Knowledge management across boundaries:
a case study of an interdisciplinary research project in Thailand

By:

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

The University of Sheffield
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Submitted October 2017

Acknowledgement

It would not have been possible to undertake this thesis without the kind help and support of many people around me. Foremost, I would like to express my sincere gratitude to my primary supervisor Dr. Ana Cristina Vasconcelos and my second supervisor Dr. Andrew Martin Cox, for the constant support of my study, for their knowledge, comments, suggestions, advice, encouragement, and patience. Your support helped me throughout my research and the writing of this thesis. Thank you for forcing and challenging me to look at my work in different ways and to improve my research skills. I have learnt a lot through this thesis, with many challenging yet valuable experiences to complete this task. I would also like to thank David Clough for helping me shape up my writing skills.

Without the financial support of the National Science and Technology Development Agency (NSTDA), and the Ministry of Science and Technology in Thailand which offered me a scholarship, this work would not have been possible. I would like to express my sincere gratitude to the NSTDA for awarding me a grant and for supporting me during the entire study period. I must also express my sincere gratitude to Praditta Siripan and Dr. Taweesak Koanantakool of the NSTDA for giving me that opportunity. Furthermore, I would like to thank all participants for their willing participation and dedication during the field work; their cooperation played a big part in this research.

I would like to express my appreciation towards my family: my parents, my brother, and my sisters, who have always been there for me no matter where I am, for moral support and continuous encouragement throughout the process of studying and my life in general. Your love, care, concern, understanding, support, and encouragement has helped me to complete this task. I can never thank you enough for what you have done for me. What I have done, I have done to make you proud and happy.

I am grateful to Karl Mark Culley, who is always by my side through good and bad times, being prepared to listen to my thoughts about life and this thesis, and providing me with encouragement throughout the research. Finally, I would like to thank my friends and my colleagues for making my stay and studies in Sheffield so enjoyable. It has been great to know you during my time here.

Abstract

Despite existing work, the nature and construction of knowledge boundaries remains little explored. Moreover, previous studies that have examined how knowledge is managed across boundaries, have usually been in the context of new product development in industry. Models developed in this context may be less applicable in the public sector because of its hierarchical structures and requirements for accountability. The aim of this research is therefore to explore the nature of boundaries and how knowledge is managed across them in a public sector context.

The research takes a case study approach focusing on an interdisciplinary research project that was set up to develop Computerised Tomography (CT) and Digital X-Ray (DR) scanners in a governmental research organisation in Thailand. This is an ongoing joint project between two different knowledge communities from different disciplines and national research centres. It proposed the first development of the cone-beam CT scanner in Thailand, called DentiiScan. The research adopts an interpretative methodology to explore multiple viewpoints and meanings that actors attach to phenomena. Data were collected through a multi-method qualitative approach based on: face-to-face interview; participant observation; and collection of documentation and other artefacts. Data were analysed through thematic analysis.

The findings from this case study suggest, in line with previous research, that there are three progressively complex boundaries: information-processing, interpretative, and political boundaries; and three progressively complex processes to overcome them: transfer, translation, and transformation. However, the findings suggest that knowledge management in such contexts is a more challenging and complicated undertaking than currently portrayed in previous work because: (i.) knowledge boundaries are dynamic and tend to change throughout the project life cycle, often co-existing and overlapping; (ii.) different actors look at the same phenomena but sometimes perceive them as different types of knowledge boundaries; and (iii.) boundaries do not only arise from differences in knowledge and disciplinary perception, but also from ignorance of these differences between interacting actors from different communities. Furthermore, in this case, the hierarchical organisational structures help to clarify differences and dependencies in knowledge and responsibility among members, and create clear lines of communication. This helps overcome boundaries though the chain of command makes decision-making slow. A framework for managing knowledge across boundaries that emerges from the analysis is proposed.

This research extends theory and a model for managing knowledge across boundaries, more specifically Carlile's three-tier model (2004, 2002), and demonstrates their applicability in a new setting. The findings bring into focus the complexity of knowledge management across boundaries by suggesting that sometimes they cannot be categorised easily. There is a need to acknowledge the dynamic nature, blurring, and simultaneity of boundaries; the potential for different actors to perceive the same phenomena as different types of knowledge boundaries; and ignorance of differences in knowledge and disciplinary perceptions between different interacting actors. The findings of this research can be used to identify the nature and construction of knowledge boundaries, the types of knowledge boundaries and processes to overcome them, including boundary-spanning mechanisms and competences that actors, whether they are individuals, groups or organisations, can develop to bridge them. In practical terms, the findings of this study suggest that: (i.) actors should pay attention to flexible and multi-dimensional perspectives for addressing the dynamic nature, blurring, fluidity, overlapping, and simultaneity of boundaries; (ii.) they should broaden their perspectives to understand differences in perceptions of where boundaries lie; (iii.) they should also expand their perceptions to understand the construction of knowledge boundaries from different dimensions such as lack of a full understanding and awareness about differences in knowledge between different knowledge communities; and (iv.) they should consider what are effective organisational structures, which combine both hierarchical and flexible elements, to support knowledge management and collaboration across boundaries.

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1. Introduction

1.1. Background to the research and the theoretical lens of research

Many studies in the knowledge management area have acknowledged the importance of collaboration between individuals or groups of individuals from different disciplinary knowledge communities (e.g. Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Mailhot, Gagnon, Langley and Binette, 2016; Smith, 2016; Wannenmacher and Antoine, 2016; Castro, 2015; Noorden, 2015; Siedlok and Hibbert, 2014; Hislop, 2013; Fellows and Liu, 2012; Jahn, Bergmann and Keil, 2012; Majchrzak, More and Faraj, 2012; Akkerman and Bakker, 2011; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Sumner and Tribe, 2007; Haythornthwaite, 2006; Cummings and Kiesler, 2005; Maglaughlin and Sonnenwald, 2005; Carlile, 2004; Bronstein, 2003; Tranfield, 2002; Wenger, 2000; Star and Griesemer, 1989). They have suggested that cross-community collaboration is a significant trigger of learning to keep individual dynamism and to reduce negative effects caused by the fragmentation of specialised knowledge (Hislop, 2013; Akkerman and Bakker, 2011; Wenger, 2000; Katz and Martin, 1997). Moreover, they have suggested that the creation of most new knowledge, creativity, and innovation requires the integration of knowledge, skills, and perspectives of individuals or groups from different disciplines (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Wannenmacher and Antoine, 2016; Scarbrough, Panourgias and Nandhakumar, 2015; Siedlok and Hibbert, 2014; Fellows and Liu, 2012; Jahn, Bergmann and Keil, 2012; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004; Tranfield, 2002; Katz and Martin, 1997; Star and Griesemer, 1989). Such benefits are regarded as essential for individuals, groups, or organisations to survive, compete, and grow in the complex, dynamic, and multifaceted environment of the knowledge economy and globalisation (Jahn, Bergmann and Keil, 2012; Russell, Wickson and Carew, 2008; Maglaughlin and Sonnenwald, 2005; Bronstein, 2003; Tranfield, 2002).

The number of initiatives promoting the development of knowledge through cross-disciplinary collaboration has increased since the early 1990s through a change of style of generating knowledge, which has been named Mode 2 knowledge production (Siedlok and Hibbert, 2014; Jahn, Bergmann and Keil, 2012). The concept of Mode 2 knowledge production was developed by Gibbons, Limoges, Nowotny, Schwartzman, Scott and Trow in *The New*

Production of Knowledge published in 1994 (original reference as cited in Tranfield, 2002). This has resulted in the emergence of a number of interdisciplinary research centres, programmes, courses, and activities (Noorden, 2015; Siedlok and Hibbert, 2014). Collaboration across communities is becoming more and more common (Hislop, 2013). However, most existing studies have suggested that building and maintaining organisational practices and competencies that draw on cross-community collaboration is difficult because of differences in knowledge and disciplinary perceptions (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Kotlarsky, Hooff and Houtman, 2015; Zhang and Pastel, 2015; Siedlok and Hibbert, 2014; Hislop, 2013; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Palmer, 1999; Becher, 1994; Brown and Duguid, 1991). In other words, boundaries can create new opportunities but also potential difficulties (Wenger, 2000, p.233).

According to Akkerman and Bakker (2011, p.133), a boundary, in this context, refers to a sociocultural difference which leads to discontinuity of action or interaction between two or more individuals or groups of individuals which are relevant to another individual or group in a particular way. Boundaries are not static and are not something that people can see or grasp easily like other boundaries which are usually well defined by physical structures (Hawkins and Rezazade, 2012; Adam as cited in Hoffmann, 2012; Carlile, 2004; Wenger, 2000). Members of different knowledge disciplines have fundamental differences in many aspects such as values, assumptions, conceptual and methodological standards, ways of thinking and use of language including interpretations of and interest in the same things and phenomena (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Wannenmacher and Antoine, 2016; Siedlok and Hibbert, 2014; Hislop, 2013; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Becher, 1994). They also tend to use their knowledge and practices in particular fields and in particular contexts of action as well as to give meaning in their practices to the same things and phenomena across different communities (Dougherty, 1992). These differences lead to limitations of common knowledge and understandings, and thus can be a source of difficulty, conflict, and discontinuity in interaction between different knowledge communities (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Bozeman, Gaughan, Youtie, Slade and Rimes, 2016; Mailhot, Gagnon, Langley and Binette, 2016; Smith, 2016; Kotlarsky, Hooff and Houtman, 2015; Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Carlile, 2004, 2002; Wenger 2000). According to

Carlile (2004, 2002), the varying degrees of difference, dependency, and novelty in knowledge between members from different knowledge communities create three different types of knowledge boundaries, as will be detailed below.

According to Noorden (2015), with the increasing importance of interdisciplinary collaborations in the science and innovation policy areas, new policies and funding structures have been developed to support interdisciplinary collaboration both inside and outside academia. The proportion of interdisciplinary work has reached an all-time high in the twenty-first century (Larivière and Gingras, as cited in Noorden, 2015). However, Noorden, (2015) argues that the dynamics of interdisciplinary collaborations remain rather poorly understood, making it difficult to manage in practice. Similarly, as will be more fully discussed in the literature review in Chapter 2 that follows, although a number of studies have examined cross-community collaboration and knowledge management, more specifically how knowledge is managed across boundaries, they have mainly focused on particular contexts; especially new product development and information technology in private sector organisations (e.g. Scarbrough, Panourgias and Nandhakumar, 2015; Zhang and Pastel, 2015; Hsu, Chu, Lin and Lo, 2014; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Kim and Jarvenpaa, 2008; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004; Bechky, 2003). To date this subject has not yet been studied in interdisciplinary research projects in public sector organisations, especially in governmental research organisations.

Carlile (2004, 2002), one of the key contributors to understanding the management of knowledge in cross-community collaborations, develops a three-tier model for managing knowledge in such contexts. According to Carlile's model, the variations in degrees of difference, dependency, and novelty in knowledge between members from different knowledge communities create three progressively complex knowledge boundaries. Difference means the difference in type and amount of knowledge. It demands effort to share and assess each other's knowledge. Dependence refers to a condition where two or more individuals or groups from different backgrounds must take each other into account if they want to meet their common goals together. As the novelty of knowledge increases, the difference and dependency will also increase. The three knowledge boundaries, which can emerge in cross-community collaboration, are namely syntactic, semantic, and pragmatic boundaries. These three boundaries link to three progressively complex knowledge processes to overcome them: transfer, translation, and transformation. Different knowledge boundaries require different boundary-spanning mechanisms and approaches to help facilitate and manage knowledge across them.

According to Carlile's three-tier model, a syntactic boundary is the first and basic level. It is assumed to be the easiest to work across as the knowledge is low in difference, dependency, and novelty between individuals or groups from different backgrounds. A common language, which is developed, is sufficient to transfer knowledge at a boundary. Thus, this boundary is primarily concerned with information processing and knowledge transfer processes through information processing capacity, taxonomies, and storage and retrieval technologies. The challenge of this boundary is to increase capacity and to develop tools to process more information. A syntactic boundary moves to a semantic boundary, the second and middle level, when novelty occurs; members from different communities interpret the same things and phenomena differently, based on their values, theories, concepts, and previous related knowledge. It makes cross-community collaboration and knowledge management difficult. Thus, a semantic boundary is mainly concerned with knowledge translation processes. That is, to resolve a semantic boundary, it requires knowledge translation capability, cross-functional interactions, co-location of working, boundary brokers, and translators to reconcile discrepancies in meaning and to develop shared understandings of knowledge between different communities. Another solution is boundary objects which provide concrete means for individuals to represent and learn differences and dependencies across a boundary such as standardised forms and methods. However, when different interests between different communities are identified, the development of common languages and meanings is not possible and not enough. Consequently, a sematic boundary moves to a pragmatic boundary. A pragmatic boundary is the last and most complex level. It often occurs when interests of different communities are different and in conflict. That is, when the knowledge developed in one community has costs and creates consequences in another different community. To overcome a pragmatic boundary, individuals in one or more communities have to change their current knowledge, create new knowledge, and be capable of transforming knowledge used by another different community to resolve the consequences that arise at a boundary in order to work together. To do this, the negotiation of different interests and the political push for knowledge transformation processes is required.

Other scholars have also identified three levels of knowledge boundary, though they have used different labels to describe them. The three boundaries are labelled: syntactic, semantic, and pragmatic boundaries by a number of other authors (e.g. Lindberg, Walter and Raviola, 2017; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Farag, Jarvenpaa, and Majchrzak, 2011; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004, 2002). They are named as: display, representation, and assembly practices by Kellogg, Orlikowski and Yates (2006); and information process-oriented, cultural, and political boundaries by Rosenlund, Rosell and Hogland (2017). Edenius, Keller and Lindblad (2010, p.136), and Kellogg, Orlikowski and Yates (2006, p.23) argued that the organisational literature on knowledge management and coordination across boundaries can be understood in terms of three primary perspectives: (i.) the information-processing aspects, the information-processing perspective, or the information-processing orientation; (ii.) the cultural aspects; and (iii.) the political aspects or the political and power perspectives.

Carlile's three-tier model has been used in different contexts such as new product development in the environmental science and technology research collaborations between triple helix sectors (Rosenlund, Rosell and Hogland, 2017); new product development in energy and domestic appliance companies (Le Dain and Merminod, 2014); a dynamic virtual space or online communities (Farag, Jarvenpaa and Majchrzak, 2011); an emergency response organisation (Yates and Paquette, 2011); a technology company (Maaninen-Olsson, Wismen and Carlsson, 2008); and healthcare research institutes and healthcare services (Kotlarsky, Hooff and Houtman, 2015; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008). However, they have mainly focused on particular contexts, especially new product development and information technology in the private sector.

Many studies have suggested that knowledge management in public sector organisations can offer specific challenges. One of the biggest challenges facing knowledge management in the public sector is how to respond to the various requirements of stakeholders from multiple parties such as governments, citizens, funding agencies, and subsidiaries in the decision-making processes and activities (Amayah, 2013; Jahn, Bergmann and Keil, 2012; Adel and Shaghayegh, 2010; Seba and Rowley, 2010; Willem and Buelens, 2007; Yao, Kam and Chan, 2007; Cong and Pandya, 2003). By contrast, private organisations are mainly responsible to their shareholders by providing returns on their investments to them (Adel and Shaghayegh, 2010; Cong and Pandya, 2003). Another challenge facing knowledge management in the public sector is its specific organisational structure and the bureaucratic cultures found within hierarchical organisational structures (Chong, Salleh, Ahmad and Sharifuddin, 2011; Seba and Rowley, 2010; Akhavan, Hosnavi and Sanjaghi, 2009; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Yao, Kam and Chan, 2007; O'Riordan, 2005; Syed-Ikhsan and Rowland, 2004). This organisational structure is often open to the criticism that it inhibits communication, cooperation, and knowledge sharing across communities (e.g. Seba and Rowley, 2010). Due to the public sector being organisationally specific, a number of studies have suggested that there is a need to develop knowledge management practices, tools, and models specific to this context (Massaro, Dumay and Garlatti, 2015; Ajay and Hans, 2013; Adel and Shaghayegh, 2010; Ermine, 2010; Cong and Pandya, 2003). This suggests that the models of cross-community collaboration and knowledge management that have been developed within the private sector context might be less applicable to the public sector. Furthermore, assessing the existing models in different contexts makes it not only possible to identify similarities and differences but also to open a perspective and to create an understanding of the subject.

Moreover, many scholars have suggested that Carlile's three-tire model (2004, 2002) provides an extensive insight into how knowledge can be managed across different knowledge communities and why knowledge management across different knowledge communities can be so difficult (e.g. Smith, 2016; Kotlarsky, Hooff and Houtman, 2015; Majchrzak, More and Faraj, 2012; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008). However, some current publications have argued that there is little knowledge about the dynamics of knowledge boundaries in Carlile's model. That is, in Carlile's model, boundary emergence and spanning occurs in a linear way and is a relatively static construct, and that only one type of knowledge boundary exists at any one time (Lindberg, Walter and Raviola, 2017; Smith, 2016; Le Dain and Merminod, 2014).

1.2. Research aim, objectives, and methodology

This section presents how and when the research objectives emerged. The research aim and research objectives of this study were developed from the knowledge background and interests of the researcher as well as the gaps in the existing literature on cross-community collaboration and knowledge management.

Firstly, the researcher has a knowledge background in information and knowledge management. The researcher graduated with a Bachelor's degree in Library and Information Science and a Master's degree in Information Management. Also, the researcher has experience of knowledge and information management by working as a librarian and knowledge officer in the National Science and Technology Development Agency (NSTDA), a governmental research organisation in Thailand.

Secondly, the researcher was awarded a scholarship from her organisation to study for a PhD in knowledge and information management. Therefore, the researcher wanted to conduct research which could be applied to and useful for her organisation. One of the most interesting topics in the organisation that needed to be studied is cross-community collaboration. Since 2006, the organisation has adopted a concept of programme-based budgeting and a research management system which focuses on problem contexts and applications through cross-community collaboration. This is to integrate its resources and capabilities as well as to create closer connections among its research centres to deliver high standards and quality output to meet the needs of its beneficiaries (National Science and Technology Development Agency, 2012). However, after speaking to a number of members of the organisation who are involved in cross-community research and development projects, some difficulties in cross-community research and development work were reported. For instance, members of one knowledge community did not understand the technical vocabularies of other different knowledge communities involved in a project. Consequently, there was a problem with communication and misunderstandings arose between members in a project. Also, there was an issue about power management in one project because the project consisted of members from different research units; thus, sometimes a project must have more than one project manager. Those issues delayed cross-community work.

Thirdly, as mentioned in the previous section, cross-disciplinary collaboration and knowledge management is an important topic and has been the focus of interest by many scholars and practitioners. Many scholars and practitioners have acknowledged cross-disciplinary collaboration as a trigger of learning designed to maintain individual dynamism and to reduce the negative effects caused by the fragmentation of specialised knowledge. Also, the creation of new knowledge, creativity, and innovation requires the integration of knowledge and perspectives from different knowledge communities. These prospective outcomes are necessary for surviving, being competitive, and growing in the complex, dynamic and multifaceted environment of the knowledge economy and globalisation. Consequently, many organisations have provided core funding and resources to support cross-disciplinary work. This can be seen from the increasing number of interdisciplinary research organisations, programmes, and activities.

As mentioned in the previous section, a number of scholars have examined cross-disciplinary collaboration and knowledge management and then proposed concepts and models for managing knowledge across boundaries. However, existing studies have mainly focused on the subject in particular contexts, especially in new product development in the private sector. Studies that examine how knowledge is shared and integrated across disciplinary boundaries in the public sector in a governmental research organisation has been little addressed in the existing literature. Furthermore, as mentioned in the previous section, there are differences in characteristics and management between the private and public sector organisations. The concepts, tools, and models of cross-community collaboration and knowledge management that have been developed within the private sector context might be less applicable in the public sector. In this context, this study aimed to explore how knowledge is shared and integrated among researchers in cross-disciplinary scientific and technological research projects in a governmental research organisation. In order to achieve this aim, five research objectives were developed:

i. to explain how disciplinary boundaries are socially constructed;
ii. to explore what kinds of knowledge are shared across such boundaries;
iii. to explore by what kinds of processes is this knowledge shared and integrated;
iv. to identify which factors are facilitators or obstacles for knowledge sharing and integration, and how they influence on these activities; and
v. to develop a framework for knowledge sharing and integration in cross-disciplinary research projects in a governmental research organisation.

However, after the first stage of data collection and data analysis the research aim and objectives of this study were reformulated. This was because the initial findings from the first stage of data collection and analysis pointed towards a different way of conceptualising issues. Furthermore, the research aim and objectives were reformulated in the light of the novel findings from the study. The research aim and objectives were extended to knowledge management, which includes knowledge sharing and integration activities. Also, a framework for managing knowledge across boundaries would not be developed just for cross-disciplinary research projects in a governmental research organisation. The cross-disciplinary research project in a governmental research organisation would be used as a case study. From the literature review, as will be more fully discussed in Chapter 2 that follows, the nature of boundaries has been little explored and explained in the existing literature. Boundaries are mainly explained as fluid and invisible in the existing literature. Furthermore, most existing studies have predominantly suggested that knowledge boundaries arise because of differences in knowledge and disciplinary perceptions between interacting actors from different knowledge communities. More specifically, differences in languages, interpretations, and interests between interacting actors from different knowledge communities create different types of knowledge boundaries. In this context, the research aim and objectives were revised and formulated as follows. This thesis aims to explore the nature of boundaries and how knowledge is managed across them particularly in a public sector context. In order to achieve this aim, four research objectives were developed:

i. To explore the nature of boundaries;
ii. To explore why knowledge boundaries arise;
iii. To explore how people manage knowledge across boundaries; and
iv. To develop a framework for managing knowledge across boundaries.

Due to the exploratory nature of the research aim and objectives, a constructivist ontology, an interpretive epistemology, and an inductive research approach are adopted. A case study strategy was selected as it allows the in-depth exploration of a complex phenomenon of cross-boundary collaboration within its real-life context (Bryman, 2012; Yin, 2009). It prompted the researcher to gather rich, in-depth, and complex data from multiple sources of evidence (Yin, 2009). It also allowed the researcher to look at the subject of the study from many aspects to obtain a rich picture and gain analytical insights from it (Thomas, 2011).

The case chosen was an interdisciplinary research project involving the development of Computerised Tomography (CT) and Digital X-Ray (DR) scanners in a governmental research organisation, the National Science and Technology Development Agency (NSTDA), of the Ministry of Science and Technology in Thailand. This research setting was selected through purposive sampling (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Matthews and Ross, 2010). That is, the case was chosen because it is a joint project between two different groups from different disciplines and organisations under NSTDA: the software group from the National Electronics and Computer Technology Center (NECTEC), and the hardware group from the National Metal and Materials Technology Center (MTEC). It is one large and well-known project of NSTDA; it is also considered successful in terms of interdisciplinary collaboration. This suggests that this case study could shed light on cross-community collaboration. This project is an ongoing project and therefore could yield a relatively rich corpus of data. For these reasons, it was felt that the scanner case study has the basic characteristics that are directly related to, and enabled the researcher to meet, the researcher's area of interest and the research objectives.

Furthermore, this research setting was a local knowledge case (Thomas, 2011). That is, the researcher was a member of the organisation, NSTDA. Being already a participant in this research context, the researcher had intimate knowledge, experience, and understanding of the case. Becoming familiar with the context of the research setting enabled the researcher to drill down into the context and circumstances of cross-community collaboration. This could help the researcher to gain a better understanding of actions being enacted in their natural setting by social actors. Therefore, the scanner case study was suitable to enable the researcher to answer the research objectives in great depth. It thus seemed natural, appropriate, and more feasible to locate the case study and sample participants of this study within NSTDA to collect data.

This thesis used a diversity of methods for data collection to maximize opportunities to capture the activities and dynamics involved in cross-community collaboration within the case study. Data collection was exploratory in nature by combining qualitative data collection methods: semi-structured face-to-face interview; participant observation; and collection of documentation and other artefacts that were constructed by different communities. Data were collected over seven months from April 2014 to June 2014 and from January 2015 to April 2015. There was a break in the data collection periods to provide opportunities for the researcher to analyse the initial collected data to identify core issues involved in the subject of the study. The second phase of data collection and analysis aimed to explore and address grey areas and new avenues of inquiry suggested by the first phase of data collection and analysis. Thematic analysis was chosen as an analysis technique (see Chapter 3 for data collection and data analysis).

1.3. Thesis structure

Following this introduction, Chapter 2 provides an overview of the notions and previous literature pertinent to cross-community collaboration and knowledge management. It examines the conceptual background of knowledge and knowledge management. It also provides a literature review on why cross-community collaboration is important and widely attempted. Next, the conceptual background to boundary and boundary spanning is presented, especially disciplinary and cross-disciplinary boundaries. Then, the existing literature is used to explain the types of knowledge boundaries and processes that can be involved in cross-boundary collaboration and knowledge management. After this, boundary-spanning mechanisms that help to move knowledge across boundaries and to facilitate cross-community knowledge processes and collaborations are presented. The research context of this study is an interdisciplinary research project in a government research organisation. Thus, Chapter 2 provides an overview of the nature and characteristics of public interdisciplinary research organisations and knowledge management in interdisciplinary research organisations. Finally, the gaps in the existing literature on the topic are linked to the aim and research objectives of this thesis.

The methodology chapter, Chapter 3, identifies and justifies the research philosophy, the research approach, and the research strategy of inquiry. It also identifies and explains the research setting, the selection of the sample, the methods of data collection, the research process, the data analysis technique and process, and the ethical considerations.

The findings emerging from this study are presented in Chapter 4. The findings are divided into five sections. The first two sections of the findings present the background and context of the case: the benefits and costs of interdisciplinary collaboration from the participants' experiences and perspective; and the types of knowledge which were shared, and types of communication and knowledge sharing channels which were used to communicate and share knowledge among project members. The last three sections of the findings present the nature of boundaries, the construction of knowledge boundaries, and types of knowledge boundaries that occur in cross-community collaboration and processes to overcome and manage knowledge across these boundaries These last three sections were presented and organised based on the research objectives.

Chapter 5, the discussion chapter, then evaluates the findings and framework from this study against the existing literature and the previous model of cross-community collaboration and knowledge management. Grey areas about the nature of boundaries, the construction of knowledge boundaries, and mechanisms for managing knowledge across boundaries, which are found in the existing literature and the previous model, are discussed. This leads to the contributions to knowledge and the theoretical implications, and the practical implications that are made in this thesis, as discussed in Chapter 6. This chapter also discusses the limitations of this study and possible areas for future work.

2. Cross-community collaboration and knowledge management

The aim of this chapter is to present the background of the existing literature related to the topic as well as to develop a research aim and research objectives based on the findings from the literature. This chapter is organised into eleven major sections. It begins by outlining why cross-community collaboration and knowledge management is important. Then, it turns to one of the fundamental questions in knowledge management studies: what knowledge is. The next section then focuses on the notion of knowledge management: what knowledge management is; how organisational knowledge can be managed; and what the processes of knowledge management are. The major contextual aspects of knowledge management including knowledge sharing, which have been mentioned in the knowledge management literature, are presented in the fourth section. The content then drills down into knowledge management and collaboration across communities. The fifth section examines the related concepts of boundaries and disciplinary boundaries, particularly the nature and construction of boundaries. After that, the notion of boundary-spanning, boundary-spanning and learning, and major types of cross-disciplinary collaboration are explained. The seventh and eighth sections look at concepts for managing knowledge across boundaries: types of knowledge boundaries that can occur in cross-community collaboration and processes to overcome these boundaries; and boundary-spanning mechanisms that can be used to facilitate communication, collaboration, and knowledge management across boundaries. The ninth and tenth sections then focus on the nature and characteristics of public interdisciplinary research organisations, and knowledge management in interdisciplinary research organisations. The chapter then concludes in the eleventh section by highlighting the gaps in the existing literature on the subject. These gaps are linked to the research aim and research objectives of this thesis.

2.1. Importance of cross-community collaboration

The level of interest in cross-community collaboration has increased over the last 25 years through a change of style of knowledge production (Siedlok and Hibbert, 2014; Jahn, Bergmann and Keil, 2012), as will be depicted below. It can be seen through the increasing number of interdisciplinary research institutes, programmes, courses, and activities that have occurred (Noorden, 2015; Siedlok and Hibbert, 2014). Moreover, a search on Google and Google Scholar using the keywords ‘interdisciplinary’ or ‘interdiscipline’ reveals the vast number of publications that have been written on the subject. Similarly, a search of one of the large academic databases, ScienceDirect, using the same keywords, shows the large number of journal articles, books, and reference works that have been written on the topic since 1948.

Siedlok and Hibbert (2014), and Jahn, Bergmann and Keil (2012) argue that cross-community collaboration has received more attention since the early 1990s through a change of style of generating knowledge, which has been named Mode 2 knowledge production. The concept of Mode 2 knowledge production was developed by Gibbons, Limoges, Nowotny, Schwartzman, Scott and Trow in *The New Production of Knowledge* published in 1994 (original reference as cited in Tranfield, 2002). It has been cited in numerous publications and also seems to have influenced science and technology policies (Hessels and Lente, 2008; Tranfield, 2002).

According to OpenLearn (2013), Hessels and Lente (2008), Tranfield (2002), and Newell and Swan (2000), Mode 1 knowledge production is as a more traditional form of knowledge generation. It is typically within a single discipline and is static. It is mainly in an academic context. That is, problems are primarily set and solved in theory by the paradigms of the traditional disciplines of knowledge by staff within those disciplines and by institutionalised research organisations. Theory is developed and then its application is considered, so there may be a difference between theory and what is applied.

By contrast, Mode 2 knowledge production is based on the assumption that cross-disciplinary working will ensure greater creativity and innovation among communities. It is regularly involved in more than one discipline or organisation within an open and dynamic environment. In Mode 2, problem-setting and solving requires the integration of different knowledge from a diverse variety of organisations: academic communities, practitioners, policy makers, and consultants. That is, there is a wide range of knowledge producers linked together in temporary teams for short periods of time to work together on particular issues in the real world. These organisations are mainly linked through communication networks and social interaction. Therefore, Mode 2 emphasises the importance of knowledge management in a collaborative context across disciplinary and organisational boundaries. It emphasises the encouragement of the way of knowledge production which is driven by cross-disciplinary and organisational collaboration to work on specific issues in social and economic contexts. Hessels and Lente (2008) argued that Mode 2 is not believed to replace Mode 1 completely, but rather to supplement or drive it. Table 2.1 below presents a comparative summary of Mode 1 and Mode 2 knowledge production.

	Mode 1 Knowledge production	Mode 2 Knowledge production
Nature of knowledge	Disciplinary; Homogeneity	Transdisciplinary; Heterogeneity
Framework	Closed and Static (academic context)	Open and Dynamic (social and economic context)
Motivation	Increased understanding	Practical goal – useful
Problem-setting and solving	By disciplinary staff and institutionalised research organisations in the context of theory	By interdisciplinary staff and society in the context of application
Process	Theory is developed and then application of the theory is considered	Theory building and application occur together
Staff	Disciplinary staff	Interdisciplinary staff
End users interaction	Limited interaction	Open interaction

Table 2.1 Mode 1 and Mode 2 knowledge production

Adapted from: OpenLearn (2013) and Tranfield (2002)

Many researchers and practitioners in the knowledge management area have acknowledged the significance of cross-community collaboration (e.g. Castro, 2015; Noorden, 2015; Hislop, 2013; Jahn, Bergmann and Keil, 2012; Akkerman and Bakker, 2011; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Sumner and Tribe, 2007; Haythornthwaite, 2006; Cummings and Kiesler, 2005; Maglaughlin and Sonnenwald, 2005; Carlile, 2004; Bronstein, 2003; Tranfield, 2002; Wenger, 2000; Star and Griesemer, 1989). According to the literature on organisational and knowledge management, the importance of cross-boundary collaboration could be explained in terms of four specific, but interrelated clusters of factors, each of which are depicted below.

Firstly, one major importance of cross-boundary collaboration which is often mentioned in most of the literature is the creation of knowledge and innovation. Knowledge, knowledge services, knowledge applications, and innovation are regarded as central resources for survival and growth in the knowledge-based economy and globalisation (Jahn, Bergmann and Keil, 2012; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Russell, Wickson and Carew, 2008; Maglaughlin and Sonnenwald, 2005; Bronstein, 2003; Tranfield, 2002). Many studies have suggested that the development of most new knowledge and innovation occurs at the boundaries between individuals or groups of individuals from different specialised knowledge backgrounds and disciplines (Castro, 2015; Scarbrough, Panourgias and Nandhakumar, 2015; Siedlok and Hibbert, 2014; Jahn, Bergmann and Keil, 2012; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Numprasertchai and Igel, 2005; Carlile, 2004; Tranfield, 2002; Katz and Martin, 1997; Star and Griesemer, 1989). Innovation can be new ideas applied to problems, new services and products, new technologies, and new processes of doing things or a recombination of old ideas (Edenius, Keller and Lindblad, 2010; Cummings and Kiesler, 2005). To take a specific example, the development of smartphones combines many things which require different knowledge and skills from systems design engineering (e.g. architecture development), electrical engineering (the development of electricity and electronics such as electronics boards and circuits), and software engineering (e.g. application development and writing code). Another example; the development of electronic-nose devices to detect, identify, and classify chemicals in the environment and in the chemical industry requires collaboration among researchers and practitioners from different disciplines such as nanotechnology, electronics and computer technology, including metal and materials technology.

Secondly, most modern industrial societies have encountered complex, dynamic, interconnected problems, and challenges such as global warming, excessive population growth, water shortages, the spread of deserts, and the epidemiology of AIDS or the emergence of infectious diseases (Jahn, Bergmann and Keil, 2012; National Science and Technology Development Agency, 2012; Maglaughlin and Sonnenwald, 2005; Bronstein, 2003; Tranfield, 2002). Such problems and challenges cannot be solved or solved easily by a single actor, group, organisation or discipline. The integration of knowledge from different disciplines and organisations is recognised as an essential tool to develop a better understanding of the different facets of these problems and challenges. This is in order to develop more comprehensive and effective solutions to cope with them (Jahn, Bergmann and Keil, 2012; Russell, Wickson and Carew, 2008; Sumner and Tribe, 2007; Haythornthwaite, 2006; Cummings and Kiesler, 2005; Maglaughlin and Sonnenwald, 2005; Numprasertchai and Igel, 2005; Bronstein, 2003; Tranfield, 2002; Katz and Martin, 1997). For instance, the production of ethanol as one alternative for solving the crisis in energy production might require different knowledge, skills, and perspectives from many actors who are members of different disciplines such as chemistry, environmental science, physics, engineering, plant biology, and economics.

