis in the case studies. Each task requires certain knowledge inputs in order to be carried out, and also generates knowledge items, as depicted in Figure 36.

Given that the entire NPD process consists of dozens of sub-processes and hundreds of tasks, and that it would not be possible to capture information about the knowledge associated with all of these tasks in the available time, it was decided that the scope of the investigation should be confined to the knowledge inputs and outputs for a selection of tasks in three sub-processes from a single phase.

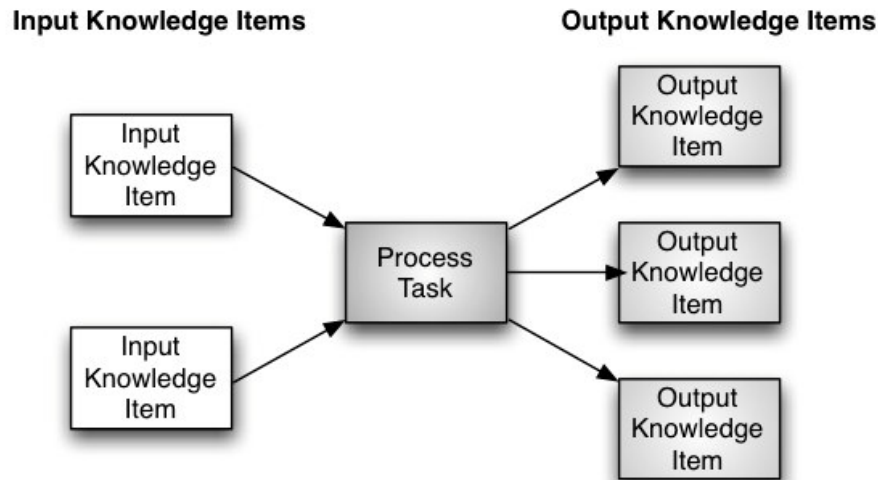


Figure 36: Depiction of input and output knowledge items for a process task.

### 8.1.2 Method for Implementing Knowledge Sharing Tool

The method used for part one of the implementation and testing of the knowledge sharing tool is documented in section 4.5.5. Section 4.5.2.2 described the method used to determine the knowledge prioritisation criteria for new product development projects.

Briefly reiterated, a five-stage process was used for the implementation and testing of the knowledge sharing tool: (1) selection of the three sub-processes, (2) elicitation of information about the tasks from which the sub-processes are comprised, (3) elicitation of information about knowledge required for and generated by these tasks, (4) capture of this information or metaknowledge in the knowledge sharing tool, and (5) translation of the English language concepts and relationships that form the ontology into a second language, for this exercise German, and the addition of multilingual labels.

Identification of the prioritisation criteria was achieved through interviews with NPD process experts. A more detailed description of the activities involved in each of these stages follows.

### **8.1.2.1 Stages 1 and 2 - Selection of sub-processes and elicitation of information about tasks**

Following a review of the company NPD business process, it was decided to select the three sub-processes from the product conception phase (see Appendix G). This is because the constituent sub-processes and tasks of this phase demand the sharing of knowledge between different functions of the NPD project team, and involve knowledge from a broad spectrum of sources. These assertions are supported by Ulrich and Eppinger (2003), and Zahay et al. (2004) respectively. Ulrich and Eppinger (2003) commented that ‘the concept development phase requires tremendous integration across the different functions on the development team’. Zahay et al. (2004) found that all eight types of information they identified in the NPD process were present in the conception phase, which they referred to as the ‘fuzzy front end’. Additionally, Hong (2004) highlighted product conception as the most important phase for knowledge sharing in a new product development project, commenting: ‘It is in this stage that knowledge sharing among product development teams needs to occur’.

Table 24 lists the names of the selected sub-processes, accompanied by a brief description. The activities in the ‘generate product proposal’ process are mostly of a technical, engineering nature, while the ‘product validation’ process involves the use of knowledge from a range of functional domains, including that of test engineers and certification experts. In contrast, the tasks in the ‘project performance’ process, use and generate knowledge associated with the stage-gate review at the end of each phase. This includes technical, cost and project management knowledge. As a result, the two selection criteria defined in section 4.5.5, which demanded that the selected processes should involve a broad range of functions (e.g. Marketing, Research and Development (R&D), Production, Quality, and so on), and involve both technical and non-technical activities, are satisfied.

Case	Sub-process Title	Description
A	Generate product proposal	Create initial product specification and prototypes from marketing proposal
B	Product validation	Test product concept and assess reliability
C	Project performance	Verify that NPD project is running to the agreed time, cost and process.

Table 24: Titles and brief description of selected sub-processes.

The aim of sub-process ‘A’, ‘Generate product proposal’, is to convert product specifications provided by the marketing department into a conceptual, technical product specification that could feasibly be developed into a real product by the R&D function. It involves representatives of the brand unit and the product programme manager on the marketing side, and the project leader from the R&D function of the company.

Two tasks were selected from this sub-process: ‘Create technical response document’ and ‘Detail CAD model assigned to product architecture’. These tasks are arranged consecutively in the process, as shown in Figure 37, and some of the knowledge item outputs from the first task feed into the second task. According to the company NPD process documentation, these tasks appeared to be the most knowledge-intensive in the sub-process, and they were selected for this reason.

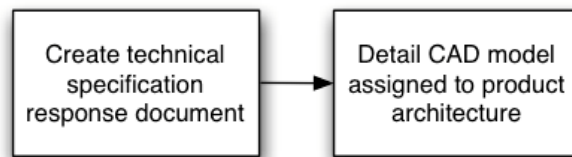


Figure 37: Tasks from ‘Generate product proposal’ sub-process.

The ‘Create technical response document’ task involves NPD team members from the R&D function assessing the feasibility of what is essentially a product concept specification ‘wish list’ from the Marketing function. This product concept specification, which includes targets for functional, visual, cost and installation requirements, is defined in a document. The targets are presented by the project leader



to development engineers from the R&D function, who determine whether or not they are technically feasible. If the targets are not feasible, the technically realistic target will be communicated to the marketing and sales people, and they will estimate the likely impact on sales figures. This in turn determines the commercial viability of the project. For the 'Detail CAD model assigned to product architecture' task, the aim is to produce a digital mock-up of a product concept. The task requires various inputs, among them a component list and an assessment of the failure risk of the various components in the product. This task is undertaken by engineers from the R&D function of the company.

In sub-process 'B', 'Product validation', the intention is to establish a product-testing plan and schedule that is tailored for the product to be developed in the project, and then to execute that plan according to the aforementioned schedule. The legislation relevant to heating systems products varies from market to market, and the tests required depend on the components in the product and the markets in which the product is to be sold. It involves roles such as the project leader, test and validation engineers, development engineers, and certification experts.

Three tasks were selected from this process: 'Establish test planning', 'Complete the test planning and plan the schedule', and 'Establish missing test descriptions'. Once again, these tasks were arranged consecutively in the process (see Figure 38).

'Establish test planning' entails the development of a project validation plan, in essence a product test plan that states what tests are necessary for that product. The aforementioned test engineers and certification experts have a significant input into this activity. 'Complete the test planning and plan the schedule' concerns the finalisation of the project validation plan and the creation of an appropriate schedule. This exercise results in a product validation project plan. In the case of some products, suitable test descriptions may not yet exist for some of the tests in the test plan. The 'Establish missing test description' task concerns the identification of such absent tests, the design of new tests, and the addition of these new tests to a test database.

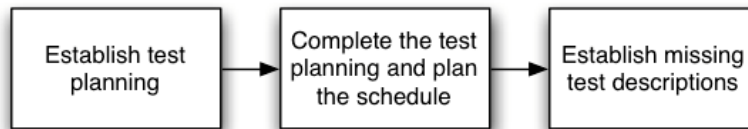


Figure 38: Tasks from ‘Product validation’ sub-process.

For sub-process ‘C’, ‘Project performance’, the expected output is a forecast of whether the project will reach its intended targets. These targets include evidence of ongoing project control, fulfilment of customer requirements, and various temporal, financial and quality objectives. A positive forecast is required if the project is to be allowed to move into the next phase of the NPD process. This forecast must be accepted by the entire project team, which consists of the programme manager, business unit manager, auditor, project performance manager and the project steering committee. It results in a signed contract between the product business unit manager and the R&D function.

Two tasks were selected from this sub-process: ‘Define corrective actions’ and ‘Carry out milestone assessment’. As with sub-processes ‘A’ and ‘B’, the tasks were arranged consecutively in the process; see Figure 39.

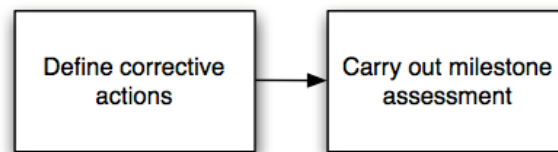


Figure 39: Tasks from ‘Project performance’ sub-process.

The task ‘Define corrective actions’ follows a task in the same sub-process in which deviations of the project from specified project performance targets are identified. Corrective actions are measures to correct these deviations and they are devised by a team of experts assembled by the project leader. Aside from the project leader, this team may also include the project auditor. The ‘Carry out milestone

assessment' task involves the assessment of project performance against an audit checklist. In this assessment activity, a team of assessors and an auditor will decide whether the project can proceed to the next phase of the NPD process.

**8.1.2.2 Stage 3 - Elicitation of information about knowledge used in three sub-processes**

Elicitation of information about knowledge required for and generated by these tasks was carried out according to the method documented in section 4.5.5.

The metaknowledge captured in the interviews relating to the input and output knowledge items for the tasks in the three sub-processes is documented in Appendix O. It should be noted that some information has been adapted, either to respect the privacy of those involved in the study, or to remove commercially sensitive data. However, no changes were made that affected the way in which information about knowledge items was captured in the tool. Furthermore, it is not claimed that all of the possible knowledge items associated with the NPD process tasks have been captured. Four prioritisation criteria were identified. A description of each criterion, along with its assigned priority may be found in Table 25.

<b>Prioritisation Criterion</b>	<b>Description</b>	<b>Assigned Priority</b>
Quality	Knowledge related to (a) product risk and safety issues, and (b) wider safety issues	High
Function	Knowledge that is relevant to the functionality of the product.	Medium
Time	Knowledge pertinent to project scheduling and timing	Medium
Cost	Knowledge that impacts the development costs of the project	Low

Table 25: Description of prioritisation criteria proposed by company NPD process experts, along with assigned priorities.

### 8.1.2.3 Stage 4 - Capture of information about knowledge using the knowledge sharing tool

Capture of information about knowledge used in a selection of tasks from the three sub-processes was carried out in three steps for each sub-process: capture of information about the sub-processes, capture of information about the sub-process tasks, and capture of information about the knowledge items connected with those tasks.

Sub-processes were created in the tool as follows. Firstly, the ‘NPD Subprocess’ class was selected in the Class Browser pane on the left-hand side of the Protégé ontology editor user interface, as shown in Figure 40.

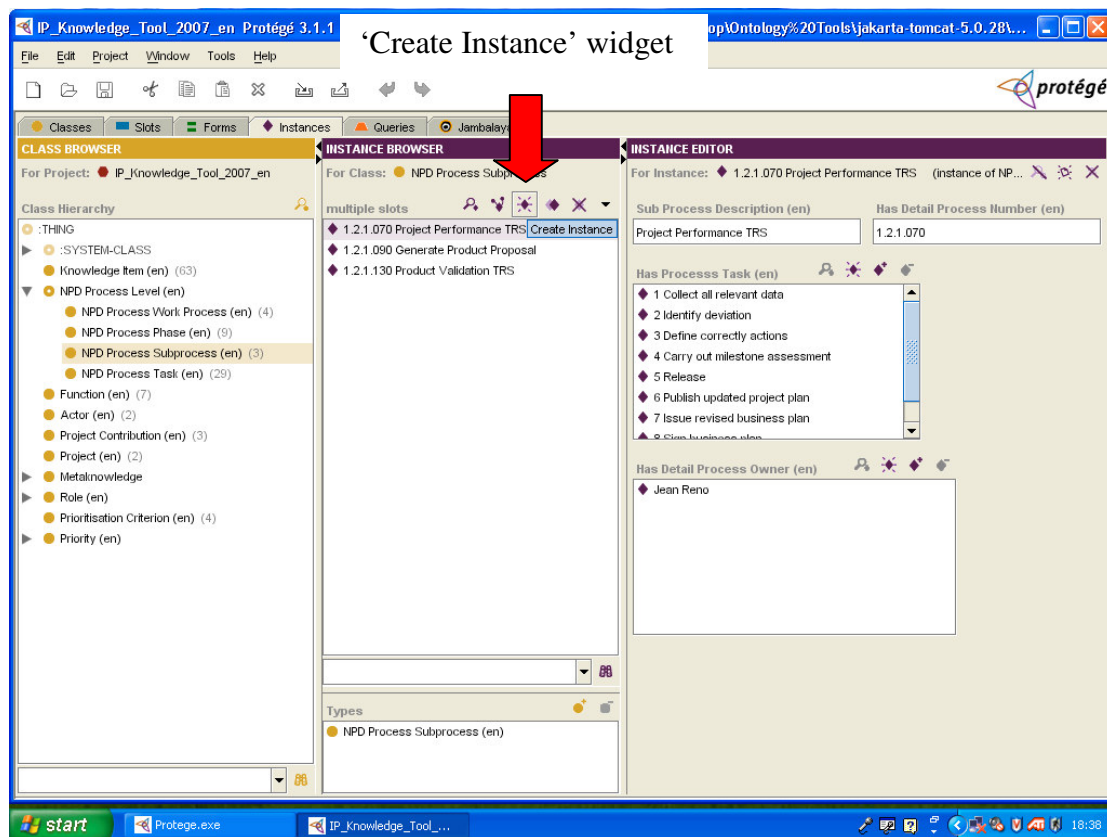


Figure 40: Protégé editor tool interface.

Then, the ‘Create Instance’ widget, highlighted in Figure 40, was clicked to create a new instance of the sub-process class. The result of this action is the generation

of an empty form that will allow information about the sub-process to be entered or added. Figure 41 shows an example of this form.

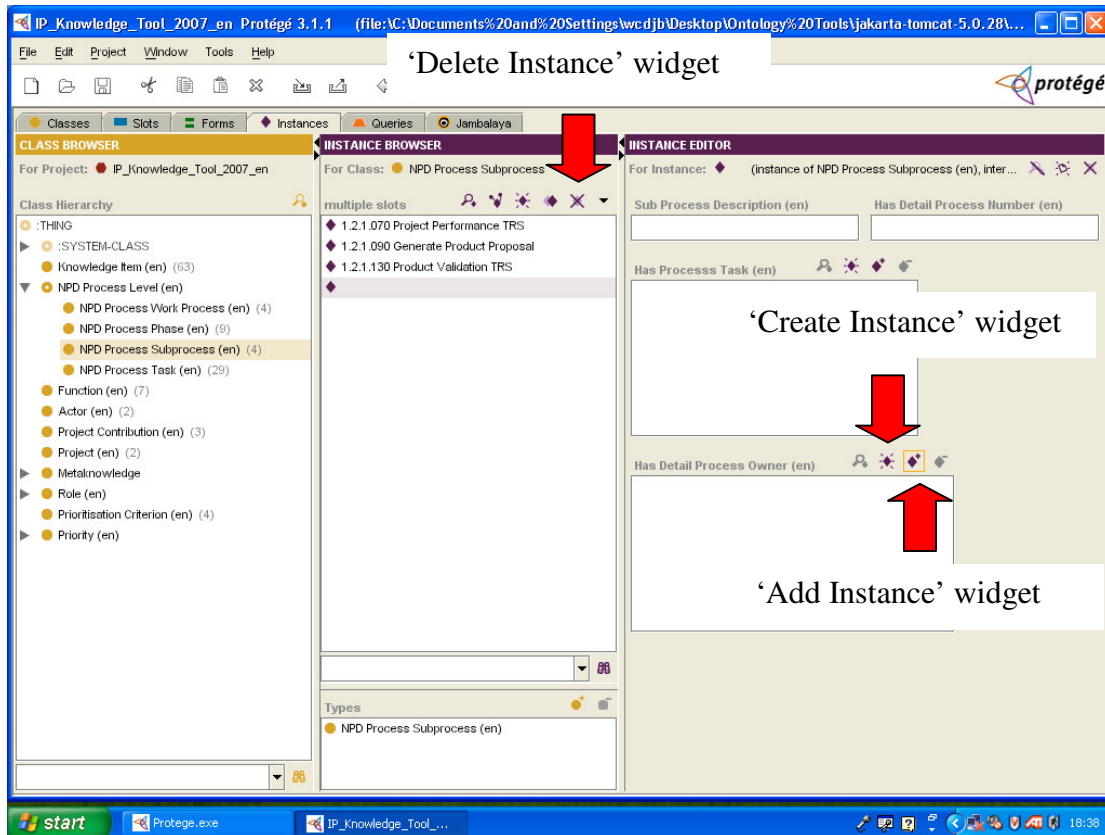


Figure 41: Newly created sub-process form.

This information includes its title, a process number where appropriate, the name of the process owner, and the tasks from which the process is comprised. The process title and number were entered in the boxes under the appropriate headings as text. Adding a process owner entailed use of the 'Create Instance' widget under the 'Has Process Owner form', which is indicated by the captioned arrow in Figure 41.

Notably, in cases where process owner names have already been added to the tool, the 'Add Instance' widget may be used instead, and the name of an individual selected from the list, see Figure 42.

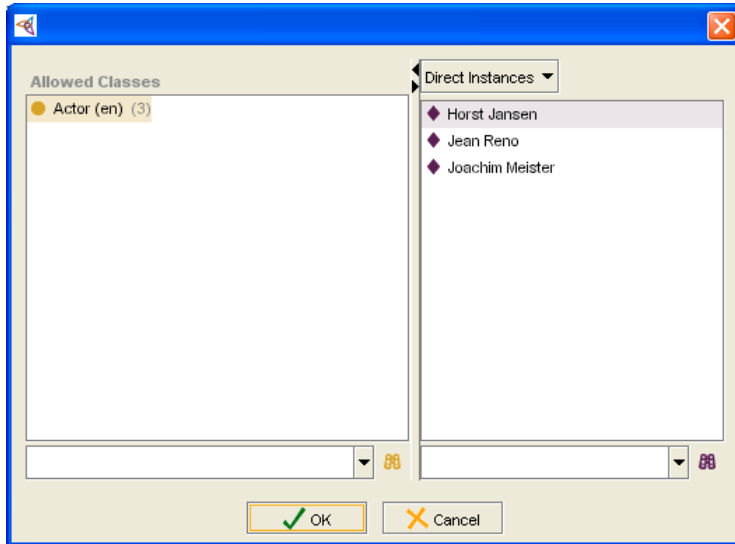


Figure 42: Instances of the 'Actor' class.

The screenshot shows a task form with the following fields and lists:

- Task Title (en):** Carry out milestone assessment
- Task Aim And/or Purpose (en):** (empty)
- Task Description (en):** (empty)
- Task Number (en):** 4
- Is Part Of Subprocess (en):** 1.2.1.070 Project Performance TRS
- Has Knowledge Contributor:** Design Engineer, Project Leader, Auditor
- Has Expert (en):** Jean Reno
- Requires Knowledge Item:** Corrective actions, Expert knowledge of auditor (experience)
- Generates Knowledge Item:** Audit checklist TRS, 'How's' and 'Whys' of decisions created in r
- Involves Function (en):** Research and Development, Marketing

Figure 43: Task form with values added to metaknowledge element slots.

Tasks associated with the sub-process were created using the ‘Create Instance’ widget adjacent to ‘Has Process Task’ slot-label heading. The task form generated upon performing this action is illustrated in Figure 43.

In scenarios where the process tasks have already been captured in the tool, the ‘Add Instance’ widget can be used rather than its ‘Create Instance’ counterpart.

It is worth noting that the ‘Create Instance’ and ‘Add Instance’ widgets are found next to all headings (actually slot labels) on a class instance form that point to instances of other classes. Indeed, subsequent references to creating or adding an instance of a class indicate that the respective ‘Create Instance’ or ‘Add Instance’ widgets should be used. Slot labels without these widgets are strings and were entered directly by typing the label into the box.

The full scope of information included on the ‘NPD Process Task’ instance form is documented in the description of slots attached to the ‘NPD Process’ class given in Appendix N. The information includes the task title, the sub-process to which the task belongs which is filled in automatically on generation of the form, and most importantly the knowledge items required for, and generated by, the task.

Input knowledge items were created under the ‘Requires Knowledge Item’ heading, and output knowledge items under the ‘Generates Knowledge Item’ heading. Once the initial few knowledge items had been created, the ‘Add Instance’ widget was used prior to its ‘Create Instance’ counterpart to see if the knowledge item connected to a task was already available in the knowledge base. For example, a knowledge item added as an output to one task might be used as an input to another task.

Critically, the form for instances of the ‘Knowledge Item’ class serves to capture information about knowledge items; see Figure 44. The slots available on the form are documented in the table for the ‘Knowledge Item’ class found in Appendix N. The sources of values for the knowledge item metaknowledge elements were the tables of knowledge item metaknowledge for each sub-process task provided in Appendix O. As in the case of the sub-process and task forms, the ‘Add Instance’ and ‘Create Instance’ form widgets were used to assign values to the form slots.

The screenshot shows a software interface for a Knowledge Item. The title is "'Hows' and 'Whys' of decisions created in review meeting (instance of Knowledge ...)". The form is divided into several sections:

- Knowledge Item Title (en):** 'Hows' and 'Whys' of decisions created in review meeti
- Knowledge Item Description (en):** Rationale behind decisions taken in technical requiremen
- Generated By Task (en):** 4 Carry out milestone assessment
- Available In Language (en):** English, German
- Provides Knowledge for Task:** (Empty)
- Has Expert Contribution (en):** Example Project 2005 (Task 'Hows' and 'Whys' of de
- Has Knowledge Domain (en):** Previous Project Decisions (Audit Experience), Business Process Knowledge
- Has Prioritisation Criterion (en):** Quality (\*\*\*)
- Knowledge Item Format (en):** Expert Advice
- Has Owner (en):** Project Team
- Is Stored In Repository (en):** Personnel

A red arrow points to the 'Add Instance' widget (a small square icon with a plus sign) in the 'Has Prioritisation Criterion' field.

Figure 44: Knowledge Item form for Carry Out Milestone Assessment task in 'Project Performance' 'sub-process with metaknowledge'.

The prioritisation mechanism was implemented in the tool using the method described in 'Approach 1' in section 7.3.2. Table 25 details the prioritisation criteria used for this implementation of the mechanism. For the purposes of illustration, three priority levels were specified, 'High', 'Medium' and 'Low', also shown in Table 25. Priorities were assigned to prioritisation criteria as described in section 7.3.2. Then, prioritisation criteria were assigned to the knowledge items, using the 'Add Instance' widget in the 'Knowledge Item' form (see arrow in Figure 44). Figure 45 shows the form containing the available prioritisation criteria, which appears when the 'Add Instance' widget is selected.



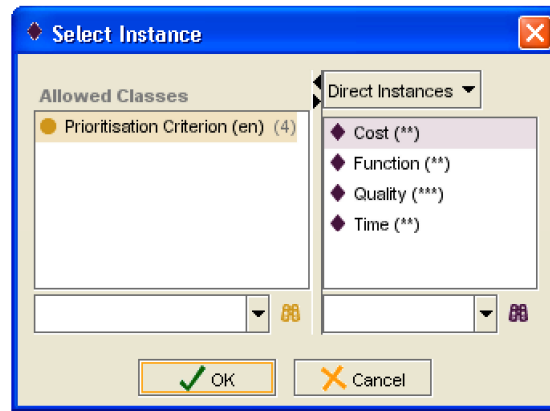


Figure 45: Prioritisation criterion selection form.

#### 8.1.2.4 Stage 5 - Addition of Multilingual Metaknowledge Labels

English and German language labels were added to the classes (concepts) and slots (relations) in the ontology component of the knowledge sharing tool. This served two purposes in the context of this implementation exercise. Firstly, it afforded the opportunity to demonstrate how the multilingual mechanism functions in practice. Secondly, it provided an illustration of the mechanism that would be meaningful to the participants of the subsequent usefulness study that comprises part two of the validation investigation, which is documented in section 8.2.

Language labels for the classes and slots in the ontology were added in three steps. In step one, multilingual language label slots for classes and slots were created using the method detailed in section 7.3.1. Then, in step two, the author carried out a rough translation of the existing English class and slot labels. Postgraduate students who were native German speakers were consulted to correct and refine this rough translation. The results of this procedure are given in Appendix P. Lastly, in step three the translated labels were added to the designated multilingual class and slot labels.

#### 8.1.3 Walkthrough of Tool Features

This section provides a walkthrough of the main features of the implemented knowledge sharing tool. The walkthrough illustrates how the tool may be used to provide NPD project team members with information about NPD process knowledge, and thereby

facilitate knowledge sharing. Three usage scenarios will be considered, as listed in Table 26.

<b>Scenario</b>	<b>Description</b>
A	Building and administration of ontology and knowledge base
B	NPD Process user
C	Knowledge Management

Table 26: Usage scenarios for knowledge sharing tool.

Scenario A focuses on the functions and features of the tool pertinent to the tool administrator. It is envisaged that a tool administrator is likely to be somebody from the information technology (IT) function of a company. Requests for changes to the tool would be gathered by the administrator from sub-process owners and NPD project leaders. The sub-process owners and NPD project leaders would of course need to agree on the necessary changes prior to such a request being made. For the purposes of this scenario, the tool administrator role has four main responsibilities. These are:

- 1) Adding instances of sub-processes, tasks and knowledge items to the knowledge acquisition tool described in chapter seven to create a knowledge base.
- 2) The maintenance of the knowledge base, which may require the addition, deletion, or editing of sub-process, task and knowledge item instances, and metaknowledge element instances.
- 3) Assigning priorities to knowledge items.
- 4) Adding metaknowledge labels to the knowledge items.

Scenario B considers the typical activities that a tool user may wish to perform with the tool in order to improve their understanding of the knowledge used in the NPD business process. A typical tool user would be a member of the NPD project team. These activities may include locating information about knowledge items pertinent to a given task, or discovering how a knowledge item generated by a task is used elsewhere in the NPD process. Consequently it may be considered the most important of the three scenarios.

Lastly, Scenario C highlights the features of the knowledge sharing tool that may assist in other knowledge management activities concerning the NPD business process. Users in this case might be NPD project leaders, NPD process owners or any party in the company concerned with knowledge management. These features include the ability to classify knowledge items by content (knowledge domain), by prioritisation criterion, and by priority. Although arguably less important than scenario B, since it does not directly address knowledge sharing barrier A by providing information about knowledge, scenario C shows how the tool may be used to nurture an improved shared understanding of knowledge used in the NPD process.

The walkthrough of the features relevant to each of these scenarios follows, citing the knowledge associated with the three sub-processes as illustrative examples.

#### **8.1.3.1 Scenario A: Tool administrator**

Adding new sub-processes, tasks and knowledge items to the knowledge base using the Protégé ontology editor component of the knowledge sharing tool has already been covered in section 8.1.2.3, as has the creation of priority levels and prioritisation criteria, and their assignment to knowledge items (refer to section 8.1.2.3).

Deletion of instances is carried out in the Protégé editor by selecting the instance to be removed on the class form and clicking the ‘Remove Instance’ widget, as indicated by the appropriately labelled arrow in Figure 41. It is anticipated that the removal of class instances will involve knowledge items, sub-process tasks or sub-processes, as these will be affected by changes made by a company to its product development business process.

#### **8.1.3.2 Scenario B: Tool user**

Knowledge items associated with some of the tasks from the three processes will be used to illustrate the way in which tool can be used by an NPD project team member. For reasons of brevity, not all of the knowledge items from the sub-processes will be referred to. However, the examples provided should prove sufficient to illustrate the key functionalities of the tool. Information about the sub-processes and tasks was transferred to the knowledge sharing tool using the Protégé Ontology editor component referred to in chapter seven, and described in further detail in Scenario C.

Rather than using the Protégé editor directly, it is intended that users of the tool will view and browse it through a Web browser interface, making it accessible to NPD project team members largely irrespective of their geographical location. As with Protégé ontology editor-based version, the user is able to navigate the tool using the familiar point and click paradigm. The resulting tool interface is shown in Figure 46.

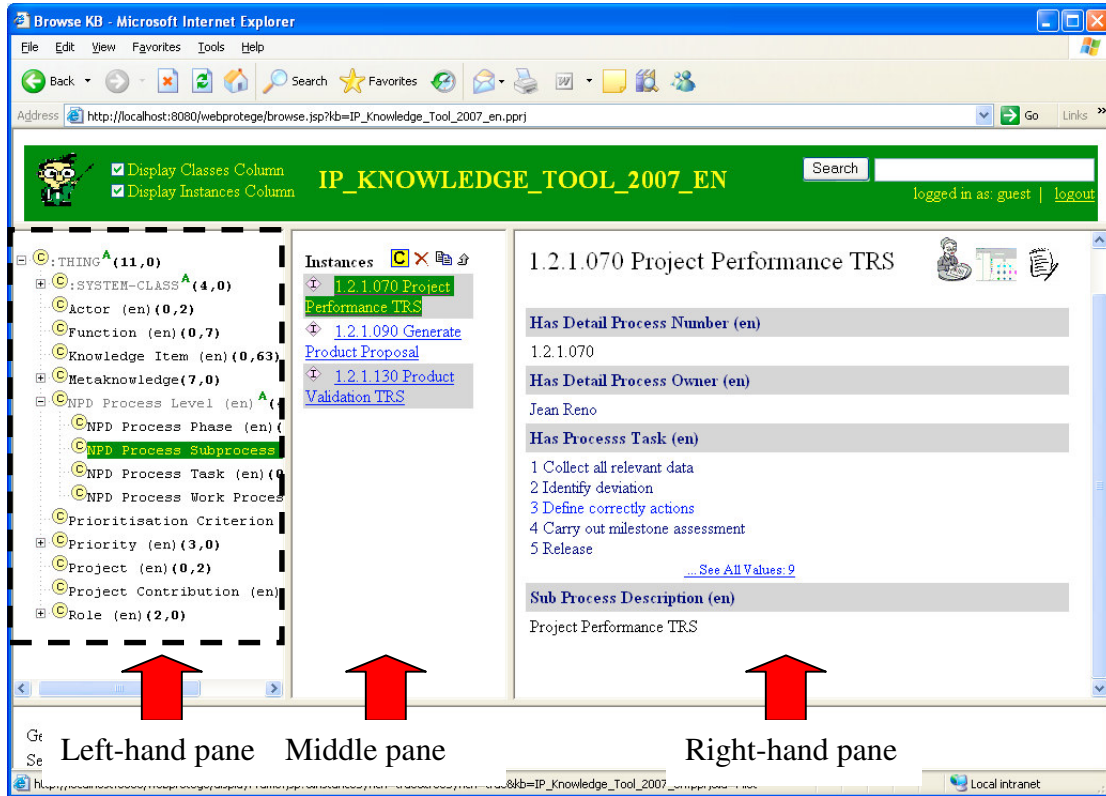


Figure 46: Tool browser window in Web browser tool.