Thirdly, no single individual will possess all the required knowledge, skills, and expertise to make contributions in more than a very narrow area of work or inquiry (Hara, Solomon, Kim and Sonnenwald, 2003; Katz and Martin, 1997). Consequently, there is an emphasis on seeking for connections and collaborations across disciplines. People search for ways to connect and collaborate across the diverse social and cultural practices of disciplines to reduce the negative effects caused by the fragmentation of scientific knowledge (Akkerman and Bakker, 2011). Based on learning theory on communities of practice (Wenger, 2000), differences in knowledge are appreciated as a resource to retain individual dynamism. Boundary-spanning is a key of learning by connecting knowledge communities and offering learning opportunities in their own right. Learning occurs because differences in knowledge need to be identified, coordinated, reflected, and transformed for communities, which will be explained in Section 2.6.1 (Akkerman and Bakker, 2011; Wenger, 2000). Therefore, cross-boundary collaboration could be considered as a trigger of learning to retain individual dynamism and to reduce the negative consequences caused by the fragmentation of specialised knowledge domains (Hislop, 2013; Akkerman and Bakker, 2011; Wenger, 2000; Katz and Martin, 1997).

Fourthly, authors such as Hislop (2013), and Brown and Duguid (1991) have argued that organisational knowledge bases have the fragmentation of specialised knowledge domains. That is, the knowledge bases of most organisations are always fragmented or are created from the localised knowledge of various knowledge communities which have some common knowledge, but which also possess considerable specialised knowledge (Hislop, 2013). The specialised and localised nature of organisational knowledge is related to the particular tasks that the different communities of organisational staff undertake. Similarly, Carlile (2004, 2002), utilizing the practice-based perspective on knowledge, argues that the nature of knowledge is localised, embedded, and invested in practice. He then argues that cross-community collaboration constitutes a boundary-spanning process. Cross-boundary collaboration has been considered as a tool for the development of organisational knowledge. Thus, one of the most important tasks of organisations is to connect these diverse communities as well as to integrate the fragmented internal knowledge resident in communities (Hislop, 2005; Grant, 1996). For instance, Cummings and Kiesler (2005), and Palmer (1999) argue that cross-disciplinary collaboration offers a better opportunity for the development of knowledge repositories and knowledge bases for other collaborative research projects and so opens up a new field of effort.

Given these clusters or drivers, many governments and policy makers have shifted their approaches to provide core funding and resources to support cross-boundary working (Cummings and Kiesler, 2005; Tranfield, 2002; Newell and Swan, 2000). The number of interdisciplinary research organisations, programmes, courses, and activities has thus increased (Noorden, 2015; Siedlok and Hibbert, 2014). Having established the importance of cross-community collaboration, it is necessary now to turn to explain the notions of knowledge, knowledge management, and boundary-spanning as the basis for understanding cross-community collaboration and knowledge management.

2.2. Notion of knowledge

When talking about how knowledge is managed, there are many fundamental and important inquiries mentioned in the knowledge management literature. Questions found have included: What is knowledge? Can it be captured and codified? What are the processes to manage it? How it can be managed? or What are the drivers and the obstacles involved in knowledge management? Therefore, first gaining an understanding of the origin and nature of knowledge has significant implications for understanding the characteristics of processes to manage knowledge across boundaries. It also has significant implications for understanding the challenges of knowledge management in such situations and where they exist (Hislop, 2013).

According to the existing knowledge management literature, knowledge is a fuzzy concept. It has different meanings and explanations (Maaninen-Olsson, Wismen and Carlsson, 2008). However, two main perspectives on knowledge and knowledge management have been mentioned in the literature; these were labelled differently by different authors as set out in

Table 2.2 (Holford, 2016; Hislop, 2013; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004; Orlikowski, 2002; Cook and Brown; 1999).

Perspectives on knowledge			**Typologies of Knowledge**
Cook and Brown (1999)	**Orlikowski (2002)**	**Hislop (2013)**	**Nonaka (1994)**
As possession	Knowledge	Objectivist perspective	Tacit knowledge
			Explicit knowledge
As practice	Knowing	Practice-based perspective	Tacit knowledge Explicit knowledge

Table 2.2 Two main perspectives on knowledge

Table 2.2 above presents a comparative list of the two main perspectives of knowledge which seem to dominate the meaning of knowledge and knowledge management in many existing studies (e.g. Holford, 2016; Paraponaris and Sigal, 2015; Maaninen-Olsson, Wismen and Carlsson, 2008; Gasson, 2005b; Carlile, 2004; Jashapara, 2004). The principles and characteristics of these two perspectives of knowledge are depicted below.

In the first perspective knowledge is regarded as something which is pre-existing (Cook and Brown, 1999) or what individuals or groups of individuals already have. It mainly resides in the heads of the individuals who possess it (Nonaka, 1994) or the groups of individuals (Swan, Newell, Scarbrough and Hislop, 1999; Spender, 1996). Moreover, one of the significant characteristics of knowledge in this perspective is that knowledge is considered as an entity or something that is free and exists apart from other things or is separate from people who produce it and who may use and understand it (Hislop, 2013).

Although knowledge is regarded as something that resides in a knowledge holder's head, this perspective assumes that knowledge can be captured, codified, and can exist in various explicit or objective forms such as documents, manuals, drawings, diagrams, videos, and prototypes of technology (Hislop, 2013; Cook and Brown, 1999; Nonaka, 1994). Such knowledge can be transferred from an isolated knowledge holder to a knowledge recipient(s) remotely (Hislop, 2013). Individuals or groups of individuals who possess knowledge might develop mechanisms to allow their codified knowledge to be easily accessed by others, who want to use it and obtain permission to access it easily. That is, a knowledge holder might create knowledge bases where they can store, categorise, index, and cross-reference their codified knowledge to help a knowledge recipient(s) who may want to use this knowledge to access it easily. The knowledge recipient(s) is able to use and understand the knowledge without social interaction with the knowledge holder (Hislop, 2013; Orlikowski, 2002; Swan, 2001; Swan, Newell, Scarbrough and Hislop, 1999; Spender, 1996; Nonaka, 1994). Hislop (2013) argued that this perspective assumes that a knowledge holder and a knowledge receiver(s) have the same language. Thus, it assumes that no crucial issues of knowledge are lost in the process of knowledge sending and receiving or that there are no problems of meaning between the knowledge holder and the knowledge receiver(s). This suggested that in this perspective knowledge is seen as a static entity and can be considered without its context.

According to the characteristics of knowledge mentioned above, in this perspective the knowledge production process is fundamentally a cognitive process which only the brain is involved in, not the body (Hislop, 2013; Swan, Newell, Scarbrough and Hislop, 1999). Furthermore, emphasising the codification of knowledge to knowledge bases to be searched and accessed suggested that computer, communication, and information-processing technologies are regarded as important tools in the knowledge management process (Hislop, 2013; Nonaka, 1994). The challenge of this perspective is the increasing of the capacity to codify and process as much knowledge as possible (Hislop, 2013).

Hislop (2013) linked the epistemology of knowledge to typologies of knowledge. Then, he argued that there is an acknowledgement that knowledge can take different forms: most importantly, either tacit or explicit knowledge. According to Nonaka (1994), tacit knowledge refers to knowledge that consists of cognitive and technical skills which deeply reside in the heads, perceptions, and actions of the individuals who possess and use it. Thus, it was difficult to codify, formalize, and communicate to another person through non-personal or codified forms of communication. By contrast, explicit knowledge could be easily codified, captured, and transferred in a number of explicit forms. Hislop (2013) argued that, in the first perspective of knowledge, knowledge can be either tacit or explicit. That is, tacit and explicit knowledge were considered as quite separate. Moreover, there was a bias towards and focus upon the management of explicit knowledge (Hislop, 2013). This was largely because explicit knowledge is assumed to be much easier to manage than tacit knowledge.

Although Nonaka suggested two separate types of knowledge as mentioned above, Nonaka viewed knowledge as dynamic. Nonaka and Takeuchi (1995) proposed the socialisation-externalisation-combination-internalisation (SECI) model to present how one knowledge type can be converted to another new knowledge type through four methods. Firstly, tacit knowledge is located in the head of the person who possesses it. Thus, it is difficult to convert it into objective forms. Andreu and Sieber (2005) argued that the difficulty is not only that people know more than they can say, but also that they may not even be aware of all their tacit knowledge. Hence, tacit knowledge sharing can happen through socialisation. Secondly, externalisation refers to articulating and converting tacit knowledge, which can be codified, into explicit knowledge through dialogue and reflection within concrete forms such as a report after attending a workshop. Thirdly, combination refers to organising and analysing different types of explicit knowledge to create new explicit knowledge, and then disseminating it through technological or social networks. Finally, internalisation represents understanding explicit knowledge which happens when explicit knowledge transforms to tacit knowledge through practice and learning. The cycle continues in the spiral of knowledge back to socialisation when individuals share their tacit knowledge.

While the first perspective of knowledge assumed that knowledge resides within individuals' heads, Spender (1996) argued that knowledge can also reside within individuals and social groups. Thus, Spender (1996) combined the tacit-explicit dichotomy with the individual-organisation dichotomy and then suggested a two by two matrix with four generic types of knowledge. Firstly, automatic knowledge refers to individual tacit knowledge which could be tacit knowledge in Nonaka's concept. Secondly, collective knowledge refers to organisational tacit knowledge which is embedded in informal social and organisational practices, systems, processes, stories, and cultures. By contrast, conscious knowledge was regarded as individual explicit knowledge which could be explicit knowledge in Nonaka's concept. Finally, objectified knowledge represents organisational explicit knowledge which is embodied in information stored, such as in documented operating procedures. To gain advantages from knowledge, Andreu and Sieber (2005) suggested that organisations need to capture individual knowledge and turn it into organisational knowledge. However, the nature and accessibility of individual tacit knowledge was limited. Thus, it could lead to a gap between knowledge that exists in individuals and groups or organisations (Tong and Mitra, 2009).

The ideas of the first perspective of knowledge were criticised by many authors, especially the limitations of knowledge codification and the mutual construction between explicit and tacit knowledge; another perspective was thus suggested. The second perspective of knowledge was labelled as the epistemology of practice (Cook and Brown, 1999), knowing (Orlikowski, 2002), and the practice-based perspective (Hislop, 2013). The principles and characteristics of the second perspective of knowledge are depicted below.

This perspective argues that knowledge is situated in people's heads but is not pre-existing. Knowledge is regarded as a result of activities, practices, social interactions, or knowing (Hislop 2013; Orlikowski, 2002; Cook and Brown, 1999; Blackler, 1995). Thus, knowledge is both from individuals and groups of individuals (Hislop, 2013). Cook and Brown (1999) explained that knowledge, which is regarded as a resource, is used as a tool of knowing or practice within interaction. Thus, this perspective argued that knowledge is not a codifiable and discrete entity but is deeply embedded within and inseparable from people's activities, practices, or interactions (Hislop, 2013; Orlikowski, 2002; Blackler, 1995). This means that knowledge is not regarded as something which can be directly managed. It is also suggested that knowledge is intrinsically relational to, and is interdependent on, its surrounding contexts. It brings out knowledge as a context-dependent process (Hislop, 2013). That is, knowledge cannot be understood outside of the culture that conditions its emergence and modes of reproduction.

From the idea that knowledge is socially constructed and culturally embedded, it leads to the idea that knowledge is subjective, non-static, and open to interpretation (Hislop, 2013; Carlile, 2004). That is, different individuals might find different meanings in the same things and situations depending on the values and assumptions of the social and cultural context in which they live and work (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Sumner and Tribe, 2007; Hislop, 2005; Carlile, 2004; Wenger, 2000; Becher, 1994; Brown and Duguid, 1991). When different individuals use different languages to talk about and attach different meanings to the same things and phenomena, lack of common knowledge and understanding occurs. Conflicts between different individuals can also occur due to attempts by different individuals and groups to make their knowledge legitimate (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Hislop, 2013; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004; Bechky, 2003). Therefore, the issues of conflicts and political influences occur and become more important than is mentioned by the first, objectivist perspective (Hislop, 2013; Carlile, 2004, 2002).

Similarly, Szulanski (2000, 1996) suggested the stickiness of knowledge or the difficulty of knowledge transfer, more specifically knowing, within an organisation. Szulanski (2000, 1996) suggested that knowledge transfer is often difficult to achieve because of four factors: the characteristics of knowledge, knowledge senders, knowledge recipients, and the context of knowledge transfer. Knowledge transfer is difficult because of the characteristics of the knowledge transferred, more specifically causal ambiguity. Causal ambiguity refers to ambiguity about what the factors of production are and how the factors interact during production (Szulanski, 1996, p.30). Causal ambiguity occurs when the exact reasons for success or failure in knowledge transfer in a new setting cannot be determined. Also, it occurs because of imperfectly understood features of the new context in which knowledge is used. In addition, knowledge without a proven record of past usefulness is difficult to transfer. This is because knowledge recipients might not want to engage in the transfer of unproven knowledge. The difficulty of knowledge transfer can occur because of the characteristics of knowledge senders. That is, knowledge senders lack motivation to transfer their knowledge such as the fear of losing their ownership. Also, they are not perceived as reliable or knowledgeable. The difficulty can occur because of the characteristics of knowledge recipients as well. That is, knowledge recipients lack motivation to support knowledge transfer such as reluctance to accept knowledge from outside. They lack absorptive capacity and retentive capacity or the ability of a recipient to institutionalise the utilisation of new knowledge. The characteristics of the context in which knowledge transfer takes place, more specifically the relationship between knowledge senders and knowledge recipients as well as organisational context, have impact on knowledge transfer. For instance, knowledge transfer that unfolds fully in one context may grow poorly in another formal structure (Szulanski, 2000, 1996). As mentioned above, in the context of Szulanski's work, boundaries can be seen as contexts where knowledge becomes sticky.

The second perspective of knowledge perceives that knowledge is tacit and explicit; thus tacit and explicit knowledge are mutually constituted and inseparable (Hislop, 2013; Orlikowski, 2002; Cook and Brown, 1999; Spender, 1996). For instance, Hislop (2013) explained that a textbook, which is often represented as a form of explicit knowledge, has tacit components such as an understanding of relevant academic topics and the language in which they are written. Thus, Hislop (2013) argued that knowledge is totally unbiased and impartial; all knowledge consists of the elements of both tacit and explicit knowledge. Similarly, Cook and Brown (1999) suggested that both tacit and explicit knowledge forms are used to facilitate the acquisition of each other; each knowledge type can thus be used as an aid in acquiring the other type. Furthermore, knowledge cannot exist in a fully explicit and codified form and cannot exist independently of human beings; all knowledge will have tacit dimensions (Hislop, 2013; Cook and Brown, 1999).

The idea that knowledge is considered as a result of activities, practices, social interactions or knowing, and tacit and explicit knowledge is mutually constituted, was explained by Hislop (2013), Orlikowski (2002), and Cook and Brown (1999). They argued that individuals and groups apply their existing knowledge (explicit and/or tacit) as parts or tools of action or knowing (Orlikowski, 2002) to construct new knowledge (both tacit and explicit). Cook and Brown (1999) gave an example that to be able to ride a bicycle people cannot put a beginner on a bicycle and then expect the beginner to be able to ride successfully. The beginner needs to have tacit knowledge about how to ride a bicycle and use such knowledge to ride around in order to find out the other way when the beginner begins to fall. However, neither tacit nor explicit knowledge on its own is sufficient for acquiring the ability to ride. To acquire tacit knowledge, the beginner has to spend an amount of time on a bicycle to practice. This means that people's knowledge develops as they conduct activities and gain experience. Thus, knowledge in this perspective is seen as less of a purely cognitive process because it involves the body. That is, knowledge tends to develop and be used and shared through undertaking activities which include both physical and cognitive elements or the doing and thinking of people who develop and possess it (Hislop, 2013).

Blackler (1995), one scholar who suggested a concept related to the practice-based perspective, suggested that when individuals participate in activities or work practices, they are involved in five types of knowledge. The tacit-explicit dichotomy and the individual-organisation dichotomy of knowledge were combined into Blackler's concept. Blackler (1995) identified five knowledge types: embrained, embodied, encultured, embedded, and encoded based on assumptions about the location of knowledge: brains, bodies, dialogue, routines, and symbols respectively. Embrained knowledge is the conceptual and theoretical knowledge people possess. It is used to cope with new problems such as an individual design engineer's skills and abilities to produce creative solutions for new problems in product design processes. By contrast, embodied knowledge is action-oriented which is dependent on people's physical presence. It is mainly used to solve familiar problems which individuals have experienced before in their daily work processes. Encultured knowledge refers to organisational tacit knowledge as well as the process of achieving shared perceptions and understanding toward motivation, co-operation or other important issues. Embedded knowledge represents knowledge rooted in organisational routines and culture which can be either explicit or tacit embedded knowledge. Explicit embedded knowledge can be formalised in words and numbers such as standard operational procedures. By contrast, tacit embedded knowledge has been kept implicit as informal routines. Encoded knowledge represents explicit knowledge in codified form.

According to the nature of knowledge from the second perspective, it is argued that knowledge is embodied (tacit), embedded (context dependent), and subjective; knowledge processes thus involve facilitating interpersonal communication between individuals or groups of individuals. To be effective, knowledge management requires social interactions between actors (Cook and Brown, 1999) (see Table 2.3 below for the different characteristics of knowledge from the objectivist and the practice-based perspective).

Objectivist perspective	**Practice-based perspective**
Knowledge is pre-existing	Knowledge arises from social interaction
Knowledge is individual or group	Knowledge is individual and group
Knowledge is an entity	Knowledge is social interaction
Knowledge is decontextualised	Knowledge is contextualised
Knowledge is a cognitive process	Knowledge is social interaction process and knowing
Knowledge is information processing	Knowledge is social interaction
Knowledge is either tacit or explicit	Knowledge is explicit and tacit
Explicit knowledge has privileges over tacit knowledge	Explicit and tacit knowledge is impartial

Table 2.3 Characteristics of knowledge from the objectivist and practice-based perspectives

Following from the two main perspectives on knowledge set out above, this thesis will adopt the concept of the practice-based perspective as a theoretical lens. This is because the nature of knowledge and knowledge management which is examined in this study corresponds to the characteristics of knowledge within the practice-based perspective. More specifically, the practice-based perspective emphasises knowledge as both an input and a result of knowing processes and knowledge as contextualised. That is, this study involves the interaction and coordination of interdependent actors, who are members of different knowledge communities. These actors share, combine, and integrate the specialised knowledge and work practices of each other which are dependent on each other in a particular way. This is in order to carry out their tasks together in the particular context they are in to achieve common goals. This means there are processes involved in the development of an understanding of an individual's tacit knowledge and an appreciation of (or some of) the subjectivities upon which the knowledge of another is based. The nature of knowledge which is investigated in this study involves sociocultural differences between interacting actors from different knowledge backgrounds. Knowledge in this study seems to be developed, used, and shared through the processes of socialisation and practice which include both physical (doing) and cognitive (thinking) elements of actors who develop and possess it. Different subjectivities of actors from different knowledge communities could lead to different interpretations among actors. Thus, social interaction and communication between different actors is required. The knowledge management processes of this study mainly involve social interaction, communication, and collaboration between interacting actors from different knowledge communities within different, unfamiliar, and novel contexts. Similarly, the practice-based perspective emphasises that knowledge is seen as a non-static entity resulting from the process of knowing which involves: interpersonal communications, social interactions, practices, and activities which are interdependent on various socio-cultural contexts. Thus, the practice-based perspective on knowledge enables this study to explain and understand the knowledge which is examined in this thesis. More specially, knowledge emerges from the interaction and integration of subjectivity such as specialised knowledge, skills, perspectives, and practices of members from different knowledge communities.

2.3. Notion of knowledge management

2.3.1. Knowledge management perspectives

The growth of knowledge management research and practices began in the 1990s (Koenig and Srikantaiah, 2004). Moving from focusing on natural resources in the manufacturing industry to knowledge resources and knowledge-intensive work in the knowledge-based society is regarded as the key interest point for knowledge and knowledge management (Ahmed, Lim and Loh, 2002; Earl, 2001). Before 1998 most knowledge management studies and initiatives were primarily driven by solutions based on information and communication technology, especially the Internet, to support knowledge sharing (Mertins, Heisig and Vorbeck, 2003). Since 1998 most researchers and practitioners have discovered that information and communication technology cannot deal with all the issues raised, particularly the capture and sharing of tacit knowledge which is generally involved in social interaction (Koenig and Srikantaiah, 2004; Davenport and Prusak, 1998). Consequently, human and social aspects have been recognised as significant elements in recent knowledge management research and practice (Chen, Sun and McQueen, 2010; Wang and Noe, 2010).

According to the existing knowledge management literature, there is no widely agreed definition of knowledge management. This is because of the number of diverse disciplines, concepts, perspectives, contents, and activities which have been included under the knowledge management banner. For instance, an information management perspective emphasises information science (Koenig and Srikantaiah, 2004), while an organisational and human resource management perspective emphasises anthropology, sociology, and management science (Hislop, 2013; Ahmed, Lim and Loh, 2002). The different perspectives of knowledge management are presented below in order to analyse knowledge management by providing a balanced appraisal of the literature.

From an information system perspective, knowledge management is regarded as a semantic process of knowledge identification, capture, and transfer (American Productivity and Quality Center, 2013). By contrast, from a human resource management perspective, Wiig (1993) suggested that knowledge management is a conceptual framework that contains perspectives and activities which are required to gain an overview of, deal with and obtain benefits from, individual and organisational knowledge in order to achieve desired objectives. From a practical view, knowledge management is seen as a set of approaches and processes to manage knowledge functions in different types of operations (Wiig, 1993).

Many authors identify the definition of knowledge management by combining both information management and human resource management perspectives (e.g. Suresh and Mahesh, 2006; Andreu and Sieber, 2005; Jashapara, 2004; Al-Hawamdeh, 2003; Ahmed, Lim and Loh, 2002; Swan, Newell, Scarbrough and Hislop, 1999; Davenport and Prusak, 1998). For instance, knowledge management is strategic management by using technology and processes to optimize knowledge transfer and utilisation, and by sharing knowledge directly between people through social interaction and communication (Suresh and Mahesh, 2006; Swan, Newell, Scarbrough and Hislop, 1999). Davenport and Prusak (1998) argued that knowledge management is the development and utilisation of an organisation's knowledge to further the organisation's objectives through human resources and organisational change management as well as through information systems management practices. Similarly, Jashapara (2004) and Al-Hawamdeh (2003) suggested that knowledge management involves the learning processes of creation, codification, organisation, sharing, transferring, application, and utilisation of knowledge within an organisation. Such processes require appropriate technologies to support the creation and maintenance of knowledge repositories. They also require cultural environments that enable the cultivation and facilitation of knowledge sharing and organisational learning to increase an organisation's performance. Ahmed, Lim and Loh (2002) argued that knowledge management consists of a set of organisational processes that seek the continuous creation of knowledge by leveraging the synergy of combining organisational cultures, organisational strategies, organisational processes, information processing technologies, and the creative and innovative capacities of human beings for the management and leverage of individuals' knowledge to the organisational benefit. Andreu and Sieber (2005) highlighted the information perspective by suggesting that knowledge management has three main aspects: information, technology, and organisational culture. Information focuses on information management processes, such as ease of access to information and information filtering, to make knowledge management operational. Technology concentrates on storing, accessing, and communication of explicit knowledge through information technology systems. Organisational culture centres on the individual, and the process of learning and tacit knowledge (see Table 2.4 below for a comparative summary of knowledge management perspectives).

Authors	Perspectives	
	Human resource and organisation	**Information system**
Wiig (1993)	Processes to manage knowledge to achieve desired objectives	
Davenport and Prusak (1998)	Development and utilisation of organisational knowledge through human resources management and organisational change management practices	Development and utilisation of organisational knowledge through information systems management practices
Swan, Newell, Scarbrough and Hislop (1999)	Creation and sharing of tacit knowledge through social networking	Capture, codification, and transfer of explicit knowledge through information systems
Ahmed, Lim and Loh (2002)	Management and leverage of individuals' knowledge to the organisational benefit	Systematic processes of managing knowledge
Jashapara (2004)	Social and organisational learning	Creation and maintenance of knowledge repositories
Andreu and Sieber (2005)	Individual process of learning, and tacit knowledge	Storing, access, and communication of explicit knowledge through information technology systems
Suresh and Mahesh (2006)	Transferring knowledge directly through social interaction and	Transferring knowledge indirectly through technology

Authors	Perspectives	
	Human resource and organisation	**Information system**
	communication	
American Productivity and Quality Center (2013)		Semantic process of managing information and knowledge

Table 2.4 Comparative perspectives of knowledge management

According to the definitions of knowledge management mentioned above, there are seven components which are generally found in those definitions: (tacit and explicit) knowledge; people; processes; organisational culture; organisational environment; information technologies; and the strategies of knowledge management. Knowledge management can be understood as organisational learning processes which consist of the capture, creation, codification, storage, retrieval, sharing, and application of knowledge. Such processes require appropriate information technologies, as well as human resources and organisational management practices, to make knowledge available and accessible for supporting and achieving the organisation's objectives and to increase the organisation's assets. This definition builds on the assumption that knowledge is an entity amenable to management (either partially or completely).

However, according to the nature of knowledge (see Section 2.2), some authors suggest the nature of knowledge includes the following: knowledge is dynamism (Nonaka, 1994); and knowledge is ordinarily embedded within and inseparable from human beings (Nonaka, 1994), human activities (Hislop, 2005; Orlikowski, 2002; Cook and Brown, 1999; Blackler, 1995), and social values (Nonaka, 1994). These characteristics of knowledge suggest that it is difficult to manage knowledge in a direct way and raises the question: 'Is knowledge manageable?' (Hislop, 2005). To answer this question, Wilson (2002) suggested that it is necessary to distinguish between knowledge and information. That is, understanding the differences between knowledge and information can help to know which knowledge can or cannot be managed. Wilson (2002) argued that explicit knowledge that can be managed should be considered and labelled as information. By contrast, tacit knowledge that can never be managed, except by an individual knowledge holder and, even then, only imperfectly, should be considered and labelled as knowledge. Hislop (2005) suggested that organisations cannot manage (tacit) knowledge itself. However, organisations may be able to manage related human resource management and organisational management processes and practices, such as communities of practice. This is in order to persuade knowledge workers to manage and share their (tacit) knowledge towards the achievement of the organisation's objectives.

2.3.2. Knowledge management strategies

The strategies of knowledge management are mentioned in the definitions of knowledge and knowledge management such as (Suresh and Mahes, 2006; Andreu and Sieber, 2005; Swan, Newell, Scarbrough and Hislop, 1999). Thus, this subsection outlines the strategies of knowledge management needed to develop knowledge management practices.

A codification and personalisation approach, as suggested by Hansen, Nohria and Tierney (1999), has been mentioned by a number of knowledge management studies such as Begoña Lloria (2008), Suresh and Mahesh (2006), Jashapara (2004), Koenig and Srikantaiah (2004), and Swan, Newell, Scarbrough and Hislop (1999). A codification approach focuses on reusing existing knowledge which is already codified and stored in organisational repositories for all qualified people. For this strategy, organisations mainly rely on technologies to manage explicit knowledge. This strategy might be appropriate for organisations encountering similar challenges and concerned with cost saving. By contrast, a personalisation approach focuses on leveraging and sharing tacit knowledge among people through social networks and social interactions. Mechanisms for knowledge sharing play a primary role, while technologies play a secondary role. Although each approach is different from all others, Hansen, Nohria and Tierney (1999) suggested that organisations which have a successful knowledge management strategy might rely heavily on one approach and use the other one supportively.

Earl (2001) proposed another knowledge management strategy which has been mentioned in many studies such as Begoña Lloria (2008), Riege (2005), Al-Hawamdeh (2003), and Liebowitz and Beckman (1998). Earl (2001) suggested three main schools of thought on knowledge management: technocratic, economic, and behavioural schools based on information technologies and commercial factors, including creation, sharing, and use of knowledge as a resource respectively. However, no claims are made that one school outperforms another school.

The technocratic school includes system, cartographic, and process schools which are based on information technologies to different degrees. The system school aims to capture, codify, organise, store, and share knowledge in knowledge bases for other qualified users to access. Since the codification of tacit knowledge is still limited, it is important to identify knowledgeable people in an organisation for others to approach for advice or knowledge exchange. The cartographic school focuses on organisational knowledge maps and knowledge directories. For the cartographic school, technologies play a role to locate knowledge sources and connect people for communication rather than to access knowledge bases as with the system school. The process school aims to enhance organisational core capabilities and performance by providing information and best practice knowledge throughout the process through information systems. Another main school is the economic school. It believes that revenue streams are created by exploiting knowledge through the development of teams and techniques. The behavioural school, the final school, addresses policies that encourage individuals and convert management practices into practices to create, share, and use knowledge as a resource (Begoña Lloria, 2007). This school consists of organisational, spatial, and strategic schools. The organisational school centres on organisational structures and networks, particularly communities of practice, to share and gather knowledge within organisations. Communities and communication play a crucial role to connect knowledge and knowledge workers together. The common object of the communities is productivity through reuse and learning to get better and faster decision-making and development of performance. The spatial school emphasises the availability and accessibility of the space where people can meet to facilitate and stimulate communication and knowledge sharing. The strategic school considers knowledge management as a dimension of the competitive strategy. That is, it concentrates on the formulation of strategies to gain competitive advantage.

Binney (2001) reviewed the knowledge management literature from 1994 to 2000, and then developed a knowledge management spectrum to present the complexities of various knowledge management theories, tools, and techniques which were found in the literature. According to Binney (2001), knowledge management applications, which are addressed in the literature, can be mapped with six elements of knowledge management based on theories, tools, and techniques for each knowledge management approach. Six knowledge management applications include: transactional; analytical; asset management; process;

development; and innovation and creation applications. Binney (2001) argued, briefly, that transactional knowledge management applications focus on the use of knowledge which is embedded in the applications of technologies such as retrieving similar cases when a similar problem is raised in customer service applications. Analytical knowledge management applications focus on large amounts of data or information which is used to derive trends and patterns. Asset knowledge management applications concentrate on processes to manage knowledge assets. Process-based knowledge management applications highlight the improvement of processes, work-practices or procedures. Developmental knowledge management applications concentrate on increasing the competencies or capabilities of knowledge workers in organisations. Innovation and creation knowledge management applications focus on providing an environment in which knowledge workers, often from different disciplines, can come together to collaborate in the creation of new knowledge. The first three elements are focused on by technologists, while the last three elements are focused on by organisational theorists (Binney, 2001).

<table>
<tr><th>Earl (2001)</th><th>Hansen, Nohria and Tierney (1999)</th><th>Binney (2001)</th></tr>
<tr><td rowspan="2">System school</td><td rowspan="2">Codification approach</td><td>Transactional knowledge management applications</td></tr>
<tr><td>Analytical knowledge management applications</td></tr>
<tr><td>Cartographic school</td><td rowspan="3">Codification or Personalization approach</td><td rowspan="2">Process-based knowledge management applications</td></tr>
<tr><td>Process school</td></tr>
<tr><td>Commercial school</td><td>Asset management knowledge management applications</td></tr>
<tr><td>Organisational school</td><td rowspan="3">Personalization approach</td><td rowspan="2">Innovation and creation knowledge management applications</td></tr>
<tr><td>Spatial school</td></tr>
<tr><td>Strategic school</td><td>Developmental knowledge management applications</td></tr>
</table>

Table 2.5 Approaches of knowledge management strategies

Table 2.5 above presents the association of three knowledge management strategic frameworks suggested by Binney (2001), Earl (2001), and Hansen, Nohria and Tierney, (1999). Earl's system school and Binney's transactional and analytical knowledge management applications can be seen as similar. This is because they rely heavily on working with information systems, particularly the access and presentation of computerised knowledge transactions, which suggests that the knowledge is codified and distributed to support reusing existing knowledge for all qualified employees. Such characteristics imply Hansen, Nohria and Tierney's codification strategy which focuses on reusing codified explicit knowledge that is stored in knowledge bases.

Furthermore, Earl's cartographic school is concerned with organisational knowledge maps and knowledge directories to identify knowledgeable people in an organisation for advice or knowledge exchange. This school corresponds with Hansen, Nohria and Tierney's codification strategy because of using technologies to locate knowledge sources and connecting between knowledge holders and knowledge recipients. However, focusing on knowledgeable people and their tacit knowledge can also correspond with Hansen, Nohria and Tierney's personalisation strategy; thus, it is half-way between the codification and personalisation strategies. Similarly, Earl's process school and Binney's process-based knowledge management applications are focused on the use of information technologies and best practices to develop organisational work-practices to enhance organisational core capabilities and performances. Focusing on information technologies and reusing codified tacit knowledge to save cost can be implied by the codification strategy. However, concern with the codification of tacit knowledge into explicit knowledge and making such knowledge available to others in an organisation can be implied by the personalisation strategy. Earl's commercial school and Binney's asset knowledge management applications are regarded as the same thing because they concentrate on re-use of codified knowledge. This implies the codification strategy, which heavily uses information technologies to support the reuse of knowledge to reduce cost. However, such knowledge is often exploited through the development of communities, social interaction, and social collaboration. Thus, this issue can be implied by the personalisation strategy.

Earl's organisational and spatial schools correspond to Binney's innovation and creation knowledge management applications. That is, they centre on knowledge workers and the encouragement of the formation of communities of practice to create and share knowledge by providing appropriate organisational structures and cultures for communication and collaboration. Such characteristics are related to Hansen, Nohria and Tierney's personalisation strategy which highlights communities of practice, social interactions, and social networks to leverage and share tacit knowledge among people in organisations. In addition, Earl's strategic school and Binney's development knowledge management applications can be seen the same way. This is because they focus on the change of people's attitude towards the idea of treating knowledge as an asset and the management of employees' knowledge competencies and capabilities towards knowledge sharing through the formulation of competitive strategies. Both approaches can be implied by the personalisation strategy because of focusing on people and collaborative skills which implies the change of attitude towards knowledge sharing and interpersonal communication. That is, Earl's behavioural schools and Binney's innovation and creation knowledge management, and development knowledge management applications, can be linked to the personalisation strategy. They focus on the encouragement of the behaviour of collaboration and tacit knowledge sharing through social interaction.

2.3.3. Knowledge management processes

According to the existing literature on knowledge management, there is no widely agreed model of knowledge management processes. Many different knowledge management processes have been mentioned by different authors. Four knowledge management process models: Bedford (2004), Davenport and Prusak (1998), Meyer and Zack (1996), and Wiig (1993), are selected to discuss processes to manage knowledge. These models were selected based on the different types of steps found in the knowledge management literature and the detailed descriptions of the knowledge management processes involved in each step (see Table 2.6 below).