The left-hand pane of the tool browser window, indicated with a dashed square, contains the NPD process knowledge taxonomy, arranged in a tree-like hierarchy of classes. Of these classes, the NPD process-level class is the focus here, since it is the starting point for finding the NPD process tasks and associated knowledge items of interest to the tool user.

Selecting the ‘NPD Sub-process’ class by clicking on it with the mouse pointer will show the instances of this class in the middle pane of the tool browser window. These instances, shown in Figure 46, are the three sub-process tasks discussed in section 8.1.2.1: Project Performance, Generate Product Proposal and Product Validation.

Clicking on a process instance using the mouse pointer shows the form for that instance in the right-hand pane. In Figure 46, the form for the Project Performance sub-process is depicted. The ‘NPD Process Sub-process’ form features a list of the tasks belonging to that sub-process, under the ‘Has Process Task’ heading.

At this point it should be restated that each heading in the form is a label for a slot (relation) in the ontology providing information about an NPD process knowledge item. Many of these slots have values that are instances of other classes. Effectively, this means that all items listed under a heading that are highlighted in blue in the Web browser tool user interface can be clicked upon to open a form which will provide information about that instance.

Selecting one of tasks under the ‘Has Process Task’ heading allows the tool user to view the input and output knowledge items for that task (see Figure 47). In the English tool interface, input knowledge items are listed under the ‘Requires Knowledge Item’ heading, while output knowledge items are listed under the ‘Generates Knowledge Item’ heading.

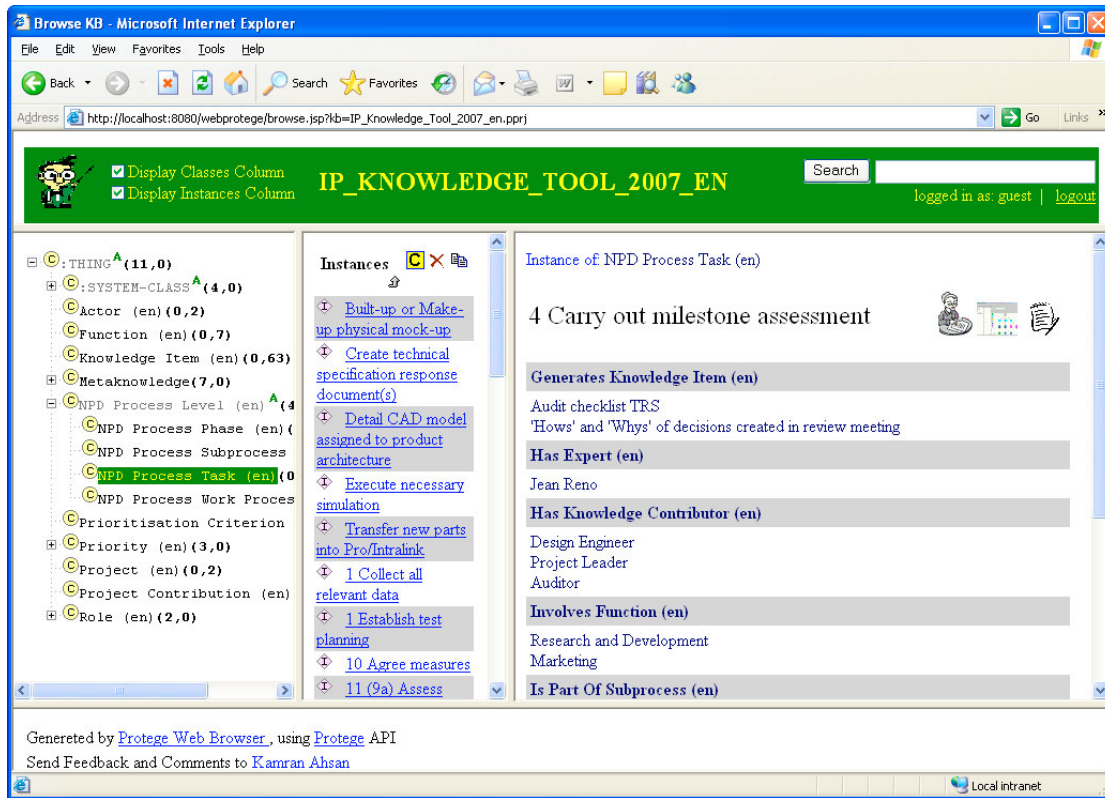


Figure 47: Task form from 'Project Performance' sub-process.

Clicking on a knowledge item title opens a knowledge item form window displaying its metaknowledge elements, see Figure 49. The available metaknowledge elements are defined in section 7.2.1. These metaknowledge elements provide information about the knowledge item which includes: the task which generated the knowledge item, the tasks which use the knowledge item as an input, the language in which the knowledge is available, its medium and format, the repository in which is stored, its owner, the content or knowledge domain of the knowledge item, the assigned prioritisation criterion, and the priority assigned to the knowledge item based on that prioritisation criterion.

Notably, only those knowledge elements for which values have been entered are actually displayed in the form in the Web browser interface.

Of particular interest, is the metaknowledge element in the knowledge item form which displays those sub-process tasks in the NPD business process that require the

knowledge item as an input (see highlighted area in Figure 48). Consider for example the ‘Corrective actions’ knowledge item, the details of which are available in Appendix O. This is an output from the ‘Define correctly actions’ task in the Project Performance sub-process and is subsequently used in the ‘Carry out milestone assessment’ task in the same sub-process.

**Audit checklist TRS**

<b>Available In Language (en)</b>	English
<b>Generated By Task (en)</b>	4 Carry out milestone assessment
<b>Has Knowledge Domain (en)</b>	Quality Knowledge
<b>Has Medium (en)</b>	Microsoft Excel file (.xls)
<b>Has Owner (en)</b>	Project Leader
<b>Has Prioritisation Criterion (en)</b>	Quality (***)
<b>Is Stored In Repository (en)</b>	IP Project Folder
<b>Knowledge Item Description (en)</b>	Completed audit checklist from milest
<b>Knowledge Item Format (en)</b>	Checklist
<b>Knowledge Item Title (en)</b>	Audit checklist TRS
<b>Provides Knowledge for Task</b>	1 Collect all relevant data

Tasks that require this knowledge item

Figure 48: Knowledge item 'Audit Checklist' from 'Project Performance' sub-process.

This information is intended to provide an NPD project team member executing a task with an understanding of how the knowledge generated by that task is subsequently used. Similarly, the ‘generated by’ task slot on the knowledge item form shows what task generated that knowledge item. The contextual information proffered


by both of these slots provides tool users with an understanding of the way knowledge is used and generated in the NPD process.

Two additional metaknowledge elements of special note include the priority assigned to the knowledge item (see boxed area in Figure 49), and expert contributions to the knowledge item made in previous projects (also indicated in Figure 49, this time by a dashed box). In this example, the knowledge item ‘Hows and whys of decisions created in a review meeting’ is encompassed by the ‘Quality’ prioritisation criterion, which the ‘\*\*\*’ symbol denotes has been assigned a ‘High’ priority.

Selecting an expert contribution title under the ‘Has Expert Contribution’ heading opens the expert contribution form, as depicted in Figure 50. The form shows the name of the project in which the contribution to the knowledge item was made, the name of the individual who made the contribution, the role of the contributor in the project, and a brief description of the contribution itself.

An illustrative screenshot in Figure 51 shows the result of implementing the multilingual labels to create a German language version of the ontology. On the left-hand side is the English interface for a knowledge item form, and on the right-hand side for comparison is the German interface for the same knowledge item. Both are taken from the same ontology and knowledge base. The language displayed in the interface can be set in the ontology editor, as described in Approach 1 in section 7.3.1.



'Hows' and 'Whys' of decisions created in review meeting 

**Available In Language (en)**  
 English  
 German

**Generated By Task (en)**  
 4 Carry out milestone assessment

**Has Expert Contribution (en)**  
 Example Project 2005 (Task 'Hows' and 'Whys' of decisions created in review meeting)

**Has Knowledge Domain (en)**  
 Previous Project Decisions (Audit Experience)  
 Business Process Knowledge

**Has Medium (en)**  
 Face-to-face advice

**Has Owner (en)**  
 Project Team

**Has Prioritisation Criterion (en)**  
 Quality (\*\*\*)

**Is Stored In Repository (en)**  
 Personnel

Figure 49: Knowledge item form featuring expert contribution, prioritisation criterion and priority metaknowledge elements.

### 8.1.3.3 Scenario C: Knowledge management

Once again, the knowledge base created using knowledge items from tasks in the three sub-processes will be employed to demonstrate some additional features of the tool. These features may help to improve the understanding of knowledge used in the NPD process.

Each of the metaknowledge element slots on the knowledge item form that points to an instance of a class also has an inverse slot. These slots are documented in Appendix N. By double-clicking on any of the instances of metaknowledge classes already added to the knowledge item form, a form will open for that metaknowledge class listing all of the knowledge items belonging to that class. This includes the Prioritisation Criterion class, as illustrated in Figure 52.

Example Project 2005 (Task 'Hows' and 'Whys' of decisions created in review meeting)



<b>Contributes To Project (en)</b>
Example Project 2005
<b>Contribution Description</b>
Provided rationale behind decision to reject advancement of project to development phase.
<b>Provided Expert Contribution To Knowledge Item (en)</b>
'Hows' and 'Whys' of decisions created in review meeting
<b>Has Knowledge Contributor (en)</b>
Jean Reno
<b>Role In Project (en)</b>
Auditor

Figure 50: Expert knowledge contribution form to document contributions made to a knowledge item in a previous project (the names of individuals and project titles have been changed to respect confidentiality).

TOPH technical response	TOPH technical response
<b>Generated By Task (en)</b>	<b>Erzeugt Von Aufgabe (d)</b>
Create technical specification response document(s)	Create technical specification response document(s)
<b>Has Knowledge Domain (en)</b>	<b>Hat Wissenskategorie (d)</b>
Technical Design Information and Knowledge (Concept and Development)	Technical Design Information and Knowledge (Concept and Development)
<b>Has Medium (en)</b>	<b>Ist Verfügbar In Folgendem Medium (d)</b>
Microsoft Excel file (.xls)	Microsoft Excel file (.xls)
<b>Has Owner (en)</b>	<b>Hat Wissensenelementeigner (d)</b>
Project Leader	Project Leader
<b>Has Prioritisation Criterion (en)</b>	<b>Hat Prioritätskriterien (d)</b>
Function (**)	Function (**)
<b>Is Revised Version Of (en)</b>	<b>Hat Vorhergende Version (d)</b>
TOPH	TOPH
<b>Is Stored In Repository (en)</b>	<b>Hinterlegt Im Wissensspeicher (d)</b>
IP Project Folder	IP Project Folder
<b>Knowledge Item Format (en)</b>	<b>Format Des Elements (d)</b>
Report	Report
<b>Knowledge Item Title (en)</b>	<b>Titel Des Wissensenelements (d)</b>
TOPH technical response	TOPH technical response

Figure 51: English (left-hand side) and German (right-hand side) versions of a knowledge item form in the Web browser interface.

Alternatively, the class browser in the left-hand pane of the tool window can be used to select the required subclass of the ‘Metaknowledge’ class. Double-clicking on any of the instances displayed in the Instance Editor will achieve the same ends.

This functionality provides the means to break down the numerous knowledge items required in the course of the product development process by each of the metaknowledge element types, such as knowledge domain (content of the knowledge), language, prioritisation criterion and so on. For example, an NPD project leader may wish to discover which knowledge items were stored in the minds of project team personnel and therefore not formally captured in a document or information system. This could be achieved by selecting the Personnel instance under the ‘Knowledge Repository’ sub-class of the Metaknowledge class, as shown in Figure 53.

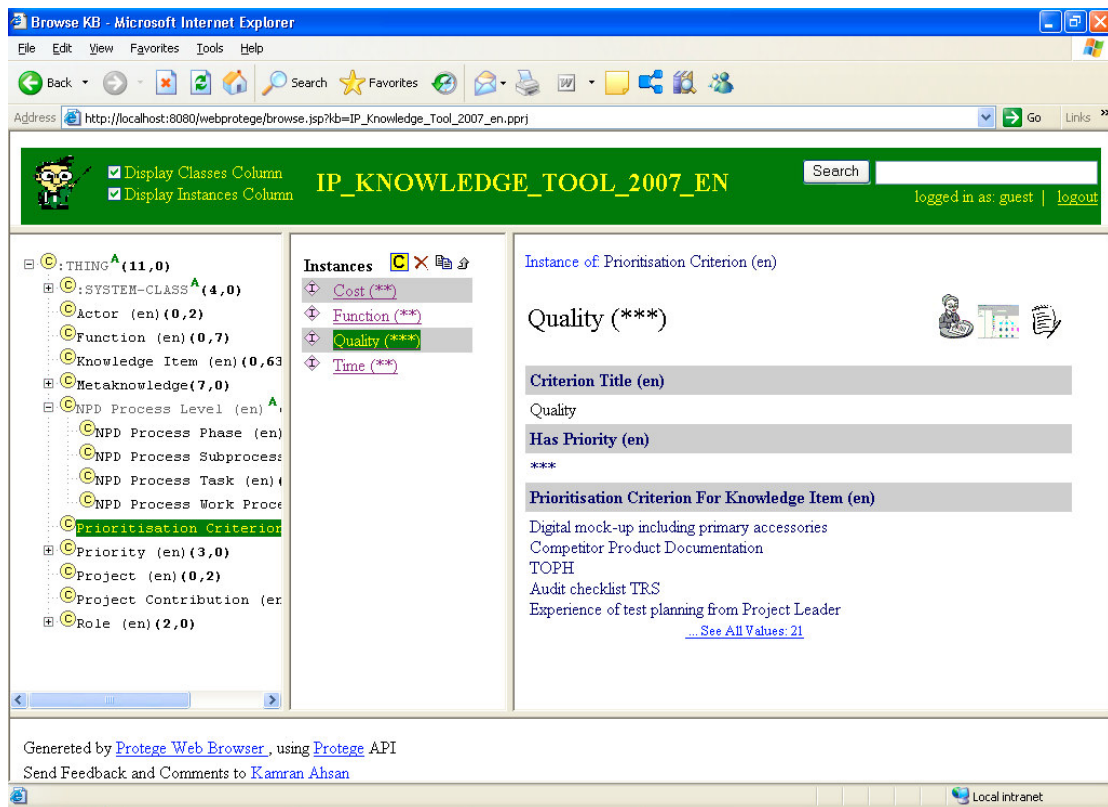


Figure 52: The form showing the knowledge items under the Quality criterion.

### 8.1.4 Discussion of Implementation Study

The use of the resulting knowledge acquisition tool to capture information about knowledge used and generated in the selected sub-processes and tasks has shown that the knowledge sharing tool can be applied to the knowledge associated with a real product development process. Capturing information about knowledge items provides answers to the competency questions specified in section 7.2.1. It is possible to include information about very diverse kinds of knowledge. For example, the ‘Product Validation’ sub-process task ‘Complete the test planning and plan the schedule’, generates the knowledge item ‘Project test plan’, which is of a highly explicit nature. The Project Performance’ sub-process task ‘Carry out milestone assessment’, generates a knowledge item called ‘Hows and whys of decisions taken in a review meeting’ which is stored in the minds of an individual and can be described as implicit knowledge. This latter kind of knowledge could not be represented in a knowledge-sharing tool that merely provides links to explicit knowledge items available in digital media.

Instance of: Personnel (en)


<b>Personnel</b>	
<b>Knowledge Repository Title (en)</b>	
Personnel	
<b>Stores Knowledge Item (en)</b>	
	Experience of test planning from Project Leader Experience of test planning from Test Lab Experience of test planning from Certification Knowledge of Microsoft Project tool Experience of test planning from Design Engineer Knowledge of SAP tool Expert knowledge of testing Product validation process experience of project leader Expert judgement to extract relevant results from tests Experience of writing test reports Experience of interpreting R-Prognosis Collective experience of project team Expert judgement of Product Manager Expert judgement of Project Leader on acceptability of risk Expert judgement of Programme Manger on acceptability of risk Decision on whether risk is acceptable 'Hows' and 'Whys' of decisions created in review meeting

Figure 53: Knowledge items stored in the ‘personnel’ repository.

All of the identified knowledge items could be classified within the knowledge domains defined in knowledge domain class of the ontology, although it should be stressed that only a small proportion of the total number of knowledge items involved in the NPD process have been examined here.

#### **8.1.4.1 Problems Encountered with the Knowledge Sharing Tool**

In the course of interviewing process experts and attempting to capture information about knowledge, several shortcomings in the knowledge sharing tool were identified.

One problem was the discovery that certain documents in the process may be used as inputs by several tasks in the process. An example of this is the 'TOPH document' used as an input to the 'Create technical response document' task of the 'Generate Product proposal' sub-process, see Appendix O. In the course of executing the task, additional data is added to this document and a revised version of it is one of the output knowledge items from the task. It may be argued that each revision of such a document is in fact a different knowledge item. However, treating them as such does not explicitly indicate to a user of the knowledge sharing tool the relationship of a given version of the document to its earlier or later revisions.

Those knowledge items that were of an implicit nature also revealed some problems, namely the assignment of an appropriate value for the knowledge item location, knowledge item medium and knowledge item language metaknowledge elements. Since implicit knowledge items reside in individuals identified by a role, rather than in an explicit physical artefact such as a paper document, the concept of them having a geographical location is not meaningful. In fact, this line of reasoning may also be extended to explicit knowledge items in a digital medium such a Microsoft Excel® file. Similarly, the notion of a knowledge medium cannot be applied to knowledge items of an implicit nature because by definition the knowledge has not yet been expressed. Once the implicit knowledge is expressed, it could be as a verbal communication or a written communication. The same argument may also be applied to the language metaknowledge element.

A final problem, encountered during the interviews to elicit information about knowledge, was deciding what knowledge items to include or exclude in the tool. On

being asked what knowledge items were required as inputs for a task, a process expert replied “oh I think we have hundreds!” Nonetheless, all of the process experts were able to articulate what they felt the key knowledge items were for each task considered in the interviews.

#### **8.1.4.2 Changes made to address problems**

In order to address some of the issues discussed above, some minor changes were made to the ontology used as the basis of the knowledge sharing tool. A description of these changes follows:

Firstly, two new slots were created for the ‘Knowledge Item’ class, called ‘has\_revised\_version’ and ‘is\_revised\_version\_of’. The former slot allows a knowledge item to be linked to revised versions of that knowledge item associated with tasks that occur later on in the NPD process. Conversely, the latter slot allows a knowledge item to be linked to previous versions of that knowledge item from tasks that take place earlier on in the NPD process. Secondly, the ‘has\_location’ slot was removed from the knowledge item class. It was reasoned that specifying the geographical location is not relevant to many knowledge items, such as digital files stored on a server, or implicit knowledge stored in the memory of people. Information about the whereabouts of a knowledge item is still provided by the ‘is stored in repository slot’. No changes were made to the ‘has\_medium’ (knowledge item medium) and ‘available\_in\_language’ (knowledge item language) slots, because they remain relevant for knowledge items in an explicit form.

The revised list of metaknowledge elements and corresponding slots for the knowledge item class is included in Appendix O.

#### **8.1.5 Discussion and Summary**

A case study considering the knowledge associated with tasks in three sub-processes, from the NPD business process of a multinational heating systems manufacturer has demonstrated how the tool and mechanisms may be used to capture and disseminate information about this knowledge. The sub-processes came from the conception phase of the product development process, but involved a broad spectrum of knowledge types, ranging from technical drawings to the rationale behind decisions taken in project

review meetings. In this way, it has been shown how the tool might be employed to facilitate knowledge sharing in a global product development environment.

Further research is required both to test the ontology and tool with knowledge items used in other sub-processes of the product conception phase, and in the other phases of the new product development processes. Additional work to determine whether other metaknowledge elements are required to describe the knowledge items would also be beneficial. The methodology and knowledge sharing tool should also be implemented in other settings, that is, NPD business processes in other industries and for different product types. In doing so, further empirical evidence as to its generalisability could be obtained.

## **8.2 Evaluation of Knowledge Sharing Tool**

### **8.2.1 Introduction**

In this section, a case study to evaluate the usefulness of the prototype knowledge sharing tool discussed in chapter seven is described. The study had two main objectives:

- to evaluate how useful potential users of the tool consider it to be as a device for the facilitation of knowledge sharing in the execution of the product development process; and
- to obtain feedback from potential users on the shortcomings of the tool.

Of particular interest was the usefulness of providing information about knowledge and the multilingual support and prioritisation mechanisms. The term useful is taken here to mean ‘capable of being used advantageously’ as employed by Laitenberger and Dreyer (1998) in their study to evaluate of the usefulness of a Web-based inspection tool.

Project development projects at the case study company tend to last in excess of fifteen months, so there was insufficient time available to the researcher to field test the tool in an actual product development project. Consequently, the focus was placed on assessing the perceived usefulness of the tool. Perceived usefulness is used in the sense adopted by Davis (1989), that is, the ‘degree to which a person believes that using a particular system will enhance [her or his] job performance’.

### **8.2.2 Method for Evaluation**

A case study approach was used to assess the usefulness of the metaknowledge concept on which the knowledge sharing tool is based, as well as the perceived usefulness of the tool itself, as already alluded to. In situations where evidence of an explanatory nature is sought, Robson (2002) advises that a qualitative investigation should be pursued. The process followed consisted of five steps, as shown in Figure 54.





Figure 54: Process for eliciting feedback about the usefulness of the prototype knowledge sharing tool.

Step one of the process involved the development of a questionnaire to capture the opinions of various parties involved in new product development projects. The questionnaire consisted of open-ended questions intended to elicit responses about the extent to which respondents believe that the tool supports knowledge sharing and the usefulness of the tool itself. Open-ended questions were chosen because they afforded the researcher the opportunity ‘to make a truer assessment of what the respondent really believes’, as advised by Robson (2002), and ‘to understand and capture the points of view of other people without predetermining those points of view without prior selection of questionnaire categories’, as counselled by Patton (1990). Questions covered the following themes:

- The usefulness of the overall tool as a means to facilitate knowledge sharing and provide an improved shared understanding of NPD process knowledge among project team members;
- The usefulness of the individual components of the tool, including the metaknowledge elements contained in the tool, the classification of knowledge by content (knowledge domain), and the prioritisation and multilingual support mechanisms;
- Initial impressions regarding the ease of use of the tool;
- The relative benefits of the tool compared to the time required to add information about knowledge to create a knowledge base, and;
- Areas for improvement.

The questionnaire protocol is included in Appendix Q.

Steps two and three of the process consisted of developing criteria for selecting individuals to take part in the study and then selecting participants based on these criteria. Three criteria were used. The first criterion was that participants should possess experience in a range of roles in product development projects. In this way, they could provide insight into the way the knowledge sharing tool might impact different roles in an NPD project team. The second criterion was that the participants should use at least two different working languages, in order that meaningful feedback about the multilingual mechanism could be obtained. The third criterion was that the individuals should be willing and able to participate in the demonstration session. This was particularly relevant in this part of the investigation, as the sessions in which the individuals were to take part would last around ninety minutes. Experienced personnel often occupy senior roles in the organisation and their time is precious. Indeed, due to the restricted access to such personnel, the scope of the study was limited to three NPD process experts.

Step four of the process involved presenting and demonstrating the knowledge sharing tool implemented in chapter seven to the three selected participants. The presentation of the tool involved an explanation of the purpose and main mechanisms of the knowledge sharing tool, followed by a demonstration of the tool itself. The demonstration covered the process of adding knowledge items to the tool along with the appropriate metaknowledge, navigating the tool, and the function of the knowledge prioritisation and multilingual support mechanisms.

This was followed by the administering of the questionnaire. The participant read through the questionnaire in the presence of the interviewer to make sure that they understood the questions. The participants then either entered answers in the protocol directly or returned a digital version by e-mail. Each session lasted about ninety minutes, with one hour required to present and demonstrate the tool and answer participant questions, and thirty minutes for the participant to fill in the questionnaire. In a quantitative study of the usefulness and usability of a software application, Davis (1989) noted that less than one hour of interaction with a prototype software system by a subject is sufficient for them to provide a meaningful assessment of its usefulness.

Step five, the analysis of the responses from the questionnaire protocols, is documented in the following section.

### 8.2.3 Findings

Information about the roles and locations of the three selected participants is summarised in Table 27. As may be seen, selected participants performed different roles and between them used two different languages.

<b>Participant</b>	<b>Role</b>	<b>Site Location (Working Language)</b>
R1	Group R&D Manager	Germany (German)
R2	Quality Planning Engineer	United Kingdom (English)
R3	Innovation Project Manager	Germany (German)

Table 27: Roles and locations of participants in the investigation of the usefulness of the tool.

The findings from the questionnaire responses (see questionnaire protocol in Appendix Q) will be discussed around the themes mentioned in section 8.2.2. All three respondents indicated that they felt that the tool would improve knowledge sharing among NPD project team members. However, any enthusiasm for the tool was tempered by concerns about the time required to create new knowledge items and to add metaknowledge for these items. Such concerns were echoed by participant R1 in responses to questions 1(a) and 1(c). On the theme of whether the tool would facilitate an improved understanding among project team members, the response was mixed. Again, this was due to effort required by personnel to add knowledge items and information about these knowledge items to the knowledge base.

In terms of the classification of knowledge by content or ‘knowledge domain’, all of the respondents agreed that it would help them find knowledge relevant to tasks in the NPD process. To this end, participant R3 opined that the classification of knowledge items by knowledge content, using instances of the Knowledge Domain class, would

assist in finding relevant knowledge items, "... because it is clearly structured by logical classes". They also concurred that the linking of knowledge items to process tasks was useful. Participant R1 noted "It would be culpable if we did not align knowledge items with processes or tasks", while participant R2 commented that this practice was "very useful" and that it "... gives structure to find relevant/required information and structure to input information". Moreover, participant R3 remarked that it was useful "because a more simple kind of workflow is created. You know where you come from and where to go next".

As far as the metaknowledge elements were concerned, no additional elements were identified as missing or redundant. Nonetheless, the participants commented that without using the tool in practice, this was difficult to ascertain (see responses to question 3(a) in Appendix Q). Further investigation then is required to clarify this issue.

It was agreed by all the participants that the prioritisation of knowledge items was useful, but R1 proposed that this job would be better performed by the NPD project leader. To this end, participant R1 remarked that "It's difficult to understand for me [sic] that a tool can replace the prioritisation done by the project leader" (see response R1 to question 4(a) in Appendix Q). Participant R2 felt that indicating the knowledge priority, "helps to identify knowledge according to business objectives" (see response R2 to question 4(d) in Appendix Q). Meanwhile, participant R3 proposed that the mechanism to assign a priority to a prioritisation criterion should be made more flexible, since priorities may vary from project to project. For example, the business focus of company might shift from quality to cost in future projects.

There was universal agreement that the multilingual support mechanism would help to achieve an improved common understanding of the knowledge used in the product development process. For example, participant R1, a native German speaker, remarked: "We still face problems created by misunderstandings due to different languages. Therefore language support features are really necessary" (see response to question 5 in Appendix Q). Participant R2, a native English speaker ventured that while a multilingual interface should be in place to help users navigate and understand the tool, the actual descriptions of knowledge items should be in English. Participant R3

warned that the tool “would not find acceptance without the languages of all sites included”.

As described in section 8.2.2, the participants only had a short period of time in which to learn about the tool. Nonetheless, they were prepared to offer some comments as to its usability and ease of use, that is ‘the degree to which a person believes that using a particular system would be free of effort’ (Davis, 1989). For someone using the tools to find about knowledge used in the new product development process, they commented that the tool seemed easy to use. Participant R2 expressed the reservation that a true assessment could only be made by using the tool for a longer interlude. In the response to question 6(a) (see Appendix Q), they made the comment: “Seems ok, but as with any new software, only time and use will tell’. This opinion was echoed by participant R3: “You have to use it a couple of time [sic] to feel comfortable with it, but it is easy to understand”. However, they also cautioned that adding new knowledge items to the knowledge base seemed to be complicated in comparison to just browsing the tool. It was though felt that this issue could be addressed through user training.

The penultimate theme addressed by the questionnaire was whether the investment of time required to build and to maintain the knowledge base would be worthwhile. This was a difficult issue for the respondents to address with only a brief opportunity to view the tool. As might be anticipated then, the responses to this question (see question 7 in Appendix Q) were mixed. Participant R2 indicated that the potential benefits to be gained from using the tool outweighed the inconvenience of adding information to construct the knowledge base. Participant R1, on the other hand was more reticent. They reiterated the same concerns they had about the effort required to add data as were articulated in response to question 1 in the questionnaire (see Appendix Q). Participant R1 lamented: “It’s again another tool that needs additional effort and a lot of discipline. People will surely try to bypass it first. Question is, how could the effort be reduced to additional informations [sic] that are not already available somewhere else so that there is no redundant input necessary?” The suggestion that the metaknowledge elements be reduced to avoid duplication with metaknowledge available in other sources is helpful, but the efficacy of this approach depends on the metaknowledge available in the environment in which the tool is to be used.

Lastly, participants were asked to identify weaknesses in the knowledge sharing tool and areas in which it could be improved, both conceptually and in the tool itself. Suggestions provided by the participant R1 about the weakness of the tool again referred to concerns about the time required to add information to the tool and the detrimental effect this may have on its acceptance and use by NPD project team members. The comments of participant R2 confined themselves to proposing new features for the tool itself, which included a search feature with Boolean operator support and the provision of an online help system and tutorial.

Similarly, Participant R3 requested an advanced search facility in the Web interface that would provide a quick way to find process tasks or knowledge items. Participant R3 also ventured that the forms for knowledge items in the format of documents should provide a link to that specific document. There are two major difficulties with this latter proposal. The first is that if such a link points to a document specific to a project, it would require that a separate knowledge base be created for every project. The second and more significant problem is that such a feature would shift the knowledge sharing tool away from the metaknowledge paradigm and towards a system to capture knowledge. The shortcomings of such a tool were alluded to in section 2.1.4.

#### **8.2.4 Discussion and Summary of Evaluation Case Study**

It was shown in section 8.1 how the knowledge sharing tool might be used to capture and disseminate information about knowledge in the NPD process and in doing so facilitate knowledge sharing in a global product development environment. This claim was broadly supported by the study to elicit feedback, from three NPD process experts at two different sites of the case study company, about the perceived usefulness of the tool. The connection of knowledge items to process tasks was considered to be useful, as were the knowledge prioritisation and multilingual support mechanisms. However, the study also highlighted some of the weaknesses of the knowledge sharing tool. The most significant of these was the time required for project team members to enter information about knowledge items, which it was felt would inhibit the usage of the tool among NPD project team members.

Given that this part of the study was qualitative in nature and restricted in scope to just three NPD process experts at one organisation, further research into usefulness of the tool is needed. For example, a quantitative approach could be adopted using a measure such as that proposed by Davis (1989), and subsequently validated by Adams et al. (1992), and Laitenberger and Dreyer (1998). This method exploits a Likert-type measurement scale to assess the usefulness of the actual tool. The data collected with this technique is quantitative in nature, complimenting the qualitative nature of techniques used in this investigation. Triangulation of methods in this manner would strengthen the validity of the findings.

## **9 Discussion of Research Findings**

This chapter discusses the findings of the research presented in the previous chapters of this thesis document. It commences by describing how each of the research objectives was met. Next, the limitations of the research are examined, followed by an exploration of the wider scope of application of the research. Finally the contributions made to the body of knowledge are stated.

The research aim, originally stated in chapters one and three, was:

To provide a prototype method and tool for facilitating knowledge sharing in early new product development.

Based on a review of the literature, it was established that this aim was to be achieved by meeting the following five objectives:

1. Further explore the nature of knowledge and approaches to managing knowledge sharing in new product development;
2. Identify key barriers to knowledge sharing;
3. Empirically inform a conceptual model for improving knowledge sharing;
4. Develop a prototype method for reducing barriers to knowledge sharing in early new product development; and
5. Conduct an initial validation of the prototype method.

The research objectives stated above provided the rationale and framework for the research presented in the earlier chapters of this thesis.



## **9.1.1 Discussion of Research Objectives**

### **9.1.1.1 Objective 1: Further explore the nature of knowledge and approaches to managing knowledge in new product development**

A wide-ranging review of literature was undertaken in two parts. Part one examined the current understanding of knowledge in the literature, models for knowledge sharing, and the types and content of knowledge used in product development. Part two focused on knowledge sharing in the context of the new product development (NPD). It considered the obstacles to knowledge sharing in organisations and modern NPD environments, and the general approaches advanced by researchers to reduce these knowledge sharing barriers. Literature from the knowledge management, knowledge engineering and product development domains was included. A detailed summary of the findings of the review is given in section 2.8.

Two views of knowledge were found in the knowledge management literature. The most prevalent and well-established of these is that of Nonaka (1991). This view describes knowledge as being available in two distinct forms: tacit knowledge and explicit knowledge, the latter of which is essentially information. Furthermore, the view permits that one form of knowledge can be transformed into the other. The other, more recent view, informed by Keane and Mason (2006) and Hislop (2002), argues that knowledge has tacit and explicit dimensions, rather than being available in distinct forms. This second view has had growing support in recent years, following criticism of the Nonaka model. In this view, it is difficult or impossible to capture the tacit dimension of knowledge. With this idea in mind, Keane and Mason (2006) implied that knowledge management systems that claim to capture tacit knowledge by converting it to explicit knowledge are actually unable to do so.

Knowledge sharing models for both views dictate that if knowledge is to be shared at all among people, social interaction is required. Clearly, such interaction may prove impossible when NPD project team members are not co-located.

Knowledge sharing is regarded by knowledge management and NPD researchers as critical to the success of a product development project. However, while much attention has been paid by researchers to managing knowledge in product development, relatively little regard has been given to knowledge sharing in this area. It emerged from

the literature review that there is a range of obstacles to knowledge sharing in a product development environment. Some of these obstacles are generic to large organisations, whilst others are more specific to the product development environment. Approaches to minimising these barriers may be divided into two categories: social policies and procedures to influence human behaviour, and information technology-based tools. Notably, it has been cautioned that information technology tools are unlikely to make knowledge sharing take place if they are used in isolation. Rather they should be deployed as an enabler as part of a wider strategy that also embraces the use of suitable organisational policies.

Various information technology tool-based knowledge management methodologies have been proposed that in some way seek to support knowledge sharing in NPD environments. However, given that there are a large number of knowledge sharing obstacles in product development, it was determined that a meaningful review of these tools could only be carried out by focusing on a key few key barriers in a product development environment.

An investigation of attempts to categorise NPD process knowledge revealed that several taxonomies have been proposed. These tended to classify knowledge based on its nature. It was considered by the author that these would be of less practical use to an NPD practitioner searching for relevant knowledge than a content or domain-based classification. Another limitation was that most of the classifications concentrated solely on the knowledge used by the design engineer and therefore excluded the other functional roles in an NPD project team. These roles include project leader, project auditor and cost analyst. One content-based classification of information and data was proposed by Zahay et al. (2004), but this was based on a broad and shallow study covering many organisations and industries, as opposed to an in-depth study involving a large number of NPD practitioners from a single company or industry.

The new product development business process has been described by Eppler et al. (1999) as a knowledge intensive process. It may involve hundreds, thousands or perhaps more knowledge items. In order to help manage this knowledge, researchers in the technology management domain have advocated prioritising knowledge assets according to their relevance to the business strategy. The author considered it to be

conceivable then, that prioritising knowledge in line with its strategic relevance to an NPD project could help to facilitate knowledge sharing. The author proposed that further research was required into the prioritisation of NPD process knowledge.

#### **9.1.1.2 Objectives 2 and 3: Identify key barriers to knowledge sharing and empirically inform a conceptual model for improving knowledge sharing**

A two-part empirical study was carried out to address research objectives two and three. Both parts of the study drew on a set of six sources of empirical evidence. One part was an exploratory study to identify key knowledge sharing barriers in the NPD environment, while the other part concerned an investigation to identify and classify NPD process knowledge. A discussion of each part follows.

##### **Identify key barriers to knowledge sharing**

Even a brief reference to the knowledge management and NPD literature uncovers a litany of obstacles to knowledge sharing in NPD environments, as discussed in section 2.4.2 of the literature review. It was considered that a meaningful and focused review of existing methodologies for the facilitation of knowledge sharing would need to be made in the context of a small selection of key knowledge sharing barriers relevant to the sponsor company.

To this end, an empirical investigation was conducted at the sponsor company to identify key knowledge sharing barriers. Importantly, the company possesses many of the traits that characterise global product development organisations, including the exploitation of local expertise and geographically dispersed multilingual product development teams. It also uses a stage gate-style product development process very similar to generic NPD models in the literature and widely employed in product development companies. The investigation and its findings partially met objective three and fully met objective two.

Evidence used in the study came from a broad range of sources and data types, as mentioned at the start of this section. These included two interview-based sources obtained in the course of knowledge management project work conducted at the three main product development sites at the company, as well as securing an internal

company survey which collected employee feedback on the NPD project business process. In this way, triangulation of data sources was achieved.

As with other manufacturing environments studied in the literature, it was observed that product development activities are subject to many knowledge sharing obstacles. Only three barriers were concentrated on here however, which were agreed upon following a presentation to senior managers at the sponsor company.

The first barrier was the lack of explicitly defined information about knowledge used and generated in the NPD process. That is, there was a lack of formally defined information about this knowledge. This information included the names and locations of human knowledge repositories and the knowledge associated with different projects. Another example was the absence of a link from tasks in the process to relevant knowledge. That is, the knowledge needed to carry out a task. The paucity of information about knowledge contributes to two important problems. Firstly, it makes it harder for NPD practitioners to find knowledge relevant to their tasks. Secondly, practitioners are unaware of what knowledge is actually available, especially on other sites. The consequences of these problems were espoused by NPD practitioners taking part in the interviews. They pointed out that significant time is spent searching for knowledge and gave examples of scenarios where duplication of effort has occurred. The result was that knowledge already available was reproduced, wasting time, effort and money.

The second barrier was the lack of a mechanism to make information about knowledge accessible to individuals in a multilingual environment. Language had already been highlighted in the literature review as a major obstacle to knowledge sharing. Three different languages are spoken at the major product development sites in the company alone. Ultimately, the challenge is to provide a mechanism to translate information unerringly among three different languages. This was not within the scope of this project or within the aptitude of the author and will remain a challenge for researchers in the Artificial Intelligence domain, among others. In this sense, the language translation problem could not be resolved in this research project. However, it was clear from the comments of NPD practitioners that the issue was significant enough

that any effort to provide information about knowledge to a multilingual environment must at least attempt to address this issue.

Similarly, defining information about NPD process knowledge is futile, if that information cannot be made accessible to, and disseminated among, geographically dispersed product development team members. Comments made by interviewees in the knowledge audit and knowledge sharing investigation in the R&D organisation of the company suggested that there is perceived to be a strong awareness of knowledge within the confines of a site. However, they also indicated that there is sometimes scant understanding of what is available at other sites. Knowledge is therefore sought locally and a heavy reliance is placed on networks of individuals who are co-located. This problem lay at the heart of the third barrier, i.e. the lack of a mechanism to disseminate information about NPD knowledge to project team members. As stated previously, these barriers conspire to inhibit the achievement of a shared understanding of NPD knowledge in a multinational, multilingual product development environment.

### **Identification and classification of knowledge in the new product development process**

The investigation to identify and classify knowledge used in the new product development process is detailed in chapter five. Classification of the knowledge was based on its content, that is, the knowledge domain it addressed. The resulting classification served to provide the knowledge domains for the 'Knowledge Domain' class of the ontology of information about NPD knowledge used in the knowledge sharing tool. In conjunction with the investigation to identify key knowledge sharing barriers, the findings of this work addressed research objective three.

Many previous attempts have been made to classify NPD knowledge, as discussed above and reported in the literature review (see section 2.2.2). Relatively little attention has been paid to classifying knowledge according to its content or domain, which is likely to be of greater use to NPD practitioners attempting to find or learn about the knowledge relevant to a given task. Court (1998), citing Rasmussen (1985), ventured that information about information should be provided to knowledge seekers in order to assist in them in finding knowledge that is likely to solve their problem. Indeed, the results of a survey carried out by Broens and de Vries (2003), supported this

notion (see section 2.2.2). In this context, classifying knowledge by content may be said to provide useful metaknowledge.

The classification of NPD data and information by Zahay et al. (2004) was based on interviews with representatives from a broad range of industries, rather than being an in-depth study in a single industry. Indeed, its aim was to be as generalisable as possible. Consequently, it was not certain that this knowledge classification would be applicable to new product development knowledge in the case study company, a heating systems manufacturer. For this reason it was deemed necessary to first identify and then classify the knowledge used in the NPD process of this company.

A case study approach was used to identify the knowledge used in the product development process of the company. The study drew on three sources of data, two of which were also used in the study to identify knowledge sharing barriers. Using multiple sources provided the opportunity to exploit the benefits of triangulation. In doing so, bias was reduced and a rich body of evidence obtained, as advocated by Patton (1990), Yin (1994) and Robson (2002) (see section 4.2.2).

The first source was a knowledge audit of the company NPD process. A knowledge audit methodology adapted from an existing methodology by Liebowitz et al. (2000) was employed. The key adaptation was the use of semi-structured interviews rather than a questionnaire protocol as the data collection technique. The rationale for this change was that face-to-face interviews would provide an opportunity for the interviewer to offer further explanation of questions to the interviewee where necessary. The interviewer would also be able to encourage the interviewee to pursue themes of further interest, where desired. Interviews were held with eight sub-process owners representing sub-processes from every NPD process phase. This provided an understanding of the types and content of knowledge used across the NPD process.

The second source was the company NPD business process documentation. The business process flow maps in this documentation indicated selected information inputs and outputs for some process tasks.

The third source was an investigation of knowledge sharing practices in the Research and Development (R&D) function of the company. One aim of this investigation was to identify the knowledge shared among members of the R&D

organisation. The evidence collected in this investigation was elicited in interviews with eight individuals in project leadership or senior engineering roles (see Table 6). This investigation differed from the knowledge audit in that the interviewees occupied a broader range of roles. Each interview considered the knowledge used in the entire process rather than a single sub-process, and explicit efforts were made to collect information about the format and repository of the knowledge.

Knowledge items identified in the three studies were collated and transferred to a mind map. Initially, knowledge items from the knowledge study were assigned to the knowledge types proposed by Zahay et al. (2004), since this was the most recent and comprehensive study of NPD knowledge and information available. New classes were created or existing classes modified to accommodate knowledge items that were not subsumable under this classification. Using the revised classification, this process was repeated for the knowledge items from the knowledge sharing investigation source. The process was terminated when a classification was obtained that encompassed all of the knowledge items. Ultimately, twelve classes of knowledge were identified, adding five to the study by Zahay et al. (2004). Anecdotal evidence of the similarity of the classification to that used by NPD practitioners to organise their personal project documentation is provided in Table 17. In the later study to carry out an initial validation of the usefulness of the knowledge sharing tool, all of the NPD practitioners interviewed agreed that the classification would help them find knowledge relevant to tasks in the NPD process (see section 8.2.3). Clearly, though, this was a small sample size and further assessment of its usefulness would be desirable (see section 10.2.1).

Classifications of the knowledge item format and repository types were also created and these were used later as part of the knowledge base of information about NPD process knowledge.

#### **9.1.1.3 Objective 4: Develop a prototype method for reducing barriers to knowledge sharing in NPD**

A method was developed which leads to the creation of a knowledge sharing tool based on an ontology of information about knowledge used and generated in the NPD process.

Development of this method was achieved in two phases: conceptual design of the tool, and tool development. The conceptual design phase commenced with a literature-based review of methodologies and tools that claimed to facilitate knowledge sharing in NPD environments. A key finding of this review was that none of the methodologies addressed all three of the key knowledge sharing barriers, as stated in section 6.1.1.9. This finding established that there was a need for further research into the development of a new methodology or tool to address these barriers.

### **Review of knowledge sharing technologies and methodologies**

It was decided early on in the research project that an information technology-tool based approach would be taken to minimising the knowledge sharing barriers (see section 2.5). In order to determine what kind of approach would form the basis of this tool a review of knowledge sharing technologies and methodologies was conducted. Two approaches that claim to nurture a shared or common understanding of a knowledge domain were examined in terms of their suitability for tackling the knowledge sharing barriers in the context of a product development environment. The two approaches scrutinised were knowledge maps and ontologies. Ultimately, an ontology-based approach was chosen because it was considered that ontologies could be used to address all three knowledge sharing barriers, as argued in section 6.1.2.2. Knowledge maps were rejected for two reasons. These were the lack of an ability to support a multilingual environment and the constraints to the amount of information that they can effectively convey.

### **Provision of an ontology-building methodology to develop an ontology of information about knowledge in the new product development process**

Having elected to adopt an ontology-based tool approach, it was necessary to provide an ontology-building methodology apposite to the task of building an ontology of information about new product development knowledge. To assist in this venture, a literature-based investigation of existing ontology building methodologies was carried out. Work pertinent to this activity is documented in chapter six.

The first part of the investigation was to identify what ontology building methodologies were already available in the literature and to evaluate their suitability



for the ontology to be developed in this work. A six-stage process for selecting an appropriate ontology building methodology was devised and executed. Stage one involved choosing whether to reuse an existing ontology or build a new one from scratch. Eight sources of published ontologies and classifications were examined, but no suitable ontology was found. On this basis it was determined that a new ontology should be built. Stage two then, was to identify methodologies suitable for this ‘from scratch approach’. Reviews of ontology building methodologies from the literature were consulted to achieve this task. As these reviews tended to be carried out by research groups which had developed their own methodologies, and the most recent was published in 2004, additional efforts were made to ensure that no methodologies had been left out. Nine methodologies were considered, seven of which were deemed to be suitable for building a new ontology.

The second part of the investigation involved reviewing the seven methodologies and selecting the most appropriate one. A framework was developed to assist in the selection task. This framework was based on seven selection criteria. These seven criteria were informed by two sources:

- Nine criteria for analysing ontology building methodologies used by Fernández-López (1999)
- The specific needs of this research investigation, such as suitability to the domain and evidence of previous applications in real world scenarios

Once the framework was in place, the review of the methodologies was carried out. The details of the review may be found in section 6.2.4. It was found that none of the methodologies fulfilled all of the selection criteria. As a result, it was decided that the selection would concentrate on the criteria pertinent to the research investigation.

These criteria were:

- The level of detail included in the description of the methodology
- The ease of use of the methodology and the availability of tools to support it
- Whether the methodology had been applied to the construction of real ontologies published in the literature (see section 6.2.4)

Based on this, it was decided to select the ontology building guidelines proposed by Noy and McGuinness (2001).

It was noted that this methodology, and indeed the six other methodologies, suffered from a major shortcoming. This was an absence of a formal method that explicitly details the information elicitation techniques and tools required at the knowledge acquisition stage of the ontology lifecycle, and that would be suitable for application in a new product development environment. In order to address this issue, a refined version of the knowledge identification methodology described in the first part of chapter five was proposed. This refined methodology acts as a knowledge acquisition method suitable for identifying and classifying the knowledge used in the new product development process. Details of the techniques and tools used for other phases of ontology development may be found in chapter six. Two changes were made to the ontology development process in the generic Noy and McGuinness (2001) methodology to accommodate this change. The result was the provision of a methodology suitable for developing an ontology of information about knowledge used in the new product development process.

### **Development of the knowledge sharing tool**

In addition to the ontology, the knowledge sharing tool was to consist of other components. These components included:

- An ontology building tool or editor to construct and maintain the ontology
- A mechanism to support a multilingual environment
- A mechanism to indicate the priority of a knowledge item
- A mechanism enable the dissemination of this information among geographically dispersed team members

The work carried out to fulfil this objective is described in chapters six and seven. Collectively these components address the knowledge sharing barriers identified in chapter five. Each of the knowledge sharing tool components will now be considered in turn.

### *Ontology building tool component*

An ontology building tool is required to build and maintain the ontology. Reference to the literature revealed that there were many such tools available, as illustrated by the findings of the survey by Denny (2004) in which ninety-four were listed. Furthermore, several reviews of such tools were available in the literature. These reviews provided useful background information about the available tools and their general traits. They also acted as a guide as to what criteria might be used to evaluate such tools. However, they were of little use in the selection of an appropriate tool for two reasons. Firstly, in the case of the actively maintained tools, newer versions of the software covered in the reviews had since been released, rendering many of their findings redundant. Secondly, a selected ontology building tool needed to meet criteria specific to the needs of the knowledge sharing tool for which it was to be used.

A four-stage process was followed to choose a suitable candidate. The first stage of this review was to identify currently available ontology building tools, also known as ontology editing tools, and produce a shortlist of tools that could then be reviewed in detail. Corcho et al. (2003) identified eight tools that they considered to be 'relevant', and placed these tools into three categories, based on when they were released and their scope of application. The category considered to be of most relevance to this investigation was the tools that were developed to facilitate the integration of ontologies in information systems. This category contained just three tools, one of which had subsequently been forked into two new projects, resulting in a short list of four tools. The second stage was to devise a framework of selection criteria for evaluating the tools in the shortlist. Eight selection criteria (see Table 21 in chapter seven) were devised for this purpose, covering technical issues related to the development of the ontology itself, and pragmatic issues related to the practical constraints of the research project. In the third stage, the tools were evaluated using these criteria and in the fourth stage the final selection of the tool took place. The Protégé ontology editor was selected. This selection of Protégé was based principally on its link to the Noy and McGuinness (2001) ontology building methodology, its perceived ease of use for inexperienced users, and features that would support the development of the multilingual support and knowledge prioritisation mechanisms.

### *Ontology and knowledge acquisition tool*

An ontology of information about knowledge used in the NPD process was developed using the ontology building methodology provided in chapter six. The ontology formed the basis of a knowledge acquisition tool, which in turn would become a knowledge base following the addition of process task and knowledge item instances. Two approaches to modelling an ontology are supported by the Protégé editor: the Protégé-Frames model for building frames-based domain ontologies and the Protégé-OWL model for building OWL ontologies. Both both approaches offered different functionalities that could potentially be exploited for the multilingual support and prioritisation mechanisms. Therefore, the final decision on which model would be used for the actual prototype ontology was postponed until these mechanisms had been explored and developed.

A critical part of developing the ontology was the formulation of competency questions, the questions that the ontology must answer. Formulation of the competency questions was based on determining what kind of information about knowledge items or metaknowledge an NPD project team member may wish to know. An initial metaknowledge element set was assembled based on the types of information about knowledge already discussed (see section 5.5.2), and an existing metadata element used in an NPD knowledge management system by Donnellan and Fitzgerald (2003). This initial set was further refined based on feedback collected in interviews with four NPD process experts located in two product development sites at the case study company.

Having established what metaknowledge was required, the competency questions for the ontology could be formulated (see Table 22 in section 6.3.1). A domain ontology and a knowledge acquisition tool were constructed in the Protégé editor by implementing the aforementioned ontology building methodology. Forms in the graphical user interface of the tool allow instances of knowledge items to be captured and metaknowledge values to be assigned to these instances. In this way information about knowledge items in the NPD process is explicitly defined. The degree to which the ontology may be considered generic to other product development processes and companies is discussed in detail in section 7.2.3, and summarised in section 9.1.2.

### *Multilingual support mechanism*

The aim of the multilingual support mechanism was to make the ontology and knowledge acquisition tool accessible to a multilingual NPD environment. In practice this meant providing a means to display the concepts and relations in the ontology in different languages. Reference to the literature revealed that there is a lack of formal methodologies for developing ontologies with multilingual support using ontology building software tools. However, informal guidelines have been published in ontology building community support forums for the Protégé ontology editor and these were adopted in the development of the mechanism.

Two approaches were investigated, one using the Protégé-Frames knowledge model and the other using the Protégé-OWL model. Both approaches adhered to an established multilingual ontology technique. This technique entails modelling domain concepts in a single language and then mapping appropriate phrases from the desired languages, in the form of labels, to the concepts and relations the ontology. In either case, the language displayed in the tool interface can be easily changed. Each approach suffered from the same limitations. The language labels can only be applied to classes and slots (classes and properties in the OWL-version), and not instances. Additionally it was found to be time consuming to add languages labels to every class and slot. The final choice of which approach to adopt was eventually dictated by the choice of knowledge prioritisation mechanism.

### *Prioritisation mechanism*

It was found in the literature review that some authors have advocated the importance of prioritising knowledge assets according to their relevance to a business strategy. For example, there might be a focus on process and product quality (see section 2.7). Moreover, previous NPD knowledge management methodologies and tools have not explicitly addressed this issue (see section 6.1.1).

A mechanism was developed to indicate the priority of a knowledge item and to provide a way to assign prioritisation criteria to priority levels. As with the multilingual support mechanism, two approaches were explored. One approach used the Protégé-Frames model and the other used the Protégé-OWL knowledge model, as documented in section 7.3.2. In the Protégé-Frames approach, prioritisation criteria must be created

as instances of a 'Prioritisation Criterion' class, and priority levels as subclasses and instances of a 'Priority' class. Priority levels are linked to the criteria, and criteria to the knowledge items, using slots. The currently allocated priority is then indicated by a symbol next to the selected prioritisation criterion on the knowledge item form in the knowledge acquisition tool interface. In the Protégé-OWL approach, it was proposed that a Description-Logic reasoner might be used to automatically classify knowledge items into different priority levels. This classification would be based on properties linking knowledge items to a given domain, such as 'Quality'. It emerged though from initial testing that the reasoner could only be used with a form of OWL that did not support the metaclass features needed by the Protégé OWL multilingual support mechanism. This led to the decision to choose the Protégé-Frames approach for the prioritisation mechanism. Consequently, the Protégé-Frames multilingual support mechanism approach and Protégé- Frames knowledge model for the ontology were also selected.

#### *Dissemination mechanism*

Global product development teams are partly characterised by being comprised of geographically dispersed members (McDonough et al, 2001). The purpose of the dissemination mechanism was to ensure that the information about knowledge items could be made available to project team members irrespective of their location. The review of literature showed that many NPD knowledge management systems made use of Web-based tools for disseminating information (see section 6.1.1). A recent survey of large enterprises operating in the European Union suggested that ninety-nine percent had Internet access, as did the sponsor company. Therefore it was decided to develop a Web-based mechanism to allow the knowledge base to be accessible via the Internet.

An add-on Protégé tool called Protégé Web Browser was exploited to carry out this task. The resulting mechanism allows ontologies and knowledge bases created in Protégé to be displayed and browsed via a Web browser. It uses a client-server architecture, with the Protégé Web Browser and a JavaServer-Pages server on the server side and a Web browser client such as Microsoft Internet Explorer® on the client side. NPD project team members only have to access a Web browser to look for relevant

metaknowledge. The shortcomings to the mechanism are discussed in detail in section 7.3.3 and summarised in section 9.1.3.2.

#### **9.1.1.4 Objective 5: Conduct initial validation of prototype method**

Objective five was to conduct an initial validation of the prototype method. This concerned implementing and testing the knowledge sharing tool developed to meet objective four. The investigation was divided into two parts. Part one involved demonstrating the functionality of the knowledge sharing tool and testing the knowledge domain (knowledge content) classification used in the ontology of information about NPD knowledge. Part two concerned evaluating the perceived usefulness of the knowledge sharing tool by its potential users, that is, the various roles that make up an NPD project team.

A case study approach was adopted for both parts. Case studies allow multiple sources of evidence to be used and allow a rich and deep understanding of a domain to be obtained. They are also well established as a means of studying information systems in organisations (Orlikowski and Baroudi, 1991), and have been used in the NPD domain by researchers including Ramesh and Tiwana (1999).

For part one, the knowledge sharing tool was used to capture information about the knowledge items associated with three sub-processes in the conception phase of the new product development business process of the sponsor company. This phase was chosen because it involves a wide range of knowledge types and functional roles. A five-stage process was developed and followed to:

- Select the candidate sub-processes,
- Elicit information about the tasks involved in those processes;
- Elicit information about the knowledge required for and generated by these tasks (including project prioritisation criteria);
- Capture the information about knowledge in the knowledge acquisition tool, and
- Add multilingual language labels to the ontology, in this case English and German.

Elicitation of information about the knowledge associated with tasks was carried out using interviews with process experts nominated by the company. The methods and techniques used to execute the five-stage process are detailed in section 8.1.2. The knowledge domain classification accommodated all of the knowledge items represented in the resulting knowledge base. A walkthrough of the main features of the tool for three usage scenarios illustrates how it might be used in practice (see section 8.1.3). Problems encountered with the knowledge sharing tool during the capture of information about knowledge items were identified and where possible addressed (see section 8.1.4). This part of the investigation demonstrated how the knowledge sharing tool might be used to capture and disseminate information about NPD process knowledge. In this way, it has been shown how the tool might facilitate knowledge sharing in a global product development environment.

In part two, a five-step process was used to elicit feedback from target users about the usefulness of the metaknowledge concept, upon which the knowledge sharing tool is based, and the perceived usefulness of the tool. A questionnaire consisting of mostly open-ended questions was developed in the first stage. Open-ended questions were used to allow respondents to explain their answers and to avoid predetermining the outcomes. Stages two and three consisted of determining selection criteria for interviewees and selecting interview candidates. Three candidates with experience of a variety of product development roles and based in two different countries, the UK and Germany, were selected (see Table 27). This meant that they would have insight into different parts of the NPD process and could provide meaningful feedback on the multilingual support mechanism. In step four, the tool was presented to the interviewees in separate sessions and its key functions demonstrated. Following this, the questionnaire was administered. Each session lasted about ninety minutes. According to Davis (1989), less than one hour of interaction with a prototype software system by a subject is adequate for them to provide a meaningful assessment of its usefulness. In step five, the responses in the questionnaire protocols were analysed. It was found that the connection of knowledge items to process tasks was considered to be useful, as were the knowledge prioritisation and multilingual support mechanisms. A fuller analysis is given in section 8.2.3. The study also highlighted some of the weaknesses of the knowledge sharing tool. These



weaknesses are considered in section 9.1.3.2 of this chapter, along with those of part one of the investigation to implement and test the knowledge sharing tool.