Wiig (1993)	**Meyer and Zack (1996)**	**Davenport and Prusak (1998)**	**Bedford (2004)**
Building knowledge	Acquisition	Knowledge generation	Knowledge creation and acquisition
Holding knowledge	Refinement	Knowledge codification	Knowledge organisation and metadata creation
Pool knowledge	Store/Retrieve	Knowledge coordination	Knowledge repository management
Use knowledge	Distribution	Knowledge transfer	Knowledge use and right management
	Presentation/Usage		Knowledge integration and discovery
			Knowledge distribution and promotion

Table 2.6 Knowledge management processes

Wiig (1993) suggested four main processes to describe how knowledge is created and used.

i. Knowledge building covers five activities. Firstly, knowledge gain can happen by three major ways: creating new knowledge through individuals' experimentation; importing knowledge from existing sources; and acquiring knowledge from media. Secondly, knowledge analysis represents extracting what appears to be knowledge from obtained sources. Thirdly, knowledge reconstruction is composed of the generalisation of analysed material to obtain broader principles, the generation of hypotheses to explain observations, the establishment of conformance between existing and new knowledge, and the update of total knowledge by incorporating new knowledge. Fourthly, knowledge codification and modelling refers to the representation of knowledge in individuals, the collection of knowledge into a coherent model, the documentation of knowledge in media, and encoding knowledge into a repository. Finally, knowledge organisation is the organisation of knowledge for specific uses and frameworks such as an organisation's standards.
ii. Knowledge can be held in many forms such as remembered in individuals' heads, embedded in processes or encoded and added in knowledge bases. Out-of-date knowledge or, less frequently, future retrieval knowledge might be archived in a library.
iii. Knowledge pool is another process which consists of knowledge coordination and gathering, including access and retrieval. Knowledge coordination normally requires the formation of collaborative teams to work together in particular tasks in order to identify a knowledge directory. Then, it is gathered into references such as in a library or repository. Afterwards, knowledge access and retrieval addresses being able to consult with experts.
iv. Knowledge utilisation happens in various ways for different purposes such as using knowledge to describe the situation, to perform routine tasks or to decide what to do.

Similarly, Meyer and Zack (1996) suggested five steps for managing knowledge which are primarily from the design and development of information products. Firstly, knowledge acquisition addresses issues regarding the sources of raw materials. Secondly, knowledge refinement is the main source of added value by creating more usable knowledge objects and by storing more flexible content for future use. It might be physical, such as the migration of knowledge migrating from one medium to another, or logical such as restructuring, relabelling, indexing, and integration. Refinement also refers to cleaning up or standardisation. Thirdly, storage and retrieval is a bridge between upstream acquisition and refinement stages that feed the repository and downstream stages of product generation. Storage may be physical (printed information) or digital (databases). Fourthly, distribution describes how the product is delivery to end users.

This agrees with the four broad processes suggested by Davenport and Prusak (1998).

i. Knowledge generation describes activities to increase the stock of organisational knowledge. Buying is one of the most direct and effective ways to acquire knowledge. However, the change of context might have effects on the acceptance and absorption of the acquired knowledge. Knowledge can also be acquired by the separation of units in an organisation to provide freedom to explore ideas. However, the organisation must ensure that knowledge is generated by dedicating resources throughout the organisation. Another way is the collaboration of actors who have different knowledge to generate creative innovation. Since different actors have different perspectives, they need to combine their existing knowledge in new ways or develop new and common knowledge together. Thus, the sharing of different languages and meanings to understand each other is important for collaboration and working together. Knowledge adaptation is another way to generate knowledge which is a result of organisational adaptation to significant changes or employment of people who have openness to learn new skills and can acquire new knowledge quickly. However, it is difficult to change something which has worked or is still working.

ii. Knowledge codification refers to the change of knowledge into a form which makes it easy to understand and access by the end users who need it. Davenport and Prusak (1998) suggested that managers need to decide organisational goals, and then identify existing knowledge to reach the goals. Managers also need to evaluate knowledge for usefulness and appropriateness. Codifiers must identify an appropriate medium for knowledge codification and distribution.

iii. Finding knowledge sources, which need to be codified, is important. If organisations cannot identify their knowledge sources, they cannot do anything with them. The codification of tacit knowledge is generally limited by the location of the knowledge sources. A seeker needs help to locate these knowledge sources and needs encouragement to interact with them. Therefore, knowledge coordination is required to map knowledge sources in order to guide important knowledge in organisations.

iv. Much tacit knowledge is often transferred through social interaction Thus, organisations should provide spaces to open opportunities for meeting and sharing knowledge. Moreover, knowledge transfer barriers should be considered such as different cultures, lack of time, and lack of absorptive capacity in recipients or belief that knowledge is the prerogative of particular individuals or groups.

Bedford (2004) suggested six processes with clear labels. Firstly, knowledge creation and acquisition covers a wide range of activities: knowledge selection, capture, representation, transformation, review, edit, versioning, translation, and formation. Secondly, knowledge organisation and metadata creation refers to: content analysis, description, cataloguing, classification, indexing, and abstracting. Thirdly, knowledge repository management includes the registration and storage of knowledge sources which may include both content and metadata repositories. Fourthly, knowledge utilisation and right management refers to the definition and application of security classification, use parameters, disclosure, and copyright structures to knowledge content. Knowledge integration and discovery represents knowledge searching and retrieval. It might include the design of parametric search systems, browse and navigation structures, thesaurus design and vocabulary crosswalks, including cross-source topic maps and ontology development. Finally, knowledge distribution and promotion includes knowledge aggregation, repurposing, sharing, syndication, and personalisation.

According to the models of knowledge management process mentioned above, there are many different processes which are labelled differently by different authors. However, some labels that appear different refer to similar processes. For instance, the knowledge refinement of Meyer and Zack (1996) is similar to the knowledge organisation and metadata creation of Bedford (2004). Table 2.7 below presents the association of the four different models of knowledge management processes which have been described above. The different knowledge management processes could be grouped into six main processes: knowledge acquisition, refinement, repository, integration, sharing, and utilisation.

Bedford (2004)	**Meyer and Zack (1996)**	**Davenport and Prusak (1998)**	**Wiig (1993)**
Knowledge creation and acquisition	Acquisition	Knowledge generation	Building knowledge
Knowledge organisation and metadata creation	Refinement	Knowledge codification	
Knowledge repository management	Store/Retrieve		Holding knowledge
Knowledge integration and discovery		Knowledge coordination	Pool knowledge
Knowledge distribution and promotion	Distribution	Knowledge transfer	
Knowledge use and right management	Presentation/ Usage		Use knowledge

Table 2.7 Mapping of knowledge management processes

i. Knowledge acquisition, which Bedford (2004) called knowledge creation and acquisition, Meyer and Zack (1996) called acquisition, Davenport and Prusak (1998) called knowledge generation, and Wiig (1993) called knowledge building, refers to activities of increasing organisational knowledge stock. Most authors indicated that this process starts with the selection of the required knowledge. However, Liebowitz and Beckman (1998) argued that before the selection of required knowledge takes place, people should first identify their needed knowledge and assess their existing levels of expertise and then follow this with knowledge selection and capture/creation. Davenport and Prusak (1998) and Wiig (1993) suggested many ways to increase organisational knowledge stock. Davenport and Prusak (1998) suggested ways to capture both individuals' and (inside or outside) organisations' knowledge such as buying knowledge, renting experts, and creating a special unit.

ii. The second stage is knowledge refinement, which Bedford (2004) called knowledge organisation and metadata creation, Meyer and Zack (1996) called refinement, and Davenport and Prusak (1998) called knowledge codification. For Wiig (1993), this stage is included in the stage of knowledge building. Knowledge refinement refers to the activities of knowledge codification and organisation: topic analysis, description, cleaning, standardisation, cataloguing, classification, indexing, and abstracting, into a form which increases accessibility.

iii. The next stage is knowledge repository, which Bedford (2004) called knowledge repository management, Meyer and Zack (1996) called store/retrieve, Davenport and Prusak (1998) called knowledge codification, and Wiig (1993) called knowledge holding. This stage deals with the storing of knowledge sources (both knowledge content and metadata in physical or digital formats). Wiig (1993) argued that not all knowledge, especially tacit knowledge, can be encoded and kept in knowledge bases or archived in libraries. It can reside in people's minds and be embedded in processes, technologies or methods.

iv. Knowledge integration, which Bedford (2004) called knowledge integration and discovery, Meyer and Zack (1996) called store/retrieve, Davenport and Prusak (1998) called knowledge coordination, and Wiig (1993) called knowledge pooling, concentrates on the processes of knowledge searching, accessing, and retrieval. It might include design of parametric search systems, browse and navigation structures, thesaurus design and vocabulary crosswalks, including cross-source topic maps and ontology development (Bedford, 2004).

v. Another stage is knowledge sharing, which Bedford (2004) called knowledge distribution and promotion, Meyer and Zack (1996) called distribution, Davenport and Prusak (1998) called knowledge transfer, and Wiig (1993) called pool knowledge. This stage is related to knowledge distribution and sharing. In other words, it focuses on the activities of aggregation, coordination, communication, sharing, and transferring knowledge from one (or more) person or place to another person or place.

vi. The final step is knowledge use, which Bedford (2004) called knowledge use and right management, Meyer and Zack (1996) called presentation, and Wiig (1993) called knowledge use. It refers to the utilisation of knowledge to achieve goals such as repeating or avoiding the processes of past successes or failures to complete current tasks, solving existing problems, developing new ideas, or decision-making. As knowledge is regarded as an organisational asset, Bedford (2004) thus highlighted the issue of right management to secure the use of knowledge for qualified people.

Focusing on the knowledge sharing process, there is considerable literature on the subject of knowledge sharing, knowledge transfer, and knowledge exchange. These terms are often considered to be interchangeable in the literature such as in Paraponaris and Sigal (2015), Chen, Sun and McQueen (2010), Wei, Stankosky, Calabrese and Lu (2008), Koenig and Srikantaiah (2004), Al-Hawamdeh (2003), and Ford and Chan (2003). However, knowledge sharing differs from knowledge transfer and knowledge exchange (Wang and Noe, 2010; Boyd, Ragsdell and Oppenheim, 2007) (see Figure 2.1 below for comparison of the knowledge flows of knowledge sharing, transfer, and exchange).

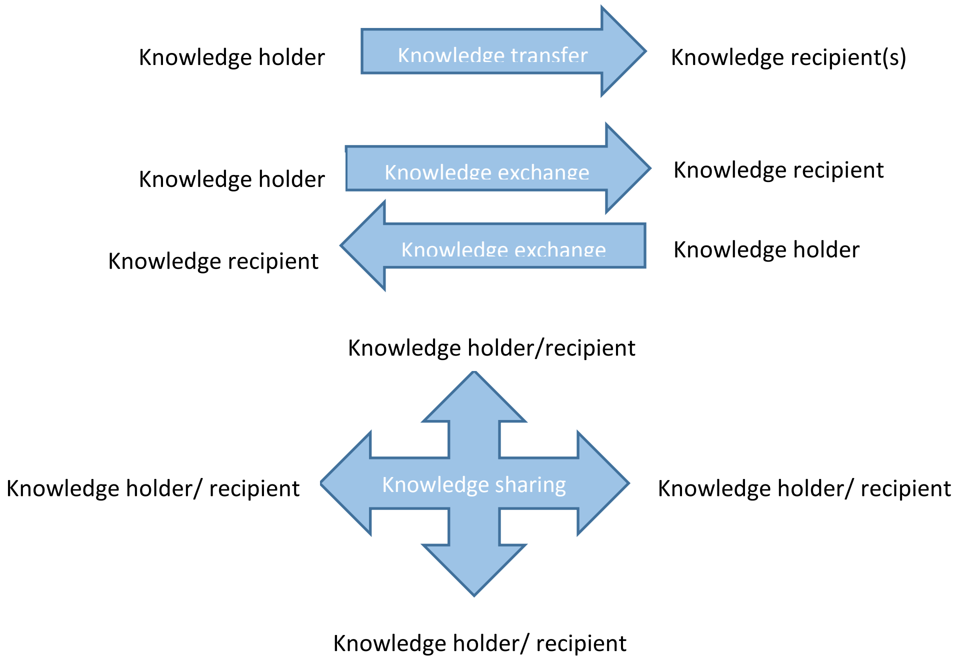


Figure 2.1 Knowledge flows of knowledge transfer, exchange, and sharing

Adapted from: Boyd, Ragsdell and Oppenheim (2007, p.140)

Knowledge sharing can be seen as the communication of knowledge which occurs when individuals are willing to assist and learn from one another in the development of new or existing knowledge (Boyd, Ragsdell and Oppenheim, 2007; Davenport and Prusak, 1998; Nonaka, 1994). Knowledge sharing provides knowledge that people are looking for about what activities are required to achieve their objectives. It also provides perceptions about how those activities should be performed to achieve the objectives (Dalkir, 2005; Fong and Lo, 2005; Gasson, 2005a).

Boyd, Ragsdell and Oppenheim (2007) depicted that knowledge exchange is the imparting of knowledge for something in return; knowledge transfer is about applying existing knowledge from one context to another context. The knowledge exchange and knowledge transfer processes are involuntary. That is, a knowledge holder may be asked to exchange and transfer their knowledge to other people or places, and which the knowledge holder is not motivated to do via contract and training (Boyd, Ragsdell and Oppenheim, 2007). However, the knowledge transfer process can sometimes be voluntary when the holder is motivated and wants to transfer knowledge to other people (Boyd, Ragsdell and Oppenheim, 2007).

Some authors used the term knowledge sharing to represent the distribution of knowledge from one person, group or organisation as a source to another person, group or organisation as a destination (Bedford, 2004; Syed-Ikhsan and Rowland, 2004; Liebowitz and Beckman, 1998). Such a definition seems to be equivalent to the knowledge flow of knowledge exchange and knowledge transfer in Boyd, Ragsdell and Oppenheim's (2007) perspective. However, Boyd, Ragsdell and Oppenheim (2007) depicted that the knowledge flow of knowledge transfer is one directional, from a knowledge holder to a knowledge recipient(s). The flow of knowledge exchange is bi-directional, but in general there is only one recipient, and is carried out in two different ways (Boyd, Ragsdell and Oppenheim, 2007). By contrast, the flow of knowledge sharing is dynamic and involves two-way communication between all knowledge holders and all knowledge recipients; an individual can be both a holder and a recipient at the same time (Boyd, Ragsdell and Oppenheim, 2007).

2.4. Contextual aspects of knowledge management

This section presents the major contextual aspects of knowledge management, which covers knowledge sharing, which have been mentioned in the knowledge management literature. In the earliest stage, much of the knowledge management literature mainly focused on information and communication technology to facilitate knowledge capture, storage, and sharing (Koenig and Srikantaiah, 2004; Mertins, Heisig and Vorbeck, 2003). This might be because most researchers and practitioners perceived that people will be willing to share their knowledge and all knowledge can be converted into a concrete form and shared via information and communication technology (Hislop, 2013). However, a number of knowledge management research initiatives have consistently exposed that not all knowledge can be codified and converted into a tangible form to share with other people via information technologies (Andreu and Sieber, 2005; Riege, 2005; Davenport and Prusak, 1998). Main barriers to success in knowledge management are: lack of consideration about the nature of knowledge which is highly tacit, context-specific, and localised in nature; and people's attitudes, behaviour and motivation, including social and cultural factors (Chen, Sun and McQueen, 2010; Tong and Mitra, 2009; Wei, Stankosky, Calabrese and Lu, 2008; Andreu and Sieber, 2005; Ford and Chan, 2003; Davenport and Prusak, 1998). Consequently, social community processes, social networks, social interactions, and trust are often indicated and required for effective knowledge management (Swan, Newell, Scarbrough and Hislop, 1999; Davenport and Prusak, 1998; Blackler, 1995; Nonaka, 1994; Wiig, 1993).

According to the literature on knowledge management, knowledge management has been studied in many various ways which could be categorised into five major areas: organisational context; interpersonal and team characteristics; cultural characteristics; individual characteristics; and motivation factors.

i. Organisational context

A number of authors have studied the organisational context in knowledge management, especially for: management support; rewards and incentives; and organisational structure, including organisational culture and climate. Management support has been identified as an important factor in knowledge management. Ajmal, Kekale and Takala (2009), for instance, reviewed some previous theoretical findings on organisational culture and knowledge management, and argued that moral and budgetary support from top management is essential for knowledge management success. They suggested two things that top management could do to facilitate this: provide sufficient resources for knowledge management activities; and create a no-blame culture to make people feel confident that there are no unfavourable consequences of openness. Similarly, Al-Adaileh and Al-Atawi (2010) investigated the impact of a number of organisational culture attributes on knowledge management within the largest telecommunications company in the Middle East. The findings indicated that the commitment of top management to create an appropriate environment for sharing knowledge is one of the most important organisational culture attributes.

Some scholars have investigated rewards and incentives (such as rewards, recognition, promotion, and higher salary) to encourage knowledge management. Many studies have suggested that rewards and incentives have effects on employees' attitudes and behaviour in knowledge sharing (Seba and Rowley, 2010; Wei, Stankosky, Calabrese and Lu, 2008; Al-Alawi, Al-Marzooqi and Mohammed, 2007). For instance, Syed-Ikhsan and Rowland (2004) found that employees need a strong motivator to share their knowledge with another employee. Similarly, Al-Alawi, Al-Marzooqi and Mohammed (2007) suggested that it is not sufficient to rely solely on the good intentions of staff to share their knowledge without motivating them. This is because unrewarded behaviours usually end up fading away due to lack of praise and appreciation. However, knowledge sharing rewards and incentives must be properly designed to be appropriate to employees' needs and perceptions (Seba and Rowley, 2010). For instance, Seba and Rowley (2010) indicated that knowledge sharing rewards and incentives in the public sector are likely to be intrinsic (respect) rather extrinsic (monetary).

Organisational structure has been identified as a key factor which has a strong impact on knowledge management (Riege, 2005). A number of studies have suggested that knowledge management works best within a flexible organisational structure that supports ease of knowledge flow, collaboration, communication, communities of practices, and cooperation between entities (Al-Alawi, Al-Marzooqi and Mohammed, 2007; Syed-Ikhsan and Rowland, 2004). Seba and Rowley (2010), for instance, argued that the traditional and hierarchical organisational structure inhibited and decelerated communication, cooperation, and knowledge sharing across functions in the Dubai Police Force. That is, different departments and units in the Force had a specific role and responsibility to complete tasks associated with that role without contact with people in other departments. Consequently, there were fewer opportunities to contact and communicate with other departments to share knowledge (see Section 2.4.1 for knowledge management in the public sector).

Organisational culture is another topic that has been mainly studied in the organisational context. Ajmal, Kekale and Takala (2009) indicated that organisational culture has significant influences on the knowledge management capability of an organisation. A number of organisational cultural aspects have been investigated, but the role of trust has attracted special research attention. Much of the existing literature has investigated how trust encourages effective group working and interpersonal interaction (Al-Adaileh and Al-Atawi, 2010; Seba and Rowley, 2010; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Hall and Goody, 2007; Riege, 2005; Newell and Swan, 2000). These scholars suggested that a lack of trust between individuals and groups is likely to inhibit the willingness of people to share their knowledge with other people. Newell and Swan (2000) indicated that perceptions of trust are important when selecting members of inter-university and multi-disciplinary research teams that need to share knowledge. Newell and Swan (2000) also indicated that communication and interaction on their own do not guarantee the development of trust among researchers who have very different perspectives.

Many scholars have studied the role of technologies, especially Web 2.0 technologies, to manage and share knowledge (e.g. Razmerita and Kirchner, 2011; Grace, 2009; Paroutis and Saleh, 2009). Grace (2009) proposed a framework as a guide for organisations to use and implement Wikis as a knowledge management tool. Razmerita and Kirchner (2011) examined the use of Wikis to collaborate, manage knowledge, and support daily practice in an IT consulting company. The findings suggested that Wikis play a crucial role to support cooperative work. Moreover, the findings suggested that management support and organisational culture are important factors to encourage knowledge sharing culture and to create a sense of community among employees. It also encourages employees to contribute new project solutions to the Wiki system. This suggests the relationships between different factors of the organisational context such as management support and organisational culture in knowledge management. Paroutis and Saleh (2009) investigated key determinants of the use of Web 2.0 technologies for sharing knowledge in a multinational technology and services corporation. The findings suggested four key determinants of knowledge sharing and collaboration by using Web 2.0 technologies: the old/established way of doing things; outcome expectations; perceived management support; and trust.

ii. Interpersonal and team characteristics

Interpersonal and team characteristics are another area that has been studied in the knowledge management literature. Wang and Noe (2010), for instance, studied the characteristics of team members which have influence on knowledge sharing activities. They argued that if a team has been formed for a long time and has a high level of team relationships, the team members are more likely to share knowledge. Lilleoere and Hansen (2011), and Chen, Sun and McQueen (2010) studied the impact of differences in knowledge of team members and knowledge management and collaboration. Lilleoere and Hansen (2011) suggested that professional differences between scientists and laboratory technicians in pharmaceutical research and development organisations have an influence on knowledge management. This is because different professional groups have different objectives, personal views, and practices for joining in knowledge management activities. Thus, the acknowledgment of professional diversities in team members should be considered for cross-community knowledge management (Lilleoere and Hansen, 2011). Similarly, Chen, Sun and McQueen (2010) argued that without common language, knowledge, and understandings, individuals who have different knowledge backgrounds will neither understand nor trust one another and then people cannot share their knowledge.

iii. Cultural characteristics

A number of knowledge management studies have suggested that national culture has crucial effects on organisational culture as well as on the attitude and behaviour of employees in knowledge management initiatives (e.g. Chen, Sun and McQueen, 2010; Tong and Mitra, 2009; Wei, Stankosky, Calabrese and Lu, 2008; Sinthavalai, 2008; Yao, Kam and Chan, 2007; Riege, 2005; Yodwisitsak, 2004). The findings of these studies are presented on pages 50-51.

iv. Individual characteristics

According to Wang and Noe (2010), not many scholars have studied the role of individual characteristics in knowledge management and especially knowledge sharing. Riege (2005) reviewed and discussed three dozen potential knowledge sharing barriers. Individual barriers were one of three knowledge sharing barriers: organisational, technological, and individual barriers. Lilleoere and Hansen (2011) argued that some key barriers of knowledge sharing based on an individual level are: different backgrounds, perspectives, and motivations; different levels and disciplines of education and experience; lack of communication and interpersonal skills; lack of time and trust to share knowledge; and low awareness of the value and benefit of possessed knowledge to others, particularly fear that knowledge sharing might jeopardise someone's job or that they are giving away power.

v. Motivation factors

A number of scholars have studied factors which are motivations for managing and sharing knowledge such as: beliefs of knowledge ownership; perceived benefits and costs; and interpersonal trust and justice. For instance, when actors believed they owned knowledge, they were more likely to report that they want to participate in knowledge sharing activities with others (Wang and Noe, 2010; Jarvenpaa and Staples, 2000). Riege (2005) argued that the perceived costs that might hinder knowledge sharing are lack of time to identify colleagues or lack of expertise. Riege (2005) depicted that people normally focus on the tasks that are most beneficial to them. Time limitations could be a reason why people might potentially hoard their knowledge rather than spend time sharing knowledge with others. Consequently, organisations need to offer sufficient space to allow staff to take the time to generate and share knowledge, as well as to identify those who may be interested in knowledge sharing.

Trust and justice have been identified as key components and motivation for interpersonal relationships in knowledge sharing (Newell and Swan, 2000; Davenport and Prusak, 1998). Riege (2005) argued that the level of trust between individuals seems to have a direct influence on the communication flow and the amount of knowledge sharing between individuals. Knowledge sharing is related to providing knowledge which is often regarded as an asset from one (or more) person(s) to another person. Most people are unlikely to share their knowledge without a feeling of trust (Riege, 2005). Therefore, knowledge sharing often occurs in informal networks where people trust each other, voluntarily share knowledge and insights with each other, and collaborate actively.

2.4.1. Knowledge management in the public sector

Cong and Pandya (2003), and McAdam and Reid (2000) argued that most public sector organisations tend to adopt new management philosophies, tools, and techniques such as Enterprise Resource Planning (ERP) and Total Quality Management (TQM) including knowledge management, from private sector organisations. Similarly, Yao, Kam and Chan (2007) argued that government organisations have grown stronger by learning practices from private companies to manage knowledge better.

Knowledge management has received attention in public organisations for a number of reasons. However, there are two main broad drivers for adopting knowledge management in the public sector. Firstly, most public sector organisations believe that knowledge management can help to improve the quality and effectiveness of work (Seba and Rowley, 2010; Yao, Kam and Chan, 2007; Cong and Pandya, 2003; McAdam and Reid, 2000). Secondly, they believe that knowledge management can help to deliver better and more cost-effective services and higher levels of responsiveness to the public (Seba and Rowley, 2010; McAdam and Reid, 2000).

Focusing on competitive pressure, many public sector organisations, especially governmental research organisations and universities, face competition and challenges both at international and national levels. At the international level, for instance, governmental research organisations have to compete with other foreign organisations which deliver similar services and products in order to attract maximum funding and investments. At the national level, for example, private companies produce services and products that directly compete with public organisations such as education. Customers who receive more customisation from private companies might expect similar benefits from public organisations (Cong and Pandya, 2003).

Many public organisations are asked to do more through cost-effective services and a higher level of responsiveness to the public (Seba and Rowley, 2010; Numprasertchai and Igel, 2005; McAdam and Reid, 2000). For instance, both universities and research organisations were encouraged to contribute more knowledge-intensive commercial activities and industrial problem solving (Jahn, Bergmann and Keil, 2012; Numprasertchai and Igel, 2005). Numprasertchai and Igel (2005) indicated that cross-community knowledge management and collaboration is an efficient strategy to acquire missing in-house resources. It helped to reduce costs and time pressures. It also helped to create new knowledge, improve research capability, and increase the potential and quality of work for academic research units, especially in developing countries.

There are many challenges for managing knowledge in the public sector. One of the biggest challenges facing knowledge management in the public sector is response to the requirements of stakeholders from multiple parties in the decision-making processes and activities of public sector organisations (Amayah, 2013; Jahn, Bergmann and Keil, 2012; Adel and Shaghayegh, 2010; Seba and Rowley, 2010; Willem and Buelens, 2007; Yao, Kam and Chan, 2007; Cong and Pandya, 2003). When governments have to make policy decisions or deliver services, consideration must be taken of the interests of stakeholders which are a range of parties such as citizens, state and local governments, private companies, and users (Willem and Buelens, 2007). By contrast, private sector organisations are mainly responsible to their shareholders by providing returns on their investments to them (Adel and Shaghayegh, 2010; Cong and Pandya, 2003). Such differences have effects on knowledge management activities. Yao, Kam and Chan (2007), for instance, argued that the public sector tends to share knowledge to decrease public frustration and employee dissatisfaction as well as to fulfil their mission of social service. By contrast, the private sector tends to share knowledge to improve operational efficiency, sales and profits growth, cost savings, innovation, and bottom-line profits. Another challenge facing knowledge management in the public sector is its specific organisational structures; e.g. the cloistered bureaucratic cultures found within hierarchical organisational structures. Many scholars have suggested these have negative effects on knowledge management and knowledge sharing in public organisations, as will be explained below (Chong, Salleh, Ahmad and Sharifuddin, 2011; Seba and Rowley, 2010; Akhavan, Hosnavi and

Sanjaghi, 2009; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Yao, Kam and Chan, 2007; O'Riordan, 2005; Syed-Ikhsan and Rowland, 2004). Due to the public sector being organisationally specific, a number of studies have suggested that there is a need to develop knowledge management practices, tools, and models that have been developed with consideration of their context (Massaro, Dumay and Garlatti, 2015; Ajay and Hans, 2013; Adel and Shaghayegh, 2010; Ermine, 2010; Cong and Pandya, 2003).

Many scholars have studied critical factors for knowledge management in public sector organisations (e.g. Amayah, 2013; Seba, Rowley and Delbridge, 2012; Chen, Sun and McQueen, 2010; Seba and Rowley, 2010; Akhavan, Hosnavi and Sanjaghi, 2009; Tong and Mitra, 2009; Wei, Stankosky, Calabrese and Lu, 2008; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Willem and Buelens, 2007; Yao, Kam and Chan, 2007; Pardo, Cresswell, Thompson and Zhang, 2006; Numprasertchai and Igel, 2005; Riege, 2005; Syed-Ikhsan and Rowland, 2004; Cong and Pandya, 2003; Newell and Swan, 2000). Organisational structure is one of the crucial factors for managing knowledge in the public sector as has been mentioned by many scholars. Some scholars have suggested that there are many limitations being experienced by public sector organisations which are related to an organisational structure that does not support knowledge management. More specifically, the centralisation, formalisation, and hierarchical organisational structure of many governmental organisations does not support knowledge management, especially knowledge sharing initiatives (Seba and Rowley, 2010; Akhavan, Hosnavi and Sanjaghi, 2009; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Syed-Ikhsan and Rowland, 2004). Seba and Rowley (2010), for instance, argued that communication and knowledge sharing across the traditional and hierarchical organisational structure in the Dubai Police Force inhibited and decelerated communication, cooperation, and knowledge sharing across functions in the Force. Similarly, Akhavan, Hosnavi and Sanjaghi (2009) studied critical success factors in the academic research context, and then suggested the organisational structure needs to be flexible to prepare the way for exploiting individuals' knowledge.

Many scholars have suggested that trust is one of the most important keys for knowledge sharing in the public sector (Seba and Rowley, 2010; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Willem and Buelens, 2007; Pardo, Cresswell, Thompson and Zhang, 2006; Numprasertchai and Igel, 2005; Riege, 2005; Newell and Swan, 2000). They suggested that lack of trust between individuals and groups is likely to inhibit their willingness to share knowledge with other people. Pardo, Cresswell, Thompson and Zhang (2006), for instance, suggested that trust encouraged two separate networks in public sector organisations to participate in information technology innovation projects in New York State. Higher levels of trust provided a basis for consensus building, learning, and practice changes (Pardo, Cresswell, Thompson and Zhang, 2006). Wei, Stankosky, Calabrese and Lu (2008) indicated trust is related to organisational commitment. That is, the degree to which trust is placed in organisations by their employees is one of the main factors to underpin the level of their organisational commitment. Wei, Stankosky, Calabrese and Lu (2008) also suggested that the level of commitment which employees gave to their organisations has an impact on individuals' knowledge sharing attitudes and behaviours. Similarly, Numprasertchai and Igel (2005) argued that a main success factor of cross-community collaboration is commitment. However, Amayah (2013) surveyed 1,738 employees at a public academic institution in the Midwest. The findings indicated that trust is not a significant predictor of people's willingness to share knowledge. He argued that most public sector employees are unwilling to share knowledge with colleagues, because they tend to believe that knowledge sharing leads to loss of power. If the knowledge which is shared is not seen as sensitive, trust might not be needed for individuals to be willing to share it (Amayah, 2013). Amayah (2013) also indicated that expected rewards are negatively related to knowledge sharing. Rewards could strain the relationship between those who win and those who do not, or that rewards weaken intrinsic motivation.

Many scholars have suggested that national culture has crucial effects on organisational culture as well as on the attitude and behaviour of employees in knowledge management initiatives, more specifically knowledge sharing activities (Chen, Sun and McQueen, 2010; Tong and Mitra, 2009; Wei, Stankosky, Calabrese and Lu, 2008; Sinthavalai, 2008; Yao, Kam and Chan, 2007; Riege, 2005; Yodwisitsak, 2004). For instance, Yao, Kam and Chan (2007) investigated how culture and attitudes affect knowledge sharing in a Hong Kong government department. The findings suggested that the collective features of Chinese culture: politeness, humbleness, shyness, and lack of confidence, prevent participants from speaking up and confronting others when different ideas are needed. Yao, Kam and Chan (2007) depicted that tacit knowledge tends to be shared among family members and colleagues with good relationships, networks, and trust, in Chinese culture. Similarly, Chen, Sun and McQueen (2010), and Tong and Mitra (2009) argued that Chinese culture has influences on the organisational culture and individuals' behaviour in knowledge sharing within the Chinese support industry and Chinese manufacturing enterprises respectively. Chen, Sun and McQueen (2010) indicated that the quality of Chinese knowledge recipients' learning and knowledge transferring is highly determined by the excellence of knowledge providers rather than the excellence of knowledge recipients as in American culture. Furthermore, Chinese knowledge providers gave a lot of information and long explanations to knowledge recipients, while American knowledge providers preferred to encourage knowledge recipients to learn something by themselves. The style of knowledge transfer that Chinese and American knowledge providers performed may reflect the relative collectivism of Chinese or Eastern culture and the individualistic nature of American or Western culture (Chen, Sun and McQueen, 2010).

Sinthavalai (2008) argued that Thai people typically preferred to work with those they have good relationships with. Thus, trust and the culture of exchange are required for knowledge sharing in Thai culture. Sinthavalai (2008) and Yodwisitsak (2004) indicated some characteristics of Thai culture have a negative impact on knowledge management. They argued that many Thai employees usually believe that people who are in higher hierarchical levels possess knowledge and experience more than others who are in lower levels. Thus, they should follow the instructions of people who are in higher levels. Furthermore, junior staff would not dare to speak out in front of senior staff because of the strong seniority culture. Yodwisitsak (2004) also argued that many Thais worry about hurting another person's feelings and take this into account together with saving face. If someone does not agree with his/her friends, he/she usually avoids giving any criticism because the person who has been criticised would have been perceived as losing face.

Some authors have suggested the support of top management is important (Amayah, 2013; Seba, Rowley and Delbridge, 2012; Akhavan, Hosnavi and Sanjaghi, 2009). They suggested that the leaders and Chief Knowledge Officers (CKO) have a responsibility for target setting, formulating strategy, and planning and evaluating the performance of knowledge management throughout an organisation. Moreover, the leadership must encourage employees to share knowledge as well as allocate time to enhance knowledge sharing among employees. Amayah (2013) argued that social interaction and the degree of courage moderate the effects of norm setting on knowledge sharing. Thus, managers in public sector organisations should encourage the development of communities of practice and social interaction to support knowledge sharing. Also, they should recognise the importance of an encouraging and supportive culture for knowledge sharing.

Another critical factor for management of knowledge in the public sector is infrastructures. For instance, Numprasertchai and Igel (2005) indicated that information and communication technology tools improved cross-community communication and collaboration in the public research context. They helped to store and share research results with others in order to reduce the time and effort needed to conduct research. However, technology should also be used to create channels to support face-to-face interaction. Similarly, Akhavan, Hosnavi and Sanjaghi (2009) suggested that knowledge storage can help both to reproduce the same knowledge and create new knowledge. Thus, the knowledge management architecture and organisational preparedness for knowledge management implementation should be in place to provide the appropriate infrastructure needed to support knowledge management activities and processes (Akhavan, Hosnavi and Sanjaghi, 2009) (see Appendix 8.1 for factors which have influences on knowledge management and knowledge sharing in public sector organisations). Having established the concepts of knowledge and knowledge management, the next sections drill down into the concepts of knowledge management and collaboration across boundaries, especially disciplinary boundaries.