### **9.1.2 Scope of Application of Methodology for the Facilitation of Knowledge Sharing in NPD Companies**

Implementation and testing of the knowledge sharing tool demonstrated that it may be used to disseminate information about NPD process knowledge among NPD project team members. However, the evidence used to develop and test this tool was derived from in-depth studies in a single organisation, a large manufacturer of heating systems appliances. These heating systems appliances, predominantly boilers, are electromechanical products of relatively low complexity and NPD projects are mostly new product platforms or derivatives of existing products (see section 5.2). No empirical evidence has been obtained as to the effectiveness of the tool for other product and process types. In spite of this, it is asserted that the knowledge sharing tool presented in this thesis bears certain traits that make it applicable and useful beyond the realm of heating systems manufacturing.

A key feature of the tool is that it provides this information about knowledge in the context of tasks in the NPD business process. The case study company NPD process model closely adheres to generic NPD process models in the literature. It is therefore proposed that the ontology employed in the knowledge sharing tool could be adapted to suit the needs of other multinational manufacturing companies using such a process model. Reference to the literature indicates that a high proportion of firms use some form of formal product development process. Indeed, according to Griffin (1997), sixty percent alone use a stage-gate process. Therefore it may be argued that the methodology could be applied in other product development firms.

One caveat is that an NPD business process defined to similar level of detail to that examined in this study would be required, probably at the sub-process level or task level illustrated in Figure 35 of chapter eight. This is necessary both to model the process hierarchy in the ontology and to associate knowledge items with a level of the process that is meaningful to NPD project team members. It may be that in the case of highly complex development projects, large numbers of knowledge inputs and outputs might be present for each task. While the selected ontology editor is able to handle

knowledge bases containing over a hundred thousand instances, the capture of information about this knowledge may be considered overly time consuming.

In section 7.2.3, the degree to which the ontology component of the knowledge sharing tool may be considered generic, that is, applicable to other NPD processes was explored. It was asserted that all of the superclasses (the highest level classes), as well as the subclasses of the 'Metaknowledge' superclass, are generic to other NPD companies, since they are not specific to any characteristic of the case study company. Those aspects of the ontology and knowledge base that cannot be considered generic include the subclasses of the NPD Process Level class (which are specific to the case study company) and instances of the 'Knowledge Item' class (also specific to the case study company NPD process). The same goes for instances of the 'NPD Process Task' class, 'Function' class, 'Actor' class, 'Project Contribution' class, 'Role' class, and 'Location' class. For the 'Metaknowledge' class subclasses, it is asserted that instances of the 'Knowledge Domain', 'Knowledge Item Format', 'Knowledge Repository', 'Knowledge Item Medium', and 'Language' classes may well be valid in other product development processes, although not necessarily complete. The instances of sub-processes, process tasks and knowledge items are essentially what make up the knowledge base. The remainder of the ontology could be used largely unchanged in other product development processes that are used to develop physical goods of similar complexity to the products of the case study company.

Moreover, the trend towards product development teams comprised of multinational, globally dispersed members (see section 1.4) implies that the multilingual support mechanism would be of increasing relevance and importance to manufacturing firms engaged in global product development activities. By virtue of their international presence, it is likely that these companies will be large enterprises. In principle, dozens of languages could be supported through the definition of multilingual labels for classes and slots using the metaclass functionality of the Protégé knowledge model. At present however, support for languages in the Protégé editor is limited to that offered by the Unicode character set, although this supports the Latin characters used in European languages, Arabic and to a more restricted degree, Japanese and Chinese.

The prioritisation mechanism should be usable in any circumstance where strategic priorities have been set for NPD projects that can then be applied to the knowledge used in those projects. For example, if development cost is the primary concern in an NPD project, a prioritisation criterion can be created for knowledge related to cost and assigned a high priority level. The number and titles of priority levels may be changed by changing or adding subclasses and instances under the 'Priority' class using the ontology editor.

Finally, the ontology editor and dissemination mechanism components of the knowledge tool should be easily deployed in other product development companies. The Protégé editor tool runs on the Microsoft Windows® operating system and requires a modest hardware platform. The dissemination mechanism, based on the Protégé Web Browser® tool employs the Apache web server software® on the server side and a Web browser application, such as Microsoft Internet Explorer®, on the client side. The Apache software runs on UNIX, Linux and Windows® platforms and Web browsers are often accessible from desktop computers. As elucidated in section 7.3.3, Internet usage among large enterprises is now widespread.

### **9.1.3 Limitations to Research**

The discussion of the limitations to the research is divided into two parts: those pertinent to the overall research methodology and those applicable to the prototype method and knowledge sharing tool. Many of these limitations are referred to in earlier parts of the thesis document, as will be indicated.

#### **9.1.3.1 Research methodology**

Limitations relating to the research methodology were discussed in section 4.7 and are mainly related to the choice of a single case study approach. The weakness of this approach is that only one industry and one company setting was involved in the development, implementation and testing of the tool. As a result, the findings cannot be generalised to other industries. In section 4.2.2, though, it was asserted that scientific generalisation is not the goal of case study research, and that a case study is intended to provide a rich and detailed understanding of a phenomenon. Rather, it is the characteristics of the case that can be related to in other cases that are important

(Bassey, 1981). Two such characteristics in this instance are the application of a formally defined product development process similar to the generic models presented in the literature and the use of global product development teams.

It was further contended that concentrating on a single company allowed a close working relationship to be developed between the company and the researcher. This in turn meant that a sustained level of access to personnel and business documents was obtained. Such access is unlikely be available in situations where the company had no formal connection with, or monetary interest in, the research project. Additionally, the freedom to pursue a multiple case approach and apply the method and tool in other companies was constrained by the temporal and financial resources available to the researcher.

There now follows a discussion of the limitations of the research in the context of the research objectives.

Fulfilment of objective three partly involved the identification and classification of knowledge in the new product development process of the case study company. The principle source of evidence for the investigation related to this research objective was the data drawn from a total of seventeen interviews across two studies. This number falls short of the twenty interviews required in order to understand a domain recommended in the literature by Griffin and Hauser (1993) (see section 5.6.3). However, the interviews were triangulated with other forms of data, notably company business process documentation which indicated some of the information inputs and outputs for process tasks, and screenshots of project folder structures to gain a better understanding of how NPD project team members preferred to classify their information and knowledge. Furthermore, it was possible to check the findings against a more general study from the literature.

Work carried out to meet objective two, the identification of key knowledge sharing barriers, drew on many of the same empirical sources as the exercise to identify and classify NPD process knowledge. As discussed in section 5.5.3, the interviews used in data sources 3, 4, and 5 (see Figure 8) were not specifically designed with the intention of eliciting information about knowledge sharing barriers. Only the findings, and not the method or the raw data of the internal company NPD process survey (data

source 2) were made available to the researcher. As a result, it is not possible to determine whether certain issues from the survey data were overemphasised or even excluded. At the same time, it may be argued that using evidence not prepared by the author helped to counter researcher bias (see section 4.6).

For objective five, it should be noted that the implementation and testing of the knowledge sharing tool was restricted to knowledge associated with three sub-processes from the conception phase of the new product development process, as stated in section 8.1.2. Work by Hong et al. (2004) and Zahay et al. (2004) emphasised the diversity of knowledge used in this phase, the range of functional disciplines involved, and the importance of knowledge sharing in this stage of the product development process. Additionally, the evidence gathered about usefulness of the tool was qualitative in nature, so there was no triangulation with quantitative techniques, and the scope was confined to just three NPD experts at the case study company. Nonetheless, the experts occupied diverse roles and were based in development sites in two different countries.

### **9.1.3.2 Knowledge sharing tool**

The first weakness of the knowledge sharing tool itself was the time required to populate the knowledge acquisition tool with process tasks and their associated knowledge items, thereby creating a knowledge base. This point was reinforced by the comments of the experts involved in the testing of the tool, as explored in section 8.2.3. Another limitation concerns the multilingual support mechanism, as discussed in section 7.3.1. The metaclass feature of the Protégé knowledge model used to add labels to classes and slots is not applicable to instances of classes. This does not affect phrases that are language agnostic like the names of people. It does however impact phrases such as the title of a knowledge item. Lastly, a deficiency concerning the dissemination mechanism should be emphasised. Any changes made to the ontology, and with it the knowledge acquisition tool and knowledge base, require that the Web-server software be restarted. This includes changing the language in which the ontology labels are displayed. A solution to this would be to use separate files for each language, but this would complicate the maintenance of the knowledge base. These issues were explored in detail in section 7.3.1.

#### **9.1.4 Contributions**

Miller (1991) stated that the purpose of applied research is ‘to create knowledge that can be used to solve pressing social and organisational problems’. Easterby-Smith et al. (2002) meanwhile asserted that applied research should result in a solution to a specific problem identified by a client. This research has made a number of contributions, not only to research published in the literature, but also to addressing problems in industry.

Three key knowledge sharing barriers associated with teams executing a cross-functional, multinational product development process have been identified, based on an industry-based empirical investigation at a leading heating systems manufacturer and the findings of a literature review. The review examined existing NPD knowledge management methodologies and tools, and found that none of them addressed all of three of the key barriers.

A knowledge sharing tool has been developed to facilitate knowledge sharing that addresses these knowledge sharing barriers, thereby contributing to the body of knowledge. The tool features an ontology of information about knowledge used in the NPD process of the heating systems manufacturer, a mechanism to indicate the priority of knowledge items, and a mechanism to add language labels to support multinational product development teams. A case study at a heating systems manufacturer demonstrated how the prototype knowledge sharing tool could be used to capture and disseminate information about knowledge used in a real NPD business process.

Researchers, notably Court (1998), Hendriks (1999) and Wright (2005) have highlighted the role of metaknowledge in the facilitation of knowledge sharing. The literature review showed that it has been largely overlooked in previous tools to support knowledge management in product development. The knowledge sharing tool is the first to adopt a metaknowledge approach rather than relying on the capture of knowledge. Initial feedback elicited from NPD practitioners in the case study to evaluate perceived usefulness indicated that knowledge sharing tool would improve knowledge sharing among NPD team members.

An ontology building methodology is provided to develop the ontology of information about NPD process knowledge. It differs from existing methodologies by

featuring a detailed knowledge acquisition method for use in a new product development environment.

Finally, a content-based classification of knowledge used in the NPD process is proffered. Unlike previous attempts to classify NPD knowledge, it is based on an in-depth study of the knowledge used by NPD process owners, project leaders and engineers in a single organisation. The classification adds to the understanding of the knowledge used in the development of heating systems products.

## **10 Conclusions and Further Research**

This chapter presents the conclusions of the research project and identifies areas for further research.

### **10.1 Conclusions**

This thesis presents a prototype method and tool for facilitating knowledge sharing in the new product development process in a manufacturing context.

A literature review conducted in the scoping phase of the research revealed that effective knowledge sharing among NPD project team members is critical to the success of an NPD project. This assertion is supported by published empirical evidence. It was found that there are numerous barriers to knowledge sharing in the new product development environment, especially in multinational companies. Approaches to facilitating knowledge sharing in organisations are of two main types: policies and procedures that influence human behaviour, and software-based methodologies and tools. The latter type was of interest in this study. Several key methodologies and tools that claimed to facilitate knowledge sharing in NPD settings were identified. Other ways of facilitating knowledge sharing were also found. Knowledge sharing among people is supported by the provision of information about knowledge or metaknowledge, the classification of knowledge, and the prioritisation of knowledge based on its strategic importance to an NPD project. It was argued that there is a need for further research into all of these issues in the context of knowledge sharing in NPD project teams.

An exploratory case study was conducted in a multinational physical goods manufacturer in order to identify key knowledge sharing barriers and provide further focus for the remainder of the research project. The study drew on four sources of empirical data, including a total of eighteen interviews with NPD practitioners and experts and an internal company survey. This investigation uncovered three barriers to knowledge sharing. These barriers were the lack of an explicit definition of information about the knowledge used and generated in the product development process, the absence of a mechanism to make this information accessible in a multilingual environment, and the lack of a mechanism to disseminate it to geographically dispersed



NPD project team members. Theoretical antecedents to all of these barriers were identified in the literature. A subsequent review of the aforementioned key knowledge sharing methodologies and tools for NPD environments showed that none of them addressed all three barriers. Indeed, there is a lack of research into the use of tools to provide information about NPD process knowledge, despite the existence of literature that asserts that metaknowledge nurtures knowledge sharing.

To address this issue, a prototype method and tool was developed to reduce the three key knowledge sharing barriers. Prior to the development of this tool, an investigation was conducted at the same manufacturing company to identify and classify new product development process knowledge, and to determine what information about specific knowledge items, essentially metaknowledge, is required by project teams. Three main sources of data were used, encompassing seventeen interviews and the official NPD business process documentation of the company. Ultimately, twelve categories or classes knowledge were identified, expanding upon a previous classification of NPD knowledge in the literature.

Based on the findings of this exploratory case, an ontology has been developed that formally defines information about this knowledge and allows it to be captured in a knowledge acquisition tool, thus creating a knowledge base. The information provided about a knowledge item includes its priority and its content or domain. Knowledge prioritisation criteria may be specified and priority levels assigned to reflect the strategic objectives of the project. By selecting the criterion that best describes a knowledge item, the priority of that knowledge item is indicated. A mechanism was provided to allow language labels to be attached to concepts and relations in the ontology, making it comprehensible to speakers of different languages. In addition, a dissemination mechanism allows the ontology and knowledge base to be viewed via a Web browser client, so that it is available in locations across the globe. In this way the ontology-based knowledge acquisition tool and mechanisms facilitate knowledge sharing.

The knowledge sharing tool was tested at the physical goods manufacturing company. NPD project teams at the company were comprised of members who spoke different first languages and were located at manufacturing sites in different countries. This study showed that the tool can be used in this industrial setting to capture and

disseminate information about knowledge. Furthermore, a series of interviews to elicit feedback from NPD practitioners about the usefulness of the knowledge sharing tool was broadly positive. However, flaws remain in the multilingual support mechanism and these must be tackled. Finally, further testing of the knowledge sharing tool is strongly advocated.

In summary, the main achievements of this project have been:

- A further exploration into the nature of knowledge and approaches to managing knowledge sharing in new product development.
- The identification of three, empirically derived and theoretically informed, knowledge sharing barriers.
- An empirical case study investigation to inform conceptual ideas from extant literature to improve knowledge sharing.
- The development of a prototype method and tool for reducing barriers to knowledge sharing in early new product development.
- An initial validation of the prototype method.

## **10.2 Further Research**

The result of this research investigation has been the provision of a method and tool for the facilitation of knowledge sharing in the early new product development process. The knowledge sharing tool is based on an ontology of information about NPD process knowledge, and it was tested at a heating systems appliance manufacturer. In section 9.1.3, certain limitations to the research were identified. Additionally, the literature review revealed that there is a lack of research into various themes related to knowledge sharing in new product development.

Consequently, it is proposed that research is required in a number of areas to enrich and develop the research presented in this thesis. Firstly, additional testing of the tool is advocated, in order to lend verisimilitude to the findings already presented in this research. Secondly, in addition to these methodological concerns, certain issues pertaining to the functionality of the knowledge sharing tool components also need to be addressed. Thirdly, the literature review showed that, in spite of evidence extolling the

importance of metaknowledge in the facilitation of knowledge sharing, there is a paucity of empirical studies on the subject. These three research areas will now be explored in more detail.

### **10.2.1 Validation of Knowledge Sharing Tool**

A limitation of the research, acknowledged in section 9.1.2, was the focus on a single, early phase of the new product development process. The selected conception phase has been identified by other researchers as the most knowledge intensive part of product development and involves individuals performing a broad range of functional roles. Testing the tool with knowledge items from other phases though, such as detail design and production, would provide evidence as to its applicability to the entire product development process.

In section 9.1.2, it was stated that testing of the knowledge sharing tool has been restricted to a single, multinational organisation producing heating systems appliances, mainly boilers. Typically the new product projects involve the development of a new product platform, which is then customised for different markets. It was conceded that no empirical evidence had been gathered about the effectiveness of the knowledge sharing tool for other product types.

Ulrich and Eppinger (2003) proposed a range of product types that are developed using variations on the generic product development process. These product types include process intensive products like food stuffs, for which new production processes must be designed alongside the actual product, and what are referred to as 'complex systems', which may have hundreds of interdependent subsystems and thousands of components and parts. Products that fall into this latter category are gas turbine generators and aircraft. Additionally, Tiwana and Ramesh (2001) considered the development of non-physical entities such as information products. Complex systems might place special demands on the knowledge sharing tool in terms of the number of process tasks and knowledge items that must be captured. Other product types may involve knowledge domains not included in the content-based classification of knowledge developed in this study.

For these reasons, a research project investigating the suitability of the knowledge sharing tool for other product types and industries would provide a valuable appendix to this study.

A further omission in the research is that it does not show to what extent the developed tool improves the performance of product development teams or product development projects. That is, it does not provide evidence as to whether NPD project teams, and by extension NPD projects, are ultimately benefited by the knowledge sharing tool. For this reason it would be useful to identify key project performance indicators for the NPD project team and then to measure these indicators prior to, and following, implementation of the tool. One possible indicator could be the time spent by NPD project team members searching for relevant knowledge before and after implementation of the knowledge sharing tool. Devising meaningful indicators that could be measured in an objective way could well be a challenging task. Two other complications with implementing the tool in a product development environment would be the resource intensive nature of the exercise, and the need for close cooperation with the host company. These problems are a typical challenge for such field experiments, as suggested in section 4.2.2.

Another issue worthy of consideration is whether the cost of building and maintaining the tool is ultimately outweighed by the benefits it provides to NPD practitioners. For example, in the study to evaluate the perceived usefulness of the knowledge sharing tool, one respondent expressed great concern about the time required by project team members to build and maintain the knowledge base (see section 8.2.3). However, the literature indicates that engineers involved in product development may spend up to forty percent of their time searching for knowledge (see section 5.5.3). If the tool could help NPD practitioners to reduce this time, then the effort expended in the administration of the knowledge base may prove to be worthwhile. Measuring the time spent by NPD practitioners maintaining the tool, possibly as part of the aforementioned field experiment, could form the basis of a cost-benefit analysis.

Sections 8.1.5 and 9.1.3.2 highlighted the limitations of the testing of the knowledge sharing tool. Of particular concern was the assessment of the usefulness of the tool, for which an exclusively qualitative approach was employed. As noted in

section 8.1.5, the triangulation of this approach with a more quantitative one, involving a larger number of interview subjects, would result in a more robust study. It is proposed that a Likert-type measurement scale, such as that proposed by Davis (1989), and subsequently validated by Adams et al. (1992), and Laitenberger and Dreyer (1998), could be used as part of such an approach.

An additional point is that each of the NPD practitioners participating in the usefulness study had several years of NPD project experience. It is conceivable that less experienced practitioners, who are likely to possess a lower awareness of NPD process knowledge, may offer a different perspective on the usefulness of the tool. This issue could be explored by conducting an investigation of the tool usefulness that involves practitioners who represent a range of experience levels.

### **10.2.2 Issues with the Knowledge Sharing Tool**

A weakness of the multilingual mechanism is that it can only be applied to classes and slots in the ontology and not to instances. In essence, this means that the mechanism allows labels to be applied to the tool user interface, but not to instances of tasks, knowledge items and metaknowledge elements captured in the tool. Instances of some slots may be common to all languages used by the company. An example of this would be instances of the 'actor\_name' slot attached to the 'Actor' class. These instances are the names of individuals, which could be reasonably expected to be the same in different languages. For other instances though, such as instances of the 'knowledge\_category\_title' slot belonging to the 'Knowledge Domain', this is not the case.

This problem could be addressed by adding slots to class instance forms with the required translations. A drawback to this approach would be that the resulting user interface could become cluttered. Otherwise, some means of creating language labels for instances is required.

### **10.2.3 Literature Review**

The literature review revealed that there are a number of broader issues related to this investigation where further research would be of value. Henriks (1999) and Wright (2005), among others, have brought attention to the importance of metaknowledge, or

information about knowledge in knowledge sharing. However, there is a lack of empirical evidence about the effectiveness of metaknowledge in the facilitation of knowledge sharing among new product development project team members.

The importance of prioritising knowledge assets based on their relevance to business strategy has been established by researchers and at least one methodology has been provided to identify knowledge areas for prioritisation. This methodology was based on a knowledge mapping technique (see section 2.6). Initial feedback from NPD practitioners, albeit elicited from a small group of individuals in one company, about the ability to prioritise knowledge items used in the NPD process was broadly favourable. A deeper and more extensive study of the ways in which knowledge used and generated in the course of product development projects is prioritised, as well as the criteria used to do this, would build upon the preliminary findings of this research.

Duineveld et al. (2000) concluded that some ontology building tools were not suitable for direct use by domain experts, that is, those parties without knowledge engineering expertise. In the intervening years, these tools have matured considerably to the extent that this may no longer be true for many of them. A similar criticism could be levelled at current ontology building methodologies and guidelines. The review of ontology building methodologies (see section 6.2) showed that in most cases only sketchy advice on the knowledge acquisition methods and techniques was offered. More work on the application of ontology building methodologies in business environments, particularly on the knowledge acquisition stages, would serve to improve the understanding of this area. Additionally, it would reduce the dependence of domain experts on knowledge engineers or specialist ontology engineers in the building of ontologies.

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# Appendices

## Appendix A

### Sources of Evidence for a Case Study

Adapted from Yin (1994, p.80-90).

Source of evidence	Strengths	Weaknesses	Examples
Documentation	Stable – can be viewed repeatedly Unobtrusive – not created as a result of the case study Exact – contains exact names, references, and details of an event Broad coverage – long span of time, many events, and many settings	Retrievability – can be low Biased selectivity, if collection is incomplete Reporting bias – reflects (unknown) bias of author Access – may be deliberately blocked	Minutes of meetings Written reports
Archival records	As for documentation Precise and quantitative	As for documentation Accessibility due to privacy reasons	Organisational charts Lists of names Personal records
Interviews	Targeted – focuses directly on case study topic Insightful – provides perceived casual inferences	Bias due to poorly constructed questions Response bias Inaccuracies due to poor recall Reflexivity – interviewees gives what interviewer wants to hear	Structured, semi-structured and unstructured interviews
Direct observations	Reality – covers events in real time Contextual – covers context of event	Time consuming Selectivity – unless broad coverage Reflexivity – event may proceed differently because it is being observed Cost – hours needed by human observers	
Participant-observation	As for direct observations Insightful into personal behaviour and motives	As for direct observation Bias due to investigator's manipulation of events	
Physical artefacts	Insightful into cultural features Insightful into technical operations	Selectivity Availability	Technological device Tool Instrument Work of art

## Appendix B

### Knowledge Audit Protocol

#### IP Detail Process : <Sub-process title> <Name of Interviewee>, <Job Title>, <Location>

Note: In this document, the term 'knowledge' may be taken to mean knowledge (in its common meaning), data or information. That is to say it is simply defined as what one needs to know to carry out a particular task.

#### 1. Background (importance of knowledge, criticality)

- What are the aims and objectives of this process?

- Do feel that you spend a significant amount of your time searching for information, data or knowledge?

- What are the most important functions of your department/unit/position?

- In your opinion, how dependent is this process on knowledge from external sources (other processes and experts)?

#### 2. Knowledge Flow (what, where/from whom, how/in what format)

- Please describe any methods you use to codify (store) knowledge (databases, rule books, who knows what maps, repository of customer problems etc.)

- What mechanisms exist to transfer knowledge from experts to non-experts?(NB These might include training, informal discussion and so on)?

- Do you require knowledge from external sources in order to successfully complete the process?

- To whom or what do you transfer knowledge generated by the process (e.g. pass on to? (Make a map of Topics, People, Documents, Ideas and Links for process)

- What areas does the knowledge you need to complete this process come from? (E.g. machine capability-material suitability)

- For each category:

–How do you use this knowledge to produce a value added benefit to the Vaillant Group?

–From which sources do you obtain this knowledge?

–Who else might need this knowledge?

–How often you might need to use this knowledge?

–What processes do you go through to obtain this knowledge?

–What are the external influences impacting this knowledge?

–What would help you to identify use, or transform this knowledge more effectively?

- Which departments/sites/people do you think have the answer to your question but may not be able to help?

- Which departments/people/sites contact you for information?

- List reports you make available for groups outside your unit (recipient, format, frequency).

- Who are the experts in Vaillant Group for this/this type of knowledge?

### **3. Knowledge Issues (problems)**

- What knowledge is missing to achieve process goals?

- Who, or what, needs this missing knowledge?

### **4. KM Training**

- How do you use training to enhance knowledge and skills?

### **5. Suggestions (to be linked with 3) (ways to do it better)**

- What would be the most effective method of delivering this knowledge (How would you do it better?)

### **6. Broader implications of the knowledge (reusability, re-applicability) (to be linked with 1)**

- Is this knowledge necessary a) in the short-term (i.e. knowledge just for his process) or b) in the long-term (i.e. knowledge that may be reused) or c) both?

- Is this reusable knowledge?

- Of the knowledge that is missing, which is related to a) job performance, b) the competitive advantage of Vaillant Group, c) simple administrative questions, d) leading to innovation & new business areas, i.e. outdated and no longer useful for business

- What are the main reasons you think errors might occur in the execution of the process?

## **Appendix C**

### **Extracts from Knowledge Audit Report**

#### **Findings for ‘Analysis of Competitor Products’ Sub-Process Interview**

##### **1 Aims of Process**

This process has two main aims:

- To learn how competitors solve design problems and design functions
- To learn what the design advantage is in terms of cost

An additional aim is to understand how labour, location and so on serve an advantage for the competition when they manufacture their products.

##### **2. Knowledge Flow**

###### **2.1 Transfer of Knowledge from Experts to Non-Experts**

Training is the main method of transferring knowledge from experts to non-experts. Three formal training programmes were identified:

- A training presentation
- An internal training programme lasting six months. Notably, each functional specialisation (e.g. electronics, plastic parts, machining) has its own customised programme.
- A one day cost analysis workshop for Vaillant employees. The workshop is held twice a year in Remscheid. It involves participants from the R&D and Purchasing areas. This session is part of the basic training plan of every employee on the Remscheid site. At the time of the interview, attendance of the session is voluntary but it was suggested by the interviewee that it would become compulsory.

###### **2.2 Areas or Scope of Knowledge to Complete Process**

The areas of knowledge for this process are listed below:

- Material types and cost
- Production technology
- Calculations in database - template for calculations
- Functions and quality of the boiler
- Knowledge about competitor
- Level of vertical integration (supply chain integration)
- Location
- A more detailed list of knowledge sources for this process is provided in the table below.



### 2.3 Knowledge from External Sources

Some of the knowledge required for this process comes from the Purchasing Marketing and Manufacturing functional areas, as indicated in the following table:

Source	Internal or External	Description of Knowledge
R&D	Internal	Functions
		Quality impression
		Material – If a material is unknown (no identification number printed on component), tests may be carried out to identify it
Purchasing (Vaillant)	External	Prices for Standard Components
Marketing (Vaillant)	External	Competitor database
		People
		Price positioning
		Sales strategy
		Sales figures
Manufacturing	External	Market share
		Machining data
		Costs
		Machine rates
		Routine - To establish machining process time and ultimately costs
		If data is unavailable from Manufacturing, a supplier will be approached at a trade fair for an offer. They may have the machining data available needed to build the cost model.

Table: Sources of knowledge for the ‘Analysis of Competitor Products’ process.

#### 2.3.1 Suggested ways to identify, use or transform knowledge more effectively

No major problems were identified. It was proposed that the delivery of knowledge should be made more efficient. The interviewee’s suggestions for achieving this included ‘pushing’ knowledge to process users, ‘joining-up’ business functions, providing an overview of Vaillant Group’s knowledge of competitor products and reaching a group-wide agreement on which competing products should be examined. Each of these suggestions is discussed in more detail below.

##### *Push knowledge to process users*

Currently, a process user must seek or ‘pull’ knowledge from a range of sources. It was proposed that the knowledge required to execute this process should be ‘pushed’ to the process user.

##### *‘Join up’ business functions*

It was suggested that certain business functions involved in competitor product analysis could be coordinated or ‘joined up’. For example, currently a boiler

purchased by a business area is then passed on to other areas. It may be better to buy, say, five boilers and send one to each of the departments with an interest in examining that model e.g. R&D, Marketing, and Cost Analysis. In this way, the departments would have faster access to knowledge about competitor products.

#### *Provide an Overview of Group Competitive Intelligence*

Each of the three main manufacturing sites (Remscheid, Nantes and Belper) carries out their own analysis of competitor products. However, there is currently no means to obtain an overview of the competitive analysis work done by the group (the competitive analysis knowledge gathered by the other sites).

#### *Agreement on which boilers are examined*

Reaching a group wide agreement on which competitor products are examined would provide a focus for competitive intelligence activities and encourage knowledge sharing among the brands.

### **2.4 Reports made available for groups outside unit**

This process generates a number of reports:

- Presentations about Competitor Products
- Photographs of competitor boilers
- Design recommendations for R and D
- Standardised cost calculations
  - In eleven standardised groups
  - The assumptions made about the competitor are shown
    - Example: Competitor employs vertical integration with supplier (supply chain integration)

### **2.5 Experts in Vaillant for this process knowledge**

There are formally designated experts for the Competitor Analysis process at each manufacturing site. All these experts receive training. Note that there is one expert for each production technology in the interviewee's team. At the time of interview, it was stated that trained experts were available at the Remscheid, Nantes and Belper sites and two more experts were being trained for the Skalica site.

### **3. Most important functions of role**

No comments were recorded for this subject.

### **4. Time spent searching for knowledge**

No comments were recorded for this subject

### **5. Dependence of Process on Knowledge from External Sources**

The Analysis of Competitor Products process would appear to be highly dependent on knowledge from external sources. This claim is supported by the high proportion of external sources listed in the earlier table.

## **6. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

### **6.1 Reasons errors might occur in execution of process**

Usually, no major mistakes are made in this process. Any problems that do occur are more likely to be caused by a lack of co-ordination.