2.5. Boundaries and disciplinary boundaries

There is no universally accepted definition of a boundary. According to Holford (2016), and Akkerman and Bakker (2011), boundaries could be understood as social intersections and sociocultural difference between different interacting actors. The difference leads to discontinuity of action or interaction between two (or more) different individuals, groups of individuals, or practices which are relevant to another individual, group, or practice in a particular way (Kotlarsky, Hooff and Houtman, 2015; Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Carlile, 2004, 2002; Wenger 2000; Star and Griesemer, 1989).

According to the definition of a boundary mentioned above, it is implied that boundary construction is part of knowledge (possession) and the process of knowing (action) (see Section 2.2 for the notion of knowledge). That is, boundaries arise or are constructed because of differences in the pre-existing knowledge of different participating actors. Abraham, Aier and Winter (2015, p.5) argued that the degree of difference among knowledge communities in terms of knowledge, goals, and assumptions can be expressed via the construction of knowledge boundaries. At the same time, boundary construction is a process of knowing, or the process of negotiation, between two (or more) different individuals or groups of individuals which are relevant to another individual or group in a particular way. That is, boundary construction involves interactions, activities, and work practices between two (or more) different participating actors.

Holford (2016, p.7), and Kotlarsky, Hooff and Houtman (2015, p.324) explain the relationship between boundary construction and the notion of knowledge (knowledge and knowing). Kotlarsky, Hooff and Houtman (2015, p.324) explain that once different practices meet, knowledge boundaries emerge, which are differences in knowledge that is localised, embedded and invested in different practices [knowing]. The diversity in expertise and knowledge background [knowledge] can create boundaries (Kotlarsky, Hooff and Houtman, 2015). Similarly, Holford (2016, p.7) suggests that the construction of boundaries can be viewed as being both a process of construction and an outcome. Such acts of construction can be considered as forms of situated action or knowing, while outcomes can be considered as forms of knowledge.

According to Wenger (2000), boundaries are always conceptualised as between two (or more) individuals or groups of individuals. Stokols, Hall, Taylor and Moser (2008) suggested that boundaries are to some extent arbitrarily defined and agreed upon by knowledge communities. Wenger (2000) also explained the nature of boundaries; they are dynamic, fluid, and changeable. Therefore, boundaries are invisible (Paraponaris and Sigal, 2015, p.886; Adam as cited in Hoffmann, 2012). They are not something that people can grasp like the boundaries of organisational units which are normally well defined by physical structures, but are in significant proportion activities undertaken by people (Adam as cited in Hoffmann, 2012, p.69). Boundaries may arise from different organisations (Hoffmann, 2012; Zheng, Yang, Pardo and Jiang, 2009; Pardo, Cresswell, Thompson and Zhang, 2006; Numprasertchai and Igel, 2005), different geographies (Zheng, Yang, Pardo and Jiang, 2009; Cummings and Kiesler, 2005), different functions (Gasson, 2005a; Carlile, 2004), different occupations (Bechey, 2003), different professions (Kimble, Grenier and Goglio-Primard, 2010), or different academic disciplines (Sumner and Tribe, 2007; Cummings and Kiesler, 2005).

A disciplinary boundary is one of a number of types of boundary which have been discussed in the knowledge management literature. It is a type of boundary which this research mainly attempts to study. A discipline, which is related to this study, refers to the branches of knowledge, studies, or research areas that are strongly associated with one academic field of study or learning (Macmillan Publishers, 2013; Oxford University Press, 2013; Kimble, Grenier and Goglio-Primard, 2010; Cummings and Kiesler, 2005). According to Stokols, Hall, Taylor and Moser (2008), disciplines are typically organised around distinctive important concerns (such as psychological, environmental, or sociological phenomena) and analytic levels (such as interpersonal, organisational, or community), including concepts, methods, and measures associated with particular fields (see Appendix 8.2 for academic disciplines and discipline classification systems).

Different disciplines have differences in many aspects such as ontological and epistemological approaches to problem definitions, traditions and the cultures of thought, assumptions, values, interests, interpretations, conceptual and methodological standards, analytical methods and techniques, and use of language (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Becher, 1994; Star and Griesemer, 1989; Biglan, 1973a; Kuhn, 1962). Moreover, each discipline determines, provides, and shares its framework of knowledge and concepts of theories, methods, techniques, and problems, with its members. Such differences lead to discontinuity of interaction between two (or more) actors or communities from different disciplines (Kotlarsky, Hooff and Houtman, 2015; Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Carlile, 2004, 2002; Wenger 2000; Star and Griesemer, 1989).

Kimble, Grenier and Goglio-Primard (2010), and Cummings and Kiesler (2005) suggest that the formal organisation of functions in organisations usually follows disciplines and professions. This suggests that one type of boundaries can involve or relate to another type of boundaries. For instance, disciplinary boundaries can involve or relate to functional and professional boundaries.

2.6. Boundary-spanning and cross-disciplinary boundaries

Boundary spanning or boundary crossing is a concept to describe potential forms of continuity and interaction across two (or more) different contexts and practices (Akkerman and Bakker, 2011; Bechky, 2003; Wenger, 2000). In other words, boundary spanning is used to represent how individuals may need to enter into territories in which they are unfamiliar (Akkerman and Bakker, 2011, p.134). It involves the challenge of representing, translating, negotiating, clarifying, combining, and transiting ingredients such as knowledge, competence, culture, and environment from different contexts to achieve a common goal together (Akkerman and Bakker, 2011; Carlile, 2004; Star and Griesemer, 1989).

As in the definition of boundary spanning mentioned above, the term crossing-disciplinary boundaries can be understood as a concept to describe establishing continuity and interactions as well as combining and, in some cases, integrating concepts, methods, and theories drawn from two or more different disciplines (Akkerman and Bakker, 2011; Stokols, Hall, Taylor and Moser, 2008; Bechky, 2003; Wenger, 2000).

According to the existing literature on knowledge management and boundary spanning, most studies have concentrated on boundaries within work: how individuals or groups of individuals collaborate across boundaries; what are the critical factors that facilitate or hinder cross-boundary working; and how to improve cross-boundary collaborations. The studies have mainly been undertaken in the private sector, particularly in new production development and information technology (e.g. Scarbrough, Panourgias and Nandhakumar, 2015; Zhang and Pastel, 2015; Hsu, Chu, Lin and Lo, 2014; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Kim and Jarvenpaa, 2008; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004; Bechky, 2003). It can be said that the creation or development of most new things requires many divergent competencies, experience, specialised knowledge, and perspectives from different individual professionals (Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004; Star and Griesemer, 1989). Thus, knowledge management across boundaries has received more attention in the new product development context. Four professional domains have been more investigated: technology and design (Holford, 2016; Scarbrough, Panourgias and Nandhakumar, 2015; Zhang and Pastel, 2015; Hsu, Chu, Lin and Lo, 2014; Le Dain and Merminod, 2014; Maaninen-Olsson, Kim and Jarvenpaa, 2008; Gasson, 2005b; Levina and Vaast, 2005; Carlile, 2004; Bechky, 2003; Carlile, 2002); science and academia (Star and Griesemer, 1989); healthcare (Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Kim and Jarvenpaa, 2008); and general and other specific work domains (Kim and Jarvenpaa, 2008; Fong, Srinivasan and Valerdi, 2007; Gasson, 2005a; Gal, Yoo and Boland, 2004). Carlile (2004, 2002) is one of the key contributors to the topic of cross-community knowledge management. He proposed a model for management of knowledge across boundaries, which will be explained in Section 2.7 below.

2.6.1. Boundary-spanning and learning

Based on learning theory on communities of practice developed by Wenger (2000), differences are appreciated as a resource rather than a barrier for learning to maintain individual dynamism. Wenger (2000, p.233) argued that boundaries are important for learning by connecting communities and offering learning opportunities in their own right. According to Wenger (2000), and Grant (1996), if two or more individuals or groups have the same competence, experience, and specialised knowledge, not much learning is likely to happen. Consequently, the community is losing its dynamism and the practice is in danger of becoming stale. By contrast, if the individuals or groups have entirely separate competences, experience, and specialised knowledge, not much learning is likely to happen either.

Akkerman and Bakker (2011) reviewed 181 studies related to boundary-crossing and boundary objects in ERIC and PsycINFO databases between 2008 and 2010. They proposed four dialogical learning mechanisms that can occur at boundaries: identification, coordination, reflection, and transformation, to present various ways of learning at boundaries.

i. Identification refers to coming to know what the diverse practices are about in relation to one another. The potential in identification resides in encountering and reconstructing the boundary. Two common processes of identification are contesting and legitimating coexistence. Contesting refers to determining how one practice differs from another practice. By contrast, legitimating coexistence focuses on how actors have to consider the interference between their multiple participations to be able to pursue each one and be accepted in this multiple membership by others.

ii. Coordination refers to creating cooperation and exchange between diverse practices. The potential in coordination resides in establishing continuity and facilitating future movement between different practices. Four processes of coordination across boundaries are identified: establishing a communicative connection between diverse practices; efforts of translation between different groups; enhancing boundary permeability which may be increased by repeatedly crossing different practices; and reutilisation, which is finding procedures by means of which coordination is becoming operational practice.

iii. Reflection is expanding one’s perspectives on the practices. Reflection emphasises making explicit one’s knowledge and understanding of particular issues as well as looking at oneself through the eyes of other worlds. Lack of reflection can result in misunderstandings.

iv. Transformation refers to collaboration and co-development which leads to changes in practices. Transformation entails the emergence of new in-between practices. It is involved in confrontation which entails some difficulty that forces the intersecting worlds to reconsider their current practices and interrelations. It is also involved in recognizing a shared problem space which is the recurrent interactional breakdown that needs to be solved as well as combining ingredients from different contexts into something new such as a new practice, a new tool, and new concepts in a new cultural form. However, transformation can be related to the process of maintaining the uniqueness of the intersecting practices or integrity of the familiar field. The crystallisation or reification of what is created or learned is another process that is found in transformation. Crystallisation can occur by means of the development of boundary objectives, new routines or new procedures. The different processes of transformation present how difficult it is to achieve.

2.6.2. Types of cross-disciplinary collaboration

There are many prefixes attached to the word disciplinary. Each term has a distinctive meaning and concept, but some terms are often used interchangeably. Five terms which are attached to the word disciplinary and are commonly found in the literature are: intra-disciplinary, cross-disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary.

Intra-disciplinary is a process in which actors from a single discipline work together within a single discipline and using the same set of methods and a shared approach (Alexarje, 2012; Stokols, Hall, Taylor and Moser, 2008). By contrast, cross-disciplinary refers to work in more than one discipline achieved by combining and, in some cases, by integrating concepts, methods, and theories drawn from two or more disciplines (Stock and Burton, 2011; Zheng, Yang, Pardo and Jiang, 2009; Stokols, Hall, Taylor and Moser, 2008; Sumner and Tribe, 2007). Three different approaches to cross-disciplinary collaboration which are commonly found and can be sorted based on the levels of interaction are multidisciplinary, interdisciplinary, and transdisciplinary (see Figure 2.2 below). However, there is no universally accepted definition for these three approaches. Alexarje (2012), and Jahn, Bergmann and Keil (2012) argued that lack of a universally accepted definition for each form of cross-disciplinary collaboration leads to ambiguity of meaning and lack of approved standards for guiding cross-disciplinary researchers and research projects. Consequently, researchers lack knowledge and understandings about which problems and challenges can occur in cross-disciplinary collaboration. Underestimation of the true challenges of each cross-disciplinary approach might thus occur. According to the existing literature, three forms of cross-disciplinary collaboration can be understood as in the following.

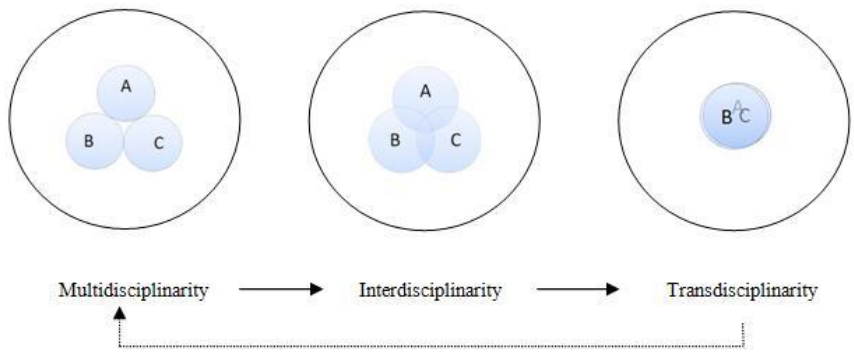


Figure 2.2 Diagrammatic presentation of cross-disciplinary

Adapted from: Alexarje (2012)

i. A multidisciplinary approach refers to work in which scholars from disparate disciplines do their best by undertaking a project based on their disciplinary knowledge and perspectives (Stock and Burton, 2011; Sumner and Tribe, 2007). The scholars work on a project independently or sequentially, periodically coming together to provide their individual perspectives and the findings for purposes of achieving broader-gauged analyses of common research problems (Stock and Burton, 2011; Stokols, Hall, Taylor and Moser, 2008). Thus, the level of internal communication is very low (Van den Besselaar and Heimeriks, 2001).
ii. An interdisciplinary approach is a step further towards integration rather than co-existence (Stock and Burton, 2011; Sumner and Tribe, 2007). In this approach, the areas of intersection between disciplines are investigated by scholars from two or more disciplines (Russell, Wickson and Carew, 2008). The scholars attempt to combine concepts and methods drawn from their disciplines. They attempt to work more intensively to integrate their different perspectives, even while remaining anchored in their own disciplines (Stokols, Hall, Taylor and Moser, 2008). All scholars co-create their own theory, concept, knowledge, method, and new solutions from the beginning and throughout the research practice to a problem based on social interactions, coordinated activities, and communication (Alexarje, 2012; Pratt, 2012; Sumner and Tribe, 2007; Rogerson and Strean, 2006).
iii. A transdisciplinary approach is an extension of an interdisciplinary approach in which boundaries between disciplines become blurred (Pratt, 2012), transgressed or transcended (Jahn, Bergmann and Keil, 2012; Russell, Wickson and Carew, 2008). A transdisciplinary approach is the creation of a unity of intellectual frameworks

thought of as the union of all interdisciplinary efforts or the complete integration of two or more disciplines with the possibility of forming a new discipline (Stock and Burton, 2011; Sumner and Tribe, 2007). Jahn, Bergmann and Keil (2012, p.7) suggested a multi-dimensional perspective of integration by distinguishing between three levels: epistemic, social-organisational, and communicative levels. For the epistemic level, different bodies of knowledge have to be demarcated. For the social-organisational level, different interests or activities of participating actors have to be explicated and connected or reconciled. For the communicative level, different means of linguistic expression and communicative practice have to be differentiated and related or synthesised in order to establish a common language that advances mutual understanding and agreement.

2.7. Model for managing knowledge across boundaries

Cross-boundary collaboration has been acknowledged as an important tool to survive, compete, and grow in the complex, dynamic, and multifaceted environment of the knowledge economy and globalisation (see Section 2.1 for the importance of cross-community collaboration). However, not many authors have explored the systematic differentiation of the different types of knowledge boundaries that can exist, how the nature of these boundaries affects the nature of cross-community collaboration and knowledge processes (Hislop, 2013, p.179), and how knowledge can be managed across these boundaries. Carlile (2004, 2002) is one of the key contributors to the topic of knowledge management across boundaries. He examined how knowledge is managed across different knowledge domains and functions that are dependent on each other in new product development in the industrial context. Then, he proposed a linear three-tier model for managing knowledge across boundaries, which will be explained below. Carlile (2002, p.442) argued that in cross-boundary collaboration, knowledge is not only the key ingredient of, but also the key barrier to, new product development. That is, the characteristics of knowledge for problem solving within a boundary actually hinder problem solving and knowledge management across boundaries.

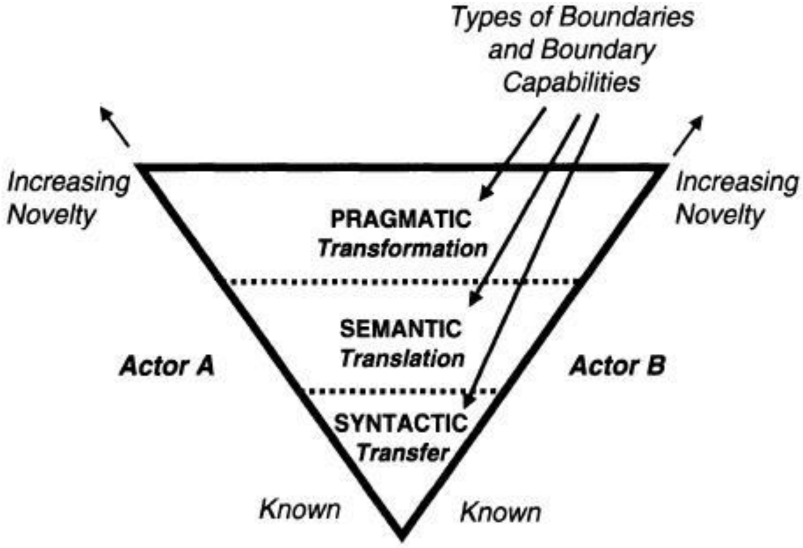


Figure 2.3 Framework for managing knowledge across boundaries

Source: Carlile (2004, p.558)

Carlile's model (Figure 2.3 above) presents three increasingly complex knowledge boundaries: namely syntactic, semantic, and pragmatic boundaries; as well as three increasingly complex processes to overcome them: transfer, translation, and transformation that can occur in cross-boundary collaboration. Carlile used the image of the vector and hierarchical representation to recognise moving up in complexity of knowledge management across boundaries. However, the process or capacity at a more complex boundary still requires the processes and capacities of those below it. Scaling the complexity of the situations at a boundary starts at the origin where differences and dependencies in knowledge between interacting actors are known; as novelty in knowledge increases the vector spreads, scaling the increasing complexity and the amount of effort required to manage the boundary.

More specifically, Carlile (2004, 2002) suggested three relational properties of knowledge at a boundary: difference, dependence, and novelty, to explain challenges that can occur when managing knowledge across boundaries. Difference in knowledge refers to a difference in the amount of knowledge and type of specialised knowledge collected by interacting actors. Dependence refers to a condition where two (or more) interacting actors must look at each other if they need to meet their common goal together. The key challenge of the properties of knowledge at a boundary is the novelty of each interacting actor. Novelty occurs when an interacting actor is unfamiliar with the common knowledge being used to represent the differences and dependencies between specialised knowledge. When novelty increases, there is often a lack of common knowledge to manage knowledge at a boundary. The different degrees or levels of the properties of knowledge at a boundary create the development of three knowledge boundaries: syntactic (language), semantic (meaning), and pragmatic (interest) boundaries.

i. A syntactic boundary is faced at the bottom of an inverted triangle. It occurs when knowledge can be transferred from one person or community to another different person or community. At this boundary, knowledge is perceived as an entity; that is, explicit and capable of being codified, captured, stored, retrieved, and transferred across different interacting actors and contexts. A syntactic boundary is assumed to be the easiest to work across because differences and dependencies in knowledge between different communities are known, while novelty in knowledge between different communities is low. A common language of different communities is developed that is sufficient to transfer knowledge at a syntactic boundary. Thus, this boundary is primarily concerned with information processing, the development of common language, and knowledge transfer across a boundary through syntactic capacity and taxonomies, including storage and retrieval technologies. The challenge of this boundary is increasing capacity to process more information. A common language is necessary but not always sufficient to share and assess knowledge across boundaries. When novelty occurs and makes differences and dependencies unclear that need to be identified, then another boundary is faced and an intermediate process is required.
ii. Although a common language is present, interpretations are often different in meaning on one or both sides of a boundary. It makes communication difficult and limits effective collaboration and knowledge management between interacting actors. Thus, the problem shifts from information processing or knowledge transfer to interpretation or knowledge translation across a boundary and particularly to developing common meanings to address interpretive differences. A semantic boundary links to the concept of communities of practice (Wenger, 2000). That is, members of different communities use their knowledge and expertise within particular contexts of action. Knowledge is embedded within members' skilled performances and shaped by the community's values and norms (Brown and Duguid, 1991). This knowledge is seen to be largely tacit, situated, and experiential. It is not easily codified. This boundary requires translating knowledge capability, cross-functional interactions, and brokers or translators to reconcile different

interpretations between interacting actors. However, when different interests between interacting actors are identified, developing shared meanings and creating a common meaning is not possible. Consequently, another boundary and process is faced where interacting actors negotiate and are willing to change their current knowledge and interests.

iii. A pragmatic boundary is the most complex and difficult type of boundary to work successfully across. It often occurs when interests are different and in conflict between actors. The knowledge developed in one group creates consequences in another group. At this boundary, knowledge is rooted in the accumulated experience and tacit knowledge of actors and invested in communities' ways of doing things and measure of worth. Knowledge is seen to be inseparable from actors' interests and actions in specific contexts. This boundary mainly concerns the political and power relations of knowledge transformation. Individuals represent, learn, negotiate, integrate and change the current knowledge and create new knowledge to resolve the consequences required across boundaries to work effectively together. That is, the challenge of a cross-boundary is not just communication difficulty, but also to resolve the consequences. Individuals have to be willing to change their own knowledge, and also be capable of transforming the knowledge used by others. Such processes are contested; it requires investment in time and relationship building as well as compromises in valued community practices, interests, and jurisdictions. Table 2.8 below summarizes the characteristics, conditions, capabilities, and challenges of different knowledge boundaries.

	Syntactic boundary knowledge transfer Information-processing approach	**Semantic boundary** Knowledge translation Interpretive approach	**Pragmatic boundary** Knowledge transformation Political approach
Circumstances	Differences and dependencies between actors are known Common languages are developed that are sufficient to send and receive knowledge between interacting actors from different knowledge communities at a boundary	Novelty creates some differences and dependencies that are ambiguous Common interpretations are developed to create common understandings and to provide an adequate means for sharing and assessing knowledge between interacting actors from different knowledge communities at a boundary	Novelty creates different interests between actors that hinder their ability to share and assess knowledge Common knowledge and interests are developed to transform different knowledge and interests as well as to provide an adequate means for engagement in joint problem-solving, negotiations, and trade-offs between interacting actors from different knowledge communities at a boundary
Objectives	Accurate communication	Accurate interpretation	Changing the current knowledge and creating new knowledge to resolve the consequences required

	Syntactic boundary knowledge transfer Information-processing approach	**Semantic boundary** Knowledge translation Interpretive approach	**Pragmatic boundary** Knowledge transformation Political approach
Boundary capabilities	Transferring knowledge; Syntactic capacity, taxonomies, storage and retrieval technologies	Translating knowledge; Semantic capacity, cross-functional interactions	Transforming knowledge; Pragmatic capacity, prototyping and other kinds of boundary objects that can be jointly transformed
Challenges	A common lexicon is necessary but not always sufficient to share and assess knowledge across boundary	Creating common meanings to share and assess knowledge often requires creating agreements	Creating common interests to share and assess knowledge requires practical and political effort

Table 2.8 Comparative summary of knowledge boundaries

Adapted from Carlile (2004, p.560)

Carlile (2004) suggested that though the line between each type of knowledge boundary is clearly defined, the transition where one boundary or process ends and another boundary or process starts is not often easily identified by the actors involved. Kotlarsky, Hooff and Houtman (2015) examined interdependencies between the three types of knowledge boundaries as described by Carlile. The findings suggested that these boundaries are interrelated. That is, the boundaries influence each other. For instance, differences in the use of languages (a syntactic boundary) are likely to lead to differences in the understanding of the problems (a semantic boundary) faced within different practices. Where a common language (a syntactic boundary) is not present, it will be impossible to create common meaning (a semantic boundary). Thus, this suggests that a syntactic boundary is likely to give rise to a semantic boundary.

Carlile's (2004, 2002) model corresponds to the practice-based perspective on knowledge. That is, Carlile depicted that: knowledge in new product development is localised around a set of problems faced in a given task; knowledge is embedded in the doing of the activity, experiences, and knowhow of individuals engaged in a given task; knowledge is also embedded in technologies, methods, and rules used by individuals in a given task; and knowledge is invested in methods, tasks, and particularly successes. When the value of the knowledge is developed and proven, individuals are less able and willing to change their knowledge to facilitate the knowledge developed by another that they are dependent on. This is because changing their current knowledge means an individual will have to face the time and costs of changing what they do to develop new ways of dealing with the challenges they face. Therefore, the nature of knowledge in practice makes communication and collaboration across boundaries difficult.

There are different labels for the three levels of knowledge boundaries used in Carlile's three-tier model; however, it is a common framework. They all look at and talk about different languages, meanings, and interests respectively. Similarly, Edenius, Keller and Lindblad (2010, p.136), and Kellogg, Orlikowski and Yates (2006, p.23) argued that the organisational literature on knowledge management and collaboration across boundaries can be understood in terms of three primary perspectives: (i.) the information-processing aspects, the information-processing perspective, the information-processing orientation, or the display practice; (ii.) the cultural aspects or the representation practice; and (iii.) the political aspects, the political and power perspectives, or the assembly practice.

Many scholars have adopted the three-tier model proposed by Carlile (2004, 2002) to study cross-boundary collaboration and knowledge management in a number of particular contexts. For instance, the model was adopted in new product development in the development of environmental science and technology research collaborations between: triple helix sectors (Rosenlund, Rosell and Hogland, 2017); energy and domestic appliance companies (Le Dain and Merminod, 2014); a dynamic virtual space or online communities (Farag, Jarvenpaa and Majchrzak, 2011); an emergency response organisation (Yates and Paquette, 2011); a technology company (Maaninen-Olsson, Wismen and Carlsson, 2008); healthcare research institutes and healthcare services (Kotlarsky, Hooff and Houtman, 2015; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008); a multinational bank (Feng, Ye and Pan, 2010); and engineering construction projects (Fellows and Liu, 2012). Major findings of these studies were in line with Carlile (2004, 2002). That is, there are three types of knowledge boundaries that can arise at interactions between members from different knowledge communities, as well as three processes to overcome them.

Fellows and Liu (2012), for instance, examined cross-boundary collaboration in engineering construction projects. Then, they suggested that a primary concern of boundary spanning is communication, cooperation, collaboration, and commitment through sensitivity to the different natures and goals of actors from different groups. Fellows and Liu (2012) agreed with Carlile (2004, 2002) by suggesting that management of boundaries requires common language, common processes and understandings, and recognition of own goals and of the goals of the other diverse groups. Moreover, trust and commitment helped to develop common knowledge and understandings among members from different groups in engineering construction projects. Trust and commitment were increased through long-term relationships (Fellows and Liu, 2012).

Edenius, Keller and Lindblad (2010), adopted Carlile's model (2004) to explore knowledge management across boundaries in the healthcare sector; the development and implementation of a medical quality register. The findings were in line with Carlile (2004). That is, there are three types of knowledge boundaries: syntactic; semantic; and pragmatic boundaries. At a syntactic boundary, knowledge was considered as an entity which can be codified, captured, stored, retrieved, and transferred across interacting actors and contexts. Thus, at a syntactic boundary knowledge was mainly transferred through information technologies as Carlile suggested. However, Edenius, Keller and Lindblad (2010) suggested that, in the case under consideration, knowledge was also transferred through training sessions. At a semantic boundary, boundary brokers, the creation of collective stories, and social interactions were three main boundary-spanning mechanisms employed to develop common interpretations for managing knowledge across a semantic boundary. At a pragmatic boundary, there were explicit conflicts of interest between interacting actors from different knowledge communities. That is, members of one group were less able and willing to change their knowledge to accommodate the knowledge developed by members of another different group. Also, members of one group opposed the register as they did not want to be controlled by the healthcare authority. The study suggested that lack of time was a barrier to using the register and joining in social interactions. Also, the study argued that a professional culture has influences on cross-community collaboration. That is, in the case being studied, being a physician was depicted as a solitary profession, only including the physician and the patient. To overcome these organisational culture and management issues is difficult and the effects of professional culture are great challenges. More specifically, to overcome these challenges and to move knowledge across boundaries it required negotiating skills and practice, investment in time, and relationship building. It also required compromises in community practices, interests, and jurisdictions (Edenius, Keller and Lindblad, 2010; Carlile, 2004, 2002).

Maaninen-Olsson, Wismen and Carlsson (2008) extended the theorisation of boundaries by using Carlile's model (2004) to explore how knowledge can be managed between different professional groups in different work settings: permanent; and project work settings. The findings suggested that there are similarities and differences in knowledge management across boundaries between permanent and project work settings. In both work settings, the lack of time for reflection, interests, and motivation had effects on the willingness and possibility to understand each other's knowledge and to integrate knowledge. The permanent work setting created routines and rules based on the knowledge that was integrated within the different communities. By contrast, in the project work setting, interacting actors adapted integrated knowledge and repeated things more in the knowledge process between the different communities. Furthermore, members in the project work setting developed and re-developed standards and tools to suit the project, to integrate knowledge, and to make knowledge less local and individual. In addition, Maaninen-Olsson, Wismen and Carlsson (2008) suggested that the three-tier model for managing knowledge across boundaries was quite stable over time in the permanent work setting, while the model changed over time in the project work setting.

Yates and Paquette (2011) examined cross-community collaboration and knowledge management in dynamic environments by referring to Carlile's concept. Yates and Paquette (2011) illustrated how social media technologies had impacts on knowledge management in a dynamic emergency environment, more specifically the Haitian earthquake in 2010, in an emergency response organisation. The study mainly focused on two social media used in the US government response: wiki and collaborative technologies such as SharePoint. These impacts were examined through the lens of Carlile's model. The findings suggested that social media helps to span the boundaries found in a disaster management system situation. At a syntactic boundary, social media helped to transfer knowledge from different agencies and helped to reduce the level of duplication of work. At a semantic boundary, social media helped to increase knowledge reuse through increasing knowledge visibility. Also, it helped to create visualisations of knowledge for other departments or agencies. At a pragmatic boundary, social media helped to alter the social dynamic of the knowledge organisation and create a bridge to outside organisations and resources. Also, it helped to transform knowledge through conversations within the system.

Some scholars have examined the relationships between types of network and cross-community collaboration and knowledge management (e.g. Tortoriello, Reagans and McEvily, 2012; Tortoriello and Krackhardt, 2010; Tiwana, 2008). Those scholars cited Carlile's model. Prior research has focused on the importance of boundary spanners in facilitating the transfer of knowledge between organisational units. Boundary spanners are in a position to use their network connections to increase the amount of knowledge transfer between units. However, boundary spanners sometimes might increase the amount of knowledge flowing between units but at other times might restrict knowledge flows (Tortoriello, Reagans and McEvily, 2012; Tortoriello and Krackhardt, 2010; Tiwana, 2008). Tiwana (2008) examined tensions and complementarities between bridging ties and strong ties in innovation-seeking alliances. Tiwana (2008) proposed the complementarities between strong ties and bridging ties and their joint effect on knowledge integration at the project level. Bridging ties provided access to diverse knowledge and provided innovation potential but lacked integration capacity; strong ties provided integration capacity but lacked innovation potential.

Similarly, Tortoriello and Krackhardt (2010) studied the advantages provided by Simmelian bridging ties in terms of innovation in a study of the knowledge sharing and patenting activities of 276 members of the research and development division of a large, multinational, and high-tech corporation. Simmelian bridging ties were a type of interpersonal tie which were concerned with more than just the strength of the relationship. They looked at the number of strong ties within a group. A simmelian tie is viewed as even stronger than a regular strong tie. Tortoriello and Krackhardt (2010) suggested that in the context of cross boundary relationships, the positive effects of bridging on innovation reflect the specific features of a subset of network ties: Simmelian ties. That is, the distinction between weak and strong bridging ties was not very informative if the forming of a bridge was considered independently of the micro context in which it was embedded. It was not the strength of a bridging tie that explained the variation in individuals' innovative capabilities; but rather, whether or not a strong bridging tie was embedded in a small group of people who spend their time together.

Tortoriello, Reagans and McEvily (2012) also investigated how network relationships facilitated knowledge transfer. More specifically, they investigated how three network approaches: tie strength, network cohesion, and network range, affected the level of knowledge acquisition across organisational boundaries. An analysis of knowledge transfer relationships among several hundred scientists in the research and development division suggested that each network feature had a positive effect on the level of knowledge acquired in cross-unit knowledge transfer relationships. The strength of the interpersonal relationships between individuals influenced their willingness to engage in knowledge transfer and the amount of effort they dedicated to the activity. Whereas network cohesion stressed the value of overlapping ties among mutual third-parties and network connections that span important organizational boundaries. Network cohesion facilitated knowledge transfer by reducing the competitive and motivational impediments that arose. Network range that spans multiple knowledge pools affected the transfer process by giving people the ability to convey complex ideas to diverse audiences.

Mailhot, Gagnon, Langley and Binette (2016) examined the nature and role of leadership in the development of a major collaborative research project. Mailhot, Gagnon, Langley and Binette (2016) covered Carlile's three types of knowledge boundaries by focusing on the role of different types of boundary objects and mechanisms to overcome those boundaries in coordination. The findings suggested that changes between different groups involved in collaborative work do not necessarily occur through the sharing of a common vision but through the ability of leaders to translate collaborative work into terms that can be appreciated by the groups that must be mobilized (Mailhot, Gagnon, Langley and Binette, 2016). Some previous studies aimed at understanding network creation and focused on the technical dimensions and instrumentalities related to various management mechanisms such as network structure, while Weber and Khademian (2008) focused on the mind-set of managers or boundary spanners to govern complex public problems. Weber and Khademian (2008) suggested that there is a need to focus on the mind-set of managers or boundary spanners as a context for actions because mind-set guided network managers or boundary spanners as they applied their knowledge, skills, strategies, and tools to foster knowledge transfer and knowledge integration across different participants and networks. Weber and Khademian (2008) cited Carlile (2002) to tie the challenges associated with network knowledge to not only the skills and competencies of managers as boundary spanners but also to the importance of a mind-set that becomes a significant component of effective collaborative problem-solving capacity when the context involved complex public problems.

According to the literature mentioned above, the three types of knowledge boundaries have been discussed in many studies in the field (e.g. Fellows and Liu, 2012; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008). Wannenmacher and Antonie (2016) mainly focused on a semantic boundary or different interpretations of the same thing between actors from different knowledge communities. Wannenmacher and Antonie (2016) examined a moment of tension or contradictory interpretations emerging during consortium meetings between communities of chemists and physicists in a collaborative project on nanoparticles. The findings suggested that collective tacit knowledge in one scientific community facilitates interactions within the community. There was no need to explain everything. However, within a cross-disciplinary research project the collective tacit knowledge led to different interpretations of the same thing. The collective tacit knowledge in that instance could be considered as a potential source of misunderstandings.

Farag, Jarvenpaa and Majchrzak (2011) examined cross-community collaboration and knowledge management in dynamic environments by referring to Carlile's concept. Farag, Jarvenpaa and Majchrzak (2011) examined knowledge collaborating in a dynamic virtual space, more specifically online communities. Farag, Jarvenpaa and Majchrzak (2011) argued that the existing theories of knowledge collaboration across diverse communities, including Carlile (2004, 2002), have traditionally characterised the collaboration process as one of people-to-people sensemaking, that challenged assumptions, and forced negotiations among individuals with different perspectives. The use of people-to-people relationships allowed for the opportunity to: identify interdependencies; open information sharing; develop common goals; identify a common problem-solving approach; and so on. However, these components are rarely found in online communities. Knowledge collaboration in online communities could occur without the structural mechanisms traditionally associated with knowledge collaboration in organisational teams, such as feelings of interdependence among group members and convergence after divergence. The lack of traditional structural mechanisms appeared to partly free knowledge collaboration from concerns about social conventions, ownership, and hierarchy. Online communities were where participants, norms, interactions, and boundaries changed over time. Fluidity characterised the highly flexible or permeable boundaries of online communities, where it was difficult to know who was in the community and who was outside. Therefore, Farag, Jarvenpaa and Majchrzak (2011) argued that the dynamics of how the online community responds to these tensions makes knowledge collaboration in online communities fundamentally different from the collaboration in traditional organisation structures. Farag, Jarvenpaa and Majchrzak (2011) suggested that knowledge collaboration in online communities was facilitated by the presence of tensions among five resources: (i.) passion, (ii.) time, (iii.) socially ambiguous identities, (iv.) social disembodiment, and (v.) temporary convergence. In summary, differences between passionate individuals could lead to interpersonal conflict. For instance, passion might reduce the participation of members who were less passionate. Time constraints would pressure people into making statements that might appear harmful to the community. That is, a participant who spends a disproportionate amount of time contributing to online communities might hamper newcomers from spending time. Anonymity tended to reduce the trustworthiness and accountability of knowledge. Also, it might decrease knowledge contributions if people were worried about not getting credit for their input and ideas. Temporary and incomplete convergence might lead to such disorganization that participants cannot find ideas, threads of ideas, or ways to enter into a topic to be able to make a valuable contribution.

Kellogg, Orlikowski and Yates (2006) examined cross-community collaboration in an interactive marketing organisation, in conditions of high speed, temporary, and rapid change. Then, they identified three cross-boundary collaboration practices: display, representation, and assembly practices. These three practices are in line with Carlile's three-tier model. However, there are some differences in the set of activities and accommodations which accomplished cross-boundary collaboration. Kellogg, Orlikowski and Yates (2006) argued that in contexts such as an interactive marketing organisation, change is continuous. Consequently, attempts to develop shared mechanisms such as boundary objects, as well as common languages, meanings, and understandings, are difficult because knowledge and contexts are changing too rapidly. Members from different knowledge communities can interact across boundaries by agreeing on the general procedures of exchange, although they may have different languages, interpretations, and interests of the same things. This perspective evokes a view of cross-boundary collaboration as temporary, ongoing, and dynamic, rather than as a static property of social systems. They identified the following cross-boundary practices:

i. Display practices. Instead of transferring knowledge and developing common languages, interacting actors make their work and commitments visible to others through posting to a common digital space that others can access. To do this, multiple information technologies can be used such as the organisation's internal networks, e-mail, and project management system.
ii. Representation practices. Rather than translating knowledge and developing common meanings, interacting actors make their work readable to others through expressing perspectives in a particular form that can be used by others. These practices differ from Carlile's knowledge translation, which involves the development of common meanings across different communities. These practices involve making work legible in a form that is tangible, observable, and readable by others, although the readings may differ from the author's. They focus on shared forms of communication rather than shared content, drawing on a repertoire of cross-boundary project genres to represent their work to each other. Genres of communication are both work being done (e.g. prototypes), and the process of doing (e.g. project schedules).
iii. Assembly practices. Instead of transforming knowledge and developing common interests, interacting actors juxtapose their diverse efforts into a provisional and emerging collage of loosely coupled contributions. These work practices involve interacting actors referring to, reusing, revising, and aligning the work products of other different communities in their construction of interdependent products.

Kellogg, Orlikowski and Yates (2006) explained that the findings from their study, which are mentioned above, are different from the findings in the existing literature. This is because the context of their study is more temporary, smaller in size, more changeable, and based on digital media rather than physical artefacts.

Rosenlund, Rosell and Hogland (2017) used Carlile's model (2004, 2002) and Kellogg, Orlikowski and Yates' model (2006), to explore knowledge boundaries that occur in the development of environmental science and technology research collaborations between triple helix sectors: the university, industry, companies, and the public sector. Rosenlund, Rosell and Hogland (2017) named the three types of knowledge boundaries as: information process-oriented, cultural, and political boundaries. Major findings from this study were in line with Carlile's study (2004, 2002). The findings suggested that difficulties in triple helix collaborations are related to different languages, different understandings, and different interests among different sectors (Rosenlund, Rosell and Hogland, 2017; Carlile, 2004, 2002).

According to Rosenlund, Rosell and Hogland's study (2017), information process-oriented boundaries (Kellogg, Orlikowski and Yates, 2006) or syntactic boundaries (Carlile, 2004, 2002) occurred because of incompatible codes, routines, and protocols among the triple helix sectors. That is, academic knowledge was perceived as too technical and jargon-rich by the other sectors. Academic publications were difficult to transfer outside of the university and were perceived as less valuable by the other sectors. Also, academics were perceived to be difficult to communicate with and difficult to reach. To overcome these information process-oriented boundaries, the findings suggested the development of a common language and transfer of knowledge by using boundary objects; more specifically, technical reports. Furthermore, the findings suggested that the transfer of academic knowledge to outside academia requires someone who can work with knowledge transfer and someone who can function as an information translator and a gatekeeper regarding communication (Rosenlund, Rosell and Hogland, 2017). This suggestion extended Carlile's study (2004, 2002) which mainly used boundary objectives such as storage and retrieval technologies to develop a common language and to transfer knowledge between members from different groups. The second type of knowledge boundaries, culture boundaries (Kellogg, Orlikowski and Yates, 2006) or semantic boundaries (Carlile, 2004, 2002), occurred because different sectors had different norms and values that shape their understanding of the area of environmental problems. Also, culture boundaries occurred because different sectors had different ways of working reflected in their different perceptions of environmental problems. To overcome cultural boundaries, three solutions were suggested which were in line with Carlile's study (2004, 2002). The first solution was the development of common understandings through negotiation and adjusting to other sectors. The second solution was cross-functional interaction, more specifically spending time in other sectors. The third solution was the use of boundary spanners to mediate between different sectors. Political boundaries (Kellogg, Orlikowski and Yates, 2006) or pragmatic boundaries (Carlile, 2004, 2002) occurred because each sector brought their own practices and knowledge as well as having different interests and goals. For instance, the public sector focused on what is best for society, while companies focused on practical, economic, and market value issues (Rosenlund, Rosell and Hogland, 2017). Political boundaries could be overcome by building relationships, trust, and common interests through practical and political efforts which were in line with Carlile's study (2004, 2002).

As mentioned above, Kellogg, Orlikowski and Yates (2006) argued that Carlile's model focuses on understanding each other's different knowledge, dependencies, and boundaries, and then traversing those boundaries through negotiation. This concept, which was called a traverse approach (Majchrzak, More and Faraj, 2012), emphasised deep dialogue (Majchrzak, More and Faraj, 2012; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Deep dialogue was needed that reveals assumptions, identities, and confronts these differences; and that negotiates across boundaries. This dialogue was needed when tasks were novel, requiring not only knowledge integration but also knowledge transformation. However, concerns have been raised with a traverse approach because the process of the development of common knowledge and understandings between members from different knowledge communities can take a lot of practical and political effort and can create interpersonal conflict (Majchrzak, More and Faraj, 2012; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Kellogg, Orlikowski and Yates (2006) argued that members of different knowledge communities may be able to develop integrative solutions without deeply sharing and assessing each other's different knowledge. That is, spending a lot of time to identify and confront each other's differences, learning from each other, and negotiating common knowledge, understandings, and interests, was not always needed (Kellogg, Orlikowski and Yates, 2006).

Majchrzak, More and Faraj (2012), who examined transcending knowledge differences in cross-functional teams, argued for Kellogg, Orlikowski and Yates's non-dialogue-based trading zone (2006) by supporting for the important role of dialogue in the process of knowledge transformation and integration between different groups, especially when tasks are novel for the groups. Majchrzak, More and Faraj (2012) extended a traverse approach by suggesting a different view about the nature of dialogue from that depicted in the traverse approach. Majchrzak, More and Faraj (2012) labelled the different view about the nature of that dialogue as one that transcends knowledge differences. They argued that knowledge differences are not first clarified with deep-knowledge dialogue and then bridged through negotiation as mentioned by Carlile (2004, 2002) and Bechky (2003). Rather, practices that minimized members' differences during the problem-solving process, helped the cross-functional teams to transcend knowledge differences rather than traverse them (Majchrzak, More and Faraj, 2012). Five practices that the cross-functional teams implicitly used to overcome the difficulty of integrating their different perspectives were identified: (i.) voicing fragments, (ii.) co-creating the scaffold, (iii.) dialoguing around the scaffold, (iv.) moving the scaffold aside, and (v.) sustaining engagement (Majchrzak, More and Faraj, 2012).

According to Majchrzak, More and Faraj (2012), in the first practice, voicing fragments, this focused on sharing potential problem definitions and solutions and avoided focusing on interpersonal differences. This practice helped to quickly create a common landscape of knowledge assets consisting of different perspectives, facts, observations, concerns, issues, problem definitions, and possible solutions. The knowledge assets were not attributed to any single individual on the team, did not require critical time or effort to surface, and were not used as points of discussion, clarification, or to resolve knowledge differences for sharing deeper knowledge about one's discipline. In the second practice, co-creating the scaffold, the cross-functional team quickly developed a visual or verbal abstract representation that included many of the voiced fragments. Then, the scaffold provided a common co-creation and elaboration experience. The scaffold served as a way for members to limit the sharing of their specialized knowledge for the joint creation of a representation without the need to engage in a lengthy dialogue of surfacing knowledge differences and dependencies. In the third practice, dialoguing around the scaffold, the teams engaged in a rapid dialogue about the scaffold in an attempt to use the scaffold to generate solutions to the problem. This practice involved using dialogue in ways that repeatedly reframed the scaffold to promote the type of creative tension that led to a creative breakthrough. By keeping the focus on the scaffold, the dialogue never devolved into an interpersonal conflict nor did it involve learning about each other's knowledge. In the fourth practice, moving the scaffold aside, the teams created a highly preliminary solution and tried it out on external stakeholders. This practice facilitated reconnection between the teams and their external stakeholders early after they had an initial solution but before the solution was well developed and thus harder to change. This not only ensured a smooth transition of the dialogue from a collectively created scaffold to an external stakeholder but also encouraged continued co-generation. In the final practice, sustaining engagement, instead of confronting individual differences that can reduce energy, the teams practiced building and sustaining engagement through the problem-solving effort. This practice helped the teams maintain the energy and focus needed to continue the process of personally transforming one's knowledge into collective knowledge as new ideas were generated without retreating into the confines of one's current bounded knowledge and confronting others with that knowledge.

Le Dain and Merminod (2014) argued that the three-tier model is mainly designed for the intra-organisational new product development setting. They also argued that the model does not clearly specify how the current contexts and activities met in a new product development project related to each type of boundary and knowledge process (transfer, translate, and transformation). The model explained the transition between the three knowledge boundaries and knowledge processes as an iterative process related to the level of novelty of knowledge between interacting actors. However, the model did not consider the relative intensity of each boundary and knowledge process according to the activity of the interactions between interacting actors. Le Dain and Merminod adapted the model to examine knowledge sharing in inter-organisational new product development projects; between customers and suppliers.

Le Dain and Merminod's (2014) findings suggested that the dynamics of knowledge sharing between customers and suppliers in new product development projects depended on each supplier's involvement configuration. There were three supplier involvement configurations identified: black box; grey box; and white box supplier involvement configurations. In black box supplier involvement configurations, the design and the industrialisation activity is primarily driven by suppliers based on customer requirement specifications. This practice requires early supplier involvement to encourage a shared definition of the customer's specifications. A knowledge transfer process is important here due to the extended responsibility of suppliers throughout the project. This knowledge transfer process requires a knowledge translation process during the initial phases. Customers must translate specific knowledge for suppliers to establish a common meaning of their need. This translation helps suppliers to meet the requirements of customers. Therefore, black box supplier involvement configurations require knowledge transfer and knowledge translation during the design phases to clearly define the common understandings on the customer requirements. In grey box supplier involvement configurations, the design activity is strongly integrated between suppliers and customers. Thus, suppliers and customers have to work together to complete the component design and development. Throughout the project, work is carried out by in-depth collaboration between suppliers and customers. Co-development requires sharing and assessing of knowledge (knowledge transfer process), creation of common understandings (knowledge translation process), and collective decision-making to solve problems and co-create solutions (knowledge transformation process). That is, grey box supplier involvement configurations require all three knowledge processes: transfer, translation, and transformation. In white box supplier involvement configurations, customers are in control of design and specification decisions, while suppliers are in control of the process of the developing activity based on the customers' specifications. Suppliers may be consulted early in the development process to provide knowledge and skills on materials, costs, and manufacturing process capability. Customers transfer boundary objects based on the contractual deliverables defined with suppliers. Therefore, white box supplier involvement configurations mainly involve knowledge transfer.

Lindberg, Walter and Raviola (2017) and Smith (2016) suggested that the processes of boundary work were dynamic whereby different types of knowledge boundaries are performed at the same time, and within the same process. Smith (2016) examined a high-novelty research and development collaboration between multiple organisations by focusing on the occurrence of knowledge boundaries and mechanisms to manage knowledge across those boundaries. Smith (2016) suggested that Carlile's model provides an extensive insight into why knowledge sharing across different knowledge communities can be so difficult. However, Smith (2016) argued that there is little knowledge about the dynamics of thought worlds or interpretive schemes that provide mutual assumptions and understandings about identity, attitude, practice, and so on between different groups. The dynamics of thought worlds were often depicted as a relatively static construct. Also, Smith (2016) argued that Carlile's model implies that a hierarchy exists among knowledge boundaries in which a syntactic boundary is associated with low levels of novelty, and a pragmatic boundary is associated with high levels of novelty. When the level of novelty increased, one knowledge boundary was replaced by another. Therefore, boundary emergence and spanning occur in a linear way and that only one type of knowledge boundary exists at one time (Smith, 2016, p.51). Smith's study (2016) explained a complex picture of knowledge boundaries that goes beyond a hierarchic and linear representation of boundaries as suggested by Carlile (2004, 2002). Smith (2016) suggested that multiple knowledge types may exist in a project either continually or simultaneously, and knowledge boundaries are highly contextual. Different tasks or practices determined which boundaries emerged.

Smith (2016) identified six different knowledge boundaries characterised by processes of sensemaking, strategizing, and group identification. However, some of six knowledge boundaries, which were identified by Smith (2016), had been suggested by Carlile (2004, 2002); more specifically, a semantic and an interest or pragmatic boundary. The six knowledge boundaries were a cognitive boundary, a semantic boundary, an interest boundary, an organisational boundary, a professional identity boundary, and an in-group/out-group boundary. They were labelled as knowledge boundaries because they presented incidents in which knowledge sharing and integration were significantly challenged and hindered.

According to Smith (2016), a cognitive boundary occurred when an individual was unable or unwilling to see the relevance of others' work and knowledge to their own work and knowledge. Consequently, difficulties in collaboration and interaction started. The second type of knowledge boundaries, a semantic boundary, emerged when individuals interpreted the same thing or same situation because of differences in their knowledge. Consequently, misunderstandings occurred between different groups. Failure to make sense of the situation and different understandings of the situation led to cognitive and semantic boundaries. The third knowledge boundary, an interest boundary, which Carlile labelled a pragmatic boundary, occurred when there was a conflict of interest and goal between an individual and another different individual or group. Another knowledge boundary was an organisational boundary. This knowledge boundary occurred when members of one organisation lacked willingness to share their knowledge to members of another organisation. Consequently, communities of practices were slowly built up as well as knowledge sharing was limited. The actions of one obstruct the possibilities of others. They led to the emergence of interest and organisational boundaries. The fourth type of knowledge boundaries, a professional identity boundary, emerged when scientists and developers viewed each other in a negative light and had difficulty collaborating. For instance, the developers complained that the scientists considered themselves to be too important to do programming, while the scientists felt that the developers obstructed a fluid academic discussion by being too practical. The final type of knowledge boundaries was an in-group/out-group boundary. It occurred when individuals from one sub-group were not aware of what was going on in the other sub-projects. Also, it emerged when individuals from one sub-group were not sharing their knowledge with team members outside their own group. The division of the group into in-groups and out-groups led to the emergence of professional identity and/or in-group/out-group boundaries.

Smith (2016) explained the mechanisms of the knowledge boundaries identified in his study by three theoretical constructs: sensemaking, strategizing, and group identification. They were processes enacted by an individual in order to reduce perceived uncertainty and enable action. When individuals from different organisations and disciplines interacted in a complex research and development project, they reacted to the uncertainty and sought to reduce it. First, they simply tried to make sense of their surroundings, either through individual or collective sensemaking processes. When successful, this process gave an individual the ability to act; but when it failed, the individual would withdraw from collaborative tasks, thus leading to a cognitive boundary. Similarly, when a group was successful in collective sensemaking, this reduced uncertainty and provided the collective ability to act. However, when different interpretations occurred between individuals, misunderstandings led to disagreements of meaning. This situation led to a semantic boundary. Furthermore, individuals tried to minimize uncertainty by defining guiding rules for dealing with the challenges and identifying possible strategies to apply. This too gave a sense of purpose and provided an ability to act. Consequently, this was goal-oriented behaviour in which the actions of one individual might obstruct the actions or possibilities of others. This led to mistrust and thereby reduced interaction and knowledge sharing. This situation was associated with interest and organisational boundaries. The third way to reduce uncertainty was to team up with similar others to avoid isolation in dealing with the challenges at hand. Group identity gave a sense of belonging and security. However, the consequence was also the division between in-groups and out-groups, thus leading to exclusion and a lack of interaction between groups. This situation was associated with professional identity and in-group/out-group boundaries.

Similarly, Lindberg, Walter and Raviola (2017) examined the processes of boundary work in relation to the introduction of new practices and new technology. They suggested that boundary work is a dynamic process whereby different types of boundary work are performed at the time, and within the same process. Boundary work built on a relationship between practice and boundaries. That is, the emerging practice drove and constituted changes in boundaries which the new configuration of boundaries stabilises and legitimises in practice. Thus, boundary work could be stabilised but never completed.

2.8. Boundary-spanning mechanisms

Cross-community collaboration and knowledge management requires boundary-spanning mechanisms or bridges across boundaries to facilitate communication, collaboration, and knowledge management between different communities (Wenger, 2000). Effective boundary-spanning mechanisms have been recognised as crucial devices to support the capacity for reconciling discrepancies and negotiating interests in order to facilitate knowledge flows across boundaries (Hoffmann, 2012; Akkerman and Bakker, 2011; Fong, Srinivasan and Valerdi, 2007; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Star and Griesemer, 1989). Three broad types of boundary-spanning mechanisms have been identified: boundary objects, brokers, and interactions.

2.8.1. Boundary objects

Boundary objects are considered as communication enablers or mediums between interacting actors from different communities (Holford, 2016; Abraham, Aier and Winter, 2015). They are abstract or physical artefacts and other forms that are created and used by interacting actors from different communities in the course of their interaction (Fong, Srinivasan and Valerdi, 2007; Gal, Yoo and Boland, 2004; Wenger, 2000; Star and Griesemer, 1989). They support overcoming knowledge boundaries by providing common knowledge, and thus support coordination among different communities (Abraham, Aier and Winter, 2015). The concept of boundary objects was first introduced by Star and Griesemer (1989), and has since been cited in many studies. Star and Griesemer (1989) suggested three major concepts of boundary objects:

i. Boundary objects are both flexible enough to adapt to local needs in each community and inflexible enough to maintain a common identity across communities;

ii. They are both strongly structured in individual-site use in each community and weakly structured in common use in different communities; and

iii. They have different meanings in different communities but their structure is common enough to more than one community to make them recognisable and function as a means of translation.

Boundary objects can be utilised to help transfer knowledge; to reconcile different meanings; and to develop and improve the level of common understandings, including developing, improving, and maintaining cooperation and working relationships between different communities (Hislop, 2013; Gal, Yoo and Boland, 2004; Wenger, 2000; Star and Griesemer, 1989). For instance, referrals, laboratory reports, and instructions for specimen taking were used to transfer knowledge about patient data and medical knowledge as well as to connect activities between a microbiology laboratory and its customer units which consist of laboratory instructors, laboratory physicians, local laboratory technicians, physicians, nurses, and assistant nurses (Maaninen-Olsson, Wismen and Carlsson, 2008). As another example, engineering drawings and bills of materials, including meeting agendas and notes, were used to communicate and link activities on a production process in a semiconductor equipment manufacturing company among engineers, technicians, and assemblers (Bechkey, 2003).

In the development of the Museum of Vertebrate Zoology at the University of California, Berkeley which involved many divergent perspectives and communities such as researchers from different disciplines, professors, university administrators, amateur collectors, and private sponsors, Star and Griesemer (1989) found four main types of boundary objects. There were both physical and abstract objects:

i. Repositories (e.g. institutional repositories, databases, and libraries) containing a vast amount of information or sets of objects which are used to deal with different things by different communities;

ii. Ideal types (e.g. diagram drawings, sketches, and atlases) are abstract objects which in fact do not accurately describe the details of any one thing;

iii. Coincident boundaries refer to common objects which have the same boundaries but different internal contents. For instance, an office building consists of different communities that work within the same physical boundary. These allow the communities to pursue different goals while operating within the same organisational scope.

iv. Standardised forms are methods of common communication across different communities such as engineering change forms, instruction manuals, and checklists. They provide shared different communities with a common way or format to communicate across different communities.

Wenger (2000, p.236) argued that boundary objects can take the forms of discourses and processes. Discourses that represent boundary objects show the existence of a common language that allows individuals to communicate and negotiate meanings across boundaries. Processes refer to shared processes which allow individuals to coordinate their actions and contributions across boundaries.

Carlile (2002) applied Star and Griesemer's (1989) concept of boundary objects to study the use of boundary objects across four different communities in the design and production of innovation within an organisation. Then, he outlined a typology of types of boundary objects. Also, he linked the typology of types of boundary objects to his three types of knowledge boundary in order to suggest that successfully working across boundaries requires the use of boundary objects appropriate to each type of boundary being crossed (see Table 2.9 below).

	Types of knowledge boundaries		
	Syntactic boundary Transferring	**Semantic boundary** Translation	**Pragmatic boundary** Transformation
Characteristics of boundary objects	Representing	Representing and Learning	Representing, Learning, and Transforming
Types of boundary objects	Repositories and Taxonomies	Standardised forms and methods	Objects, Models, and Maps

Table 2.9 Characteristics of effective boundary objects

Adapted from: Carlile (2002)

According to Carlile (2002), different types of knowledge boundaries require different types of boundary objects.

i. A syntactic boundary focuses on the information-processing process. Thus, effective boundary objects should provide common languages for individuals to represent their knowledge. Ontology, taxonomies, institutional repositories, and databases are examples of boundary objects for this boundary. These are as a common reference point of data across different communities. They provide shared definitions and values for better understanding and then solving problems.
ii. A semantic boundary recognises the knowledge translation process. Using a concrete method such as standardised forms in cross-boundary working provides a concrete means for individuals to specify and learn differences and dependencies across boundaries. For instance, the code of the Content Management System (CMS), together with the framework and rules, acted as a means for transferring and translating knowledge between groups of software engineers from different companies in the Science Park (Kimbel, Greniera and Goglio-Primard, 2010).
iii. A pragmatic boundary; effective boundary objects which facilitate knowledge transformation processes are physical prototypes such as objects, models, and maps. For instance, maps of boundaries can help to clarify dependencies between different

cross-boundary problem-solving efforts that share resources, deliverables, and deadlines.

Although, the categories and characteristics of boundary objects between each type of knowledge boundary are clearly defined, all categories of boundary objects affect each other (Carlile, 2002).

2.8.2. Boundary brokers

Studies on knowledge management across boundaries have emphasised the importance of individuals who perform as boundary brokers (Akkerman and Bakker, 2011; Kimble, Grenier and Goglio-Primard, 2010; Kim and Jarvenpaa, 2008; Maaninen-Olsson, Wismen and Carlsson, 2008; Hislop, 2005; Levina and Vaast, 2005; Wenger, 2000). According to Wenger (2000, p.253), boundary brokers are someone who acts as a broker between different communities. They have intercommunity social relations to stay at the boundaries of many practices. This is in order to create connections and engage in transferring elements of practices from one or more communities to another different community (Wenger, 2000) through the translation, coordination, and alignment of perspectives (Gasson, 2005a). They use their knowledge and understanding to facilitate the development of mutual understating between different communities (Hislop, 2013). Boundary brokers also create, cultivate, develop, and maintain awareness and the environment among communities by ensuring that boundary objects are used effectively for communication and collaboration (Hislop, 2013; Carlile, 2004). For instance, in Kimble, Grenier and Goglio-Primard (2010) a systems administrator acted as a boundary broker by giving the final formal approval to the two groups of software engineers from different fields and companies for developing an information system together. The systems administrator also built trust, maintained a balance, and managed the relationship between the groups. To do this, the systems administrator created a sense of commitment between the groups which allowed them to share their knowledge and develop mutual understandings (Kimble, Grenier and Goglio-Primard, 2010).

Boundary brokers can take many different forms. Wenger (2000, p.235), for instance, suggests four forms of boundary brokers: boundary spanners who take care of one specific boundary over time; roamers who go from place to place, create connections, and move knowledge across boundaries; outposts who bring back news from the front, and explore new territories; and those who act as brokers between different communities through a personal relationship between two (or more) people from different communities. Another role of boundary brokers, which is based on negotiation, is as a representative and a gatekeeper (Friedman and Podolny, 1992). A representative refers to people who manage to communicate the content outflows to people outside a community; while a gatekeeper refers to people who manage to communicate the content inflows into the community (Friedman and Podolny, 1992). A translator refers to actors who have the ability to translate knowledge or some elements created in one community into the language of another different community where there is no common knowledge. This is in order to make sure that the communities can understand what they share with each other (Kim and Jarvenpaa, 2008).

Dalkir (2005), and Jashapara (2004) used the term knowledge brokers which has a similar meaning to the term boundary brokers. Knowledge brokers are professionals who can move among more than one community to facilitate knowledge management in an organisation. They also assume the role of gathering, repackaging, and promoting knowledge throughout the organisation (Dalkir, 2005; Jashapara, 2004). Moreover, some authors use the term boundary spanners as an alternative to the term boundary brokers. For instance, boundary spanners are individuals who are well-connected internally and externally (Kim and Jarvenpaa, 2008, p.1) or individuals who facilitate the sharing of expertise by linking two or more groups of people (Levina and Vaast, 2005, p.338).

Although boundary brokers require multiple roles, Friedman and Podolny (1992) suggested that in practice an organisation should assign different roles of boundary brokers to different individuals to prevent role conflict. Furthermore, for the role of boundary brokers in cross-community collaboration, boundary brokers need to be trusted by the different communities for effective cross-boundary collaboration and knowledge management (Newell and Swan, 2000; Davenport and Prusak, 1998). On the one hand, boundary brokers are in a very rich and valuable position since they are the ones who can address and articulate elements, meanings, and perspectives of one community to the other different communities. On the other hand, they may face a difficult position because the brokers often do not fully belong anywhere and may not contribute directly to any specific outcome. Thus, the value they bring can easily be overlooked (Akkerman and Bakker, 2011; Levina and Vaast, 2005; Wenger, 2000).

Some researchers, such as Kimble, Grenier and Goglio-Primard (2010), have focused on the role and importance of boundary brokers to facilitate knowledge flows and transformation of knowledge across boundaries. Levina and Vaast (2005) suggested conditions for individuals to become boundary spanners in practice (individuals who, with or without nomination, engage in spanning boundaries of diverse communities). To become boundary spanners in practice, individuals have to develop an ability and inclination to participate with different communities in negotiating relationships between the communities. Kim and Jarvenpaa (2008) investigated the interaction between boundary spanners in practice and nominated boundary spanners (individuals formally nominated to span boundaries). The findings suggested that boundary spanners in practice, or informal boundary brokers, have become an effective and efficient channel for getting information and knowledge, especially for urgent situations. This is because they were always going to be more aware of what is going on in other communities and who is responsible for what. So, it is easier to contact them directly for useful and relevant information and knowledge.

2.8.3. Boundary interactions

Wenger (2000, p.236-237) suggested other types of bridges across boundaries as boundary interactions, or the forms of interactions among different communities: boundary encounters, boundary practices, and peripheries. Firstly, boundary encounters refer to direct exposure to a practice such as visits or discussions. For instance, seminars and forums were regarded as a bridge between two different groups of software engineers (computer services and software development) who collaborated to build a Content Management System (CMS) in the Sophia Antipolis Science Park. The engineers were able to discuss the objectives and the technical problems of the CMS with their colleagues, their customers, and members of the research institutions in seminars; forums were also used as a tool (Kimble, Grenier and Goglio-Primard, 2010). Similarly, Haythornthwaite (2006) examined types of knowledge as well as the interactions of learning and knowledge management in interdisciplinary research teams. The findings suggested that factual knowledge ranks high in this type of knowledge sharing. The knowledge is mainly shared though formal and informal meetings because professionals can share knowledge and lessons learned with team members directly during meetings (Haythornthwaite, 2006). He also argued that cross-community learning occurs though learning the process of doing something, joint research, learning about technology, generating new ideas, socialisation into the profession, and accessing a network of contacts and administration work. Palmer (1999) explored the process of boundary-crossing, especially the information activities involved in interdisciplinary research in an interdisciplinary scientific research institute. The study suggested that personal networks, conferences, and the published literature were the primary means for exchanging information. Secondly, boundary practices refer to so much work that it becomes the topic of a practice on its own. Finally, peripheries refer to indirect exposure to a practice by creating facilities which outsiders can connect with, such as lists of frequently asked questions on websites (Levina and Vaast, 2005).

Some scholars have suggested the importance of specific collaborative technologies and tools to support: communication; learning; knowledge sharing, exchange or transfer; and collaboration between different knowledge communities. Palmer (1999), for instance, suggested that interdisciplinary researchers should call for information systems and technologies to probe knowledge, to support learning in unfamiliar domains, and to allow consultation and knowledge exchange between different knowledge communities. Similarly, Cummings and Kiesler (2005) addressed the importance of specific collaborative communication and learning technologies for cross-disciplinary and organisational boundaries such as tools for ongoing conversation, tools for meetings across distance, and tools to support simultaneous group decision-making. The use of communication technologies such as e-mail, instant messaging, telephone meetings, and video-conferencing did not give interacting actors an added advantage. These technologies encouraged too much task and too little sharing and learning (Cummings and Kiesler, 2005). Similarly, Fong and Lo (2005) found that databases and teleconferencing were not fully utilised for sharing knowledge across boundaries in the Architectural Services Department of the Government of the Hong Kong Special Administrative Region. However, they argued that information and communication technology such as e-mail is one of the most popular knowledge sharing channels because it is fast and user-friendly. At the organisational level, Akhavan, Hosnavi and Sanjaghi (2009) suggested that organisations should look at the knowledge management architecture and organisational preparedness by providing an appropriate infrastructure to support knowledge management activities. They should also look at knowledge storage for the reproduction of the same knowledge and the creation of new knowledge.

The limitation of time to reflect and motivate individuals' willingness and possibility to understand each other's knowledge and to integrate knowledge was identified as one major challenge for knowledge sharing and integration across professional groups (Maaninen-Olsson, Wismen and Carlsson, 2008). Consequently, organisations should offer enough space to allow people to take time to generate, reflect, share, and integrate knowledge in cross-disciplinary collaboration. Akhavan, Hosnavi and Sanjaghi (2009) argued that the organisational structure should be flexible to provide the way for exploiting individual knowledge and cross-community collaboration. Akhavan, Hosnavi and Sanjaghi (2009) also suggested another critical factor for interdisciplinary collaboration, especially at an organisational level. Firstly, the Chief Knowledge Officer (CKO) should pursue target setting and formulate strategies, including to plan and evaluate the performance of knowledge management throughout the organisation. Finally, an organisation should benchmark itself against other successful competitors in order to obtain more productivity and higher performance.

2.9. Nature and characteristics of public interdisciplinary research and development organisations

Over the past decade, scientific research and development has been carried out by collaborations between individuals or groups from different disciplines and organisations (Siedlok and Hibbert, 2014; Jahn, Bergmann and Keil, 2012). One reason is the complex, dynamic, and interconnected challenges facing the world today such as global warming and climate change, the emergence of human infectious diseases, and the rapid loss of natural resources resulting from human activities, which cannot be solved by individual scientists or researchers working alone within single disciplines (Jahn, Bergmann and Keil, 2012; Russell, Wickson and Carew, 2008; Sumner and Tribe, 2007; Haythornthwaite, 2006; Cummings and Kiesler, 2005; Maglaughlin and Sonnenwald, 2005; Numprasertchai and Igel, 2005; Bronstein, 2003; Tranfield, 2002; Katz and Martin, 1997). Moreover, it is evident that the creation of most new knowledge, creativity, and innovation requires the integration of knowledge, skills, and perspectives of individuals or groups from different disciplines (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Wannenmacher and Antoine, 2016; Scarbrough, Panourgias and Nandhakumar, 2015; Siedlok and Hibbert, 2014; Fellows and Liu, 2012; Jahn, Bergmann and Keil, 2012; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004; Tranfield, 2002; Katz and Martin, 1997; Star and Griesemer, 1989). In response to these realities, government policy and research funding has increasingly emphasized interdisciplinary research (Cummings and Kiesler, 2005; Tranfield, 2002; Newell and Swan, 2000). Spurred by these trends, universities and other public research organisations have taken measures to promote interdisciplinary research and collaboration, including setting up new interdisciplinary research programmes, centres, and institutes (Noorden, 2015; Siedlok and Hibbert, 2014).