### **6.2 Knowledge missing to achieve process goals**

There is not an awareness of the way other companies analyse process goals

### **6.3 Problems with knowledge**

No major problems were identified. An example of a minor problem was identified relating to a lack of feedback about initiatives. For example, a booklet was produced containing an analysis of competitor products in 2003. This booklet was sent to group managers, but little feedback was received.

## **Findings for ‘Strategic ‘Make or Buy’ Evaluation’ Sub-Process Interview**

### **1. Aim and Objective of Process**

#### **1.1 Aim**

The aim of the Strategic ‘Make or Buy’ (MoB) Evaluation process is to decide on one supplier for a component. The supplier may be either internal (within the Vaillant Group) or external, it does not matter which. This exercise is carried out for each component on the Bill of Materials (see also the findings for the ‘Definition of System on Component Level’ process in Appendix 6).

#### **1.2 Objective**

The objective of the process is to compare the offers from external suppliers with the "in-house" supplier (Vaillant) cost. Although the price is important, other issues such as the supplier’s flexibility, manufacturing capability, quality and financial standing are also important.

### **2. Knowledge Flow**

#### **2.1 Transfer of knowledge from experts to non-experts**

No formal means of transferring knowledge from experts to non-experts was identified for this process. Transfer of knowledge takes place through informal, ‘on the job’ training. This training involves the teaching of purchasing processes “on demand”. The materials used for this training include IP flow charts, document templates (to illustrate the expected process results) and other documentation. These materials were claimed to be available on the Vaillant intranet.

#### **2.2 Reports made available for groups outside unit**

This process generates the following reports for external parties:

##### **1. Supplier Decision Sheet**

The output from this process is a decision sheet, which is signed (approved) by R&D and Quality.

##### **2. Top 80 Supplier Sheet**

A top 80 supplier sheet submitted to the Quality department. The Quality department then produces a supplier ranking in terms of Quality

#### **2.3 Experts in Vaillant for this process knowledge**

The experts (individuals and teams) in Vaillant Group for this process are:

- Group Commodity Buyer
- Group Quality
- Local (site) commodity buyer
- Local Quality
- Financial Control
- Project Buyer

- R&D (Designers)

## **2.4 Methods used to store knowledge**

The following methods are used to capture and store knowledge for this process:

- Lists and Rankings
- Top 80 supplier list obtained from purchasing
- Quarterly supplier ranking from Quality department "supplier evaluation sheet"
- Reports
- Monthly Quality report from SAP
- Monthly delivery performance report from SAP
- Internal cost validation (verify internal cost calculation)
- People
- Group Commodity Buyer
- Previous supplier performance knowledge is taken from the Group Commodity Buyer for a given commodity
- Information Systems
- Internet database for suppliers
- Storage
- Softcom
- Soon to be replaced by SAP
- Contains data about suppliers
- Uses data from MOVEX system
- Other Documents
- Bill of Materials
- IP flow charts
- Concept drawing from R and D

## **2.5 Areas that knowledge needed to complete this process comes from**

Knowledge needed to complete this process concerns the following issues:

- Quality of the supplier
- Manufacturing capacity of the supplier
- Financial situation of the supplier
- Flexibility and capability of supplier
- Price offers from internal and external suppliers
- IP process execution knowledge
- Bill of Materials

## **3. Most important functions of role**

No comments were recorded for this subject.

## **4. Suggestions**

### **4.1 Other kinds of knowledge to improve process outcomes**

Some suggestions were made about further sources of knowledge to improve the process outcome. These were:

- Further information about supplier, especially quality data
- For an internal offer, it would be beneficial to have more knowledge about the basis of a calculation. This is because the audit of an internal offers is not always clear. It was proposed that in many cases, it would be better to conduct a review, say a year later, to assess whether another offer would have been better.

## **5. Dependence of Process on Knowledge from External Sources**

The process is highly dependent on the knowledge from these areas:

- Financial control
- R&D
- Quality
- Cost analysis (cost calculators)
- External suppliers

## **6. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

### **6.1 Reusability of Knowledge**

The knowledge created by this process may be reused. Decisions made about suppliers are useful in the future. Indeed, the current performance of a supplier (indicated in the supplier ranking) is related to previous decisions. Knowledge related to these decisions is forwarded to the Group Commodity Buyer.

Unfortunately, although the Group Commodity Buyer's documents are accessible and open for scrutiny by other employees, they are stored locally and are available mostly as hard copies (paper format). Currently, there is no electronic archive, such as a server accessible to all the Vaillant sites. It was suggested that consequently, decisions about the supplier are ultimately very dependent on the experience of the Group Commodity Buyer.

### **6.2 Missing knowledge**

#### **1. Product Concepts from R&D**

Most of the time, R&D product concept drawings are not presented in a detailed form. The analogy provided was “drawing on the back of some toilet paper”. This makes it hard to negotiate an appropriate price level with a supplier. However, defining an appropriate level of detail is not easy. It is that is sometimes better to let supplier to do more of the work in developing the detail of a design (since, it is a conceptual design), but then one risks giving the supplier more control over determining the price.

There is a design template or a check list for the conceptual design that must be submitted to suppliers. However, this is not always used. This is located somewhere in the IP documentation on the Intranet. Parts of this design may not be complete or contain tentative descriptions or estimates.

## 2. Part rejects

The data relating to part reject incidents in production or in the field is not always self-explanatory. Two examples of part rejection scenarios were provided:

### **Example Scenario 1**

The first scenario involves the failure of part on the production line during assembly of the boiler. In this instance, it is easy to calculate and monitor the failure rate (parts per million (ppm) level) of a part, so it can quickly be seen when the problem is significant enough to require action. If a significant problem occurs, the part concerned is sent back to the supplier along with a report. However, there is no standard system to follow-up these failures. Consequently, it is necessary for users of this process to ‘phone around the company’ to search for reports or experience related to previous parts provided by a supplier.

### **Example Scenario 2**

The second scenario concerns the failure of parts in service. Service engineers for the Vaillant brand have laptops and feedback tools so they are able to collect data in the field. Therefore there is a good knowledge of parts failure issues in Remscheid. Service Engineers in the UK, France and Skalica do not have these tools, so the knowledge of parts failure issues at those sites is a less consistent quality (possibly even a lower quality) than that in Remscheid.

An additional problem is that not every part that fails in the field is returned to the Brand centre. Instead, a quick repair is carried out and no feedback report about the incident is made. The process for capturing knowledge about field rejects is not yet standardised for the group, although this issue is being worked on by [name deleted] (responsible for supplier quality). Such incidents affect customer perception of product quality.

3. There is no knowledge system from which a process user can get the data they require. The process is heavily dependent on knowledge from the Quality experts.

## **6.3 People or departments that require this missing knowledge**

The people or functions requiring the missing knowledge are listed in the table below.

<b>Knowledge</b>	<b>Person or Function Requiring Knowledge</b>
Part line reject and field reject knowledge	Quality
Supplier capability	R&D
"Better" conceptual designs from R&D	Supplier
Improved knowledge of the basis for the calculation of internal offers	Financial control

Table: Missing knowledge in the ‘Strategic “Make or Buy” Evaluation’ process.

# **Findings for ‘House of Quality I - Definition of Marketing Requirements’ and ‘House of Quality II: Definition of Technical Specifications’ Sub-Process Interviews**

## **1. Aim and Objective of Process**

The aim of these processes is to define the market requirements for and technical specification for a new product. The objective is to summarise the ways (e.g. performance and price) in which the Vaillant product is uncompetitive compared to competitor products.

## **2. Knowledge Flow**

### **2.1 Transfer of knowledge from experts to non-experts**

No formal methods for transferring knowledge from experts to non-experts for this process were mentioned by the interviewee. Informal methods for knowledge transfer include reference to the IP documentation. For example, a new recruit could study the ‘TOPH’ matrix (a Microsoft Excel spreadsheet used to facilitate the House of Quality process).

### **2.2 Knowledge from external sources**

External sources of knowledge for this process include markets and customers (e.g. National Service and Sales (NSS), installers and end users (direct contact is established with them)) and Vaillant teams in the brand markets (wholesalers).

### **2.3 Areas (scope) of knowledge to complete process**

#### **2.3.1 Knowledge Areas**

The knowledge required to complete this process comes from the following areas:

- Global strategy for the brand
- Brand identity
- Brand design
- Market needs
- Laws and regulations
- Competition context

#### **2.3.2 Knowledge sources**

The sources of knowledge for this process include:

- Wholesalers and Service
- The knowledge from these sources is used to determine product requirements
- End Users
- The knowledge from the end users is used to determine brand requirements
- E-mail communications with sources inside the process team and with external parties



- IP files on shared drives
- Expert advice via telephone
- Competitor
- Competitor web sites
- Competitor brochures

## **2.4 What? Where? From whom? How?/In what Format?**

### **TOPH**

The TOPH (Technics, Optics, Price, Handling) is a document containing requirements from the marketing department or 'Brand Unit'. It summarises the product needs for a specific market and is used to devise strategies to gain market share. As the document is generated by a phase in the strategy work process of the IP, it contains very little detail (just descriptions of customer requirements). The TOPH document is a Microsoft Excel file that includes a matrix tool to support the House of Quality method.

### **2.5 To whom or what is knowledge generated by the expert transferred?**

Knowledge generated by experts in this process is eventually transferred to a PowerPoint presentation outlining the product strategy. The knowledge also resides in the completed TOPH. The TOPH is subsequently audited and so the knowledge may find its way into audit reports.

### **2.6 Departments/people/sites that contact you for information**

The team involved with this process is occasionally contacted by people at other sites, in this case the Remscheid site. Normally this contact involves answering questions about ongoing projects. The interviewee commented that their team was not always informed about this in advance.

## **3. Most important functions of role**

No comments were recorded for this subject.

## **4. Time spent searching for knowledge**

The interviewee commented that executing these processes involves searching for knowledge. Typically, this takes the form of weekly contact with the market. This knowledge is used in order to fill in a "bubble box" (Price position vs. Satisfaction of customer).

## **5. Dependence of Process on Knowledge from External Sources**

No explicit statement was made about the dependence of this process on knowledge from external sources. However, based on the number and role of external sources discussed in the interview, it would seem reasonable to claim that both of these processes depend significantly upon knowledge from external sources.

## **6. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

### **6.1 Reasons errors might occur in execution of process**

It was proposed that errors may occur in the execution of this process for the following reasons:

- Insufficient knowledge of requirements by market - local groups are relied upon to explain Vaillant Group's customer's needs
- A failure to anticipate of changes in market (e.g. new laws and regulations)
- The placing of insufficient emphasis on the needs of the installer. This is because end users are usually not the real decision makers in a purchase of a boiler. In most cases, installers tend to make the purchasing decision. The matrix, which is sent out to the markets to fill-in/approve) plays an important role in avoiding this error.

### **6.2 Knowledge missing to achieve process goals**

The interviewee noted that Vaillant brands have the same competitors in all markets, so the knowledge about them is reusable across these brands. In Remscheid there is a special department that dismantles boilers, performing a function similar to competitive intelligence. The interviewee mentioned that they would like to have a similar operation in Nantes.

The interviewee also commented that while competitor benchmarking works well, the reports from the team performing this work are always in the German language, which limits the sharing of any knowledge they contain. Furthermore, it was remarked that the Vaillant Group may often be buying and investigating a given model of competitor's boiler two to three times, rather than just once, because different brand units do not share their knowledge.

Finally, it was stated that it would be beneficial to take more comments from end users, especially relating to their levels of satisfaction with the Vaillant products that they own.

## **Findings for ‘Risk Analysis Concept’ Sub-Process Interview**

### **1. Aim of Process**

The aim of the Risk Analysis Concept process is to identify the potential risks associated with a product concept and identify solutions to these risks. It is an important input into the decision on whether the quality of the selected product concept is sufficient to meet the project targets.

### **2. Knowledge Flow**

#### **2.1 Transfer of knowledge from experts to non-experts**

According to the interviewee, at the time of the interview there was no formal training programme and no formal documentation for transferring knowledge from experts to non-experts. Rather knowledge is transferred from expert to non-expert through learning by observation. That is to say, the non-expert will observe an expert executing the process.

#### **2.2 Knowledge from external sources**

Knowledge is taken from various external sources:

- Quality strategy (requirements)
- Project Manager (provides various information about the product)
- FMEA/APIS expert (to teach/validate APIS)
- Field Experts
- These are similar to Centres of Competence (CoCs), but are based in the field

#### **2.3 Subsequent transfer of process knowledge output**

Maintenance solutions are created and communicated to field experts. These solutions address issues such as:

- Improving maintenance processes and solutions
- Preparing for the introduction of spare parts (inventory)
- Improving or upgrading existing products
- Implementing an update in the design rules

#### **2.4 Areas (scope) of knowledge to complete process**

##### **2.4.1 Knowledge sources**

See 'Knowledge from external sources' in section 2.2.

##### **2.4.2 Value added benefit**

The MIS/MOP data of market product is used to generate a prognosis (estimated failure) for a new product. The knowledge may also be used to improve maintenance processes and solutions and improve the competence of the Boiler designers.

#### 2.4.3 Other parties that might need this knowledge

This knowledge is also used for validation of the initial specifications in the Project Status Review process. It may also be used in the development of future products.

#### 2.4.4 Frequency knowledge is needed

The knowledge is always needed when carrying out the FMEA. Beyond this, it may be required occasionally to establish a common viewpoint about a product concept across the company.

#### 2.4.5 Processes to obtain this knowledge

Knowledge is obtained by means of telephone conversations and e-mails.

#### 2.4.6 Departments/sites/people that contact process team for information

The process team is contacted by the following people and functional areas:

- Heads of CoCs
- Field experts (during project)
- Quality

### **2.5 Reports made available for groups outside unit**

The following reports are made for groups outside of the process team:

- FMEA reports
- APIS-based reports
- Maintenance requests
- Solution requests

### **2.6 Experts in Vaillant for this process knowledge**

See 'Knowledge from external sources'.

### **2.7 Methods used to codify (store) knowledge**

The following methods are employed to codify and store knowledge:

- APIS (which contains FMEA information - part structures, failures, risks, solutions)
- Design rules
- MIS/MOP data
- Customer surveys in different countries
- Intranet

## **3. Most important functions of role**

The most important functions for employees carrying out this process are to:

- Perform risk analyses
- Ensure that solutions are identified
- Produce FMEA analyses
- Collect necessary data

## **4. Suggestions**

### **4.1 More effective ways of delivering this knowledge**

It was proposed that a definition of “who knows what” is needed (see section 0 below), so that experts with the required knowledge may be identified quickly. Furthermore, it was suggested information, such as that contained in e-mails should be better organised so that it is easier to find. Finally, the interviewee posited that it might be possible to model the IP in a way that better illustrated the knowledge links between processes.

## **5 KM Training**

No formal training is provided for this process, learning is facilitated by observation of process experts at work. However, training is provided for the FMEA method. For example, in Nantes, the local FMEA expert ([name deleted]) trains novices. The training culminates in an exercise to fill in hypothetical FMEA boxes.

## **6. Time spent searching for knowledge**

The interviewee estimated that about ten percent of a process user’s time is spent searching for knowledge. Mostly, this searching has the aim of establishing “who knows what” and is facilitated by making telephone calls.

## **7. Dependence of Process on Knowledge from External Sources**

The process is highly dependent on knowledge from external sources.

## **8. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

### **8.1 Reasons errors might occur in execution of process**

Errors can be caused by not completing the task on time. For example, if a design should become delayed, the team will move to the next task, but it is too late for the task before. Another problem is that the quality of information received from human sources might be questionable, because we do not know if the source is the 'right' expert.

### **8.2 Reusability of Knowledge**

Knowledge from the FMEA is reusable and has implications all the way through the IP.

### **8.3 Missing knowledge**

The knowledge identified as missing for the process is summarised in the table below:

<b>Missing Knowledge</b>	<b>Timescale in which knowledge is needed</b>	<b>Adversely affects</b>
Who knows what?	Short term	Job performance Competitive advantage of Vaillant Group
Links between inputs/outputs in IP	Long term	Job performance Competitive advantage of Vaillant Group
What product or component is produced/designed where	Short term	Job performance Competitive advantage of Vaillant Group

Table: Missing knowledge in the 'Risk Analysis Concept' process.

## **Findings for ‘Definition of System on Component Level’ Process Interview**

### **1. Aim and Objective of Process**

The aim of this process is to produce a fixed definition of which components are used to realise a product concept. This is the first point in the IP that this level of definition is achieved. More specifically, it is the first opportunity that one can state not just, "it's a gas valve with modulating control", but "a gas valve of type x with dimensions of x and y".

The process objective is to create a Bill of Materials (BOM). Initially, this is created in Microsoft Excel and then it is transferred to SAP. At this stage, the BOM is more or less exact and should be very similar to the BOM for the final manufactured product. The SAP system will contain one Bill of Materials and this must cover production, controlling etc.

The process should define a list of components. The Assembly instructions for the components are defined at a later stage. Additionally, a digital prototype of the product is produced which serves as the model for the definition of assembly steps. In an ‘ideal’ process, only one BOM is needed. At the end of this process, it will be known exactly what design is for the major components of the boiler. It may not be known exactly what the design is for minor or new components.

### **2. Knowledge Flow**

#### **2.1 Transfer of knowledge from experts to non-experts**

Training is used to transfer knowledge from process experts to process novices. The training, known as a “start-up” programme, is provided by a Vaillant Group expert. The focus of the training is on Quality excellence.

#### **2.2 Areas (scope) of knowledge to complete process**

##### **2.2.1 Knowledge sources**

Knowledge for the Definition of Component Level process is taken from the following sources:

- Risk analysis reports
- Test protocols
- Calculations
- Analysis report - Qualification of supplier by purchasing department
- Quality Management planning

##### **2.2.2 Reports made available for groups outside unit**

Twenty to thirty test reports are produced containing knowledge generated by this process. The main challenge was stated to be providing people with the knowledge that they are looking for.

### 2.2.3 Experts in Vaillant for this process knowledge

In addition to the process owner, the following experts were identified as sources of process knowledge:

- One person for the digital model of the product (3D CAD model)
- One person for testing
- One person for drawings
- In the Development phase of the IP there is less to do, so this person will also be responsible for the BOM
- One person for the BOM

Any design changes that emerge from tests, construction, quality or design must be submitted to the person responsible for the BOM. Examples of such changes include new part IDs, deleted components etc. This is a key role in this phase of the project.

### **3. Most important functions of role**

No comments were recorded for this subject.

### **4. Time spent searching for knowledge**

No comments were recorded for this subject.

### **5. Dependence of Process on Knowledge from External Sources**

No comments were recorded for this subject.

### **6. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

#### **6.1 Reasons errors might occur in execution of process**

Knowledge related reasons suggested for errors in the execution of the process include:

- Two different tools exist to deliver information to other people/functions. The Bill of Materials is created in Microsoft Excel and saved centrally in the R&D folders (“everyone knows where this is”). There is a defined structure into which the project folder has to be organised. Nonetheless, the following problems may occur:
  - Files get put in different places (e.g. folders)
  - Data can be hard to find without consulting the project leader
  - File names are not standardised, consequently files are difficult to find

Note that a Bill of Materials file should have the name BOM\_<year><month><day>  
This has been defined by [name deleted] and added to the IP documentation on the Vaillant Intranet.



## **Findings for Phase In / Phase Out Realisation Sub-Process Interview**

### **Aim of Process**

The aim of the Phase In/Phase Out process is “to put a product on the market at the right quality and in the right quantity according to market requirements and at the right cost.”

### **Knowledge Flow**

#### **2.1 Transfer of knowledge from experts to non-experts**

Some training is provided, although the details of this were not obtained. Otherwise, Transfer of knowledge from experts to non-experts takes place by allowing the non-experts to gain 'in the field' experience. For example, the non-expert may perform a task once with the assistance of an expert. After this, the task will be performed alone. Non-experts are not trained about functions/activities and companies (suppliers).

#### **2.2 Knowledge from external sources**

Much of the knowledge used in this process is taken from external sources. These external sources include R&D, Industrialisation, Purchasing (or suppliers) and Quality departments. A brief description of the knowledge required from each function follows:

##### **R&D**

The R&D department is approached first, since it is the first function to define the product. At this point, the team involved in this process examine the structure of the product. Some parts may already be used in other products, so a supplier may already be known.

##### **Industrialisation**

Industrialisation and manufacturing experts must be approached to discuss themes related to the fabrication of the boiler and assembly issues such as tooling.

##### **Purchasing (or supplier for external work)**

The questions posed to the Purchasing department or supplier concern whether the required part is available, the date upon which the part will be ready and whether the part is available in the required volumes.

##### **Quality department**

The Quality department answers the question, “is the supplied component available at the right quality?” Typically, prototypes of the part will be obtained from the supplier before serial production begins. These parts will then be subjected to a quality assessment. If the component arrives too late for this assessment (e.g. a day before production is due to begin, it must be determined whether the supplier has subjected the component to an appropriate Quality control process.

## **2.3 Areas (scope) of knowledge to complete process**

### **2.3.1 Knowledge sources**

The interviewee claimed that no specific knowledge is required to manage the phase in / phase out process. Judgements were made by process users based on experience. Process users develop their own “checks” to ensure that the necessary knowledge has been gathered.

### **2.3.2 Other parties that might need this knowledge**

Suppliers may also require the knowledge that is needed for this process.

### **2.3.3 Processes to obtain this knowledge**

The processes used to obtain knowledge for this process are:

- Internal View - Core Team Meetings
- External View - Communicate with Suppliers
- There is no official method
- Tools (Microsoft Excel spreadsheets) that are shared with suppliers

### **2.3.4 Suggested ways to identify, use or transform knowledge more effectively**

The suggestion from the process owner was to have one tool for every department that we can all share.

## **2.4 Reports made available for groups outside unit**

Reports made available outside of the unit carrying out this process include the following:

- Balanced Scorecard
- Key Performance Indicators (KPI)
- The main indicators are checked (assessed)
- There is one indicator for the Phase In/Out process
- Pre-launch report

No other outputs are produced and no “official alert” is made about the outcome of this process. That is, the knowledge is not widely disseminated.

## **2.5 Experts in Vaillant for this process knowledge**

The interviewee opined that there are no ‘experts’ for the knowledge used in this process.

## **3. Most important functions of role**

No comments were recorded for this subject.

## **4. Broader Implications of the Knowledge**

### **4.1 Importance of the knowledge for this process**

The knowledge generated by this process is of short-term and long-term importance.

#### 4.2 Reusability of Knowledge

The knowledge is reusable in other projects and in other IP processes.

#### 4.3 Missing knowledge and its Impact

The interviewee did not specify any knowledge as 'missing' from this process. However, if any of the knowledge described previously earlier on as necessary to the process is unavailable, the likely impact is described in the table below:

Area Affected	Description of Impact
Job/Process Performance	Loss of time
Competitive Advantage of the Vaillant Group	Loss of sales credibility and loss of image for the plant and group.
Innovation and New Business Areas	Missing knowledge does not directly affect innovation or the development of new business areas, although more time could be spent on these issues if less of the organisation's time is spent searching for knowledge.

Table: Impact of missing knowledge on the 'Phase In / Phase Out Realisation' process.

#### 5. KM Training

No comments were recorded for this subject.

#### 6. Suggestions for Management of the Knowledge

- Make sure appropriate knowledge from projects is captured
- Training for all services, to understand constraints of other jobs/roles
- Helps understand why there is a problem on the "other side"
- Ideal situation would be to have access to all information, but only be "shown" your information

## **7. Time Spent Searching for Knowledge**

It was estimated by the interviewee that ten percent of the time spent on the Phase in / Phase out process is spent searching for knowledge. Decisions with long-term consequences taken during the process involve knowledge related to process development and production planning. It was postulated that this type of decision accounts for most of the time spent searching for knowledge. Those decisions made for the short-term concern situations such as quick changes to production operations. In this scenario, knowledge must be obtained to answer questions such as whether the required components are available and is a sufficient stock is available?

## **8. Dependence of Process on Knowledge from External Sources**

This process is highly dependent on knowledge from the Marketing department, which serves as a first contact point. The sources of knowledge include management reports, graphs and charts, the original supporting data for these charts (usually contained in spreadsheets) and sales and forecasting data.

## **9. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

### **9.1 Knowledge Problems**

The knowledge problems identified for this process are listed below:

- There are no real experts for this kind of knowledge
- There is no formal capitalisation on what has been learned in the course of a project. For example, there are no debriefings to discuss what was good or bad.
- Many components are validated quite late
- There are more difficulties dealing with external suppliers (big problems) than internally. This situation could be improved if knowledge from each project was captured, so that it could be reused later on.
- Groups outside of Phase In/Out do not understand the constraints of this process. For example, it would be beneficial for R&D to be aware that it can take many weeks to develop a part with a supplier. Furthermore, even if a prototype is obtained from a supplier, one cannot automatically be sure that the part will be available every week.

## **Findings for 'Project Status Review' Sub-Process Interview**

### **1. Aim and Objectives of Process**

The aim of the Project Status Review process in this context is to check whether the project leader has fulfilled the project specification. It is worth noting that for the purposes of this interview, the specification considered was the 'Technical Requirement Specification' (TRS). This is the technical specification of a product.

The objectives of this process are to:

- "Establish whether we have an agreement with Marketing", and
- "Agree on what the buyer is going to buy, in terms of specification".

### **2. Knowledge Flow**

#### **2.1 Transfer of knowledge from experts to non-experts**

There is no formal method to transfer knowledge from experts to non-experts. Rather, knowledge is transferred from experts to non-experts by means of informal 'on-the-job' training. A brief summary of this training follows:

A trainee will follow the auditor like an assistant and their degree of involvement will depend on how skilled they are. The auditor normally comes from within the Vaillant Group, typically occupying a role such as 'Quality Engineer for Projects'. Typically, it takes one to two audits to learn the process before a trainee can carry out an audit independently. It should be noted that the auditor's spirit is critical to the success of the process audit and therefore to the success of the Project Status Review process. The auditor must not only consider the Quality documentation, but also the background to each of these documents e.g. why was 'x' or 'y' done? For example, even an e-mail from an NSC saying work has been done must be investigated further.

#### **2.2 Suggested ways to identify, use or transform knowledge more effectively**

Design rules must present be in any knowledge capture system.

#### **2.3 Methods used to store/codify knowledge**

Important design knowledge is encoded in the 'Design Rules'. This knowledge was described as "extremely important". After a period of two years, a rule is checked to see if it is still valid. An example of such a rule is knowledge about a component known as an 'O-Ring'. Not all O-Ring validation processes will be performed if the material has already been validated against chemicals including benzene, glycol etc. in the past.

### **Most important functions of role**

No comments were recorded for this subject.

#### **4. Time spent searching for knowledge**

Preparation for the review can take between three days and one week, depending on the phase. Various data and specifications must be collected. The National Sales Centres (NSC) must accept the boiler and the market must accept the boiler. Auditor must ensure that this will happen.

Consequently, the auditor must know what really lies behind a quality document. For example, the cost analyst might ask, who really did a test? Was it an industrial engineer, service people or a manager looking to 'speed up' an audit? The auditor must obtain documentary evidence to confirm the answers to these questions.

#### **5. Dependence of Process on Knowledge from External Sources**

No comments were recorded for this subject.

#### **6. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

##### **6.1 Reasons errors might occur in execution of process**

Errors might occur in the execution of the process for the following reasons:

- If the auditor does not have the design rules available, the risk is that an unsuitable or non-required product may be released
- A product could be signed-off and pass audit, but the auditor may never have actually checked the evidence provided for a given activity

##### **6.2 Reusability of Knowledge**

As already alluded to, the knowledge generated by this process may find its way into the design rules. Furthermore, the results of the process audit may be referred to on a future occasion.

##### **6.3 Missing knowledge**

The knowledge that the interviewee considered to be 'missing' in the process includes:

- A statement to say what we are expecting from each part of the audit
- Evidence that activities examined during audit have really been carried out. Examples of this evidence are records of tests, meetings and so on, which prove there was a meeting with after sales service personnel. This evidence might take the form of photographs of an assembly being handled.

## Findings for 'Target Costing and Cost Tracking' Process

### 1. Aim of Process

The aim of this process is to validate the financial validity of a product development project. This means being sure that there is a return on investment and that the project is financially viable. Effectively, the process involves consolidating design information and financial information.

### 2. Knowledge Flow

Vaillant Group defines several tools for cost analysis (see table below). Microsoft Excel is very useful tool and widely used in the execution of this process.

Role of Knowledge in Process	Description of Knowledge Item
Input Knowledge	Tracking Tool – Absolute Cost Control (ACC)
	Template used in business plan (same result whatever the location of the project)
Output Knowledge	ERP systems
	Many other (information) systems

Table: Knowledge flow in the 'Target Costing and Cost Tracking' Process.

#### 2.1 Transfer of knowledge from experts to non-experts

The transfer of knowledge from non-experts to experts is achieved through both formal and informal means. There are formal training programmes for new costing employees in Remscheid and Nantes in the following areas:

- Absolute Cost Control (ACC)
- Business plan
- Technical knowledge
- Technical benchmarking

All cost analysts receive training on more than one site. Additional training of an informal nature involves learning 'on the job', much of it through oral instruction and explanation.

#### 2.2 Knowledge from external sources

It was emphasised that in costing, data and information comes from 'everywhere'. Knowledge is also obtained from telephone calls to colleagues.

### 2.3 Subsequent transfer of process knowledge output

Knowledge output is always linked to parties that need to know about cost issues, but to whom it is provided will vary. Two examples of parties who use knowledge output from this process are project leaders and the finance director.

### 2.4 Areas (scope) of knowledge to complete process

As already mentioned, the knowledge required for the Target Costing and Cost Tracking process comes from a wide range of sources:

- Highly technical knowledge
- People
- Raw materials
- All the financial aspects from a finished product point of view that are required to fill in the ACC
- An understanding of what the effect is on profit/loss, cash flow, return etc. in another part of the project, should part of the project go wrong

For all the knowledge required by the cost analyst, the aim is the same: understand, appropriate, analyse and add value.