A number of studies have talked about the nature and characteristics of public interdisciplinary research and development organisations (e.g. Corradini and Propris, 2017; Rosenlund, Rosell and Hogland, 2017; Bark, Kragt and Robson, 2016; Coccia and Rolfo, 2015;

Juan, 2015; Almquist, Grossi, Helden and Reichard, 2013; Gulbrandsen, 2011; Jin and Sun, 2010; Coccia, 2009; Hall, et al., 2006). Interdisciplinary research and development organisations are where scientists or researchers from different disciplines can meet, share their expertise and open up new fields of inquiry to meet social and economic needs, including joining forces in the acquisition of external funding (Gulbrandsen, 2011). Public interdisciplinary research and development organisations tend not to be organised according to strict academic criteria (Hall, et al., 2006). Also, as will be detailed below, they have been encouraged to undertake research and development by collaboration with industry and/or universities (Coccia and Rolfo, 2015; Hall, et al., 2006).

Public interdisciplinary research and development organisations mainly focus on what is best for society (Rosenlund, Rosell and Hogland, 2017; Bark, Kragt and Robson, 2016; Hall, et al., 2006). Gulbrandsen (2011) suggests that many public interdisciplinary research and development organisations have been established with specific public missions (e.g. public health and geography), tasks related to nature and natural resources (e.g. environmental mapping), and national interests (e.g. alternative energy) in mind. In addition, some public interdisciplinary research and development organisations have been started with explicit goals of industrial and economic growth (Gulbrandsen, 2011). It could be argued that, in general, public- and policy-driven research is a typical function for public interdisciplinary research and development organisations (Bark, Kragt and Robson, 2016). Public interdisciplinary research and development organisations perform more and various tasks in response to change (Bark, Kragt and Robson, 2016). The outputs of public interdisciplinary research and development organisations range from scientific publications to products, testing, policy advice, and more (Gulbrandsen, 2011). However, private interdisciplinary research and development organisations mainly focus on profit (Rosenlund, Rosell and Hogland, 2017; Hall, et al., 2006) and tend to be constrained by the practical problems that companies need to solve (Corradini and Propris, 2017; Rosenlund, Rosell and Hogland, 2017).

A major source of funding for public interdisciplinary research and development organisations is the government (Jin and Sun, 2010; Hall, et al., 2006). Therefore, the goals of public interdisciplinary research and development organisations must respond to the government's requirements. Scientists or researchers must demonstrate that their topic and operation is of significant governmental and public concern (Hall, et al., 2006). This suggests that there are relationships between the source of funding and the goals of public interdisciplinary research and development organisations. However, because of decreasing public funds, it is impossible to conduct research and to support organisational structure with public funds alone (Coccia and Rolfo, 2015). Consequently, public interdisciplinary research and development organisations have been forced to apply for external projects from market (external) funds to conduct research and development activities (Hall, et al., 2006). This strategic change is not only to cope with decreased public funds, but also to encourage interdisciplinary research for the market and collaboration between the public and the private sectors (Coccia and Rolfo, 2015; Hall, et al., 2006). Public (interdisciplinary) research and development organisations should be market-oriented institutions (Coccia and Rolfo, 2015). Therefore, public interdisciplinary research and development organisations need to meet the needs and demands of those providing the resources (Coccia and Rolfo, 2015).

As mentioned above, public interdisciplinary research and development organisations are mainly funded by governments and receive a large amount of funds from the external market. They have been generated by academic capitalism through entrepreneurial research units that commercialise their research. Consequently, public interdisciplinary research and development organisations have a quasi-market-oriented approach (Coccia and Rolfo, 2015). According to Gulbrandsen (2011), public interdisciplinary research and development organisations can be considered as a hybrid organisation in two dimensions. That is, they exist on a middle point between science and society. Also, they mostly often have characteristics of both private agencies and government bureaucracies. In the science and society dimension, this reflects tensions primarily between academic and civilian cultures. In the private and public dimension, public interdisciplinary research and development organisations need to have a close relationship with their users in the private sector, as well as needing to retain the characteristics of public service organisations in order to keep the privileges of public funds and tax regimes. Gulbrandsen (2011) explains that the science and academic culture emphasises autonomy and academic freedom. The industrial culture emphasises values like competitive advantage and innovation. Interdisciplinary research and development is typically seen as a tool to promote these values. The governmental bureaucratic culture emphasises values associated with rules, rationality, and planning. The civil society culture can be seen in protest movements against the values of some (or all) of the other three cultures. This hybrid nature of public research and development organisations introduces specific tensions and challenges in relation to their industrial and academic counterparts.

A wild range of actors and demands have been involved in the operation of public interdisciplinary research and development organisations such as foundations and other agencies including both private and intergovernmental actors. The organisations have to balance norms and values streaming from the four different cultures of the hybrid dimensions: the academic, industrial, bureaucratic, and civil cultures (Coccia and Rolfo, 2015; Gulbrandsen, 2011). Researchers at Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), for instance, reflected that it was difficult to manage multiple sources of requirements. They had to divide their attention in order to respond to those requirements (Bark, Kragt and Robson, 2016). Moreover, public interdisciplinary research and development organisations are typically restricted by legislation (Rosenlund, Rosell and Hogland, 2017). They must operate with openness, transparency, and accountability in all their research activities (Rosenlund, Rosell and Hogland, 2017; Coccia and Rolfo, 2015; Hall, et al., 2006). In addition, Coccia (2009) suggested that bureaucracy is still present in a large number of public administration bodies, universities and public (interdisciplinary) research organizations.

A successful career for interdisciplinary researchers is largely dependent on their results and outcomes, which are representative of their achievements in research such as publications, patients, projects finalised, a portfolio of projects, grants received from governments, enterprises, and foundations, and agreements with businesses (Coccia and Rolfo, 2015; Jin and Sun, 2010).

2.10. Knowledge management in interdisciplinary research and development organisations

Knowledge is regarded as a significant resource of competitive advantage (Wan Zaaimuddin, Goh and Eze, 2009). To achieve competitive advantage, organisations must generate, share, and apply new knowledge to their new product development and innovation processes continuously. In order to make new product development and innovation performance a success, one has to realise the importance of knowledge management in an organisation (Jin and Sun, 2010; Wan Zaaimuddin, Goh and Eze, 2009). Furthermore, new product development and innovation typically requires some level of integration between research and development. Thus, there is interdependence between new product development and innovation, research and development, and knowledge management (Jin and Sun, 2010; Wan Zaaimuddin, Goh and Eze, 2009). A search on Google Scholar using the keywords 'knowledge management' and 'interdisciplinary research organisations' reveals a few publications that have been written on knowledge management in interdisciplinary research and development organisations (e.g. Bark, Kragt and Robson, 2016; Zi-qi, Hua and Xiao-hong, 2011; Jin and Sun, 2010; Chiesa, Christoph and Hinton, 2009; Coccia and Rolfo, 2009; Wan Zaaimuddin, Goh and Eze, 2009).

Wan Zaaimuddin, Goh and Eze (2009), for instance, explored the knowledge management processes and new product development strategy that have effects on new product development performance in research and development organisations. Wan Zaaimuddin, Goh and Eze (2009) suggested that organisations involved in the development of new products need to ensure that their employees are involved in knowledge creation and knowledge sharing as espoused in the Socialisation, Externalisation, Combination and Internalisation (SECI) model, developed by Nonaka and Takeuchi (1995). That is, knowledge management processes are about the compilation of explicit knowledge and involve interactions among individuals, groups, and organisations through socialisation, externalisation, combination, and internalisation. Socialisation is the process of knowledge sharing that occurs through social interaction and communication between individuals or groups of individuals. It is the conversion process of knowledge through shared knowledge, skills, experience, and practices between individuals or groups of individuals. Externalisation is wheretacit knowledge is expressed and translated into forms such as diagrams, models, or prototypes so that it can be understood and used by others directly. Combination refers to the existing explicit knowledge combined with the different types of explicit knowledge obtained from the virtual world of the collaborative environment. At this stage, explicit knowledge can be disseminated through information storage and retrieval technologies. In the internalisation stage, explicit knowledge is made into tacit knowledge. The known and available explicit knowledge is made into tacit knowledge by broadening, extending, and reframing organisation members' tacit knowledge. That is, individuals have to understand and internalise the knowledge obtained.

Jin and Sun (2010) highlighted some knowledge management processes; they suggested that knowledge communication, sharing, and especially integration play important roles in the knowledge management process of interdisciplinary research and development teams. This is because although interdisciplinary researchers might have differences in perspectives on interdisciplinary research, they still tend toward communication and sharing their knowledge, perspectives and experiences in the research and development process; this is an important means to achieving the integration of knowledge. Focusing on knowledge sharing, knowledge dissemination and sharing are crucial among new product development team members in research and organisational organisations during new product development and innovation processes (Wan Zaaimuddin, Goh and Eze, 2009). It involves the transfer of knowledge as well as a complex process of teaching and learning, in which both knowledge senders and knowledge recipients work together over an extended period of time to reach a common understanding (Jin and Sun, 2010). Interdisciplinary researchers should communicate and share their knowledge, perspectives and experiences adequately in order to provide a crucial means for knowledge integration. To improve the degree of knowledge communication, sharing, and integration, a number of approaches have been proposed such as formal and informal project leadership, horizontal structural or cultural mechanisms, and the use of communication technologies. Jin and Sun (2010) also mentioned Nonaka and Takeuchi's SECI model (1995) by suggesting that interdisciplinary research and development teams should establish appropriate knowledge management strategies for knowledge innovation, in order to realise the socialisation and externalisation aspects of individual knowledge, and to encourage the flow of knowledge communicated constructively within each research and development team. Furthermore, knowledge integration is a key process following communication and sharing. The intention of knowledge integration is to enable fragmented knowledge to combine and support the new product development and innovation process. This is to highlight combination and internalisation.

Similarly, Zi-qi, Hua and Xiao-hong (2011, p.148) used Nonaka and Takeuchi's SECI model (1995) and Bhatt's model to propose a static view of the knowledge innovation process of interdisciplinary research in an interdisciplinary organisation. Zi-qi, Hua and Xiao-hong (2011) suggested that a static view of the knowledge innovation process consists of five individual processes: (i.) knowledge acquisition, (ii.) knowledge accumulation, (iii.) knowledge integration, (iiii.) knowledge verification and correction, and (v.) knowledge transmission. That is, in the knowledge acquisition process, members from different disciplines in interdisciplinary research had to shape problem awareness, detect, and define problems in the process of research activities according to organisational goals. In the knowledge accumulation process, the members had to accumulate certain knowledge and the relevant knowledge. They had to generate and integrate new ideas in order to create new knowledge or expand personal knowledge accumulation by using interdisciplinary methods or reciprocal transformation of explicit knowledge and tacit knowledge. In the knowledge verification and correction process, the members had to review and correct the new knowledge as well as pick off the reasonable innovative knowledge. After selection and evaluation, the new knowledge, the reasonable, and the available knowledge was ultimately transferred to the other members of the organisation for their deeply integration in the knowledge transmission process. In this process, the new knowledge and existing knowledge continues to be condensed, compressed, concentrated, and ultimately assembled into the necessary knowledge sets for achieving organisational goals.

Furthermore, Zi-qi, Hua and Xiao-hong (2011, p.149) suggested a dynamic view of the knowledge innovation process of interdisciplinary research in an interdisciplinary organisation. They suggested that knowledge innovation is the interaction process of different discipline knowledge units under the influence of the organisational innovation target, research atmosphere, innovation motivation, cognitive style, and so on. This interaction process referred to the heterogeneity of knowledge units concentrate into different levels of knowledge nodes, through continuous transmission, intersection, deconstruction, integration, construction, and links.

Some scholars have mainly talked about social communication and interaction between interdisciplinary researchers in knowledge management and research and development (e.g. Jin and Sun, 2010; Wan Zaaimuddin, Goh and Eze, 2009). However, other scholars have mainly suggested collaborative information and communication technologies (e.g. Bark, Kragt and Robson, 2016). Bark, Kragt and Robson (2016) evaluated a large interdisciplinary research project undertaken by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), a large and matrix-managed governmental research organisation. Their findings suggested that collaborative Information and Communication Technology (ICT) supported interdisciplinary researchers to collaborate with another researcher within the organisation. That is, interdisciplinary researchers had access to the organisation's internal ICT that facilitated rapid exchange of knowledge, viewpoints, and queries. More specifically, sharing of computer-screens across various locations, as well as video and telephone conferencing technologies, facilitated communication between researchers in different geographic locations. The modelling and Geographic Information System (GIS) data of the project were stored and shared across projects in the organisation's central repository.

In the case of the Interdisciplinary Institute for Broadband Technology (IBBT), both face-to-face communication and ICT were used to facilitate communication and collaboration among members from different disciplines (Duysburgh, Naessens, Konings and Jacobs, 2012). Face-to-face communication was the most popular tool for discussing things. Most research groups had an open door policy to stimulate conversation and knowledge exchange between researchers. It was reported that this sometimes hinders working activities. Physical meetings still made up an extensive amount of the work time for IBBT researchers. There were different types of meetings taking place in IBBT research groups such as ad-hoc meetings, planned meetings, and brainstorm sessions. E-mail was the most popular electronic communication tool, both within and between groups. Instant messaging (IM) tools were little used. IM was mainly used for small and quick questions, also often of an informal nature. Most IBBT researchers at the junior level were reluctant to use their telephone to contact colleagues. They saw it as the last channel of communication when other contact attempts had failed. Half of the IBBT groups have shared electronic agendas. These shared agendas were not entirely open, with access to the agenda of senior researchers often restricted. Fears over privacy and control were also noted.

Within knowledge management, difficulties and barriers in moving knowledge across disciplinary boundaries have been discussed (e.g. Jin and Sun, 2010; Chiesa, Christoph and Hinton, 2009). Chiesa, Christoph and Hinton (2009, p.19) suggested that the difficulties and barriers of knowledge transfer across disciplinary boundaries involve two dimensions: individual/collective and structural/political-cultural. That is, individual barriers affected knowledge transfer between individuals and led to a less-than-optimal use of the knowledge base. Collective barriers affected knowledge transfer between groups of individuals or organisations and caused a less-than-optimal use of the knowledge base of a group or organisation. Structural barriers impeded knowledge transfer within an organisation due to specific structural circumstances within the organisation. Political–cultural barriers, which arose from the established principles and restrictions of an organisation, could hinder knowledge transfer. These dimensions could be put together in a matrix, creating four categories of transfer barriers: individual-structural; individual-political-cultural; collective–structural; and collective-political-cultural. For instance, from an individual-structural aspect, some staff members lacked emotional-motivational activation. From an individual-political-cultural aspect, there was belief in specific causal relationships. From a collective–structural aspect, there were conflicts of cooperation between diverse groups of individuals. From a collective-political-cultural aspect, there was overemphasis of a common disciplinary culture.

The knowledge of individuals from different disciplines could be one of the barriers (Zi-qi, Hua and Xiao-hong, 2011; Jin and Sun, 2010). That is, knowledge from different disciplines has its own patterns, specialisations, complexities, and adaptabilities. Also, different disciplines tend to have different ways of thinking, different ways of problem solving, and different methodological tools. Members from one discipline could not always understand the language and thoughts of members from other different disciplines. Misunderstanding occurred and caused barriers to knowledge communication. Ineffectiveness and inefficiency in the research and develop process happened (Jin and Sun, 2010). Chiesa, Christoph and Hinton (2009) suggested that the development of a common language is required to solve communication problems across disciplines as well as to make the knowledge of different disciplines accessible and understandable for all in an interdisciplinary research and development project in a governmental research organisation.

2.11. Gaps in the existing literature

According to the existing literature on cross-community collaboration and knowledge management, there are some gaps, which were presented in the previous sections, and will be highlighted again below. These gaps will be linked to the research aim and research objectives of this thesis.

The level of interest and prominence in cross-community collaboration has been increasing continuously since the 1990s. However, the recent knowledge contributions and understandings about the dynamics and challenges of collaboration and knowledge management across boundaries remain poorly covered and understood. Firstly, in the existing literature, the nature of boundaries has been little explored and depicted. It is primarily explained as dynamic, fluid, changeable, and invisible. Secondly, the construction of knowledge and disciplinary boundaries has been mainly explained as the degree of difference in terms of knowledge and disciplines between interacting actors from different knowledge communities. The different degrees of difference, dependency, and novelty in knowledge between interacting actors, who are members of different knowledge communities, create different types of knowledge boundaries. Finally, little effort has been made to systematically differentiate between the different types of knowledge boundaries that can exist in interaction between different individuals or groups of individuals from different knowledge communities, and how the nature of these boundaries affects boundary-spanning collaboration and knowledge processes. These topics have been addressed through the development of the three-tier model for managing knowledge across boundaries. However, boundary construction, and cross-community collaboration and knowledge processes have been explained as a linear process. Furthermore, this model is predominantly defined for cross-functional working within intra-organisational new product development in the private sector context. Moreover, the model has been mainly adopted by particular contexts, especially new product development and information technology in private sector organisations. The model and the existing literature have not examined how context can influence the model and its contributions. The model might not be compatible with, or might be less applicable to, different contexts, especially in the public sector context which has different characteristics and challenges, reflected in its hierarchical structures and requirements for accountability.

These gaps identified above are converted into one research aim and four research objectives in this study. This thesis aims to explore the nature of boundaries and how knowledge is managed across them in a public sector context. In order to achieve this aim, four research objectives are created:

i. To explore the nature of boundaries;
ii. To explore why knowledge boundaries arise;
iii. To explore how people manage knowledge across boundaries; and
iv. To develop a framework for managing knowledge across boundaries.

As mentioned above, most existing studies have mainly paid attention to how knowledge is managed across boundaries in particular contexts, especially new product development in private sector organisations. Thus, this thesis explores the topic in the context of an interdisciplinary research project in a governmental research organisation. The next chapter, Chapter 3, presents the context of this study. Before expanding on the research context however, research philosophies, the strategy of inquiry, and research methods are discussed in the next chapter.

3. Research methodology

This chapter explains the research methodology which was adopted in this study. In summary, this thesis was based on an interpretive epistemology, a constructivist ontology, an inductive approach, a case study strategy, and a qualitative research approach. Data were collected from an interdisciplinary research project involving the development of Computerised Tomography (CT) and Digital X-Ray (DR) scanners in a governmental research organisation in Thailand. Data were collected by combining qualitative data collection methods based on: semi-structured face-to-face interview; participant observation; and collection and analysis of documentation and other artefacts. The data were analysed through thematic analysis.

3.1. Research philosophy

This section identifies and explains the research philosophy which relates to the nature of knowledge and the development of knowledge. There are two major aspects of research philosophy: epistemology and ontology (Saunders, Lewis and Thornhill, 2015; Bryman, 2012). Each refers to underlying assumptions and decisions which affect the way in which researchers think about the research process.

3.1.1. Epistemology

Epistemology is a theory of knowledge. It is concerned with the nature of knowledge and more specifically with the question of what can be regarded as knowledge in a field of study (Saunders, Lewis and Thornhill, 2015, p.112; Bryman, 2012, p.27; Matthews and Ross, 2010, p.26). According to Bryman (2012, p.27), there are two opposing epistemological perspectives: positivism and interpretivism.

According to Saunders, Lewis and Thornhill (2015), Bryman (2012), Robson (2011), and Matthews and Ross (2010), a positivist perspective is concerned with facts rather than impressions. It centres on the static and objective knowledge which is made up of hard facts. It argues that knowledge can be acquired by observing and measuring phenomena. Thus, the use of a highly structured methodology is required to measure phenomena and to facilitate replication. Researchers are dependent on and have no impact on the data. It centres on statistical analysis.

By contrast, an interpretivist perspective argues that social phenomena are far more complex and cannot easily be measured (Saunders, Lewis and Thornhill, 2015, p.115). Social phenomena have a meaning for social actors and their social actions are meaningful. That is, it has a meaning for them and they act on the basis of the meanings that they attribute to their acts and to the acts of others (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Matthews and Ross, 2010). Therefore, it is the job of researchers to enter the social world of research subjects, to gain access to people's common-sense thinking, and hence to interpret and understand their actions and their social world through the eyes of the people being studied (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Matthews and Ross, 2010). Thus, an interpretivist perspective prioritises people's subjective interpretations and understandings of their own social actions and social phenomena (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Matthews and Ross, 2010). However, this perspective has its own limitations in that the researcher's interpretation tends to be influenced by prior experiences, subjective views, and views obtained by interacting with others (Saunders, Lewis and Thornhill, 2015; Bryman, 2012).

This research adopted an interpretivist perspective because the research objectives seek exploration, rather than validation. They were concerned with the exploration of the impressions, interactions, practices, and experiences of social actors in cross-community collaboration rather than in facts. They emphasised grasping the social actors' meanings for their social actions and social interactions in cross-community collaboration. The interpretation and understanding of social actors and their social actions and social interactions in collaboration across boundaries was its focus, rather than measuring phenomena that they experience. An interpretivist perspective was an appropriate approach because of its ability to explore meanings that social actors attach to phenomena (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Matthews and Ross, 2010). It was concerned with multiple viewpoints and meanings that social actors from different disciplines attach to social interactions in complex phenomena as cross-community collaboration through the eyes of these social actors (Saunders, Lewis and Thornhill, 2015; Matthews and Ross, 2010).

Furthermore, as mentioned in Chapter 2, the literature review, boundaries are dynamic and are always conceptualised as between two (or more) interacting actors or groups of actors. Moreover, when actors from different knowledge communities attach different languages or terminologies, meanings, and interests based on their knowledge communities to the same things and phenomena in interactions with other different actors, knowledge boundaries are constructed. These points suggest that knowledge boundaries are directly related to social interactions between social actors from different knowledge communities. The exploration of cross-community collaborations suggests the social practices, interactions, and experiences of social actors that need to be understood. Gaining interpretation and understanding about social interactions between members from different knowledge communities in their role as social actors in their worlds and from their viewpoints was important to explore cross-community collaboration.

Saunders, Lewis and Thornhill (2015) argued that an interpretivist perspective is highly appropriate in the case of management research, particularly in fields such as organisational behaviour and human resource management. This is because situations are complex and unique. Also, they are a function of a particular set of circumstances and individuals coming together at a specific time. Briefly, this thesis subscribed to an interpretivist perspective.

3.1.2. Ontology

Ontology is concerned with the way the social world and the social phenomena or social entities that make it up are viewed (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Matthews and Ross, 2010). There are two major opposing ontological perspectives: objectivism and subjectivism or constructionism (Saunders, Lewis and Thornhill, 2015, p.110; Bryman, 2012, p.32).

An objectivist perspective implies that social phenomena should be considered objective entities that have a reality external to social actors (Saunders, Lewis and Thornhill, 2015; Bryman, 2012). That is, social phenomena are independent from social actors who are involved (Matthews and Ross, 2010).

By contrast, a subjectivist or constructionist perspective implies that social phenomena should be considered subjective entities. Social phenomena should be considered social interactions built up from the perceptions and actions of social actors (Saunders, Lewis and Thornhill, 2015, p.11; Bryman, 2012, p.33). Moreover, social phenomena are not static but are in a constant state of evolution by social actors through social interactions (Bryman, 2012; Matthews and Ross, 2010). Therefore, there is need to study the details of the social phenomena to understand the reality. This links to the interpretivist epistemology stance that it is necessary to explore the meanings motivating the actions of social actors in order to be able to understand these actions (Bryman, 2012; Matthews and Ross, 2010).

This study adopts a subjectivist or constructionist perspective. This is because boundaries are constructed through the social interactions between actors or groups of actors from different knowledge communities. Cross-community collaborations are social practices and social interactions built up from the actions and interactions of social actors who are members from different knowledge communities. Boundaries and cross-community collaborations are dynamic and are continually being changed as a result of social interactions between interacting actors from different knowledge communities. These suggest that boundaries and cross-community collaborations are dependent on the social actors who are involved. Therefore, there is need to study the details of the boundaries and cross-community collaborations to understand the reality. It is the job of researchers to seek to understand the impressions, interactions, practices, and experiences of interacting actors from different knowledge communities in order to be able to make sense of and understand their actions in a way that is meaningful.

3.2. Research approach

In what concerns the use of theory in research and the relationship between theory and research, there are two broad types of research approaches: deductive and inductive approaches (Bryman, 2012; Robson, 2011; Matthews and Ross, 2010; May, 2001; Creswell, 1994). A deductive approach is concerned with the testing of existing theories and hypotheses. In this research approach, theorizing comes before research. Then, research functions to produce evidence to test theories. Theories and hypotheses guide the process of gathering data to test the theories and hypotheses (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Matthews and Ross, 2010; May, 2001; Creswell, 1994). By contrast, an inductive approach is concerned with the development of theories emerging from the data analysis. In this research approach, research comes before theories. Then, research functions to generate theoretical propositions from the collected data. An inductive approach starts from a particular aspect of social phenomena to infer broad general ideas or theories. Such ideas or theories are a result of explicit data and data analysis (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Matthews and Ross, 2010; May, 2001; Creswell, 1994).

Deductive and inductive approaches are associated with the research philosophies. A deductive approach owes more to the positivistic epistemology, while an inductive approach owes more to the interpretive epistemology (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Creswell, 1994). That is, for the positivistic epistemology, the focus is on analysing causes and effects to test established theories and hypotheses by using a deductive process. By contrast, for the interpretive epistemology, the focus is on analysing themes that emerge during data collection and analysis by using an inductive process (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Creswell, 1994).

This study adopted an inductive approach due to the exploratory nature of the research objectives. This means that the findings and theories are grounded in and are the result of the exploring of the empirical data, rather than in the existing literature as is the case with a deductive approach. The research objectives mainly emphasised gaining an understanding of the meanings actors attach to cross-community collaboration in the real-social context. This relied on the collection of qualitative data and use of a flexible approach for investigation. The result of analysis is the formulation of a theory. In other words, the research objectives lend themselves to an inductive approach. By contrast, a deductive approach is mainly based on scientific principles, moving from an existing theory and hypothesis to data, the collection of data, and use of a highly structured approach (Saunders, Lewis and Thornhill, 2015).

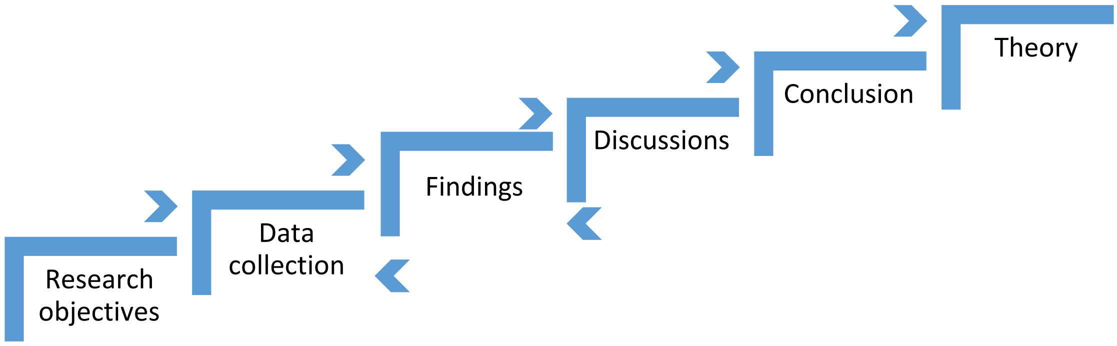


Figure 3.1 Process of induction

Figure 3.1 above provides a representation of how an inductive approach can be visualised. Firstly, the research objectives were generated from existing studies on cross-community collaboration and knowlegde management. The most relevant and significant theoretical models and concepts about cross-community collaboration and knowlegde management were reviewed. This was to help the researcher to know the current status of the subject or what was going on, to gain knowledge background and understanding about the subject of the study, to refine the research objectives, to avoid simply repeating work that has been done already, to get an idea about research techniques that might be appropriate to this study. Secondly, the relevant site and subjects were selected and relevant data were collected in order to meet the research objectives. Thirdly, the findings from the gathered data were presented. Then, the findings were interpreted and compared to the existing literature on the subject. Further data (might be) was collected and analysed to explore and address grey areas and new avenues of inquiry suggested by the first set of gathered data. The findings were then presented as a theoretical discussion with conclusions generated from the gathered data. Finally, the researcher inferred the implications of the findings from the study for the theory. The findings were then fed back into the stock of theory on organisational and knowledge management.

3.3. Research strategy

Research design (Bryman, 2012) which was called 'research strategy' by Saunders, Lewis and Thornhill (2015) refers to the plan of how researchers will go about answering the research question(s) or objectives(s).

According to Bryman (2012, p.50), there are five different types of research designs which are associated with qualitative or quantitative research: case study design; comparative design; longitudinal design; experimental design; and survey design.

i. Case study design entails the intensive and detailed investigation and analysis of a particular phenomenon within its natural context by using multiple sources of data (Saunders, Lewis and Thornhill, 2015; Thomas, 2011). Creswell (2009) argued that the aim of a case study is to catch the complexity and look for the detail of actions or interactions within its real-social contexts. Thus, case study design helps to gain a rich understanding of the context of the research and the processes being enacted (Saunders, Lewis and Thornhill, 2015). It is appropriate to generate answers to the question 'why' as well as to 'what' and 'how' questions (Saunders, Lewis and Thornhill, 2015, p.146).

ii. Comparative design is different from case study design which looks at a single entity or phenomenon. Comparative design involves studying two contrasting entities or phenomena using more or less identical methods. It addresses the logic of comparison (Bryman, 2012, p.72). However, Thomas (2011) and Matthews and Ross (2010) included comparative design in case study design and argued that a case study includes either a single entity (case study design) or a small number of entities (comparative design).

iii. Longitudinal design is the study of a particular phenomenon/phenomena over two or more time periods by using the same variables and samples (Saunders, Lewis and

Thornhill, 2015; Robson, 2011). Regarding the issues of time and attrition, longitudinal design helps to capture some insight into social change (Thomas, 2011).

iv. Experimental design is a form of research that owes much to the natural sciences (Saunders, Lewis and Thornhill, 2015, p.142). It aims to study whether a change in one independent variable produces a change in another dependent variable. That is, it involves studying the size of the change and the relative importance of two or more independent variables under controlled conditions (Saunders, Lewis and Thornhill, 2015; Thomas, 2011). This implies a quantitative approach, which was supported by Saunders, Lewis and Thornhill (2015), Bryman (2012) and Creswell (2009).

v. Survey or cross-sectional design involves the collection of data from more than one case (normally quite a lot more than one) and at a single context over time in order to collect data in connection with variables (Bryman, 2012, p.58). This research strategy is quite popular as it allows the collection of a large amount of data from a sizeable population (Saunders, Lewis and Thornhill, 2015). It is appropriate to generate answers to the ‘what’ and ‘how’ questions (Saunders, Lewis and Thornhill, 2015; Bryman, 2012).

According to the research aim and objectives of this study, the philosophical underpinnings and the amount of time available, it is argued that a case study strategy is appropriate. Cross-community collaboration and knowledge management is a social interaction and a process with a dynamic character; therefore, it is preferable to study it in a natural setting. Thus, this research selected a case study strategy in order to capture and explore the dynamic and complex processes and phenomena of knowledge management and collaboration between different knowledge communities within its real-life context (Saunders, Lewis and Thornhill, 2015; Thomas, 2011; Yin, 2009). Similarly, Moore (1983) argued that a case study is commonly used when the research is attempting to understand complex social worlds or the diffuse causes and effects of change within their real-life context.

A case study strategy focuses on one entity or case by looking at it in detail and at various dimensions of it as a whole (Matthews and Ross, 2010). A case study allows the researcher to look at the subject of the study as a whole (Thomas, 2011): cross-community collaboration and knowledge management (events or activities) between members from different knowledge communities (social actors and social worlds) in a governmental research organisation (context or setting). Thomas (2011) argued that the important distinction between the case study and the other types of research strategy is the number of cases investigated and the amount of detailed information which can be collected. Taking a case study approach prompted the researcher to gather rich, in-depth, and complex data from multiple sources of evidence (Yin, 2009). This is in order to gain a rich picture and understanding of the subject of the study and its context as well as to gain analytical insights from it (Saunders, Lewis and Thornhill, 2015; Thomas, 2011). Case study is often used in explanatory and exploratory research (Saunders, Lewis and Thornhill, 2015). Moreover, it has considerable ability to generate answers to the why, what, and how questions which correspond with the research objectives of this study. Examples of previous relevant research that adopted a case study strategy are found in Le Dain and Merminod (2014), Edenius, Keller and Lindblad (2010), Kim and Jarvenpaa (2008), Maaninen-Olsson, Wismen and Carlsson (2008), Pardo, Cresswell, Thompsom and Zhang (2006), Fong and Lo (2005), Carlile (2004), and Syed-Ikhsan and Rowland (2004).

A comparative strategy was not selected because in this strategy the case itself is likely to be less important than its comparison with other cases. The main focus of a comparative strategy is on the nature of the differences between one case and other cases (Thomas, 2011), while this study concentrated on an in-depth exploration and understanding of a complex phenomenon of cross-community collaboration. The dynamic of boundaries and cross-community collaboration in an interdisciplinary research project relates to changes. Longitudinal strategy could enable this study to look at the actors and situations regarding cross-community collaboration at key points in time and to consider how the changes over time have affected the actors and situations (Saunders, Lewis and Thornhill, 2015; Matthews and Ross, 2010). However, a longitudinal study was not selected because of the considerable amount of time and financial resources required to collect data. Also, the researcher would not have access to the case study in the chosen organisation during the duration of the PhD. Furthermore, there is a significant risk of gathering data from the same participants on each of the data-gathering occasions. For instance, the participants have moved and cannot be contacted, or because they no longer wish to participate. These situations could affect the data collection and analysis processes. It is argued that an experimental strategy is not appropriate as the research is at an exploratory stage and is in the natural setting. A survey or cross sectional strategy is not appropriate because of the large scale and considerable amount of time required to collect data. Also, the data collected by a survey study is unlikely to be wide-ranging (Saunders, Lewis and Thornhill, 2015).

Action research and ethnography research were the other two qualitative methods that were considered but rejected for this study. Action research is a strategy for studying change in organisations, in personal, group, or organisational levels (Creswell, 2009). The main aim of action research is either to solve an immediate or particular problem or to reflect on a process of progressive problem-solving led by social actors with other social actors in a collaborative context to improve strategies and practices in organisations (Brannick and Coghlan, 2007; Reason and Bradbury, 2001). It aims at both taking action and creating knowledge or theory about the action (Brannick and Coghlan, 2007). This research strategy is appropriate to study a complex social process as well as personal and organisational change by introducing changes into the process and context in the case being studied, involving close collaboration between researchers and participants, observing phenomena of study, and reflecting of researchers (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Creswell, 2009; Brannick and Coghlan, 2007; Reason and Bradbury, 2001). As mentioned above, action research could enable this study to explore the complex social process, phenomena, and changes in collaboration and knowledge management between members from different knowledge communities in the research project.