The main areas may be broadly divided into technical, financial, and cost analysis knowledge. A summary of the properties of each knowledge type is provided in the following table.

Property	Knowledge Area		
	Technology	Finance	Cost Analysis
Description of knowledge	Technical knowledge concerns raw materials, machines and time.	Finance knowledge concerning financial domain	Experience of the cost analysis exercise
Value-added benefit	At the training in Remscheid, the opinion and experience of the expert is what is used in the machine routing/raw material database	Essential for understanding financial information and tools used in this process	Supports fundamental function of this process and is built on upon knowledge of the technology and finance domains
Knowledge Sources	Sharing Database	Colleagues in financial department	Colleagues
Other parties that might need this knowledge	Routing - highly localised to the Nantes site. This is not used much for Remscheid/Belper. The same goes for raw materials	Many other colleagues	-
Frequency	Maybe one day per week	-	Always



knowledge is needed	(not everyday)		
Processes to obtain this knowledge	Telephone call to someone with expertise Refer to databases Use existing experience	-	Formal and informal training (see section 0)
External influences impacting this knowledge	New machines Environmental legislation Note: Build a cost system Refresh/update it every year "Virtual Company" Model	Finance rules and regulations well defined and do not change much or very often	
Suggested ways to identify, use or transform knowledge more effectively	<p>1. 'Details' often forgotten. Knowledge of previous work needs to be refreshed, so knowledge is exchanged between colleagues. They share their experience (some means of supporting this would be useful).</p> <p>2. Roles do not map directly between Nantes and the other sites. This could be improved.</p> <p>3. Too much time is spent dealing with details and bureaucracy in the IP.</p> <ul style="list-style-type: none"> <li>• Concentration on 'process' can lead to blinkered approach</li> </ul> <p>4. However, IP has made the process more organised (less instances of confusion e.g. once per month)</p>	-	<p>Problem</p> <ul style="list-style-type: none"> <li>• Analysis knowledge is about experience, rather than 'tangible' (explicit) knowledge. Cost controllers tend to exist in "their own world". They have their own rules and their own language. These rules and language are very difficult to understand if one does not work within this "bubble". Once the initial training period is over, there is insufficient time for the expert (in this case the 'boss') to share their knowledge with new (inexperienced) employees.</li> </ul> <p>Proposed Solution</p> <ul style="list-style-type: none"> <li>• Make more time</li> </ul>

			available for expert (in this case, a 'boss') to share his knowledge after the initial training.
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Table: Areas of knowledge required to complete the 'Target Costing and Cost Tracking' process

**2.5 Reports made available for groups outside unit**

The following reports are created for groups outside of the process team:

- Absolute Cost Control (ACC) report
- Template for Business Plan

**2.6 Experts in Vaillant for this process knowledge**

Experts in Vaillant for this process knowledge include all of the cost analysts.

**3. Most important functions of role**

Two of the most important functions of the role are (1) to consolidate information about costs and expenditure, and financial reports and (2) to draw attention to a positive or negative deviation in the present or may be future costs.

**4. Time spent searching for knowledge**

Five to ten minutes is spent at the desk searching for a component, the responsible person and information about where the component is used. However, the total time to compile this information could be two to three hours. Once the information has been compiled, it must be analyzed and interpreted. An example of the knowledge generated by this process could be "why a designer has drawn a part this way".

**5. Dependence of Process on Knowledge from External Sources**

The process is completely dependent on knowledge from external sources.

**6. Knowledge Issues (Problems) and Broader Implications of the Knowledge**

**6.1 Reasons errors might occur in execution of process**

Less experienced colleagues with insufficient training may be asked to provide the cost for a part. A certain level of knowledge is needed to use the cost analysis tools and produce a result. The cost analyst's interpretation is partly based on assumption and so errors may occur if the analyst has insufficient experience.

**6.2 Reusability of Knowledge**

The types of knowledge considered reusable were the experience gained, thought processes involved and principles employed in carrying out the cost analysis process. A

type of knowledge considered non-reusable was the process outputs (e.g. data). An estimated cost is very much "for now" or "du jour" and may be not be valid later on.

## **Appendix D**

### **Knowledge Sharing Investigation**

#### **Interview Protocol**

#### **R&D Questions**

**Interviewee:**

**Role:**

**Date:**

**Location:**

#### **Questions**

1. What is your understanding of the term ‘knowledge’?

#### **Information or Knowledge Needs**

Note to interviewer: Please inform the interviewee that any reference to “you” in isolation, means “you and your project team”, rather than “you personally”.

2. What kind of information/knowledge do you and your project team need in the course of a project?

(For example: Reports, expert advice etc.)

3. What is the format of this knowledge?

4. (a) Where do you and members of your project team look for knowledge?

(b) Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group’s knowledge, or even outside of the Vaillant Group?

5. (a) How do you and your project team search for the knowledge?

(b) Do you and your project team use tools to find knowledge? If so, what are the tools, and can you give real examples of tools and systems that support the search?

(c) Do you feel the tools could be improved? If so, how could the tools be improved?

(d) If no tools are used, what methods of searching for knowledge do you and your project team use and how could they be improved?

6. What (kind of) knowledge do you and your project team have problems finding?

7. What is the minimum knowledge that you and your project team expect to be able to find?

8. In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?

9. What frustrates you and you project team about searching for knowledge?

10. Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?

11. Could you explain why this knowledge is unavailable?

### **Knowledge Sharing**

12 (a) What kind of information or knowledge do you and your project team generate?

(b) Do you and your team currently collect and organize this information somewhere?

If so, where?

13. Is this knowledge reusable in other projects or in other processes within the IP?

14. (a) What kind of information would your team be prepared to contribute to an shared R&D knowledge base:
- Now?
  - In the future?
- b) How and when could you and your project team prepare this shared information? What storage formats and what kind of support (e.g. tools, systems, methods) would you recommend?
- c) Should this information or knowledge be shared among the different R&D sites?
- d) How important is sharing this knowledge among the sites? Would you describe it as mandatory?

#### **Use of the Vaillant Intranet as a Search Tool**

15. Do you or your project team use the Intranet to search for knowledge?
16. Is there any functionality that you feel could improve the process of searching for knowledge on the Intranet?

## Appendix E

### Selection of Exemplar Interview Protocols from Knowledge Sharing Investigation

#### (Data Source 3)

This document contains five exemplar interview protocols. The roles and locations of the interviewees are listed in the table below.

<b>Role</b>	<b>Location</b>
NPD Project Leader	UK
Boiler Project Manager	France
Project Manager, Controls Expertise	Germany
Programme Manager, Hydraulics and Accessories	Germany
Engineer and Project Manager	Germany

## **Pilot R&D Integration Study**

### **Interview Protocol**

#### **R&D Questions**

**Interviewee:** [deleted]

**Role:** NPD Project Manager

**Date:** 7<sup>th</sup> February 2006

**Location:** UK

#### **Questions**

1. What is your understanding of the term 'knowledge'?

"Knowledge. I would say was the record of learnings or experiences. Whether that's mentally recording or physically recording, or..."

#### **Information or Knowledge Needs**

Note to interviewer: Please inform the interviewee that any reference to "you" in isolation, means "you and your project team", rather than "you personally".

2. What kind of information/knowledge do you and your project team need in the course of a project?

(For example: Reports, expert advice etc.)

"The biggest bit of knowledge that we would need is, a knowledge of, it sounds stupid, but a knowledge of what knowledge there already is. Because nine times out of ten, when we start something,, you get half way through it thinking that you're starting from scratch, and then you find out that somebody's already done it somewhere else six months ago, but nobody knows about it.

"It's what do we know that we know. It sounds stupid, but that is the one big thing that would help. A lot of the things, I mean you know about our [NPD Business Process]? A lot of the problems we have here certainly is knowing what's required for it. We've got this huge system ... process that's all broken down, but when you read it, it still doesn't tell you what you need to do for it."



3. What is the format of this knowledge?

"Reports. Historically we are very bad at recording information. A lot of what we do is still based on experience. Properly formatted reports are getting more popular. Suppliers websites for information about materials. Test laboratory in Remscheid. Again, nobody knew it was there, the big materials testing laboratory in Remscheid. A lot of documented history... I've got two contacts now in the materials lab. And also with their life testing over there... But again it's just a case of knowing what's available. And that's the biggest thing I've come up with."

4. (a) Where do you and members of your project team look for knowledge?

"Up until recently it would have been local servers, internet, generally asking other people in the department. Probably in the last six months, certainly in the last three months, we've started using the Group servers. A materials database on the servers. We still use the Internet... Drawing Office for design and spec [specification] and materials specs and suitability. Lab [Laboratory] for test standards, test requirements and results from previous testing, just for comparison. Paper in filing cabinets, but this is no good if you don't know where to look."

(b) Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group's knowledge, or even outside of the Vaillant Group?

"More and more it is the group, especially for myself."

5. (a) How do you and your project team search for the knowledge?

"There is a huge problem with translation for intergroup knowledge. We use a lot of test specifications now for life testing that were written by Remscheid, We've adopted their test planning documents, we've adopted their specifications for this, but again, a lot of it is still in German and we're not good at translating, there's and awful lot to translate."

"I think knowledge sharing across the group is a brilliant idea because there is so much out there, but your biggest problem is gonna be language. Language was the biggest problem we had with IP [NPD business process] in the first place. It was all set up, it was all done in German. And the reason it didn't get adopted properly in the UK and implemented and driven through the business is because bits were translated into Pidgin English, it just didn't make sense and it was too difficult to work your way through."

(b) Do you and your project team use tools to find knowledge? If so, what are the tools, and can you give real examples of tools and systems that support the search?

"Windows Explorer"

(c) Do you feel the tools could be improved? If so, how could the tools be improved?

"Retrieving knowledge is very slow. Unless you know exactly what you're looking for and where it is, you're gonna be looking for a while."

(d) If no tools are used, what methods of searching for knowledge do you and your project team use and how could they be improved?

Other methods:

6. What (kind of) knowledge do you and your project team have problems finding?

"The knowledge we have problems finding? It's the same as I said at the start. It's trying to find out what's available. Once you've found out what's available, you can generally find it. But it's finding out that there is something there to find. It might sound silly, but..."

"The new format for specifications is dual language. It's written in German and English. It's written paragraph by paragraph in two languages. But the problem we have... it's easier, the Germans will write that, and they'll write it in German and English, but when it comes to us, we'll ignore the German part and just write the English part because we don't have the language skills to do it. We can't translate back. That's something that is a problem."

7. What is the minimum knowledge that you and your project team expect to be able to find?

"Test reports. That's field trials, combustion testing, validation testing, life tests, function and wear tests, endurance tests..."

8. In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?

"Access rights... physically connecting to the server [in Germany]"

9. What frustrates you and you project team about searching for knowledge?

"What frustrates us? What certainly frustrates me is when you spend hours and hours trying to find the document that you want, and then you get it and it's in German. It's as good as not having it."

10. Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?

"Not really. All the project managers in the UK are R&D "

11. Could you explain why this knowledge is unavailable?

See answer to question 10.

## **Knowledge Sharing**

12 (a) What kind of information or knowledge do you and your project team generate?

"Drawings. Design side you've got drawings and specifications. Lab side you've got the whole host of all your approvals testing, all your development work, all your efficiencies, combustions, temperature. All this endless everything that you've got to develop to meet a CE approved appliance at the right level that you want it. Most things are electronic for things like that"

(b) Do you and your team currently collect and organize this information somewhere? If so, where?

"Radocs server local to UK, Group server – generally just used for IP and documentation for milestones. Drawings are from ProE and are in Intranet viewable via ProductView."

13. Is this knowledge reusable in other projects or in other processes within the IP?

No answer recorded to this question.

14. (a) What kind of information would your team be prepared to contribute to an shared R&D knowledge base:

No answer recorded to this question.

b) How and when could you and your project team prepare this shared information? What storage formats and what kind of support (e.g. tools, systems, methods) would you recommend?

No answer recorded to this question.

c) Should this information or knowledge be shared among the different R&D sites?

"I think we should share as much as we can."

d) How important is sharing this knowledge among the sites? Would you describe it as mandatory?

See answer to 14(b).

## **Use of the Vaillant Intranet as a Search Tool**

15. Do you or your project team use the Intranet to search for knowledge?

"Very rarely. For IP [NPD business process] stuff."

16. Is there any functionality that you feel could improve the process of searching for knowledge on the Intranet?

No response was recorded for this question.

## **Pilot R&D Integration Study**

### **Interview Protocol**

#### **R&D Questions**

**Interviewee:** [deleted]

**Role:** Boiler Project Manager

**Date:** February 2006

**Location:** France (interview protocol returned by e-mail)

#### **Questions**

##### **General**

1. What is your understanding of the term 'knowledge'?

“From my point of view, knowledge means: the skill of a person to be able to “do something”. The information you need in order to do your task.”

##### **Information or Knowledge Needs**

Note to interviewer: Please inform the interviewee that any reference to “you” in isolation, means “you and your project team”, rather than “you personally”.

2. What kind of information/knowledge do you and your project team need in the course of a project?

(For example: Reports, expert advice etc.)

“To be sure of the client needs (internal or external). When the needs change the project leader has to inform the team properly about the change, why the change, and what are the consequences. The needs and the technical requirements are described in:

- Marketing technical specifications
- Powerpoint files
- E- mails.”

3. What is the format of this knowledge?

The interviewee provided no response to this question.

(a) Where do you and members of your project team look for knowledge?

“- In the project folder.  
In the project panel hanging in the project meeting room.”

(b) Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group’s knowledge, or even outside of the Vaillant Group?

“Depends on the projects. In Nantes, 75% (in accordance with my estimation) of the knowledge is in Nantes.”

(a) How do you and your project team search for the knowledge?

“In Nantes: We speak with the best person in the plant who (from our opinion) should have the best information or must know the person who knows. External to Nantes: Same, even it’s more difficult (our company is not too big).”

(b) Do you and your project team use tools to find knowledge? If so, what are the tools, and can you give real examples of tools and systems that support the search?

“No.”

(c) Do you feel the tools could be improved? If so, how could the tools be improved?

“Yes, a simple tool can be imagined. A real location for sharing data (like the common drive), but reliable, simple to use, with a standard skeleton for all the project in order to be sure that a team member will find the information in another project folder. The current common drive is not a good solution because is not user-friendly enough. For instance I (with the help of the IT support) have tried to copy my project folder since December on the drive without success!!!”

(d) If no tools are used, what methods of searching for knowledge do you and your project team use and how could they be improved?

“See above.”

6. What (kind of) knowledge do you and your project team have problems finding?

“All kinds of information, technical, financial etc.”

7. What is the minimum knowledge that you and your project team expect to be able to find?

“It depends...”

8. In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?

“In the case of our company size, very often men will never replace the IT tools. We can of course, improve the tool (see above) but it’s so simple to phone one of our colleagues (in Nantes, UK or Germany). If the colleague doesn’t have the information, may be he can help me and direct me to the right person. Next time it will be his turn to help one of our colleagues. More and more the European team builds itself.”

9. What frustrates you and your project team about searching for knowledge?

“Sometime when the IT tool already exist he doesn’t work and when the tool exists is too complicated and nobody wants to use it. (See MS project server implementation 3 years ago)

Simple is beautiful and useful!”

10. Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?

“All kind of information can be missing.”

11. Could you explain why this knowledge is unavailable?

“Very often we haven’t enough standard documents and template. Each project or site reinvents the wheel! Defining standard templates for each task is also a priority for us. When the common templates are defined and used it will be easier to find them on the IT drives.

With a software research tool or without.”

### **Knowledge Sharing**

12 (a) What kind of information or knowledge do you and your project team generate?

“Status reports, Financial reports, pictures etc.”

(b) Do you and your team currently collect and organise this information somewhere? If so, where?

“Yes of course, each team member uses the project folder. The knowledge is shared through the folder and the weekly team meeting.”

13. Is this knowledge reusable in other projects or in other processes within the IP?

“Yes.”

14. (a) What kind of information would your team be prepared to contribute to an shared R&D knowledge base:

Now?

“We have defined a common template for MSP used by the 3 project managers in Nantes. One of us started to build it, a second improved it.”

In the future?

“I would like to improve the project WEB base for the project development. It’s a kind of workflow for the projects which are not on SAP. Currently this tool works at 50% of its capacity. We are improving it. This tool can be used in each plant and can help people to share information of the parts “under development”. I invite you to Nantes, if you are interested in testing it!”

b) How and when could you and your project team prepare this shared information? What storage formats and what kind of support (e.g. tools, systems, methods) would you recommend?

“See above.”

c) Should this information or knowledge be shared among the different R&D sites?

“Of course.”

d) How important is sharing this knowledge among the sites? Would you describe it as mandatory?

The interviewee provided no response to this question.

### **Use of the Vaillant Intranet as a Search Tool**

15. Do you or your project team use the Intranet to search for knowledge?

“Yes.”

16. Is there any functionality that you feel could improve the process of searching for knowledge on the Intranet?

- “- A common template for project management.
- A common skeleton for the project organisation in the folders.
- Real common drive for sharing project folders.
- A simple tool for information searching on the intranet and the common drive (like Google)
- Simple workflow for parts “under development”. The need is to be able to share information between the project team (In Nantes or between two sites) before the parts are added to SAP.”



## **Pilot R&D Integration Study**

### **Interview Protocol**

#### **R&D Questions**

**Interviewee:** [deleted]

**Role:** Project Manager, Controls Expertise

**Date:** 15<sup>th</sup> February 2006

**Location:** Germany

#### **Questions**

1. What is your understanding of the term 'knowledge'?

"Knowledge is mainly high value information combined especially with experience, context, reflection, based on 5 would call it on the one hand trial and error, on the other hand learning from tests experiences and so on; Scientific methods."

#### **Information or Knowledge Needs**

Note to interviewer: Please inform the interviewee that any reference to "you" in isolation, means "you and your project team", rather than "you personally".

2. What kind of information/knowledge do you and your project team need in the course of a project?

(For example: Reports, expert advice etc.)

"Future trends, for example, future technologies, test reports, test plannings, erm, test specifications, FMEA, patents, I think these are the most important ones."

3. What is the format of this knowledge?

"So in general we start every-time with advice from colleagues, so we start to organise meetings, the colleagues are defined only by, ja I think the, know the people very well, you know the background, you know their performance, their knowledge performance, so we organise meetings. The next point is the Internet, it's clear, or through Intranet, Patent gate, where you can make patent research, for example, literature, this is also clear, and don't forget the external suppliers."

4. (a) Where do you and members of your project team look for knowledge?

"Mainly visiting fairs or something else. We take our existing systems supplier or preferred supplier and on top we try to find new suppliers or new ideas mainly on fairs or on the Internet or something else and then we call down the supplier and make a meeting together."

(b) Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group's knowledge, or even outside of the Vaillant Group?

"To be honest, from group point of view, from the internal view it's mostly locally. Ok, suppliers and so on, this is defined. There is also Universities, but it's a very small part."

5. (a) How do you and your project team search for the knowledge?

"Meetings, personal contact with colleagues visits, the Internet."

(b) Do you and your project team use tools to find knowledge? If so, what are the tools, and can you give real examples of tools and systems that support the search?

"Mainly the Internet. Really only a small part [comes from project drives]. Very often you ask the colleagues directly to meet each other and to discuss about the information or the knowledge of the project."

(c) Do you feel the tools could be improved? If so, how could the tools be improved?

"What really should be improved is the searching for patents. Because I had some software here to search in patents to different objects, but this is really not very comfortable."

(d) If no tools are used, what methods of searching for knowledge do you and your project team use and how could they be improved?

"Meetings... Custom search tools. Very difficult to search for a special object."

6. What (kind of) knowledge do you and your project team have problems finding?

"Patents, but also the FMEAs. To find the relevant person, to be sure that they have the right knowledge for your project, your question, so this is also a big problem here. But this is only based on your network. You have to know the people. If you don't know the people..."

7. What is the minimum knowledge that you and your project team expect to be able to find?

"All FMEAs and all relevant patents. "

8. In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?

"And also access for my team members placed in Nantes to this R&D drive, because the performance is very, very bad, and that's the main reason why they don't use this common R&D drive."

9. What frustrates you and your project team about searching for knowledge?

"APIS! Slow drive, again Patents."

10. Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?

"One of the problems, is if we start to discuss, for example, new technologies, or something else, the next question is always what are the performance costs behind of this future technology and there we have a big problem to make the calculation based on our heating business for such new technology. For example, wireless LAN or something else. The manufacturing costs and so on. Not the cost to develop it."

11. Could you explain why this knowledge is unavailable?

"If I take my example of wireless LAN, so it's our business totally different and we cannot use wireless LAN with our past protocols and so on. So, the changes we have to do in front to be able to use wireless LAN are very big and also the quantities behind are very low."

"The luck [indistinguishable] is where you can feel free to develop without looking on the cost, but normally it's in parallel to an integration project, So you start with a pre-developed [unit] at the beginning of the innovation project and they ask directly due to the business plan what are the costs and this is every-time the problem and this is a big risk to take the wrong decision."

### **Knowledge Sharing**

12 (a) What kind of information or knowledge do you and your project team generate?

"Mainly the FMEA from our side. The specification for standard modules by communication or something else, which is used all over the group. We update special milestone checklists which are part of the IP [NPD business process]."

(b) Do you and your team currently collect and organize this information somewhere? If so, where?

"The R&D drive. Mainly in the project folder."

13. Is this knowledge reusable in other projects or in other processes within the IP?

"Yes, if they find this information, yes."

14. (a) What kind of information would your team be prepared to contribute to an shared R&D knowledge base:

- Now?
- In the future?

"So what we do now is to store our FMEAs to define checklists for the IP, to define test rules for hardware components , to define test rules for software components, and in the future, I don't know. Difficult."

b) How and when could you and your project team prepare this shared information? What storage formats and what kind of support (e.g. tools, systems, methods) would you recommend?

No answer recorded for this question.

c) Should this information or knowledge be shared among the different R&D sites?

"Yes. Yes!"

d) How important is sharing this knowledge among the sites? Would you describe it as mandatory?

"It's a must. I see no difference between the sites."

### **Use of the Vaillant Intranet as a Search Tool**

15. Do you or your project team use the Intranet to search for knowledge?

"Yes, especially for the IP. Also methods like House of Quality, FMEA and so on."

16. Is there any functionality that you feel could improve the process of searching for knowledge on the Intranet?

"One common Intranet for all the brands, English language, because sometimes we are searching also for very easy information about functionalities of applications which are only sold by Saunier Duval, Glow Worm and something else. Ok and it's very difficult to go then on a SD [Saunier Duval] Intranet page and to search inside this page, it's any impossible."

## **Pilot R&D Integration Study**

### **Interview Protocol**

#### **R&D Questions**

**Interviewee:** [name deleted]

**Role:** Programme Manager, Hydraulics and Accessories

**Date:** 15<sup>th</sup> February 2006

**Location:** Germany

#### **Questions**

1. What is your understanding of the term 'knowledge'?

"Knowledge is at the end all informations [sic] I could need for doing the job and it could be test reports, it could be documentations [sic] about positions, it could be business plans, business figures, it could be ideas for new developments to every kind of knowledge what I need in the end for the job."

#### **Information or Knowledge Needs**

Note to interviewer: Please inform the interviewee that any reference to "you" in isolation, means "you and your project team", rather than "you personally".

2. What kind of information/knowledge do you and your project team need in the course of a project?

(For example: Reports, expert advice etc.)

"It general you could say, all the documents what we have in the IP [NPD business process], yeah, more or less. But some of them are more important and some are less important. I would say the main important things, data from the markets, for example a system product running in the market, how many parts do we sell, what would was in the past, what will be in the future so we have a tracking curve, or could make a tracking curve about this. Prices and all stuff, so that they could evaluate the business very clear. Competitor informations [sic] are useful, so, especially main competitors, what are the prices, about price positioning, markets, what are the advantages and disadvantages of the product, all the things what we get from competitor analysis.

"To evaluate a new product against a competitor's, for example. What we make as well and what we have available in the Intranet is competitor analysis. In general, we should

have access to all kind of specification and to all kinds of contracts and test reports. So, these are the main things that you get during development and during negotiations. Prices should be clearly available, so prices from parts what you buy, calculations, this is done by SAP. I'm not so really interested in general about decision documentation. This could change from time to time. And, anyway, two years later all the parameters has [sic] changed. And on the other side I would also say, we have to balance the things what [sic] we have to document because it's necessary. And do we really need it, do we have really to sit people down and to spend the time making these things.

“In general, due to the fact that we could have sooner or later problems with suppliers, let's say quality issues for example, then we need to document which [sic] we had exchange with the suppliers. So we should have a link where we could place these documents, only the e-mails, and store it. In case, if there is a problem in the future, we could have access, but this is enough at the end. It's useful when you have a special hierarchy in the document store, but it's not in any way necessary. Principal is that we can get access five to ten years later if we have a problem.”

### 3. What is the format of this knowledge?

“Well, normally, I think the most common way to send out informations [sic] is e-mail, in the company. If you open the e-mails you have there Excel, PowerPoint, Win-Word. I think it's nothing particular, it should only be a storage where you can find all the e-mails inside. Business figures are mostly done as you know in Excel report or in SAP, for example, in SAP you also use the history at the end, because you could also look for prices which are two or three years made ago for a project. Test reports mainly done as a Win-Word document. And we have for Remscheid, we have a common storage. This is in the test department under the direction of [name deleted]. I'm not sure if the test reports from Belper and Nantes are also collected there; this could be a weak point.

“Mostly difficult is not during a running project to find informations [sic], because there you have networks and know who is storing what and so on. It's more or less an informal base. The main problem is if you have two or three years later any problems to find it again, because there is no rule how to store such informations [sic], especially e-mails.”

### 4. (a) Where do you and members of your project team look for knowledge?

“There are some standard systems we have, I mentioned the test report database, ok Quality data you could get from the Quality department. The link to SAP or link to Internet where you have a lot of information. Another point is that if you are looking for new information which are not present in the company, then well normally we go to Internet, make some researches, or we have some networks to some Universities or suppliers, from other companies and so on. But then it's not really a structured base, it's more or less you find it [by chance] at the end. For some things, for example [you use a network of experts you know]. If you step in something completely new, it's difficult.”

(b) Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group's knowledge, or even outside

of the Vaillant Group?

“What we also have is an informal network. This Hydraulics There we had each four weeks a meeting together for two days and discussing topics and there at the end there is an informal network and you could ask for informations [sic] there, or if you have a problem you could ask Nantes, Belper and so on, to give you some informations [sic]. This will also work.

“If you have some new technologies or you are looking for a new supplier then you are looking inside or you go to a [technology] fair. There is a tradition. We have [a brand name] and there it is very difficult for me to get information. To ask and get several people to get information and so on. This is a little bit more difficult.”

5. (a) How do you and your project team search for the knowledge?  
See above. Also “Personal contacts, e-mails, documents.”

(b) Do you and your project team use tools to find knowledge? If so, what are the tools, and can you give real examples of tools and systems that support the search?

“SAP, Internet, Test database is our main things, now we have also introduced APIS software where we have the FMEAs. At the end they are also linked afterwards to the Intranet. There is also project files. We have one project file [folder on R&D server] and each project stores its information there, what's not stored are the e-mails.”

(c) Do you feel the tools could be improved? If so, how could the tools be improved?

“There was a presentation from [name of a major CAD software company]. They showed a tool that could be linked to SAP or Interlink, what we use for data storing, where we could add also some files to that. For example, if you have a drawing or specification or so on, this linked today and this is stored there. We could add also some other things, we could prepare a complete catalogue. What was not included was, for example was how to store the e-mails and to ‘Interlink’ it with that.”

And on the other side we have the common group share, where we store all the files, like Excel, Win-Word, ProE data maybe are stored in these files. During a project you can find it. The problem is always afterwards.”

(d) If no tools are used, what methods of searching for knowledge do you and your project team use and how could they be improved?

“Networks of colleagues.”

6. What (kind of) knowledge do you and your project team have problems finding?

“Well, at the moment for example, I am looking for contracts, I am looking for contracts with customers, because we have some OEM products, I am looking for business

figures to evaluate the business what we are making. Which is important if you make for example for a new project the business plan . It's very good to look only at the old business plan to look for the other changes behind it. You have a guideline at the end. If you don't have such things, you have to build up everything from scratch, from new.”

7. What is the minimum knowledge that you and your project team expect to be able to find?

“I've pointed out some issues. Business figures is important, technical data is important, test reports are important, drawings and specifications are important. Contracts or important agreements with clients, not all agreements with external suppliers are written down and are easy to find. Sometimes it's only done in an e-mail, but there's not really a written contract that you can find in a lawyer department.

“I forgot one thing, quality data. Quality data from existing products and also from former products or from comparable products, to be able to understand what are the failures, what is the failure rate and to analyse and to make improvements at the end, forecasts for the new project, as well. There we had a very good system in the past, but in the moment, I think we are missing some data due to changing of the computer system and all this stuff. And FMEA is also important, there we have started to make all FMEAs with APIS, and if everybody will do that, if we have a link from Internet to APIS, it's normally easy to find out the things and then you could make your new FMEAs and build up knowledge based on this.. And then we document potential risks for products, for example.”

8. In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?

“To make it short, e-mails are not linked to this project drive.”

9. What frustrates you and you project team about searching for knowledge?

“In general I think each site, so Nantes, Remscheid, Belper and so on has made decisions in the past. And each company or each brand has its own history. And it's very difficult to understand the history and to get the information out of this history, because at the end you have to stay several years in a company and have to feel the spirit of the company or brand. And it's different and it's ok. But this is the point that. For example, some informal things which are clear for everybody in Remscheid and clear for everybody in Nantes, but the link is difficult. And the other thing is that the project drive is always fully loaded with information. As I mentioned and then you get e-mails and you have to take information out. The question is why we collect the information when we then have to take it out, away. Sure then we make some hard copies, but what about the hard copies?”

10. Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?

“I think it's a repetition of the points which been made. Another point is more for the



future. If you're looking for new developments, I think the network what we have to Universities for example, to experts, this is not so really common and not divided to the whole group. Everybody has a network, but it's not linked together, Big important point for example is approvals and standards. So we have in each location some people who has a good contact to an approval association in France, or to Germany or wherever. But it's not necessarily that if somebody in Nantes has access to the information, that everybody has the information and vice versa.

“Another thing is, for example in approvals and standards, it's not really only knowledge but there's in principle the possibility to drive. We have this strategy and I want to drive approval standards in this direction. So knowledge could not only be what we can get, knowledge could be what we make.”

11. Could you explain why this knowledge is unavailable?

See response to question 10.

### **Knowledge Sharing**

12 (a) What kind of information or knowledge do you and your project team generate?

“If you look on the IP, are you familiar with the IP? So in each phase of the IP we are putting data together. Normally, it's not completely that we are going along this line and collecting all this data, but it's a guideline. And along this guideline we put all these things. So beginning from the strategy, calculating the business, making analyses, testing things, document our tests and our results and drawings and so on. Specifications, all this stuff, workshops with customers. So along this line all of these things will be documented.”

(b) Do you and your team currently collect and organise this information somewhere? If so, where?

“Yes. Project drive and tools like SAP.”

13. Is this knowledge reusable in other projects or in other processes within the IP?

“In principal, yes. So not everything, but especially business figures, strategies, tests FMEA, specifications. Those are the main items... Contracts.”

14. (a) What kind of information would your team be prepared to contribute to an shared R&D knowledge base:

- Now?
- In the future?

Interviewee indicated their agreement with the statement made by the interviewer:  
"Anything that's on the R&D drive."

b) How and when could you and your project team prepare this shared information? What storage formats and what kind of support (e.g. tools, systems, methods) would you recommend?

“What I would like to have is a kind of Google and that's it. And I would be very interested as I have mentioned how do it other companies.”

c) Should this information or knowledge be shared among the different R&D sites?

“Yes, it's clear. I would also be very interested in Marketing information.”

d) How important is sharing this knowledge among the sites? Would you describe it as mandatory?

See response to question 14(c).

### **Use of the Vaillant Intranet as a Search Tool**

15. Do you or your project team use the Intranet to search for knowledge?

“Intranet clear, we do. But Intranet is mostly at the moment linked side by side. Vaillant in Remscheid, Saunier Duval in Nantes. We have a common Intranet, but okay sometimes you find the information is French and so it's not always translated for example. The Standard in English for example. There is also another point, which is at the end difficult. If a project team is mostly for example located in Germany, then it's clear that the language is German. To transfer everything in English... then it's difficult to get all the things together and find it out. The question is, what is the right balance?”

16. Is there any functionality that you feel could improve the process of searching for knowledge on the Intranet?

“We have also a kind register at the moment. But this means that you have to place it there. It's not like Google.”

## **Pilot R&D Integration Study**

### **Interview Protocol**

#### **R&D Questions**

**Interviewee:** [deleted]

**Role:** Boiler Project Manager

**Date:** 15<sup>th</sup> February 2006

**Location:** Germany

Comment: This protocol contains notes compiled using the original interview transcript.

#### **Questions**

1. What is your understanding of the term ‘knowledge’?

- Experience
- Rules
- Standards
- What you know

#### **Information or Knowledge Needs**

Note to interviewer: Please inform the interviewee that any reference to “you” in isolation, means “you and your project team”, rather than “you personally”.

2. What kind of information/knowledge do you and your project team need in the course of a project?

(For example: Reports, expert advice etc.)

- Basis of customer requirements from marketing departments in countries
- Regulations and standards
- Experience from former projects – to avoid (“reinventing the wheel”)
- Responsibilities in former projects – who was the project leader? This is important in order to exchange experience

3. What is the format of this knowledge?

- Old test reports (.xls/.doc)
- Regulations and standards – Vaillant Intranet updated regularly
- Personal contact e.g. designers

4. (a) Where do you and members of your project team look for knowledge?

- Intranet – Regulations etc
- SAP – old and new drawings
- Personal contacts

(b) Do you and your project team search for knowledge just locally (at your site), or is the search extended to the whole Group's knowledge, or even outside of the Vaillant Group?

Yes.

Group knowledge:

- Search for knowledge in complete group, since the CoCs are located on all sites. Regular meetings with colleagues in Nantes. The knowledge searched for is very dependent on the topic.
- External knowledge sources:
- Search Internet for competitors. Normally this is to look for Boilers, but it is useful to obtain manuals.
- This is not really a requirement for a knowledge database, since there would be too many competitors and appliances.

5. (a) How do you and your project team search for the knowledge?

See answer to Question 4(a).

- Personal contact with experts
- Search for drawings for old products
- Intranet for regulations and standards
- Must navigate to right place
- No direct link to homepage

(b) Do you and your project team use tools to find knowledge? If so, what are the tools, and can you give real examples of tools and systems that support the search?

"Yes."

- Intranet
- SAP – Drawings, part lists for products still in production.

(c) Do you feel the tools could be improved? If so, how could the tools be improved?

- Intranet not user friendly

- Especially for regulations and standards - could be improved

(d) If no tools are used, what methods of searching for knowledge do you and your project team use and how could they be improved?

Does not like SAP.

- A search engine (like Google) would be good) and get relevant
- Search results must be up-to-date and relevant
- Does not have to be fast (a wait time of 1 to 2 seconds for results would be acceptable)
- Would be good to have a “search within a search feature”

6. What (kind of) knowledge do you and your project team have problems finding?

- “It is always difficult to find information that has been purely documented.”
- Locating the information is difficult, even if it is on the project drive
- A project leader must look for files created in his or her own project folder
- Files must be stored in a simple structure e.g. in line with the functional roles of the user, Testing, R&D, Purchasing. The simpler, the better.

7. What is the minimum knowledge that you and your project team expect to be able to find?

- The experience of the people working on parallel projects or former projects
- It would be great to have testing protocols in order to avoid repetition if testing. It is mandatory that everyone involved in the development of an appliance can have access to these testing protocols.
- A problem is that the company loses experience of people when they leave the company. For example, one must currently ask people in the testing department for information about a particular test, which becomes impossible if the relevant person has left.

8. In the case of knowledge sought on the company's network (e.g. Project drive), is there any knowledge that you feel your project team needs, but has difficulty accessing?

- On Intranet site for regulations and standards
- A search engine
- Currently must link many links to find huge table of results, some of which may not be there.

9. What frustrates you and you project team about searching for knowledge?

- Time spent searching for knowledge
- Big space for search
- Multiple search terms (synonyms) e.g. Stroemungsversicherung, draft diverter, hood, draft collector

- Languages are a big problem

10. Is there any knowledge that you consider is missing (e.g. information that would assist you in making a decision, but is unavailable)? If so, what is it?

(i) "Most important data has never been written down. This is the experience of people, which is so detailed and difficult to write down. Consider which role someone played in a project. For new people or could be for people on another site. It is important to know whom to contact. Can be found on the Intranet phone book, but need the name first. The roles of people change very quickly and people leave."

(ii) "A link to the IP must be included. There should be one point in each phase in the IP where knowledge must be stored in a database."

(iii) Document management system. Already put knowledge in database a few years ago.

11. Could you explain why this knowledge is unavailable?

"People leave the company."

### **Knowledge Sharing**

12 (a) What kind of information or knowledge do you and your project team generate?

Create knowledge related to:

(i) Realisation of customer requirements

e.g. 3 star efficiency rating for Italy

(ii) Internal topics peculiar to post merger scenarios

Cross country activities

(iii) Experience about a lot of topics e.g. use of a special material that cannot be handled easily

(b) Do you and your team currently collect and organize this information somewhere? If so, where?

"Yes."

(i) R&D drive. Each project has a special number and special folder. Subfolders are used for special items such as Phase In / Phase Out information.

(ii) Drawings database. Intranet. This system is still not connected to all the sites and people, so one cannot easily exchange drawings. The drawings must be e-mailed to colleagues. In Nantes, this is done via an Intranet tool (hgl or CAD files).

(iii) Normal paper folders in cupboards.

13. Is this knowledge reusable in other projects or in other processes within the IP?

“Yes it is.”

14. (a) What kind of information would your team be prepared to contribute to an shared R&D knowledge base:

- Now?
- In the future?
  
- Decisions taken during project that will be valid as guidelines for subsequent projects.
- Why decisions were taken.
- Some parts of the IP we did not use.
- Realisation of special topics e.g. relating to special requirements of markets

b) How and when could you and your project team prepare this shared information? What storage formats and what kind of support (e.g. tools, systems, methods) would you recommend?

To motivate people, formats from known tools must be used e.g. Microsoft Word, Microsoft Excel and Microsoft PowerPoint. Some may use PDFs. This makes sense in certain cases, since a PDF cannot be easily changed e.g. test reports, single decisions. However, some documents may need to be amended later on (e.g. by original author). Should be a supervisor who can delete files. The author should be able to delete old files.

c) Should this information or knowledge be shared among the different R&D sites?

- Yes.
- More of a “must” than a “can”.

d) How important is sharing this knowledge among the sites? Would you describe it as mandatory?

"Absolutely mandatory. We do the same jobs on each site for similar products in the same markets. It is a big help to share experience or at least to know who has this experience."

### **Use of the Vaillant Intranet as a Search Tool**

15. Do you or your project team use the Intranet to search for knowledge?

"Yes, to find out more about products."

Download manuals, pictures

“Document Server” on Intranet is very useful. Can download manuals with a different release version.

16. Is there any functionality that you feel could improve the process of searching for knowledge on the Intranet?

PDF Archive on Intranet

- Must login and interface is unwieldy
- Must know exactly what one is searching for
- The names of the documents vary from project to project
- Easier to do a keyword search – This is possible, but currently it is only possible to search with a single word. Also it is not possible to perform a search within a search
- This would be a brilliant start



## **Appendix F**

### **Protocol Interview with company NPD business process architect**

#### **Questions**

##### **Innovation Process (IP) (Company term for ‘NPD business process’)**

1. The IP is evolving. Where do you think the future of IP lies?
2. In Germany the IP is fully implemented. Is it followed closely? How about France?
3. Do the training programmes being booked over the intranet about IP involve only Germany?
4. Are the training programmes compulsory or optional?
5. Is the IP an ideal approach to how things should be done group wide during the product development phase or is IP evolving to achieve an ideal state currently?  
For instance, is the input/output information for each process supplied to the receivers in a complete state, in order to go on to the next stage, or a satisfactory level of input/output is enough, depending on the choice of the process owner? In other words, is the input/output specification theoretical, or, practical and compulsory for the process to be complete?
6. In the IP documentation PDM is mentioned. Is a PDM system implemented in Germany? If so, what are the specifications of the system; and are there any plans for implementing a group wide standardized system to improve communication?  
In Germany we work with SAP and with the VH Group file server network. There is no real PDM system and workflow management implemented so far. This is one reason why we contacted Commasoft for Infonea.
7. In your personal point of view, what would be the information flow bottlenecks occurring during the IP? What would your recommendations be to improve the group wide as well as local (in this case, Germany) knowledge sharing?

##### **Research and Development Organisation**

8. Which Concurrent Engineering (CE) methods are employed in Germany, and group wide, in your point of view? Which departments would you say are ahead with the application of CE ?
9. The group-wide view is to involve Manufacturing during the IP as early as possible. How early is Manufacturing in Germany involved during the IP? What would your comments be in this issue.

10. There exists a shared drive for R&D between Germany, UK and France. Manufacturing in the UK will have read-only access to the drives by the end of January. Will German and French Manufacturing divisions also have this type of access? If the group wide Manufacturing had a shared drive would having a read-only access benefit the R&D as well?

11. Are any Knowledge Based Engineering (KBE) tools employed in Germany during the design phase?

12. In the UK, the design communication between small scale suppliers and the R&D design team sometimes may prove problematic due to the design communication being in the form of 2D drafts therefore elongating the interpretation time. Does Germany have a similar problem when dealing with small scale suppliers? If so, do you have any initiatives for solving this problem?

13. During conceptual design, ideas are formed during contact with suppliers. The ideas are then compared and accepted or discarded for various reasons. In the future, the reasons could change making the conceptual ideas valuable for re-assessment. Is there a formal request/storage method for keeping this tacit information (in Germany or in the case of international projects group wide)?

### **Product Improvement and Testing**

14. The linking of APIS (Failure Analysis tool based on FMEA methodology) with Warranty data would prove useful to examine cause-effect relationships. Is there a plan for developing a standard system at the moment in Germany or group wide?

15. Will there be a group wide standardization of the level of detail in the warranty data? (For instance the manufacturing dates of each individual component is a higher level of data than the manufacturing date of the assembly.) If so, when is this to commence?

16. Is there a historical database of tests performed for each component? Is this information shared with UK and France where relevant? How is the relevancy determined? Does Germany Testing search if the particular component has been tested in a similar fashion in UK, or France, before the testing of a product?

17. Remscheid has a database of test procedures. There is a plan to standardize test procedures group wide. When is this to commence?

18. For international projects the plant with the highest test capability for individual components and the assembled appliance is chosen. However when the project is local all testing is done on the local site. Is this a valid statement? If not, could you elaborate?

*Thank you for your time!*

## Appendix G

	<b>Title in Ulrich and Eppinger (2003)</b>	<b>Stage Description in Ulrich and Eppinger (2003)</b>	<b>Corresponding Stage Title in Kahn (2005)</b>	<b>Stage Description in Kahn (2005)</b>	<b>Corresponding Stage Title for Company Process</b>	<b>Corresponding Stage Description in Vaillant Group (2005)</b>
1	'Planning'	Commences with reference to the corporate strategy. Technology developments and market objectives are assessed. Output is a project mission statement. Typically occurs prior to project sign-off.	'Scoping'	'Prescribed activities include preliminary market, technical assessment, and business assessment'.	'Strategy'	A product strategy is developed based on all available market information. Project is released for further development
2	'Concept development'	Requirements of market are identified. Various product concepts are formulated and assessed. A few of these are chosen for more advanced development and tasting.	'Build the Business case'	Carry out a detailed market analysis, assess user requirements, benchmark competitors, test product concepts and undertake a detailed technical evaluation of the product. A 'supply assessment' and a 'detailed business analysis' should be carried out. Outputs include a business case and a plan for remaining phases of the project.	'Conception'	'Translation of "Needs and Wants" into product "Functions and Features" is transferred into the target specification. 'Estimates of performance, costs, project timing, potential suppliers and quality are the base for the management to release the project.' Release follows a gateway review.
3	'System-level design'	The product architecture is defined and the product system is broke down into sub-systems and components. Outputs include a definition of the final assembly, a functional specification of detail design of the sub-systems and a process-flow diagram for assembly.	'Development'	Product development plan is executed and a physical version of the concept developed. Laboratory-based tests are conducted on physical product mock-ups. Limited testing of product with customer may occur. The output from this stage is a product prototype that has passed laboratory-condition tests.	'Development - Function'	Key functions of the new product are validated by subjecting prototypes to laboratory tests.
4	'Detail design'	Geometry, materials and tolerances of the unique parts in the product are specified in detail. Parts to be purchased from external suppliers are known.			'Development – Detail'	The product design and production plan are fixed. Necessary are parties receive drawings and relevant documents. Following the gateway review, funds are made available for production.
5	'Testing and refinement'	Pre-production versions of the product are built and tested. These contain parts with the same material and geometric properties specified for the final product, but may be built using a different production process.	'Testing and validation' and 'Launch'	Testing and validation of the product is achieved through various tests e.g. field-testing. Testing of the production process through limited production runs, followed by trials by selected customers. A business case for full production and launch is provided.	'Industrialisation – Process'	Products are tested in the field to 'conform the satisfactory performance of the product.' Preparations are made for pre-serial production.
6	'Production Ramp-up'	Fabrication of product using chosen production system. The aim of this phase is to provide training for the workers and identify and solve problems in the production process. During this process, the product launch occurs.	'Launch'	Production commences and commercial launch activities begin. Planned product lifecycle activities for maintenance are executed.	'Industrialisation – Launch'	Analysis of production process and implementation of improvements. Commencement of serial production run, accumulation of inventory for release to markets.
7			'Post launch review'	A year or more after product launch an assessment is made of the actual project performance compared to the predicted outcome. Lessons learned are recorded. Project ends and project team are disbanded.	'Review'	Must demonstrate fulfilment of project targets. Feedback of remaining problems to continuous improvement initiative team. Project activities are finished.

## Appendix H

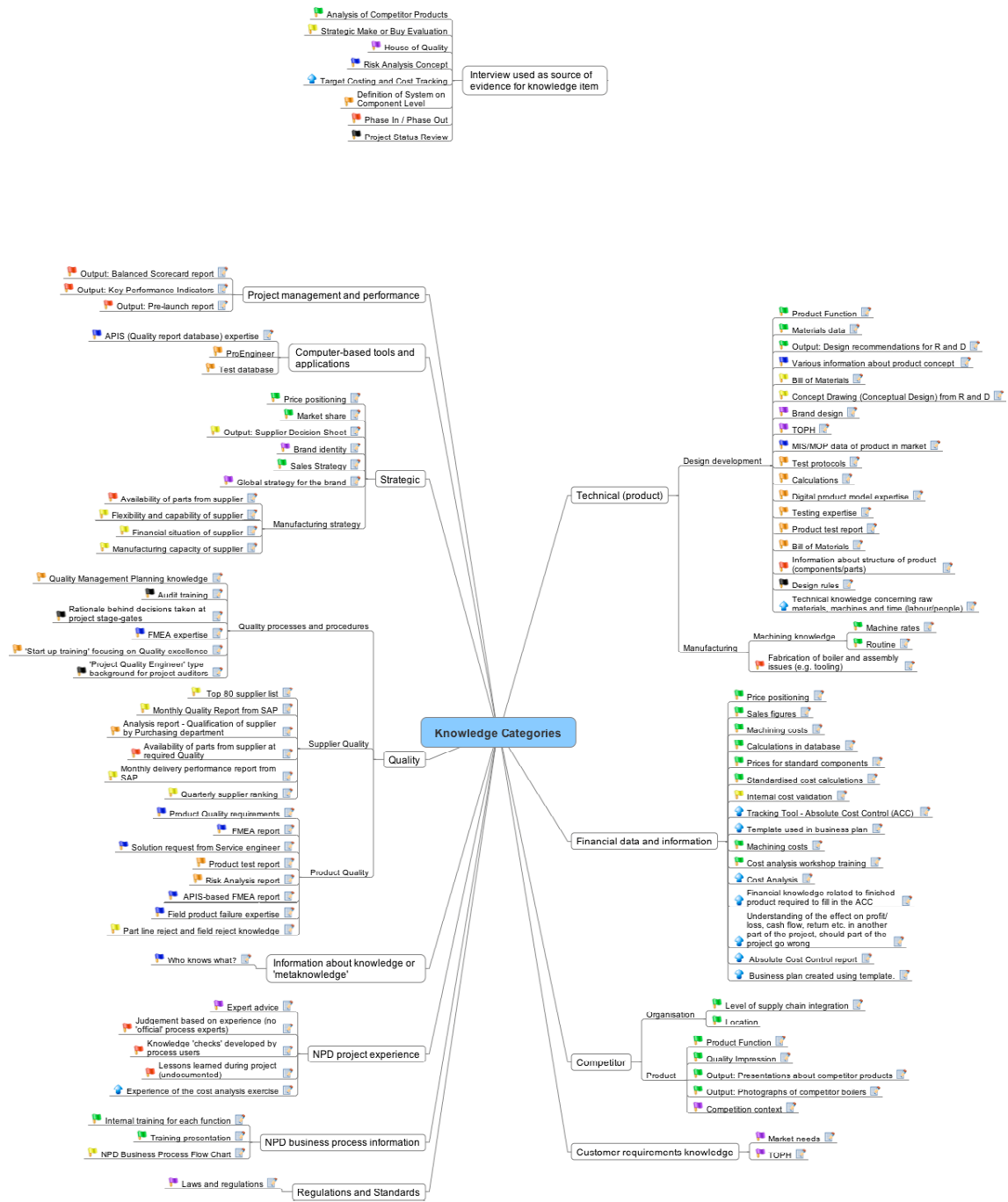
This table shows which questions from Liebowitz et al. (2000) were excluded from, or adapted for inclusion in, the NPD process knowledge audit. The reasoning for each action is also included. Question numbers refer to the numbering system used in the knowledge audit protocol (see Appendix B).

<b>Question in Liebowitz et al. (2000)</b>	<b>Corresponding question in NPD Process Knowledge Audit</b>	<b>Reason for removal or change (where appropriate)</b>	<b>Is NPD knowledge audit question relevant to identification of knowledge items?</b>
<b>Step 1</b>			
Question 1		Integrated with other questions e.g. 2.3, 2.6, 2.7, 2.8, 2.9, 2.10, 2.11, 2.12 and 3.2	Yes
Question 2	3.1 (opposite question posed)		Yes
Question 3		Use of knowledge not important at this stage	No
Question 4	2.3 (external sources), 2.7 (rephrased)	External sources are referred to in 2.3. Simplified version of question used in 2.7.	Yes
Question 5	2.8 (minor change), 3.2 (adapted)	Simplified version of question used in 2.8. Refers to missing knowledge and all parties that may require it	No
Question 6	2.9	-	No
Question 7		Superfluous; knowledge items were the main concern	No
Question 8	2.10		No
Question 9	2.6		No
Question 10	2.11		No

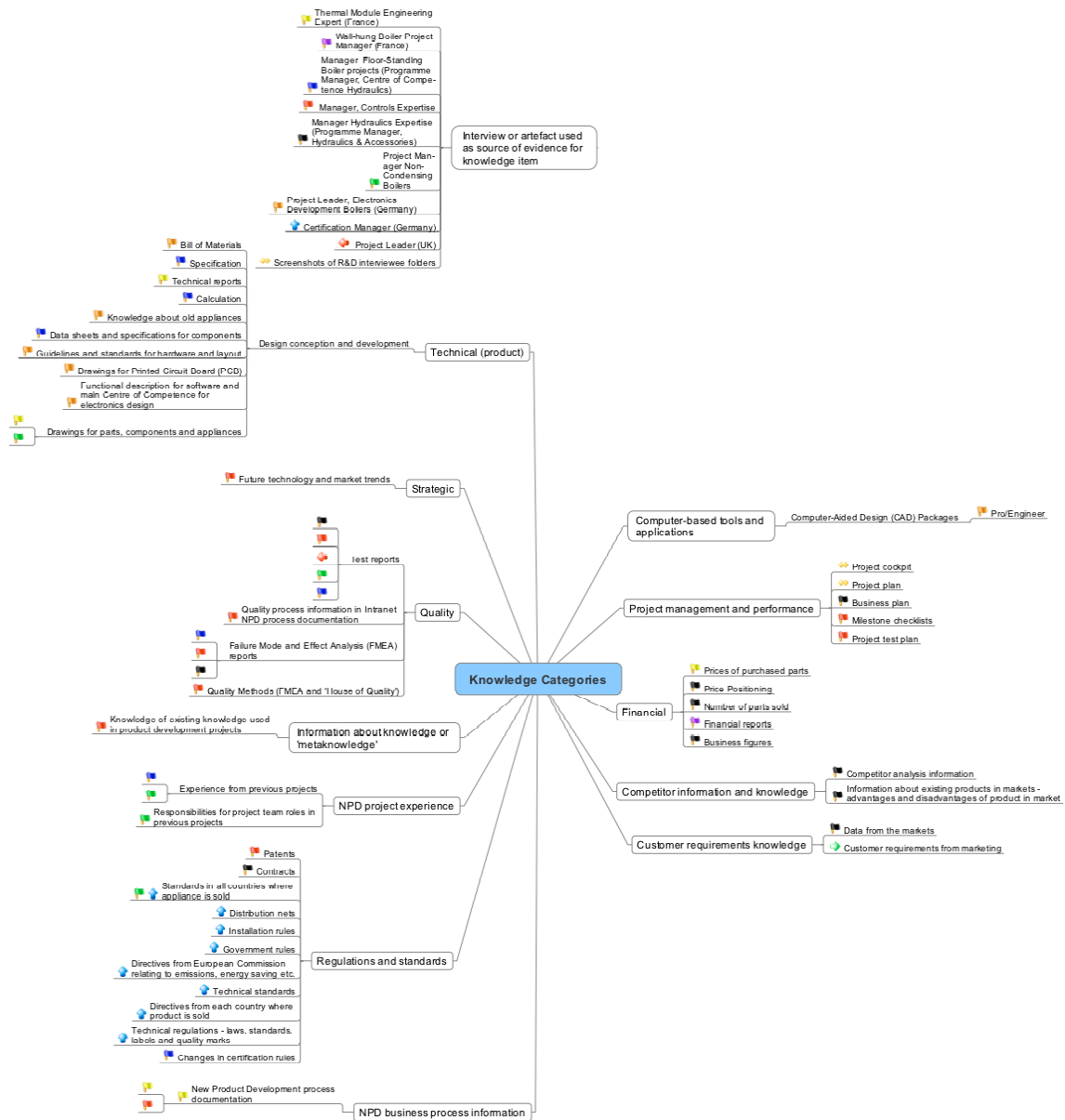
Question 11	2.12		No
Question 12		Superfluous; not the focus of the study	No
Question 13	2.2(?)	Rephrased to place emphasis on transfer of knowledge from non-experts to experts	No
Question 14	2.16 (slight change)	Rephrased slightly to refer to company NPD process	Yes
Question 15		Explained by interviewee when they described the knowledge	Yes
Question 16	1.4, 2.3	Split into two questions	Yes
Question 17		Superfluous; not the focus of the study	Yes
<b>Step 2</b>			
Question 1			Yes
Question 2	6.2 (adapted)	Asked about reusability using a simpler question in NPD knowledge audit.	Yes
Question 3		Redundant; concerned job performance	No
Question 4		Concerned potential sources of knowledge, not sources for specific knowledge items	Yes
Question 5		Related to questions that cannot be answered (missing knowledge)	Not directly
Question 6	6.3	Concerns missing knowledge referred to in Question 5	Yes
Question 7	2.13	Concerns missing knowledge referred to in Question 5	No
Question 8		Concerns missing knowledge referred to in Question 5	No
Question 9		Concerns missing	No

		knowledge referred to in Question 5	
Question 10	2.14	Asks about individuals looking for information, not knowledge items	No
Question 11		Refers to question 11	No
Question 12		Refers to question 11	No
Question 13		Concerns requests made for knowledge	No
Question 14	5.1	Asks about mechanisms for encouraging knowledge sharing and transfer	No
Question 15		Asks about barriers to effective knowledge management	No
Question 16	6.4	Asks about reasons for making errors on the job	No
Question 17		Asks about outsourcing	No
Question 18		Asks about outsourcing	No
Question 19		Asks about outsourcing	No
Question 20	1.2	Asks about time spent searching for knowledge	No

# Appendix I



# Appendix J





## Appendix K

### Sources of Published Ontologies and Classifications.

Source of Published Ontologies	Description	References
DAML Ontology Library	Library of 282 ontologies (at the time of writing)	<a href="http://www.daml.org/ontologies/">http://www.daml.org/ontologies/</a>
DMOZ – Open Directory Project (Netscape Communications Corporation)	Hierarchical ontology scheme for the organisation of Web site listings	<a href="http://dmoz.org/">http://dmoz.org/</a>
Enterprise Ontology (sponsored by the UK Department of Trade and Industry (DTI))	‘... a collection of terms and definitions relevant to business enterprises’	<a href="http://www.aiai.ed.ac.uk/project/enterprise/enterprise/ontology.html">http://www.aiai.ed.ac.uk/project/enterprise/enterprise/ontology.html</a>
Ontolingua	‘The Ontology Server is a tool that supports distributed, collaborative editing, browsing and creation of Ontolingua ontologies’	<a href="http://www.ksl.stanford.edu/software/ontolingua/">http://www.ksl.stanford.edu/software/ontolingua/</a> and <a href="http://www-ksl-svc.stanford.edu:5915/">http://www-ksl-svc.stanford.edu:5915/</a>
Protégé Ontology Libraries	Library of ontologies	<a href="http://protege.cim3.net/cgi-bin/wiki.pl?ProtegeOntologiesLibrary">http://protege.cim3.net/cgi-bin/wiki.pl?ProtegeOntologiesLibrary</a>
Process Specification Language (PSL) – National Institute of Standards and Technology	‘... defines a neutral representation for manufacturing processes that supports automated reasoning.’	<a href="http://www.mel.nist.gov/psl/">http://www.mel.nist.gov/psl/</a>  (Schlenoff et al, 2000)
TOVE – Enterprise Ontology	‘... a set of integrated ontologies for the modelling of both commercial and public enterprises.’	<a href="http://www.eil.utoronto.ca/enterprise-modelling/tove/index.html">http://www.eil.utoronto.ca/enterprise-modelling/tove/index.html</a>
United Nations Standard Products and Services Code (UNSPSC) (version 91201)	‘... an open, global multi-sector standard for efficient, accurate classification of products’ and services	<a href="http://www.unspsc.org/Defaults.asp">http://www.unspsc.org/Defaults.asp</a>  <a href="http://www.unspsc.org/Default.aspx?sid=41812">http://www.unspsc.org/Default.aspx?sid=41812</a>

## Appendix L

### Criteria Used by Fernández-López (1999) to Analyse Methodologies (adapted)

Criterion	Description
Inheritance from knowledge engineering	Consideration of the influence of traditional Knowledge Engineering on the methodology in question.
Detail of the methodology	Consideration of whether the activities and techniques proposed by the methodology are exactly specified
Recommendations for knowledge formalisation	Consideration of the formalism or formalism proposed for representing knowledge
Strategy for building ontologies	Discussion of which of the following strategies are used to develop ontologies (a) Application-dependent: (b) Application-semi-dependent (c) Application-independent
Strategy for identifying concepts	Bottom-up, middle-out and top-down approaches
Recommended life-cycle	Analysis of whether the methodology implicitly or explicitly proposes a life cycle
Differences between the methodology and IEEE 1074-1995 (IEEE, 1996a)	Discussion of which of the processes and activities proposed by the IEEE standard 1074-1995 are not mentioned in the methodology.
Recommended techniques	Specification of whether particular techniques are proposed for performing the different activities of which the methodology is composed.
What ontologies have been developed using the methodology and what systems have been built using these ontologies	The ontologies and systems developed will be listed and briefly described.