However, action research was not selected for this study because the development of understandings on phenomena of study and the formulation of theory in action research occurs by introducing changes into the phenomena and observing the causes and effects of these changes. During action research, researchers not only observe the phenomena of study, but also intervene and closely participate in the subject under study and in a change situation (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Thomas, 2011; Creswell, 2009; Brannick and Coghlan, 2007; Reason and Bradbury, 2001). The context and social actors tend to be controlled. This study wanted to capture and explore actions, interactions, activities that research project members attach to phenomena in cross-community collaboration and knowledge management naturally in their real world. Thus, this study did not want to introduce changes about cross-community collaboration and knowledge management into project members and phenomena being studied, and observe the causes and effects of these changes. Also, this study did not want to intervene in project members and phenomena being studied. The intervention of researchers might have effects on project members' actions and responses. This situation might raise an issue about the validation of the study.

Ethnography research was another qualitative research strategy that was considered but rejected for this study. Ethnography is a qualitative research study where researchers observe and/or interact with participants in their natural environment (Saunders, Lewis and Thornhill, 2015). This is to study social interactions, behaviours, and perceptions that occur within groups and organisations (Reeves, Kuper and Hodges, 2008). Ethnography is primarily based on observation and a prolonged period of time spent by researchers in the field (Creswell, 2009; Reeves, Kuper and Hodges, 2008). The main aim of ethnography research is to provide rich, holistic insights into social actors' views and actions; more specifically, how social actors interact with things or other social actors in their natural setting (Saunders, Lewis and Thornhill, 2015; Creswell, 2009; Reeves, Kuper and Hodges, 2008). As mentioned above, ethnography research could enable this study to gain in-depth insights into research project members' perspectives and actions related to cross-community collaboration and knowledge management they encountered during their day in their natural environment. It could provide this study with an understanding of how project members perceive cross-community collaboration and how they interact with the other project members or things in the collaboration.

However, this study did not select ethnography research because the amount of time it takes to conduct; ethnography research normally requires a long period of time (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Thomas, 2011; Creswell, 2009; Reeves, Kuper and Hodges, 2008). Also, the researcher would not have access to the case study during the duration of the PhD. Although ethnography research was not selected, this study adopted an individual data collection method which is associated with ethnography as observation to observe actions and interactions of research project members. This was to explore and explain what happened, who or what were involved, when and where things happened, how they occurred, and why things happened in collaboration between different knowledge communities in the real setting (see Section 3.6.3 for participant observation).

Thomas (2011) defined the classification of case studies based on their subject or how to select the case study, together with their purpose, approach, and process, to guide how to undertake the case study. These issues are all related to one another.

Subject	Purpose	Approach	Process Single/Multiple
Outlier case	Intrinsic	Testing a theory	Nested
Key case	Instrumental	Building a theory	Parallel
Local knowledge case	Evaluative	Drawing a picture	Sequential
	Explanatory	Interpretative	Retrospective
	Exploratory	Experimental	Snapshot
			Diachronic

Table 3.1 Types of case studies

Source: Thomas (2010)

Table 3.1 above summarises the types of case studies suggested by Thomas (2010). Firstly, the subject or main reason(s) for choosing a particular subject for a case study; Thomas (2011, p.76) divided the three broad reasons for a case study into: outlier case; key case; and local knowledge case. An outlier case is a case that may reveal something interesting and its difference from other examples and the norm. A key case is a case that may provide a particularly good example of something. A local knowledge case is a case that researchers are familiar with it. A local knowledge case thus aims to understand some feature of the subject.

Secondly, Thomas (2011, p.98) divided the two broad purposes for a case study into: intrinsic and instrumental. With an intrinsic case study, the subject is undertaken because the case itself is of interest. There is no a secondary purpose in the researchers' idea apart from out of interest. By contrast, an instrumental case study is undertaken with a purpose in the researcher's mind. Researchers use case study as a tool to evaluate something or to understand something better. Beyond differences between the intrinsic and the instrumental, a case study can be further divided according to whether its purposes are for evaluation, or are explanatory and/or exploratory – or some combination of these (Thomas, 2011, p.99). Evaluation research is to see how well something is working or has worked as well as to see whether something has been changed or a new idea has been introduced. Evaluation research is also to find out what the change has led to. Explanatory research is to drill down into phenomena to provide explanations of phenomena. Exploratory research is to know more about what is happening and why.

Thirdly, an approach involves how the study is conducted: testing a theory; building a theory; drawing a picture; is experimental; or interpretative – or some combination of these (Thomas, 2011, p.111). In a theory-testing case study, the case study is being undertaken to test an existing framework and theory. By contrast, in a theory-building case study, the case study is being undertaken to develop ideas. An illustrative case study aims to make a topic more real for the reader by illustrating a phenomenon. An interpretative case study is a form of study that employs a particular approach that assumes an in-depth understanding and deep immersion in the context of the subject in order to answer questions. An experimental case study is where ideas are being tested under controlled conditions.

Finally, process involves how the case study will be structured (Thomas, 2011, p.137). There are two broad forms of case study: a single case and multiple cases (Thomas, 2011; Robson, 2011; Matthews and Ross, 2010). A single case is further divided into three cases: retrospective (involving the collection of data relating to a past phenomenon, situation or event); snapshot (looking at the case in one period of time); and diachronic studies (looking at the case over time to see changes). A multiple case is further divided into: nested case studies (breakdown of the unit of analysis); parallel studies (the cases are happening and being studied at the same time); and sequential studies (the cases happen one after the other).

In this study, the main reason for selecting a particular subject for the case study was 'a local knowledge case'. The major purposes of undertaking a case study were 'instrumental', 'explanatory', and 'exploratory'. A case study was carried out through two approaches: 'building a theory' and being 'interpretative'. A 'snapshot' was adopted to collect data. Figure 3.2 below summarises how the case study of this research was designed. The details of these choices are depicted below.

Subject	Purpose	Approach	Process Single/Multiple
Outlier case	Intrinsic	Testing a theory	Nested
Key case	Instrumental	Building a theory	Parallel
Local knowledge case	Evaluative	Drawing a picture	Sequential
	Explanatory	Interpretative	Retrospective
	Exploratory	Experimental	Snapshot
			Diachronic

Figure 3.2 Design of the case study of this research

Adapted from: Thomas (2010)

This study was based on a local knowledge case; the researcher carried out the case study in her place of work. The major reason for this was that the researcher had intimate knowledge, experience, and understanding of the case. The researcher also had easy access to the people involved. Thus, the researcher had more opportunity to gain access and drill down into the case and the subject of the study (see Section 3.5.1 for research context). The researcher had a purpose for using the case study as a tool to gain a better understanding of the nature of knowledge boundaries and how knowledge is managed across the boundaries. Specifically, this study consisted of two purposes for undertaking the case study: exploration and explanation. That is, the researcher would use the case to explain and explore the nature of knowledge boundaries, the construction of the boundaries, and how people manage knowledge across them in the natural setting. Depending on the research objectives, the case study of this research was in line with a theory-building and an interpretative case study. That is, the case study was used to develop a framework for managing knowledge across boundaries. To do this the case study was examined to uncover and interpret the nature of knowledge boundaries, why boundaries arise and how the boundaries are overcome to move knowledge across them. Due to the complex and dynamic nature of knowledge boundaries and the processes to manage knowledge across boundaries, the researcher employed various data collection methods to gain understanding about the subject in its environment. As mentioned above regarding the selection of a case study strategy and a comparative strategy, this study was a single snapshot case study. This helped to obtain rich, in-depth, and naturalistic data of events in order to gain a better understanding of the interconnections of events taking place in one period of time.

3.4. Qualitative approach

A qualitative research approach was selected because the nature of the research objectives of this study was considered to be more associated with this than with a quantitative research approach. That is, this study intended to explore the nature of boundaries, which was dynamic; and how people manage knowledge across boundaries, which was difficult and complex. This study sought to gain rich and in-depth understandings of the perspectives, perceptions, feelings, and experiences of actors in cross-community collaboration that the actors reported in their own words and using their own frames of reference. This study sought to gain rich and in-depth understandings of the stories, processes, and activities of cross-community collaboration being studied. The researcher wanted to achieve a comprehensive understanding of the meanings of actions and interactions that actors attach to their actions during doing a cross-community research project in the natural setting.

According to the nature of the research objectives mentioned above, it was in line with the nature of qualitative research. This is because a qualitative research approach concentrates on processes which are a sequence of people and collective events, actions, and activities unfolding over time in a given context (Bryman, 2012; Thomas, 2011). It aims to explore complex issues involving human behaviour, actions, and interactions (Bryman, 2012; Thomas, 2011). By contrast, a quantitative research approach concentrates on people and events in terms of aspects of amounts and frequencies (Thomas, 2011). A qualitative research approach is linked to the subjective nature of social reality; it provides insights from the perspective of participants. It thus enables this study to see things as the participants do; especially why knowledge boundaries arise and how participants manage knowledge and collaboration across boundaries (Bryman, 2012; Holloway and Wheeler, 2002). A qualitative research approach considers that the context of participants' lives or work affects their behaviour. Thus it realises the context and culture in which the study takes place. It suggests that if researchers understand the context, they can locate the actions and perceptions of individuals and grasp the meanings that they communicate (Holloway and Wheeler, 2002).

Furthermore, the research objectives were concerned with explanation; they involved 'what' and especially 'why' and 'how' questions. The research objectives typically emphasised non-numeric data as well as detailed and rich descriptions rather than numeric data and quantification in the collection and analysis of data. Bryman (2012) argued that qualitative studies are much more inclined than quantitative studies to provide a great deal of detailed and rich descriptions of what goes on in the setting being examined. A qualitative research approach focuses on non-numeric data and often uses words in the presentation of the analyses of data (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Thomas, 2011). This is because the rich descriptions are important for their subjects as well as providing an account of the context within which people's behaviour occurs (Bryman, 2012). By contrast, a quantitative approach is mainly related to and focused on numeric and static data (Saunders, Lewis and Thornhill, 2015; Robson, 2011). It often uses quantities in the presentation of the analyses of data (Bryman, 2012, Thomas, 2011).

Moreover, a qualitative research approach is often unstructured and flexible. It enhances the opportunity of immersing the researcher in the real world of people and revealing the perspectives of the people they are studying (Bryman, 2012; Holloway and Wheeler, 2002). It thus allows researchers to develop understanding of the context within which actors' behaviours, actions, and activities take place (Bryman, 2012). A qualitative research approach helped this study become immersed in the real world of the actors and revealed their perspectives, feelings, and experiences about cross-community working in their own words though use of flexible methods: semi-structured interviews and observation. A consequence could be the provision of a great deal of detailed and rich descriptions on the natural setting that the study was researching as well as descriptive detail on the participants' perspectives, feelings, and experiences. By contrast, a quantitative research approach is often highly structured and in a contrived context (Bryman, 2012). It often uses numbers and statistical methods (Saunders, Lewis and Thornhill, 2015; Bryman, 2012, Thomas, 2011). Highly structured and statistical methods are less appropriate to reveal the required data for this study, which is a sequence of actors and collective events, actions, and interactions unfolding over time in the natural setting, to meet the research objectives of this study.

3.5. Research setting

3.5.1. Research context

3.5.1.1. Sampling

As mentioned in Section 3.3, a case study strategy was selected. A single interdisciplinary research project in a single organisation was deliberately chosen to explore knowledge management and collaboration across disciplines within that single project and organisation. The research context of this research was a governmental research organisation, the National Science and Technology Development Agency (NSTDA), in Thailand. As mentioned in Section 3.3, this research context was a local knowledge case (Thomas, 2011, p.76). That is, the researcher knew about the research context and wanted to understand some feature of the research context. This research context was selected through purposive sampling (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Matthews and Ross, 2010).

That is, firstly, this research context was relevant to, and enabled the researcher to meet, the research objectives. NSTDA was a governmental research organisation. It also adopted the concept of cross-disciplinary and organisational boundaries, as will be depicted below. Thus, it had the basic characteristics that are directly related to the researcher's area of interest and the research objectives, and would allow the researcher to study the research topic in-depth. Secondly, it was also relatively easy to reach participants and was the most familiar context to the researcher because the researcher was a member of the organisation, NSTDA. Therefore, it seemed natural, appropriate, and more feasible to locate the case study and sample participants of this study within NSTDA to collect data. Being already a participant in this research context, the researcher had pre-understanding and experience about it. This provided important knowledge and understanding about what the organisation is really like. The researcher knew the organisation's everyday life as well as the legitimate and taboo phenomena of what can be talked about and what cannot (Saunders, Lewis and Thornhill, 2015, p.292). The researcher could draw on her own experience in interviewing and was able to follow up replies, and so obtain rich data. Also, the researcher was able to observe what was going on and could participate less without drawing attention and creating suspicion. Being familiar with the context of the research setting also enabled the researcher to drill down into the context and circumstances concerning cross-community collaboration. Moreover, it was key to gaining a better understanding of actions being enacted in their natural setting by the social actors. However, there might have been some issues about being a member of the organisation and a participant observer (see Section 3.9.3 for researcher reflexivity and research setting).

NSTDA is one of the leading scientific and technological centres in Southeast Asia (Centre for Social Innovation, 2012). NSTDA's major responsibilities are: to conduct research and development; to call for scientific and technological innovation in the main areas critical to Thailand's development; to transfer knowledge from research projects to meet stakeholders' needs; to develop scientific and technological human resources; and to enhance the scientific and technological infrastructure (National Science and Technology Development Agency, 2016). NSTDA consists of four different national research centres in different branches of science, together with one technology management centre. Each research centre is comprised of a number of Research Units and Laboratories (National Science and Technology Development Agency, 2016).

i. The National Center for Genetic Engineering and Biotechnology (BIOTEC)

ii. The National Electronics and Computer Technology Center (NECTEC)

iii. The National Metal and Materials Center (MTEC)

iv. The National Nanotechnology Center (NANOTEC)

NSTDA, like other research organisations, has been confronted with many challenges such as facing competitors who deliver similar services and products; and being required to deliver more knowledge-intensive commercial outputs, with a limited increase in government funding. To overcome these challenges, NSTDA has adopted a system of programme-based budgeting and a research management system which focuses on problem contexts and applications through cross-community collaboration since the fiscal year 2007 (National Science and Technology Development Agency, 2012). This is in order to integrate its resources and capabilities as well as to create closer connections among its national research centres for the delivery of high standards and quality output to meet the challenges and the needs of its beneficiaries (National Science and Technology Development Agency, 2012). This suggests that NSTDA is likely to be an appropriate context that this study needs to investigate; more specifically, it is relevant to cross-community collaboration.

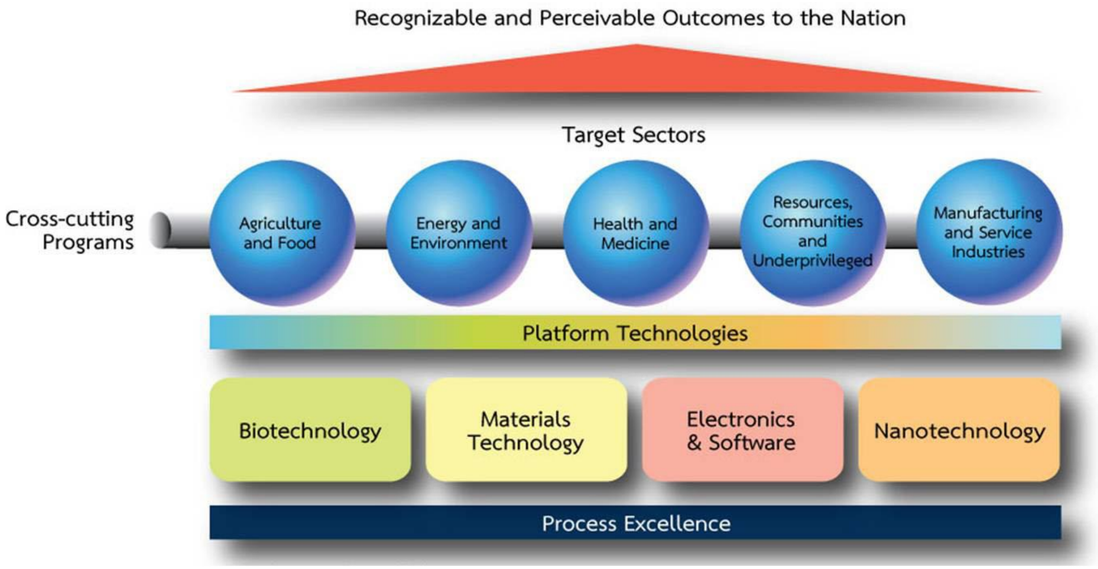


Figure 3.3 NSTDA research and development strategy and direction (2012-2016)

Source: National Science and Technology Development Agency (2012, p.6)

Figure 3.3 presents NSTDA's research and development strategy and direction between 2012 and 2016. NSTDA intends to conduct research in major five clusters: agriculture and food; energy and the environment; health and medicine; resources, communities and the underprivileged; and manufacturing and service industries. Each cluster consists of many research programmes and each programme comprises several research projects. The four national research centres: biotechnology; materials technology; electronics and software; and nanotechnology centres, play a key role in the conduction of research within this framework. In addition, each research centre develops new and important technology bases within its field. NSTDA also supports cross-cutting programmes to link the various research clusters.

NSTDA recognises the importance of knowledge management as a critical trigger to improve its performance, to increase quality output to meet stakeholders' needs, and to gain a better potential for competitive advantage through innovation. NSTDA also responded to the requirements of the Office of the Public Sector Development Commission of Thailand which has listed knowledge management as a key indicator for measuring a governmental institution's performance (Office of the Public Sector Development Commission, 2007). Thus, NSTDA established its knowledge management initiative and has assigned knowledge management into its corporate strategic plan since 2008 (National Science and Technology Development Agency, 2008).

In 2015, NSTDA had 2,715 employees. These included 1,858 full-time research and technical staff (around 68.43%). In the fiscal year 2015, NSTDA conducted 1,483 projects of which 454 projects were completed, published 642 articles in international journals, and registered 189 patents (National Science and Technology Development Agency, 2016).

3.5.1.2. Administration and timeline

For access to the research setting, the researcher sent a letter that included the research proposal, the researcher's curriculum vitae, the information sheet, and the consent form to the president of NSTDA in order to ask the president for permission. After receiving consent from the NSTDA's president, the researcher was asked to submit documentation and present the research proposal to the Thai Committee for the Development and Encouragement of Research Ethics in Humans of the National Science and Technology Development Agency for ethics approval. The research proposal received ethics approval from the Committee on 5th June 2014. After receiving ethics approval, key informants in NSTDA were contacted to select the most appropriate research case study (see Section 3.5.2 for research case study).

There were two phases planned for the data collection to provide opportunities for the researcher to analyse the initial gathered data from the first phase to discover significant issues involved in the subject of the study. The second phase of data collection and analysis then aimed to explore and address grey areas and new avenues of inquiry suggested by the first phase of analysis, as will be depicted below. Therefore, the research setting was visited from April 2014 to June 2014 to undertake the first phase of data collection. It was then revisited from January 2015 to April 2015 to undertake the second phase.

3.5.2. Research case study

3.5.2.1. Sampling

A cross-disciplinary research project of NSTDA involving the development of Computerised Tomography (CT) and Digital X-Ray (DR) scanners was selected as a case study for this thesis. This research case study was selected through purposive sampling (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Matthews and Ross, 2010).

In connection with this selection, the researcher consulted key informants in NSTDA to gain a list of interdisciplinary research projects in the organisation. The researcher consulted: (i.) the two researchers who had been involved in cross-organisational and disciplinary research projects; (ii.) the senior programme director of the Cluster Program Management Office who monitored the organisation's research projects; (iii.) the analyst of the Business Development and Technology Transfer Division; and (iv.) the senior director of the Organisational Assessment Department. From this, six research projects were suggested by the key informants. The researcher then reviewed the available information on these six projects from the associated documentation. The researcher also talked to a number of people who were involved in these projects to find out which project would best provide the required data to meet the research objectives. As mentioned in Section 3.3, a single research project was deliberately chosen to explore cross-community collaboration and knowledge management. The development of CT and DR scanners was selected as a case study for this thesis because this case study was relevant to, and enabled the researcher to meet, the research objectives. It had the basic characteristics that are directly related to the researcher's area of interest and the research objectives, and thus would allow the researcher to study the research topic in great depth.

That is, this project is co-developed by two different knowledge communities from different disciplines and from different national research centres under NSTDA; more specifically, the software group from the National Electronics and Computer Technology Center (NECTEC) and the hardware group from the National Metal and Materials Technology Center (MTEC). The project aims to integrate computer and information technologies, material technologies, and management to develop CT and DR scanners for medical diagnosis and operations which have been developed in response to Thai doctors' needs. It also aims to reduce the costs of scanner imports which are very considerable, to improve scanner development knowledge and to increase the country's competency in medical industries and services. This project is an ongoing joint project and has been evolving since 2007. Also, because the case is ongoing, it therefore yielded a relatively rich corpus of data. Furthermore, this project is one large and well-known project of NSTDA. It is considered successful in terms of interdisciplinary collaboration because it proposed the first development of the cone-beam CT scanner in Thailand, called DentiiScan. The dental CT scanners, version 1, of this project have been used in both public and private hospitals in Thailand. This suggests that this case study could shed light on cross-community collaboration. For these reasons, it was felt that the scanner case study was suitable to enable the researcher to answer her research objectives in-depth.

The other five research projects were not chosen because some of them were completed projects and therefore it was difficult to retrieve data from the participants; there were also no opportunities to observe collaboration among project members. These research projects could thus not help to gain rich and in-depth understandings of the perspectives, perceptions, feelings and experiences of actors in cross-community collaboration in the natural setting. Moreover, some of five research projects were conducted independently or sequentially by project members from different knowledge communities. Thus, the level of communication and collaboration across boundaries was very low. Therefore, they exhibited no characteristics that are directly related to the researcher's area of interest and the research objectives.

This project team of the development of CT and DR scanners consists of four sub-projects: the development of a dental CT scanner; a mobile CT scanner; a mini CT scanner; and a DR scanner. These sub-projects are conducted in parallel. Project members are assigned to participate in more than one sub-project. Also, some researchers and engineers in the project not only researched and developed the scanners but also sell the scanners because of limitations on the number of project members. These four sub-projects present different knowledge challenges. For instance, there are differences in the bodies of each scanner, as well as in the parts of the patients' bodies requiring X-ray scanning.

The project consists of 23 members: the project director; the project managers of the software and the hardware groups; and the other 20 project members of the two groups. Moreover, the hardware and software groups have different sub-groups based on the knowledge and responsibilities of members in the groups. For instance, in the software group, there are sub-groups concerned with viewer development (focusing on computer programs) and reconstruction (focusing on mathematical theories and algorithms). Project members include researchers, research assistants, engineers, and project analysts. Most project members have knowledge backgrounds in engineering. However, there are differences in their sub-fields and academic disciplines. For the software group, most members graduated in electrical engineering and computer science. They have knowledge and skills in fields such as signal processing, image processing, electronics and computer systems, computer graphics and visualisations, including computer programs and databases. By contrast, most members of the hardware group graduated in: electrical engineering (such as control systems engineering); chemical engineering; mechanical engineering (such as design, industrial, manufacturing, and production); and biomedical engineering, including mechatronics. This suggested that there is a range of academic disciplinary boundaries involved in this case study; knowledge management and collaboration across boundaries could thus be strongly expressed for analysis. Also this suggested that there is potential for considerable complexity arising from this. Table 3.2 below summarises the knowledge backgrounds and skills of project members in the case study; thus making it an interdisciplinary research project.

<table>
<tr><th>Main disciplines</th><th>Sub-disciplines</th><th>Groups</th></tr>
<tr><td rowspan="5">Engineering</td><td>Biomedical engineering:
Implant
Medical device
Medical imaging
* The software group focuses on programs, while the hardware group focuses on machines and physical components</td><td>HW+SW</td></tr>
<tr><td>Chemical engineering</td><td>HW</td></tr>
<tr><td>Electrical engineering:
Control systems engineering
Electronics and computer systems
Signal and digital signal processing
Image processing
*Electrical engineering is related to other disciplines including computer engineering, computer science, biomedical engineering, and mechatronics

* The software group focuses on programs, while the hardware group focuses on machines and physical components</td><td>HW+SW</td></tr>
<tr><td>Mechanical engineering:
Design
Manufacturing and industrial
Production
*Mechanical engineering overlaps with electronic engineering, chemical engineering and may also work in biomedical engineering</td><td>HW</td></tr>
<tr><td>Mechatronics:

* Mechatronics is a multidisciplinary field of engineering which includes a combination of electrical engineering, mechanical engineering, telecommunications engineering, control engineering, and computer engineering</td><td>HW</td></tr>
<tr><td>Computer science</td><td>Theoretical computer science: logical and mathematical aspects of computing; algorithm and coding theory; and programming language theory
Artificial intelligence: image processing; medical image computing.
Computer architecture and engineering
Computer graphics and visualisations
Computer networks</td><td>SW</td></tr>
</table>

Main disciplines	Sub-disciplines	Groups
	• Databases • Information science • Software engineering • Digital signal processing *Computer science overlaps with electronic engineering	
Humanities and social sciences	• Marketing	SW+HW
	• Information management	SW+HW
	• Technology management	SW

Table 3.2 Knowledge backgrounds of participants

3.5.2.2. Administration and timeline

After receiving consent from the NSTDA's president and ethics approval, the project manager of the software group of the development of the CT and DR scanners was contacted for their permission and participation. The research proposal, the researcher's curriculum vitae, the information sheet, and the consent form were sent to the project manager via e-mail. Once receiving consent, the researcher met the project manager to introduce herself, to depict the research and data collection processes, and to answer questions or explain unclear points in the information sheet and the consent form. This meeting was also an opportunity for the researcher to ask the project manager to talk about the background of the research project and collaboration among project members. Furthermore, the meeting was used as a tool to become familiar with the project manager, the key informant. After the meeting, the project manager took the researcher to visit the project laboratory to introduce the research project to her and for her to see the project scanners. After that, the researcher was invited by the project manager to join in one project's monthly meeting in order to introduce herself and her research study to the other project members.

Prospective participants were then contacted for interviews (see Section 3.6.2 for interviews). The other two key informants and contact persons for the software and hardware groups, who were nominated by the project manager, were contacted to obtain the schedule for the project monthly meetings for observation purposes (see Section 3.6.3 for observation). The researcher kept in contact with these two key informants to also receive the schedule for the meetings about the implementation of ISO 13485 and risk management, again for observation. These meetings consisted of project members from both groups. Furthermore, the researcher received permission to observe collaboration among project members in the project laboratory (see Section 3.6.3 for observation).

As mentioned above, there were two phases of the data collection process. The research case study site was first visited for three months between April 2014 and June 2014. It was then revisited for four months between January 2015 and April 2015. Thus, the case study site was visited for a total of seven months to collect data. Interviews and observation, including the collection and analysis of documentation and artefacts, were arranged and conducted throughout the seven months to ensure that they could be conducted and analysed before another round was undertaken and analysed (see Section 3.6 for each data collection method and Section 3.7 for data analysis).

3.6. Data collection methods

This section presents data collection methods which were used in other relevant studies in cross-community collaboration. Then, it presents the data collection methods which were used in this study: semi-structured face-to-face interview; participant observation; and collection of documentation and other artefacts.

3.6.1. Selection of data collection methods

A multi-method qualitative approach was found to be one of the most popular data collection methods used in many of the studies on cross-community collaboration (e.g. Holford, 2016; Castro, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Gasson, 2005b; Carlile, 2004; Bechky, 2003). These studies have combined different qualitative data methods to collect data; especially interviews, observation, and document analysis. Some studies have adopted a mixed-method approach, with qualitative data collection method(s) and surveys, to collect data (e.g. Kotlarsky, Hooff and Houtman, 2015; Akhavan, Hosnavi and Sanjaghi, 2009; Haythornthwaite, 2006; Cummings and Kiesler, 2005). A few researchers have adopted a mono-method quantitative or qualitative approach to collect data. For instance, Fong and Lo (2005) used questionnaires to study the frequency of and need for interdisciplinary knowledge sharing as well as the channels and types of knowledge which were shared across professional disciplines in a government department. Similarly, Syed-Ikhsan and Rowland (2004) used questionnaires to examine the relationship between organisational elements and the performance of knowledge transfer in a public organisation. By contrast, Palmer (1999) used interviews to gather data from interdisciplinary scientists in an interdisciplinary scientific research institute; more specifically, information activities and process as well as the research environment involved in cross-disciplinary research. Use of different data collection methods mainly depended on the research aim(s) and objectives of each study.

As also mentioned in the literature review, the nature of knowledge at a boundary is tacit and dynamic, as well as cross-community collaboration and knowledge management is a difficult phenomenon. This research project found that there is a need to carefully select a toolkit of data collection methods to study such contexts. According to the research aim and objectives of the thesis, this study sought deep, rich, and naturalistic data in the situations which are taking place rather than on a large quantity of data. This study recognised the selection of data collection methods which help to reveal the experiences, perspectives, and meanings of the actions and interactions of social actors in cross-community collaboration in the natural setting. It also focused on the diversity of tools for data collection to maximise opportunities to capture the dynamics and complexities involved in cross-community collaboration and knowledge management.

A rigid structured methodology such as questionnaires was not selected because it was not appropriate to reveal alternative explanations of what is going on, how things occur and why they happen in the real-social setting (Boeije, 2010; Thomas, 2011). Unlike semi-structured interviews and participant observations, questionnaires rarely offer a convenient way for participants to elaborate their answers and explain conditions that affect their opinions or actions (Thomas, 2012). Consequently, the researcher will know little of the context in which participants' comments are set and so their precise meanings when participants make their responses (Saunders, Lewis and Thornhill, 2015). Moreover, questionnaires rarely provide an opportunity for participants to give clarification of confusing items (Thomas, 2011) which might have impact on the quality of the collected data.

Another key data collection method that has been employed in some previous studies, but was not chosen for use in this study, is focus groups. A focus group method is a specific set of group interviews that underline interactive patterns among group members and how they come to generate mutual understanding and ideas (Boeije, 2010). Boeije (2010) argued that this method helps to explore rich information if participants feel willing to share their viewpoints and experiences. However, if the participants feel that their viewpoints are not respected, they could become upset and angry which could have impact on the data collection. This method was not deemed appropriate for this study because of two major reasons. Firstly, most participants were very busy and had many ongoing parallel projects and tasks needing their attention. Consequently, it was difficult to find mutually-convenient times to invite participants to participate with others. Secondly, there was the issue of Thai culture. Yodwisitsak (2004) argued that Thai junior staff do not dare to speak out in front of senior staff because of the strong seniority culture. Also, many Thai people are concerned about taking another person's feelings into account and saving face (Sinthavalai, 2008; Yodwisitsak, 2004). If someone does not agree with his/her friends, he/she usually avoids giving any criticism because the person who has been criticised will have been perceived as losing face (Sinthavalai, 2008; Yodwisitsak, 2004). This suggests that some participants might feel uncomfortable in stating their opinions freely in group interviews. This might impact on exploration for this study.

According to the research aim and objectives, the dynamic nature of knowledge at a boundary, the complexity of cross-community collaboration, and the appropriateness of some data collection methods, this study was therefore designed to employ a multi-method qualitative approach. Semi-structured face-to-face interview, participant observation, and collection of documentation and other artefacts which were developed by different project members, were selected to collect data. They were selected based on their ability to offer an understanding of dynamic interactions and complex events within a real-life context (Bryman, 2012; Thomas, 2011). Specifically, semi-structured face-to-face interview and participant observation were flexible and therefore they could reveal multiple viewpoints held by different actors, unlike more rigid structured methods such as a questionnaire (Bryman, 2012). A diversity of methods for data collection maximised opportunities to capture the activities and dynamics involved in cross-community collaboration within the case study. Details are depicted below. The diversity of methods used to collect the data enabled a triangulation approach (Yin, 2009). Different data collection methods were used to collect data parallel. Data were collected from April 2014 to June 2014 and from January 2015 to April 2015. There was a break in the data collection periods to provide opportunities for the researcher to analyse the initial collected data and to discover core issues involved in the subject of the study. The second stage of data collection and analysis aimed to explore and address grey areas and new avenues of inquiry suggested by the first stage of analysis.

3.6.2. Semi-structured face-to-face interview

3.6.2.1. Interview data collection method

Semi-structured face-to-face interview was selected as the major source of data for this study. This is because it is flexible and therefore can reveal multiple viewpoints as well as deep and rich data about cross-community collaboration held by different actors in the research project. That is, semi-structured face-to-face interview was flexible. It helped to explore and capture data about differences in knowledge, skills, perspectives, ways of thinking, experiences, practices, and activities between members from different knowledge communities in cross-community collaboration. Such data enabled the researcher to explore and explain why boundaries arise. The data from the semi-structured face-to-face interviews also enabled the researcher to explore and explain types of knowledge boundaries that could occur in interactions between different knowledge communities which made knowledge working across boundaries very difficult. Furthermore, it enabled the researcher to explore and explain processes and mechanisms which are used to overcome these boundaries for effective cross-boundary collaboration.

The interviews allowed interviewees to use their own words to express their ideas freely. They helped to capture the interviewees' own words and feelings about cross-boundary working. For instance, some participants expressed their feelings about the difficulty of cross-boundary working, which they described as "tiring and gruelling".

However, all interview processes took time, such as for making arrangements for the interviews, getting answers, transcribing the interviews and data analysis. Consequently, only a small number of interviews could be conducted. Furthermore, under time pressure, the interviewer's gestures, manner, or verbal behaviour might cause interviewer bias in the interview which may influence the way that interviewees respond to the questions being asked and thus the validity of the study (Bryman, 2012).

3.6.2.2. Sampling

The interviewees were selected through purposive sampling technique primarily. They were selected through snowball and then purposive sampling techniques. The snowball sampling technique helped to identify prospective participants from people who knew which key informants were in the research project. It also helped to draw connections among project members in cross-community working. The purposive sampling technique was used to ensure that the prospective participants had the required data for meeting the research objectives. The combination of different sampling techniques to collect the data enabled a triangulation approach to be used (Yin, 2009). That is, the key and initial participant was asked to name others with the same characteristics as him/herself as well those who coordinated and were closely involved in cross-community collaboration in the research project. Each named participant was then evaluated against certain criteria before being formally invited to participate in the study. This was to ensure that the prospective participants had the basic characteristics or experiences that were directly related to the researcher's areas of interest and the research objectives. That is, the named participants should have been involved in the project for three or more years.

The project was initiated in 2006. Thus, the researcher designed to collect data from participants who had been involved in the project for three or more years. This is because participants who had been involved in the project and the organisation for longer periods of time (three or more years) seemed to know the project's and organisation's background, culture, everyday life, activities, and communication and decision-making flow better than project members who had recently joined the project and the organisation. Participants might know and understand differences, dependencies, and novelties in knowledge and tasks in collaboration between the different groups in the project as well as between project members and external actors. They could provide more rich and in-depth data about interdisciplinary collaboration and knowledge management in the project to the researcher.