## Appendix M

### Description of Concepts Represented by Classes and their Genericity

Super Classes	Sub-classes	Description of concept	Are classes/instances generic?
'Knowledge Item'		An item of knowledge: an abstract concept referring to any piece of knowledge, explicit or otherwise	Instances, no
'NPD Process Level'	NPD	Level in NPD process hierarchy from NPD process, down to NPD process sub-process and then the tasks in each sub-process	Subclasses, no Instances, no Specific to case study company
'Metaknowledge'	'Knowledge Repository'	Repository in which the knowledge item is stored e.g. computer information system or person	Classes, probably Instances, Some
	'Knowledge Source'	Internal and external sources	Instances should be valid, but may lack completeness
	'Knowledge Domain'	Functional domain that the knowledge concerns e.g. Quality, Product Strategy, Regulatory knowledge	Instances, yes
	'Knowledge Item Format'	Format of the knowledge item e.g. report, data sheet, expert decision in review, patent	Instances, yes
	'Language'	Languages in which a knowledge item is available	Instances should be valid but may lack completeness, depending on languages used in company
	'Knowledge Item Medium'	The medium in which the knowledge item is available. Encompasses digital (e.g. Excel files, E-mail archives) and non-digital (e.g. documents, verbal advice) subclasses	Instances may be valid, but not necessarily complete in other organisations
'Function'	-	Company function to which actor belongs e.g.	Instances, may be common to other organisations engaging in NPD
'Actor'	-	Individual person acting as a knowledge broker	Instances, no
'Project Contribution'	-	Contributions made to a given knowledge item by an individual in a previous project that is considered worthy of note. Typically, not all aspects of this contribution are available in an explicit form.	Instances, no
'Project'	-	NPD Project	Instances, no
'Role'	-	Job role of actor	Instances, no
'Location'	-	Geographical location of an actor	Instances, no

## Appendix N

Tables showing:

- A. The classes, slots and corresponding competency questions for the ontology.
- B. The types and values for the slots in the ontology.

### A. Ontology Classes, Slots and Corresponding Competency Questions.

Class	Slot	Competency Question	Description of slot
<b>Actor</b>	actor_name		Name of actor (an individual person'
	contributes_knowledge_to_task		
	expert_for_method		
	expert_for_task		
	has_location		
	owner_for_knowledge_item		
<b>Project</b>	project_has_contribution		
	project_title		
<b>Project Contribution</b>	contributes_to_project		
	has_knowledge_contributor		
	provided_expert_contribution_to_knowledge_item		
	has_role		
<b>Role</b>	role_title		
<b>Knowledge Item</b>	available_in_language	In what languages is the knowledge item available?	
	generated_by_task	What task generated the knowledge item?	
	has_expert_contribution	Who has contributed to this knowledge item in previous projects?	
	has_knowledge_domain	To what functional domain does the knowledge item belong?	
	has_medium	In what medium is the knowledge item available?	
	has_owner	Who owns the	

		knowledge item? (where applicable)	
	has_prioritisation_criterion		
	is_stored_in_repository	Where is the knowledge item stored?	
	knowledge_item_description	What is the knowledge item?	
	knowledge_item_format	In what format is the knowledge item?	
	knowledge_item_location	Where is the knowledge item (geographical location)?	
	knowledge_item_title		
	provides_knowledge_for_task	What tasks require this knowledge as an input?	
<b>Priority</b>	is_assigned_priority_for_criterion		
	priority_title		
<b>Prioritisation Criterion</b>	criterion_title		
	has_priority	What priority is a given knowledge item? What priority is a given knowledge domain (criterion)?	
	prioritisation_criterion_for_knowledge_item	What is the prioritisation criterion for a knowledge item?	
<b>Metaknowledge</b>			
Knowledge Repository	knowledge_repository_title	Where is the knowledge item stored (repository)?	
	stores_knowledge_item		Inverse of 'knowledge repository' slot
Knowledge Source	knowledge_source_title	String	
Knowledge Domain	knowledge_category_title	What domain does the knowledge item belong to?	

	knowledge_domain_for_knowledge_item		
Knowledge Item Format	format_description	In what format is the knowledge item available?	
	is_format_for_knowledge_item		Inverse of 'format description' slot
Language	language_name	In what languages is the knowledge item available?	
Knowledge Item Medium	medium_title	In what medium is the knowledge item available?	
Location	location_description	Where is the knowledge item (geographical location)?	

## B. Slot Types and Values

Class	Slot	Slot Type /Value
<b>Actor</b>	actor_name	String
	contributes_knowledge_to_task	Instance of 'NPD Process Task' class
	expert_for_task	Instance of 'NPD Process Task' class
	has_location	Instance of 'Location' class
	owner_for_knowledge_item	Instance of 'Knowledge Item' class
	owner_for_subprocess	Instance of 'NPD Process Subprocess' class
<b>Project</b>	project_has_contribution	Instance of 'Project Contribution' class
	project_title	String
<b>Project Contribution</b>	contributes_to_project	Instance of 'Project' class
	has_knowledge_contributor	Instance of 'Actor' class or instance of 'Role' class
	provided_expert_contribution_to_knowledge_item	Instance of 'Knowledge Item' class
	has_role	Instance of 'Role' class
<b>Role</b>	role_title	String
<b>Knowledge Item</b>	available_in_language	Instance of 'Language' class
	generated_by_task	Instance of 'NPD Process Task'
	has_expert_contribution	Instance of 'Project Contribution' class
	has_knowledge_domain	Instance of 'Knowledge Domain' class
	has_medium	Instance of 'Knowledge Item Medium' class

	has_owner	Instance of 'Role' class
	has_prioritisation_criterion	Instance of 'Prioritisation Criterion' class
	is_stored_in_repository	Instance of 'Knowledge Repository' class
	knowledge_item_description	String
	knowledge_item_format	Instance of 'Knowledge Item Format' class
	knowledge_item_location	Instance of 'Location' class
	knowledge_item_title	String
	provides_knowledge_for_task	Instance of 'NPD Process Task' class
<b>Priority</b>	is_assigned_priority_for_criterion	Instance of 'Prioritisation Criterion' class
	priority_title	String
<b>Prioritisation Criterion</b>	criterion_title	String
	has_priority	Instance of 'Priority' class
	prioritisation_criterion_for_knowledge_item	String
<b>Metaknowledge Classes</b>		
Knowledge Repository	knowledge_repository_title	String
	stores_knowledge_item	Instance of 'Knowledge Item' class
Knowledge Source	knowledge_source_title	String
Knowledge Domain	knowledge_category_title	String
	knowledge_domain_for_knowledge_item	Instance of 'Knowledge Item' class
Knowledge Item Format	format_description	String
	is_format_for_knowledge_item	Instance of 'Knowledge Item' class
Language	language_name	String
Knowledge Item Medium	medium_title	String
Location	location_description	Instance of 'Location' class

## Appendix O

### Values of Metaknowledge Slots for Knowledge Items Associated with Three Sub-Processes

#### Process title: Product Validation

Task title: Establish test planning

#### *Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Experience of test planning from Project Leader
Description	An experienced project leader must draw on their own knowledge of test planning and assemble a team of experts to provide advise on the issue.
Provides Knowledge for Task(s)	Establish test planning Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Expert advice
Knowledge Medium	Meeting
Language	English (Project leaders speak English)
Repository	Personnel
Owner	Project Leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	Experience of test planning from Test Engineer
Description	An experienced test engineer may provide advice on available tests, and previous tests carried out for a given product type.
Provides Knowledge for Task (s)	Establish test planning Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Expert advice
Knowledge Medium	Meeting
Language	



Repository	Personnel
Owner	Test/Validation Engineer

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 3</b>
Title	Experience of test planning from Certification Expert
Description	A certification expert may provide advice on legislation in product markets that would necessitate the carrying out of a particular test.
Provides Knowledge for Task(s)	Establish test planning Complete the test planning and plan the schedule.
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Expert advice
Knowledge Medium	Meeting
Language	
Repository	Personnel
Owner	Certification Expert

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 4</b>
Title	Experience of test planning from Design Engineer
Description	A Design Engineer must provide input on the tests to be carried out and the development of the test schedule.
Provides Knowledge for Task(s)	Establish test planning Complete the test planning and plan the schedule.
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Expert advice
Knowledge Medium	Meeting
Language	
Repository	Personnel
Owner	Design Engineer

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 5</b>
Title	Tests in test database
Description	Database of existing product tests
Provides Knowledge for Task(s)	Establish test planning
Generated by Task	

Knowledge Domain	Quality Knowledge
Knowledge Format	Database
Knowledge Medium	Intranet Database
Language	German
Repository	Test Database
Owner	Test/Validation Engineer

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value</b>
Title	Project validation plan
Description	Test (validation) plan on Microsoft Excel sheet with worksheet for each phase. Contains links to test descriptions on Intranet test database.
Provides Knowledge for Task(s)	Establish test planning
Generated by Task	
Knowledge Domain	Quality Knowledge
Knowledge Format	Project Plan
Knowledge Medium	Microsoft Excel file (.xls)
Language	English, German
Repository	IP Project Folder
Owner	Project Leader

Task title: Complete the test planning and plan the schedule

*Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Knowledge of Microsoft Project tool
Description	Knowledge of how to use the Microsoft Project tool
Provides Knowledge for Task(s)	Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Methods and Tools
Knowledge Format	Training
Knowledge Medium	
Language	
Repository	Personnel
Owner	Project leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	Knowledge of SAP tool
Description	Knowledge of how to use the SAP tool for project planning
Provides Knowledge for Task(s)	Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Methods and Tools
Knowledge Format	Training
Knowledge Medium	
Language	
Repository	Personnel
Owner	Project leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 3</b>
Title	Experience of test planning from Project Leader
Description	An experienced project leader must draw on their own knowledge of test planning and assemble a team of experts to provide advise on the issue.
Provides Knowledge for Task(s)	Establish test planning Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Expert advice
Knowledge Medium	Meeting
Language	English (Project leaders speak English)
Repository	Personnel
Owner	Project Leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 4</b>
Title	Experience of test planning from Test Engineer
Description	An experienced test engineer may provide advice on available tests, and previous tests carried out for a given product type.
Provides Knowledge for Task(s)	Establish test planning Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)

Knowledge Format	Expert advice
Knowledge Medium	Meeting
Language	
Repository	Personnel
Owner	Test/Validation Engineer

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Project Test Plan
Description	Product test plan for project
Provides Knowledge for Task(s)	Complete the test planning and plan the schedule
Generated by Task	
Knowledge Domain	Quality Knowledge
Knowledge Format	Project Plan
Knowledge Medium	Microsoft Project (.mpp)
Language	English
Repository	IP Project Folder
Owner	Project Leader

Task title: Establish Missing Test Descriptions

*Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Expert knowledge of testing
Description	Expert knowledge of testing to develop required test descriptions
Provides Knowledge for Task(s)	Establish missing test descriptions
Generated by Task	
Knowledge Domain	Quality Knowledge
Knowledge Format	Expert Judgement
Knowledge Medium	
Language	
Repository	Personnel
Owner	Test/Validation Engineer

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Test description in Test Excel Sheet
Description	Test description in Test Excel Sheet
Provides Knowledge for Task(s)	Start tests according to test description
Generated by Task	Establish missing test descriptions
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development) Quality Knowledge
Knowledge Format	Report
Knowledge Medium	Microsoft Excel File (.xls)
Language	German
Repository	IP Project Folder
Owner	Project Leader

**Process title: Project Performance**

Task title: Define correctly actions

*Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Knowledge about testing expertise in company
Description	Knowledge about organisation to create team to develop corrective actions
Provides Knowledge for Task(s)	Define correctly actions
Generated by Task	
Knowledge Domain	Previous Project Decisions (Audit Experience)
Knowledge Format	Expert Judgement
Knowledge Medium	
Language	
Repository	Personnel
Owner	Project Leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	Identified deviations
Description	Deviations from project plan, business plan and forecast etc.
Provides Knowledge for Task(s)	Define correctly actions
Generated by Task	Identify deviation
Knowledge Domain	
Knowledge Format	
Knowledge Medium	
Language	
Repository	Personnel
Owner	Project Leader

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item</b>
Title	Corrective actions
Description	Actions to address deviations
Provides Knowledge for Task(s)	Carry out milestone assessment
Generated by Task	Define correctly actions
Knowledge Domain	
Knowledge Format	Design Rule
Knowledge Medium	
Language	English
Repository	IP Project Folder
Owner	Project Leader

Task title: Carry out milestone assessment

*Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item</b>
Title	Corrective actions
Description	Actions to address deviations
Provides Knowledge for Task(s)	Carry out milestone assessment
Generated by Task	Define correctly actions
Knowledge Domain	
Knowledge Format	Design Rule
Knowledge Medium	
Language	English
Repository	IP Project Folder
Owner	Project Leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	Expert knowledge of auditor (experience)
Description	Tips and suggestions from auditor as to how project documentation can be better presented to meet targets in audit checklist
Provides Knowledge for Task(s)	Carry out milestone assessment

Generated by Task	
Knowledge Domain	Quality
Knowledge Format	Expert Advice
Knowledge Medium	Meeting
Language	English, German or French
Repository	Personnel
Owner	Auditor

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Audit checklist TRS
Description	Completed audit checklist from milestone assessment meeting
Provides Knowledge for Task(s)	Organise the kick off in sub-process 'Kick-off Project' Collect all relevant data in sub-process 'Project Performance - Functional Requirements'
Generated by Task	Carry out milestone assessment
Knowledge Domain	Quality Knowledge
Knowledge Format	Checklist
Knowledge Medium	Microsoft Excel file (.xls)
Language	English
Repository	IP Project Folder
Owner	Project Leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	'Hows' and 'Whys' of decisions created in review meeting
Description	Rationale behind decisions taken in technical requirements specification review meeting
Provides Knowledge for Task(s)	
Generated by Task	Carry Out Milestone Assessment
Knowledge Domain	Previous Project Decisions (Audit Experience)
Knowledge Format	Expert Advice
Knowledge Medium	Meeting
Language	English
Repository	Personnel
Owner	Project Team



**Process title: Generate Product Proposal**

Task title: Create technical response document

*Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Dimensional Drawing
Description	Rough conceptual 3D drawing of product
Provides Knowledge for Task(s)	Create technical specification response document
Generated by Task	Present at Design Conference in sub-process 'Product Design Conception'
Knowledge Domain	Technical Design Information and Knowledge (Conception and Development)
Knowledge Format	Drawing
Knowledge Medium	Pro Engineer
Language	English
Repository	IP Project Folder
Owner	Design Engineer

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	Marketing Requirements (TOPH)
Description	Represents product requirements from Marketing
Provides Knowledge for Task(s)	Create technical response document
Generated by Task	Marketing Requirements in sub-process 'Product Strategy'
Knowledge Domain	Quality, Cost, Function
Knowledge Format	Report
Knowledge Medium	Microsoft Excel file (.xls)
Language	English
Repository	IP Project Folder
Owner	Programme Manager, Sales Manager, Marketing Manager

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Technical response to the marketing specification (TOPH)
Description	Marketing specification and technical response from R&D signed by Project Leader
Provides Knowledge for Task(s)	Define 3D CAD model of product main components and primary accessories in sub-process 'Physical non-Functional Mock-Up' Preparation of FMEA-Session in sub-process 'System FMEA'
Generated by Task	Create technical response document
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Report
Knowledge Medium	Microsoft Excel file (.xls)
Language	English
Repository	IP Project Folder
Owner	Project Leader

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	Conceptual Pro Engineer Studies
Description	Rough 3D CAD models of product concept proposed by Marketing to assess feasibility and experiment with configuration of components
Provides Knowledge for Task(s)	Define 3D CAD model of product main components and primary accessories in sub-process 'Physical non-Functional Mock-Up' Preparation of FMEA-Session in sub-process 'System FMEA'
Generated by Task	Create technical response document
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Drawing
Knowledge Medium	Pro Engineer
Language	
Repository	Project Folder
Owner	Design Engineer, Project Leader

Task title: Detail CAD model assigned to product architecture

*Input Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 1</b>
Title	Defined CAD Models of Modules
Description	Defined CAD Models of Modules
Provides Knowledge for Task(s)	Detail CAD model assigned to product architecture
Generated by Task	
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Drawing
Knowledge Medium	Pro Engineer
Language	English
Repository	IP Project Folder
Owner	Design Engineer

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 2</b>
Title	R-Prognosis Product Strategy
Description	Quality forecast for product concept
Provides Knowledge for Task(s)	Detail CAD model assigned to product architecture
Generated by Task	Create Failure Prognosis in sub-process 'Analysis of Product Quality and Customer Complaints'
Knowledge Domain	Quality Knowledge
Knowledge Format	Report
Knowledge Medium	Microsoft Excel file (.xls)
Language	English
Repository	IP Project Folder
Owner	Programme Manager

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item 3</b>
Title	CAD Mock-up
Description	Rough CAD Model of concept from Hydraulics engineering function
Provides Knowledge for Task(s)	Detail CAD model assigned to product architecture
Generated by Task	Define 3-D CAD Model of product, main components and primary accessories in sub-process

	'Physical non-functional Mock-up'
Knowledge Domain	Technical Design Information and Knowledge (Concept and Development)
Knowledge Format	Drawing
Knowledge Medium	Pro Engineer
Language	
Repository	Project Folder
Owner	Design Engineer

*Output Knowledge Items*

<b>Metaknowledge Element / Slot</b>	<b>Value: Knowledge Item</b>
Title	Digital mock-up including primary accessories
Description	Digital representation of product concept
Provides Knowledge for Task(s)	Define 3-D CAD Model of product, main components and primary accessories in sub-process 'Physical non-functional Mock-up'
Generated by Task	Detail CAD model assigned to product architecture
Knowledge Domain	Technical Design Information and Knowledge (Conception and Development)
Knowledge Format	CAD Model
Knowledge Medium	Mentor Graphics HPGL
Language	
Repository	Project Folder
Owner	Design Engineer

## Appendix P

### English and German Language Labels for Ontology Classes and Slots

Class	Sub-Class	Slot	English Label	German Label
<b>Actor</b>			Actor	Aktor
		actor_name	Actor Name	Title/Name der Person/Funktion
		contributes_knowledge_to_task	Contributes knowledge to task	trägt Wissen zur Aufgabe bei
		expert_for_method	Expert for method	Experte für Methode
		expert_for_task	Expert for task	Experte für Aufgabe
		has_location	Has location	Hat Ort
		owner_for_knowledge_item	Owner for knowledge item	Eigner des Wissenselements
		owner_for_subprocess	Owner for subprocess	Verantwortlicher für Detailprozeß
<b>Project</b>			Project	Projekt
		project_has_contribution		
		project_title	Project title	Projektsbezeichnung
<b>Project Contribution</b>			Project Contribution	Projektbeiträge
		contributes_to_project	Contributes to project	trägt Wissen zum Projekt bei
		has_knowledge_contributor	Has knowledge contributor	Folgende Personen/Funktionen tragen zum Wissen bei
		provided_expert_contribution_to_knowledge_item	Provided expert contribution to knowledge item	geleistete Expertenbeiträge zum Thema
		has_role	Role in Project	Rolle im Projekt
<b>Role</b>			Role	Projektrolle
		role_title	Role title	Rollebezeichnung
		is_owner_for_knowledge_item	Is owner for knowledge item	Eigner für den folgenden Wissenselemente
<b>Knowledge Item</b>			Knowledge Item	Wissenselement
		Available_in_language	Available in language	Verfügbar in folgenden Sprachen
		Generated_by_task	Generated by task	Erzeugt von Aufgabe
		has_expert_contribution	Has expert contribution	Hat Expertenbeitrag
		has_knowledge_domain	Has knowledge domain	Hat Wissenskategorie
		has_medium	Has medium	Ist verfügbar in folgendem Medium
		has_owner	Has owner	Hat Wissenselementeigner
		has_prioritisation_criterion	Has prioritisation criterion	Hat Prioritätskriteria
		is_stored_in_repository	Is stored in repository	Hinterlegt im Wissensspeicher

		knowledge_item_description	Knowledge item description	Beschreibung des Wissenslements
		knowledge_item_format	Knowledge item format	Format des Elements
		knowledge_item_location	Knowledge item location	Ort des Wissenslements
		knowledge_item_title	Knowledge item title	Titel des Wissenslements
		Provides_knowledge_for_task	Provides knowledge for task	Liefert Wissen für folgende Aufgabe
		has_revised_version	Has revised version	Hat überarbeitete Version
		is_revised_version_of	Is revised version of	Hat vorhergehende Version
<b>Priority</b>			Priority	Prioritätsgrad
		is_assigned_priority_for_criterion	Is assigned priority for criterion	Zugewiesener Prioritätsgrad
		priority_title	Priority	Prioritätsgrad
<b>Prioritisation Criterion</b>			Prioritisation Criterion	Prioritätskriterium
		criterion_title	Criterion title	Kriterium
		has_priority	Has priority	Hat Prioritätsgrad
		prioritisation_criterion_for_knowledge_item	Prioritisation criterion for knowledge item	Prioritätskriterium für Wissenslement
<b>Metaknowledge Classes</b>				
Knowledge Repository			Knowledge Repository	Wissenslager
		knowledge_repository_title	Knowledge repository title	Wissenslagerbezeichnung
		stores_knowledge_item	Stores knowledge item	Lagert Wissenslement
Knowledge Domain			Knowledge Domain	Wissensbereich
		knowledge_category_title	Knowledge category title	Name des Wissensbereiches
		knowledge_domain_for_knowledge_item	Knowledge domain for knowledge item	Wissensbereich für Wissenslement
Knowledge Item Format			Knowledge Item Format	Form des Wissenslements
		format_description	Format description	Beschreibung des Formats
		is_format_for_knowledge_item	Is format for knowledge item	Form des Wissenslements
Language			Language	Sprache
		language_name	language_name (en)	Sprache (d)
		language_for_knowledge_item	Language for knowledge item	Sprache für folgenden Wissenslemente
Knowledge Item Medium			Knowledge Item Medium	Datentyp/Form des Wissenslements
	Digital Medium		Digital Medium	Digitale Form
	Non-Digital medium		Non-digital Medium	Andere Datenform

		medium_title	Medium title	Mittelsbezeichnung
		is_medium_for_knowledge_item	Is medium for knowledge item	Ist Medium für folgenden Wissens-elemente
Location			Location	Ort
		location_description	Location description	Beschreibung des Ortes

## **Appendix Q**

Note: Responses for all respondents are included in the protocol and are quoted verbatim. The text in brackets has been added by the researcher to help clarify the meaning of the response provided. Interviewees are labelled R1, R2 and R3.

### **Validation of Knowledge Sharing Tool - Interview Protocol**

#### **Overall Usefulness of Tool**

1. (a) Do you feel that the tool would help to improve knowledge sharing among members of a product development project team?

R1. Yes, but limited.

R2. Yes.

R3. Yes.

Please explain the reasons behind your answer

R1. As I told you during our meeting in Belper all those kind of tools are only helpful if people are disciplined to type in the key words. As more complicated it is, as less it will be used to store documents. For sure people will try to get informations out of the system, but it should be more easy [sic] to take them in.

R2. One repository for information.



R3. Project members can access knowledge easily.

(b) Do you feel that the tool would help provide a improved understanding among project team members of knowledge used in the new product development process (Vaillant Innovation Process)?

R1. No.

R2. Yes.

R3. Yes

Please explain the reasons behind your answer

R1. The understanding is already present in our project teams and we always search for helpful possibilities to share knowledge in a better way than we are currently doing. But like explained before it needs a much more simple and easy to use way. People must have fun by doing it and they need a short term success by using it. Otherwise they will refuse any tool even it is ordered by management for use.

R2. Capture of known problems and solutions.

R3. Team members can check what is needed for the next milestone assessment, and in which detail.

(c) Do you feel that it would provide a better understanding of the knowledge used in the NPD process than the current Vaillant IP business process (as featured on the Vaillant Intranet)?

R1. No.

R2. Yes.

R3. Yes.

Please explain the reasons behind your answer

R1. Like explained before. In Vaillant Group knowledge is stored in documents in a file share of the Windows explorer. Every MS Office document meanwhile has an identity card inside which is in content similar to the Meta informations asked by your tool. With a search machine it is currently possible to find the missing informations. But again: discipline is key. And people don't like to be disciplined whilst storing a document if it is in combination with additional work. I haven't seen a tool so far that is able to store informations [sic] without any additional effort by the author.

R2. Route of inputs/outputs for processes.

R3. Current Intranet version of the [company NPD business process] is not clearly arranged/too detailed without a clear directive what to do.

## **Usefulness of Tool Components**

### *Classification*

2(a) Do you feel that the knowledge classification would help you find knowledge relevant to tasks in the Vaillant Innovation process? Please explain the reasons behind your answer.

R1. Yes. Of course any classification helps to better find knowledge. We do the classification by using a given structure of the file share which is already in line with the task structure. This is at least a high level classification without additional effort for the people.

R2. Yes. Gives structure to find relevant/required information.

R3. Yes, because it is clearly structured by logical classes.

(b) In your opinion, how useful is the connection of knowledge items to processes and tasks in the Vaillant Innovation Process? Please explain the reasons behind your answer.

R1. You know that we are working in processes especially with our Innovation Process. It would be culpable if we would not align knowledge items with processes or tasks.

R2. Very useful. Again, gives structure to find relevant/required information and structure to input information.

R3. Yes, because a more simple kind of workflow is created. You know where you come from and where to go next...

*Information about knowledge*

3. Referring to the information provided about knowledge in the tool:

(a) Do you feel any information is missing?

R1. Don't remember, but as far as I understood it is possible to add additional informations [sic] if necessary and if missing.

But once again: From my point of view there is only one tool which has a chance of success. This tool has to provide the possibility to store a document at least as easy as it is with a normal Windows Explorer file share. It should not ask for additional informations [sic] but ideally it finds the meta informations [sic] by itself by screening the document.

R2. No, but without use of tool (experience) impossible to be sure.

R3. Yes.

(b) If so, what information should be added and why?

R2. See (a).

R3. Links to documents.

(c) Do you feel any of the information is not required?

R2. See (a).

R3. No.

(d) If so what information should be removed and why?

R2. See (a).

*Prioritisation mechanism*

4. From a knowledge management perspective

(a) How useful do feel the prioritisation mechanism would be? Please explain the reasons behind your answer.

R1. We are organised 100% in project work. Prioritisation is given by the project necessities. It's difficult to understand for me that a tool can replace the prioritisation done by the project leader. If so, it would be of big help for the project leader.

R2. Useful to prioritise according to business requirements/objectives: quality, cost, time etc.

R3. Very useful, but should be handled more flexible [sic], because priority may change from project to project.

(b) Do you feel it make sense to prioritise knowledge according to business objectives?

R1. This is of course helpful.

R2. Yes.

R3. Yes.

(c) If not what would be a better criterion for prioritising knowledge used in a new product development project?

(d) How useful is an indication of the knowledge priority?

R2. Helps to identify knowledge according to business objectives.

R3. See 4(a).

*Multilingual support*

5. Do you feel that the language support features in would help to achieve a better common understanding of the knowledge used in the Vaillant Innovation Process?

R1. Yes.

R2. Yes.

R3. Of course!

Please explain the reasons behind your answers

R1. We still face problems created by misunderstandings due to different languages. Therefore language support features are really necessary. In addition to that during our last trial to implement a knowledge management tool... we were not allowed by workers council to go on air [sic] without multilingual user surfaces.

R2. For understanding of the use of the tool – but inputs should be in English or translated into English.

R3. Tool would not find acceptance without the languages of all sites included.

### **Usability**

6. What are your initial impressions on how easy you think the tool is to use?

As someone using the tools to find out about knowledge in the Vaillant Innovation Process?

R1. If all informations [sic] are put in by the authors, it seems very easy to use.

R2. Seems ok, but as with any new software, only time and use will tell.

R3. You have to use it for a couple of time [sic] to feel comfortable with it, but it is easy to understand.

As someone adding information about knowledge to the tool?

R1. To put in informations [sic] seems to be quite easy.

R2. See (a).

R3. Adding knowledge seems to be more complex, as the tool is unknown – after a short training it should be easy to use.



## **Investment of Time**

7. Building the tool involves the addition of data by each process owners and project team members involved at each stage which would take effort and time

Based on your limited access to the tool, would any potential benefits from the tool be worth the investment of time?

R1. No.

R2. Yes.

R3. Yes.

Please explain the reasons behind your answer.

R1. As explained many times before. It's again another tool that needs additional effort and a lot of discipline. People will surely try to bypass it first.

Question is, how could the effort be reduced to additional informations [sic] that are not already available somewhere else so that there is no redundant input necessary.

R2. Other projects can access data to help if they have problems.

R3. See answer to question 1.

## **Areas for Improvement**

8(a) What do you think are the main weaknesses of the tool?

R1. See answers above.

R2. 'Boolean' search engine could be improved to help find information.

R3. Search engine (enable more detailed search).

(b) Do you have any suggestions for improving the tool?

(Conceptually or the tool interface)

R1. See answers above.

R2. Provision of context help/tutorial.

R3. Easy import of knowledge (e.g. documents from project drives).

## **Other Comments**

If you have any other comments about the tool, please add them below.