However, time spent within the project of participants might have impacted on the participants' perception of boundaries and on participants' ability to bridge the boundaries. That is, participants might have familiarity with the areas of intersection and knowledge boundaries between the different groups. Consequently, they might not notice, perceive, or report boundaries that had occurred in interaction between the different groups in the project completely. They might perceive the same things and phenomena about knowledge boundaries differently based on their knowledge and experience which had been accumulated in the project. For instance, participants who had been involved in the project for a prolonged period of time might have more knowledge and be more familiar with the terminologies of the other different groups than project members who had recently joined the project. Consequently, participants might not perceive or report difference or difficulty in language and the construction of an information-processing boundary between the different groups in the project. Project members who had been involved in the project for shorter periods of time might spot differences, dependencies, and novelties in knowledge and tasks between the different groups as well as difficulties in cross-community collaboration easily and entirely. Furthermore, having much knowledge, experience, and understandings in differences, dependencies, and novelties in knowledge and tasks between members from different groups in the project, participants might have more knowledge and ability to bridge knowledge boundaries between the different groups in the project than project members who had recently joined the project. For instance, participants might know better about effective mechanisms or tools in the project for sending and receiving knowledge across an information-processing boundary. They could identify and might know better about knowledgeable people in the project to develop common language and interpretations than project members who had recently joined the project. To minimise this concern, the researcher collected and compared the results obtained with different methods: observation and documentation. To gain a broader view and a better understanding about cross-community working, project members with different functions (researchers, research assistants, engineers, and project analysts) and hierarchical positions from the two groups in the research project (the project director, project managers, and other project members) were also selected.

A pilot study was carried out with two interviewees who had been involved in the digitisation of rare Myanmar books under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn. This project involved cross-community collaboration between members who had knowledge backgrounds and skills in electronics, computer science, humanities and social science. A pilot study was carried out to provide the researcher with experience of interviewing, to refine the data collection plan, and to develop relevant lines of questioning (Creswell, 2009; Yin, 2009). Especially, it helped to make sure the interview questions would actually work in practice.

As mentioned above, there were two phases of data collection. In total, the interviews were conducted a total of 21 times with 14 participants over approximately 17 hours. That is, eight participants were interviewed in the first phase of data collection between April 2014 and June 2014, while six participants were interviewed in the second phase from January 2015 to April 2015. Moreover, seven of the eight participants from the first phase were interviewed again in the second phase to explore grey areas and new avenues of inquiry suggested by the first stage of data collection and analysis. One interviewee from the first phase of data collection was not selected for interview in the second phase because she seemed to be less involved in the development of the scanners. Guest, Bunce and Johnson as cited in Saunders, Lewis and Thornhill (2015, p.247) argued that 12 in-depth interviews should suffice for studies aiming to understand commonalities within a homogeneous group or if the focus of the research question is not wide ranging. In this study, data were collected until the additional data collected from the second phase provided few new insights or data saturation was reached (Saunders, Lewis and Thornhill, 2015; Bryman, 2012). Interview guides in the first and second stages are presented in Appendix 8.3

3.6.2.3. Administration and instruction

For recruitment and access purposes, the researcher contacted a prospective participant who was the key informant and the key actor in the research project via telephone and/or e-mail. More specifically, this prospective participant was the project manager of the software group in the project. The project manager was chosen because from the project documentation she was the key actor of the project and had been working for this project since its initiation.

The prospective participant received an information sheet and a request to participate in the study via e-mail. The prospective participant was fully informed of the research background and research process as well as receiving as much information as might be necessary to make a decision about whether or not she wished to participate in the study. Furthermore, the prospective participant was clearly informed that before starting the interview she would need to give consent for her responses to be used in an anonymous and aggregated form.

Once the prospective participant confirmed participation, a suitable date, time, and place was set up. Before these were confirmed with the interviewee, and in preparation for the interview, a participant information sheet, a participant consent form, and an interview guide or the set of interview questions was prepared and printed out. The interview guide was a list of issues rather than specific questions that the researcher intended to cover. The guide gave the researcher a reminder of what she wanted to cover. A list of issues is presented below.

At the start of the interview, the interviewee was thanked for considering the request for access and for agreeing to the interview. The background and purpose of the study and the interview were outlined briefly. After that, the interviewee was asked to read the information sheet. The right to confidentially and anonymity was reiterated. The interviewee’s right not to answer any question was highlighted and that the interview would be stopped if the participant wished. Then, the interviewee was asked to sign the consent form. All these points were handled within about five minutes. The signed consent form was collected and electronically scanned as well as being physically archived. The interview was tape-recorded and note-taken with the permission of the interviewee. Before the end of the interview, the interviewee was asked to name other project members who had the same characteristics as herself, who worked closely with her and who were closely involved in cross-community collaboration in the project. Once the interview was concluded, the interviewee was thanked for her time and support for the study. Each interview lasted approximately 45-60 minutes, and was conducted individually with each participant in private offices, meeting rooms or a project laboratory.

The audio file was uploaded onto the secure computer and external hard disk drive of the researcher. Subsequently it was transcribed into Microsoft Word, usually within 48 hours, and sent to the interviewee via e-mail in order to give the interviewee the opportunity to make amendments if so desired. Once transferred onto the secure computer, the content of the document was validated through simultaneously reading the text and listening to the original audio file. After the document was confirmed, it was analysed (see Section 3.7 for data analysis). The data collection and the initial data analysis processes were conducted in parallel. An interview was conducted and initially analysed, before another interview and analysis took place, until a regular pattern in the data emerges.

For the other candidates who were named by the initial participant, the researcher checked the profiles and responsibilities of these candidates with the project documentation such as project proposals and manuals. This was in order to ensure that they were inside actors who were closely involved in cross-community activities in the project and had been involved in the project for three or more years. The participants were chosen based on basic characteristics that were directly related to the research area and research objectives. They were chosen with the purpose of enabling the researcher to explore the research objectives. Then, the researcher contacted the named participants to invite them to interviews. They were interviewed using the same interview processes as with the initial participant.

As mentioned above, there were two phases for data collection. The first phase, including the interviews was conducted from April 2014 to June 2014. The set of interview questions was divided into three broad parts. The first part focused on the demographic data, knowledge backgrounds and skills, period of time working for the organisation, and the projects the interviewees were involved with. The second part focused on the types of activities involved in the project and the role of the interviewees. The final part of the questions was created to progressively focus the interviewees on knowledge boundaries. The interviewees were encouraged to talk about: the differences and similarities of the project members; the flow of communications and making-decisions; communications and interactions with the other project members; types of knowledge which were created and shared among the project members; and knowledge sharing and communication channels. Furthermore, the interviewees were asked to discuss difficulties in undertaking activities in cross-community working and how these were coped with. These questions were designed to explore the interviewees' experiences and perspectives about: cross-boundary collaboration; the construction of boundaries; types of knowledge boundaries; and processes and mechanisms to overcome the boundaries. In addition, the interviewees were asked to discuss their regular use of artefacts to communicate and coordinate with the other project members to explore boundary objects for moving knowledge across boundaries.

There was a break in the data collection periods to provide opportunities for the researcher to analyse the initial collected data in order to discover core issues involved in the subject of the study. The second stage of data collection including the further interviews was conducted from January 2015 to April 2015. It aimed to explore and address grey areas and new avenues of inquiry suggested by the first stage of analysis.

Following phase one and revision of the interview questions, phase two was primarily concerned with the dynamic and blurred nature of boundaries, the construction of boundaries, and the unique mechanisms that were used to overcome boundaries found in the case study. This phase also explored boundaries among members from the same group but from different sub-fields/groups. The set of interview questions was divided into four broad parts. The first part focused on the demographic data, knowledge backgrounds and skills, and period of time working for the organisation and the project the interviewees were involved with. The second part focused on the nature of boundaries and the construction of boundaries. The interviewees were asked to talk about the characteristics of project members and their differences and similarities. The third part drilled down to the construction of boundaries and types of knowledge boundaries. The interviewees were encouraged to talk about types or sources of difficulties, and conflicts and obstacles in cross-community working. The final part focused on processes and mechanisms designed to overcome knowledge boundaries and manage knowledge across them. The interviewees were asked to talk about how to manage conflicts, facilitators, and required capacities for cross-community collaboration.

The researcher mainly used open questions to allow the participants to define and describe their perspectives and experiences as well as situations and events in cross-community collaboration. Examples of questions included: “Could you talk about the nature and characteristics of your team and the other project members from the other team?”; “Could you describe a workflow for scanner development?”; “Could you talk about difficulties you have experienced when working with people from different fields or sub-fields?”; and “How do you cope with those difficulties?”.

3.6.3. Participant observation

3.6.3.1. Participant observation data collection method

Robson (2011, p.316) argues that interview data is notorious for discrepancies between what people say they have done, or will do, and what they actually did or will do. To corroborate the interviewees’ statements and with the research objectives in mind, participant observation or unstructured observation (Thomas, 2011, p.165) was selected as another main method to collect data. More specifically, this study adopted ‘observer as participant’, in which the researcher observed the phenomena of the study without taking part in the activities in the same way as the real participants, to collect data (Saunders, Lewis and Thornhill, 2015, p.294; Robson, 2011, p.323-324; Matthews and Ross, p.258). The details of this and another roles of the participant observer are depicted below (see Section 3.6.3.2).

Participant observation refers to a method to collect data in which the researcher immerses himself or herself in a social setting that they are researching for a period of time to observe behaviour, listen to conversations, ask questions, examine documents, and write up experiences in observational field notes (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Thomas, 2011). It emphasises the discovery of the meanings that people attach to their actions within their real-life context (Saunders, Lewis and Thornhill, 2015; Robson, 2011; Thomas, 2011; May, 2001). May (2001, p.149) suggested that it is important to participate in and seek to understand social actions within their context. This is because people act and make sense of their world by taking meanings from their environment. Therefore, researchers have to become part of that environment to gain understandings of the actions of the social actors.

In line with the research objectives, participant observation was chosen for its ability to offer opportunities for the researcher to be close to participants’ everyday working lives in their natural contexts in cross-community working. Participant observation heightened the researcher's awareness of significant social processes and interactions in cross-community collaboration. It was used to capture actions, interactions, activities, perspectives, feelings, and meanings that social actors attach to phenomena in cross-community collaboration. It was used to explore and explain what happened, who or what were involved, when and where things happened, how they occurred, and why things happened in collaboration between different knowledge communities (Saunders, Lewis and Thornhill, 2015; Thomas, 2011; Boeije, 2010).

Participant observation was also used in order to understand the nature of boundaries, why boundaries arise, as well as what types of knowledge boundaries existed and how the boundaries were constructed between different knowledge communities in the development of the scanners. Further, it was to identify activities, processes or mechanisms which were used to move knowledge across boundaries and to facilitate cross-community collaboration. The links between social actors' behaviour and their contexts could be mapped out (Bryman, 2012), and so can help to develop a better understanding of cross-community working. For instance, the collaboration and the process of knowledge sharing between members of the hardware and software groups was captured during observation of resolving a delayed X-ray shooting issue in the laboratory. A hardware group member shared knowledge about the shooting behaviour of an X-ray detector system with the software group members while they were trying to solve the problem together. Observation was combined with taking photographs to help capture specific events and provide a powerful extension of the analysis (Bryman, 2012).

Structured observation was not selected because it systematically watches for particular kinds of behaviour (Thomas, 2011, p.165). Essentially, structured observation tends to make assumptions that social activities can be broken down into quantifiable elements – that can be counted (Thomas, 2011, p.165). Similarly, Saunders, Lewis and Thornhill (2015, p.288) argued that structured observation is quantitative and focuses on the frequency of social activities. By contrast, as mentioned in Chapter 2, the literature review, boundaries are dynamic and are directly related to social interactions between social actors from different communities. The construction of boundaries and cross-community collaboration directly associates with social interactions between social actors from different communities. That is, it is emphasised that social actions are not fixed, but changing. Furthermore, the research objectives of this thesis looked at cross-community collaboration as qualitative elements –

that also cannot be counted. They were not concerned with the frequently of social actions. Therefore, structured observation was not an appropriate approach.

Some scholars argued that participant observation scores very highly on validity because it involves studying social actors and phenomena in their real-social contexts (Saunders, Lewis and Thornhill, 2015; Matthews and Ross, 2010). However, the issue of observer bias is frequently raised as a criticism (Saunders, Lewis and Thornhill, 2015; Bryman, 2012, Thomas, 2011), as will be depicted below (see Section 3.9.3).

3.6.3.2. Role of the participant observer

According to Saunders, Lewis and Thornhill (2015, p.293), Robson (2011, p.319), Matthews and Ross (2010, p.257-258), Gold (1958), there are four roles of the participant observer: complete participant; participant as observer; observer as participant; and complete observer. They depicted each role of the participant observer as follows.

i. Complete participant. In this instance, the researcher tries to become a complete member of the group of people being researched. That is, the researcher is a full participant. To achieve this, the real purpose of the research and the status of the researcher are not revealed to the group members. The real role of the researcher will always be covert.

ii. Participant as observer. This is different from being a complete participant in that the researcher takes an overt stance as well as revealing both her presence and her research role to the group members. This stance means that as well as observing through participating in activities, the observer can ask members to explain various aspects of what is going on. The researcher then tries to establish close relationships with members of the group.

iii. Observer as participant. The researcher is starting to move away from the idea of participating in the research group. The researcher is attending to observe without taking part in the activities in the same way as the real members of the group. The researcher is not naturally and normally part of the setting. The researcher is a spectator. The real purpose of the research and the status of the researcher are revealed to the group members.

iv. Complete observer. The researcher is a full observer and does not take part in the activities of the group of people being researched. The researcher is invisible. The real purpose of the research is unknown to the group members. Table 3.3 below summarise the different roles of the participant observer.

Complete participant	**Complete observer**
• Fully participate in group of people being studied • Do not reveal the real purpose of the research and the role of the researcher	• Fully observe and do not participate in group of people being studied • Do not reveal the real purpose of the research and the role of the researcher
Observer as participant	**Participant as observer**
• Observe, but do not fully participate in group of people being studied • Reveal the real purpose of the research and the role of the researcher	• Fully participate in group of people being studied • Reveal the real purpose of the research and the role of the researcher

Table 3.3 Comparative roles of the participant observer

Matthews and Ross (2010, p.257) argued that it is believed that the participants will perform normally if no researcher is present. Therefore, it is believed that the method of a complete participant will produce the most accurate data. However, in this study, the method of a complete participant was not selected because to achieve this role, the real role of the researcher had to be covert (Matthews and Ross, 2010). The researcher might also lose objectivity by becoming a member of the group of people being researched and adopting all its values and practices (Saunders, Lewis and Thornhill; Matthews and Ross, 2010). Furthermore, this method was likely to require a significantly large time commitment. In addition, the researcher might have to work hard at gaining the acceptance and trust of the group of people being researched. Similarly, the researcher might have to work hard by being a complete member of the group due to differences in many aspects such as knowledge backgrounds, skills, and functions in the organisation.

For a complete observer, it is claimed that the observer will be unbiased because of lack of involvement and will have a small influence on the group of people being researched (Matthews and Ross, 2010). However, the role of a complete observer was not adopted in this thesis. This is because, if the researcher was completely detached from the observed group, there was no chance of discussion to eliminate misunderstandings and to gain better understandings.

The method of a participant as observer allowed the observer to ask the group of people being researched to explain various aspects of what is going on and what is being observed (Robson, 2011). However, Matthews and Ross (2010) argued that if people know they are being researched, it is likely that they will change their behaviour. Therefore, the method of a participant as observer was not chosen. Moreover, maintaining the dual role of participator and observer was not easy.

The method of an observer as participant was chosen because without taking part in the activities in the same way as the real members of the group, the researcher was able to focus on her researcher role and objectivity. Also, the real purpose of the research and the status of the researcher were revealed to the group of people being researched. The researcher could thus write down as evidence occurred to her. Moreover, the researcher still had chances to mention and discuss unclear points with the group members.

The researcher observed the events, activities, and interactions of project members in the development of CT and DR scanners that are directly related to the research objectives and the researcher's area of interest, cross-community collaboration and knowledge management. The researcher informed the project members about the real purpose of the research and the real role of the researcher. Also, the researcher acted as a librarian for the research project and organisation by providing information that the project members might need. These things were done to gain the trust of the group and to make clear that the reason for asking questions was in order to enhance the researcher's understanding. The researcher could ask project members to explain various aspects of what is going on in interdisciplinary collaboration in the research project. Although, the researcher acted as a librarian, the researcher did not fully participate in the research setting being studied and was not a normal part of the project. The researcher has only minimal involvement in the research setting being studied. The researcher observed activities without taking part in the activities in the same way as the actual project members. This was different from a participant as observer which the researcher must fully participate in group of people being studied.

3.6.3.3. Sampling

The researcher decided to observe cross-community collaboration of the project members in three places: the laboratory; the monthly meetings; and the meetings of the implementation of ISO 13485 and risk management. These three places were chosen because these places were common places where most project members from different knowledge communities can meet up. That is, the project monthly meetings were a place where each project member can meet, report, update, and discuss their tasks about scanner development with most project members. Moreover, members of the hardware and software groups in the research project normally work in different offices in different buildings. The laboratory was used as a work place of both groups in the development of the scanners together. The laboratory was a place for meeting and coordination among project members. Social activities and social interactions of project members mainly occurred in these places. For instance, project members had to assemble, install, and develop the scanners in the laboratory together. Discussions and making decisions mainly occurred in the monthly meetings because they were attended by most project members, especially the key decision makers of the project such as the project director and the project managers.

The researcher continuously observed and recorded the activities and interactions of project members that are directly related to the research objectives and the researcher’s area of interest. This was in order to obtain rich, in-depth, and naturalistic data of the events, activities and interactions to gain a better understanding of the subject of the study.

There were two phases of the data collection process: between April 2014 and June 2014; and between January 2015 and April 2015. Within the two phases of the data collection process the researcher observed the activities and interactions of project members 12 times for 31 hours. That is, the researcher observed: 4 monthly meetings for 12 hours; 3 meetings of the implementation of ISO 13485 and risk management for 6 hours; and 5 collaborations in the laboratory and at the customer’s site for 13 hours (see Table 3.4). The observation and interview data were given equal attention in the coding and analytical process. The data from observation were coded and analysed alongside the interview data

Activities/Times/Hours	APR 2014 - JUN 2014		JAN 2015 - APR 2015	
	Times	Hours	Times	Hours
Monthly meeting	3	9	1	3
Meeting of the implementation of ISO and risk management	0	0	3	6
Collaboration in the laboratory and other sites	3	7	2	6
Total	6	16	6	15

Table 3.4 Samplings of observation

3.6.3.4. Administration and instruction

For recruitment and access purposes, the researcher contacted the project manager of the software group of the development of the CT and DR scanners for the project permission and participation. The software project manager was one of three key decision makers of the research project and more approachable by the researcher. The research proposal, the researcher's curriculum vitae, the information sheet and the consent form were sent to the project manager via e-mail. The project manager was fully informed of the research background and the research process as well as receiving as much information as might be needed to make a decision about whether or not the project wished to be observed. The researcher would make observation (with note-taking and photograph-taking for later analysis) with the permission of the project manager and the other project members. The project members had control over the right to record any of their responses where a camera was used. Once receiving consent, the researcher met the project manager to introduce herself, to depict the research and data collection processes, and to answer unclear points in the information sheet and the consent form. In the meeting, the researcher and the project manager discussed the times and places the researcher would observe. The project manager agreed that the researcher would observe the project monthly meetings, the meetings of the implementation of the ISO 13485 and risk management, and collaborations among project members in the laboratory.

The project manager asked the researcher to contact two key administrators of the project to obtain and check a schedule of meetings that the researcher could observe. As mentioned above, different data collection methods were used to collect data in parallel. If an interview and the project meeting happened to be scheduled for exactly the same time and date, the researcher asked the interviewee to select another time and date.

In the first monthly meeting observation, the project manager introduced the researcher to the other project members. The researcher then introduced herself, talked about the research and data collection processes, and answered questions about observation from the project members. In this meeting, the researcher also explained the role of the researcher in the case study to the other project members.

To collect data, a formal observational approach was chosen (Robson, 2011). That is, there was a direction or guide on what was to be observed. The researcher mainly focused on everything that was considered relevant for the researcher's area of interest and the research objectives. Robson (2011) argued that a formal observational approach can create reliability and validity. It also helped with the complex and difficult tasks of collection, synthesis, and organisation of the gathered data. The researcher was immersed in the laboratory and meetings to observe project members' behaviour, work practices, activities, and interactions in the scanner development. The researcher listened to conversations, discussions, and negotiations, examined documents, and asked questions about the practices, activities, and interactions of cross-community collaboration that were directly related to the researcher's area of interest and the research objectives. More specifically, the researcher tended to observe the:

i. nature and characteristics of project members;

ii. differences and similarities of project members;

iii. differences and dependencies in knowledge and tasks between project members;

iv. roles of each project member in the project;

v. types of activities where project members need to work together or work apart;

vi. communication and knowledge sharing channels;

vii. types of knowledge that were created and shared in the project;

viii. objects that were created and used among project members;

ix. making of decisions in the project;

x. difficulties, disagreements, oppositions or conflicts between project members in cross-community working;

xi. processes and mechanisms to reduce conflicts between project members; and

xii. facilitators and obstacles of cross-community collaboration.

In notes, the researcher also collected data about:

i. events or occasions of interactions such as meetings or working together in the laboratory to develop the scanners;

ii. places, environments and atmosphere of meetings or collaborations such as in meeting rooms or the laboratory;

iii. time period of meetings or collaborations;

iv. purposes of meetings or collaborations such as to discuss solutions for resolving blurred X-ray photographs or to plan the testing of the scanner;

v. names and relevant backgrounds of the people involved;

vi. activities of cross-community collaboration among project members;

vii. acts or specific individual actions;

viii. objects of communication or collaborations such as presentations, scanners, and X-ray photographs; and

ix. feelings and emotions of project members in activities and contexts.

Photographing was used to provide an extension of observation. That is, it helped to capture the places and environments of collaboration, actors involved, activities, and objects of cross-community collaboration. Taking photographs helped the researcher to capture data far more quickly than the researcher could with observational field notes. The captured data enable the researcher to freeze things in time for subsequent analysis (Thomas, 2011). For instance, it helped to capture and identify that where each project member sat in a meeting directly related to levels and groups of members in the research project. That is, in the meetings the members of the hardware and software groups often sat opposite each other. Moreover, the project director sat at the head of the table, the power position. The project managers of the hardware and software groups sat opposite each other and next to the project director.

Observational field notes were transcribed into Microsoft Word, usually within 48 hours. Then, the transcription and photographs were uploaded onto a secure computer and external hard disk drive of the researcher. The text of the transcription was read and checked with the original field notes. After the text was checked, it was analysed (see Section 3.7 for data analysis). The data collection and the initial data analysis processes were conducted in parallel. Once the field notes of the first observation had been transcribed, sorted out, and initially analysed, another observation took place. The sample of observation notes is presented in Appendix 8.4.

3.6.4. Collection and analysis of documentation and other artefacts

Not only primary data collection methods, but also documentation and artefacts were used to gather data. The latter were chosen as a further source of data to explore and explain cross-community collaboration between members from different knowledge communities in the case study. Furthermore, they were chosen to compare to the data derived from the other methods. This might enhance the credibility of the study.

There were many types of documentation and artefacts in the development of the scanners in the case study. However, according to the research objectives, the researcher selected to examine the collections of documentation or written materials and artefacts, which were created and used by different knowledge communities in the project. The types of documentation and artefacts examined included project proposals, project plans and schedules, project reports, documentation of scanner development procedures, and prototypes of the scanners. These collections of documentation and artefacts contained the content of cross-community communication and collaboration between different knowledge communities. That is, documentation and artefacts mainly aimed to provide data in order to explain differences and dependencies, as well as communication, collaboration, discussion, negotiation, and agreement between different knowledge communities in the development of the scanners. This data helped to explain why boundaries are constructed and how people manage knowledge across boundaries. For instance, the project Gantt chart helped to clarify the differences and dependencies in knowledge and given tasks that exist between the members of the hardware and software groups.

Using documentation and artefacts was likely to be quicker than data obtained by primary data collection methods; this is because they had already been collected and so were existing. Unlike data collected through primary data collection methods, secondary documentary data generally provided data sources which could be checked relatively easily by others (Saunders, Lewis and Thornhill, 2015). Consequently, it could help to enhance credibility. However, most documents had been created for specific and different purposes. Such purposes might not meet the research objectives. Thus, it was difficult to collect the required data. In addition, some needed information was rarely accessed because of permission issues. That is, some project members were concerned about leakage of the project information assets and intellectual property which directly related to the invention of the project scanners.

To access the collection of documentation and artefacts, the project manager of the software group was contacted for permission. Permission for observation and access to the collection of documentation and artefacts was asked at the same time. The project manager confirmed that data from the documentation and artefacts of the project could only be used for academic purposes.

To collect data from the collection of documentation and artefacts, the researcher adopted the document analysis processes which were suggested by Thomas (2011). Firstly, the researcher developed broad themes for data collection. These themes were developed based on the research objectives such as differences and similarities among project members, types of knowledge shared, types of communication and knowledge sharing channels and activities, objects that were created and used by different knowledge communities, collaboration between members from the different communities, and workflow.

Secondly, the researcher identified types of documentation and artefacts which might be required data with the help of two key informants. These two informants had an administration job on top of a scientific role. That is, they were a researcher from the software group and an engineer from the hardware group who were asked to manage the documents of each group. Thirdly, the researcher generated keywords to guide the examination of the documentation and artefacts. For instance, under the theme of 'differences among project members' the researcher generated keywords such as 'group', 'team', 'field', and 'task'. After that, the keywords were applied to explore the documentation and artefacts. Finally, the relevant documentation and artefacts were skimmed; useful and required data were then recorded. To evaluate the suitability of the data, it was necessary to address the research objectives and clear data sources.

The researcher accessed and examined the collection of documentation and artefacts during use of the other methods to collect data. This was in order to explore and explain cross-community collaboration between members from different knowledge communities, to compare the data derived from the other methods, and to develop interview and observation guides. For instance, at the beginning of the data collection process, the researcher examined the project proposals to gain an understanding of the project background, the scanner development procedure, the sets and levels of project members, and differences and dependencies in knowledge and given tasks among project members. As another example, after the interviews the researcher examined the project proposals and documentation of scanner development to check when members from different knowledge communities needed to work together or apart. This was in order to collect data about boundaries between different knowledge communities.

3.7. Data analysis

After initial data collection, interview audio records, observational field notes, and notes from photographs, documents, and artefacts were transcribed into text format, using Microsoft Word. All data were analysed through thematic analysis. Thematic analysis is a method for identifying, analysing, and interpreting themes within data (Clarke and Braun, 2017).

Thematic analysis was selected because of its flexibility (Clarke and Braun, 2017). That is, thematic analysis is not necessarily associated with a particular theoretical framework (Robson, 2011; Braun and Clarke, 2006). It can be applied across different theoretical frameworks (although might not suit all) (Clarke and Braun, 2017; Robson, 2011). By contrast, some other qualitative analytic methods are tied to or stem from particular theoretical frameworks. They are mainly or only compatible with particular theoretical frameworks such as the narrative analysis method and the grounded theory analysis method. Furthermore, thematic analysis was a relatively easy method to learn and use by comparison with other methods which call for considerable time and effort to understand and require an appreciation of their philosophical and theoretical basis to use legitimately such as for the grounded theory analysis method.

Moreover, thematic analysis can be used for both inductive (data-driven or bottom up) and deductive research (theory-driven or top down) approaches (see Section 3.2) (Clarke and Braun, 2017; Robson, 2011). This study adopted an inductive approach due to the exploratory nature of the research objectives. This suggested that the themes identified were strongly linked to the data themselves.

Braun and Clarke (2006) argued that thematic analysis can be used to examine experiences, meanings, and the reality of actors. Also, it can be used to examine the ways in which events, realities, meanings, and experiences are the effects of a range of discourses operating within society. In this study, the data analysis procedure consisted of six stages: familiarising with the collected data; generating initial codes; identifying themes; reviewing themes; defining and naming themes; and producing the report (Robson, 2011; Braun and Clarke, 2006).

i. Familiarising with the collected data

The first step of analysis involved a familiarisation with the collected data. That is, after initial data collection, the data were transcribed into text format, using Microsoft Word. The researcher immersed herself in the data by reading and reviewing transcripts as soon as possible to check the quality and accuracy of the transcriptions against the interview audio records, the observational field notes, and notes from photographs, documents, and artefacts. The researcher searched for initial meanings and themes, made marginal notes, and wrote memos about significant remarks for initial thoughts about coding and themes within the transcriptions.

ii. Generating initial codes

According to Robson (2011, p.478), codes refer to the basic segment or element of the raw data or information that can be assessed in a meaningful way regarding the phenomenon. Robson (2011, p.478) also suggested that the process of coding is part of analysis as the researchers are organising their data into meaningful groups. Once the researchers have coded the data, they can begin deciding what themes the researchers can see in them.

At this stage, the researcher coded individual extracts of the data. The data from observation and collection of documentation and artefacts were coded alongside the interview data. As mentioned above, this study adopted an inductive research approach, meaning coding was mainly data-driven. That is, the researcher looked for and then coded extracts relevant to the analysis because they seemed potentially relevant to the areas of interest and the research objectives. A process of coding the data was not driven by the existing relevant literature and frameworks. It did not try to fit the data into a pre-existing coding frame or the researcher's analytic preconception. Some typical and broad things the researcher coded included the following:

a. Nature and characteristics of actors (e.g. having knowledge backgrounds and skills in image processing);

b. Roles and positions of actors (e.g. "I am a project director");

c. Acts and behaviours of actors (e.g. sending the drawings of the scanners to the other project members, sharing the results of scanner testing with the other project members, and pulling people from different groups);

d. Activities or things actors did; these were longer than acts and often took place in a particular setting and might have many other actors involved (e.g. discussing blurred X-ray photographs in the project monthly meeting, and solving X-ray delay in the laboratory);

e. Events or things people did; these were usually brief (e.g. working in the organisation and conducting research about image recovery, joining in the project by the invitation of the project director, generating reconstructive images);

f. General conditions experienced by actors or found in the project and the organisation (e.g. hierarchical organisational structures, having a flow of communication, sharing different types of knowledge with different levels or sets of project members, and having different knowledge communities in the project);

g. Conditions or things that had effects on behaviour or actions (e.g. workload, losing project members' (tacit) knowledge after they left, getting new requirements and complaints from customers and stakeholders, changing the scanner development to compete with another scanner company, "working with the different centre", "each group lives in different fields", having differences in perspectives and ways of thinking, and having different understandings of the same things or situations);

h. Consequences (e.g. the project members stopped creating low-resolution images to create high-resolution images to meet the doctors' requirements; having criticisms in collaboration between different groups);

i. Meanings referred to the meanings of actors' actions such as concepts or symbols that were used by actors and actors' feelings (e.g. "too many cooks spoiling the broth", and "It is crazy to do this");

j. Strategies or activities aimed towards some goal (e.g. reducing the size and costs of the scanners, and improving the business models);

k. Participation or actor's involvement and relationships or interaction between project members (e.g. "we are like partners", "different groups must go together", conferring with the other groups during doing their own tasks, training helping to develop common understandings between the different groups);

l. Settings or the context of the events (e.g. the customer's site or hospital and the laboratory).

The researcher coded extracts of the data manually. The manual data analysis was selected because the researcher was closer to the data. Also, it was easier to maintain consistency and to ensure the right data was under the codes as well as to compare codes side by side manually. Data analysis software required time and effort to learn and understand the software. The researcher could save time and effort spent on learning about the software to consider and to interpret meanings in the collected data. The researcher coded the data by writing notes on the texts that the researcher was analysing. The researcher matched each code with data extracts that demonstrated that code and named the places of the data extracts within each transcript. To do this, the researcher copied extracts of the data from individual transcripts, and collated each code together.

Figure 3.4 presents an example of codes applied to a short segment of data. There are four

Interaction and coordination

> The software group asked the hardware group to create a head support for patients while the patients were being scanned. The hardware group thought about the beauty, fineness and safety of the head support, while the software group thought about the effects of the head support on image processing and X-ray photographs
>
> [N13, P3-4, L92-110].

Ways of thinking, Different understanding, Difficulties

Figure 3.4 Data extract, with codes applied

codes: ‘interaction’; ‘ways of thinking’; ‘different understandings’; and ‘difficulties’. This example also demonstrates that individual extracts of data could be coded as more than one initial theme as they fit into several. Thus, an extract might be uncoded, coded once, or coded many times, as was relevant.

iii. Identifying themes

All data were coded and collated, and a list of the different codes was created at the previous stage. At this stage, the different codes were sorted into themes and all the relevant data extracts were collated within the created themes. To do this, the researcher analysed the different codes and considered how the different codes could combine to form a theme. The researcher used a visual presentation, more specifically mind-maps, to sort the different codes into main themes and sub-themes. An initial thematic map of this early stage can be seen in Figure 3.5. It presents some examples of themes, sub-themes and codes within an initial thematic map, including places of the data extracts within each transcript.

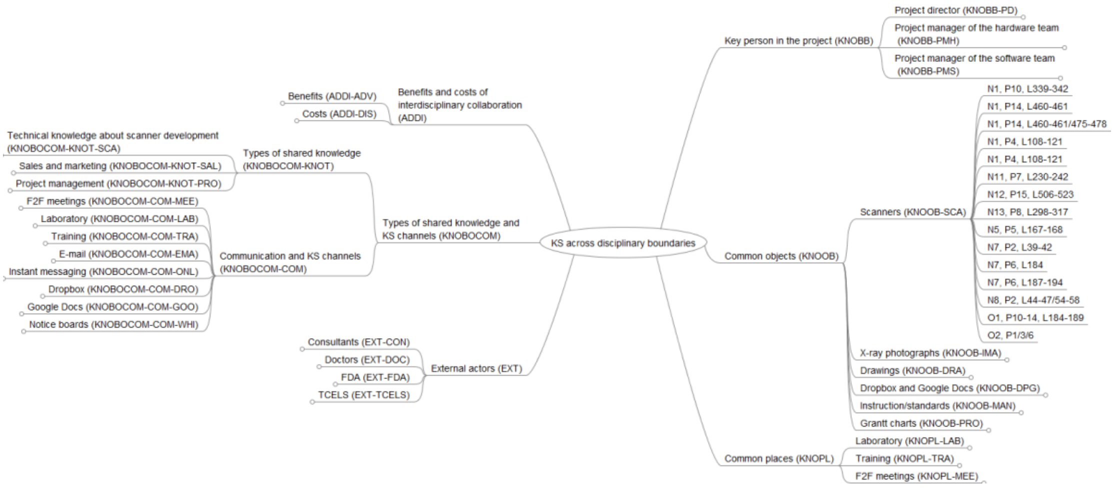


Figure 3.5 Initial thematic map, showing some themes, sub-themes, and codes

From Figure 3.5, there are six main themes: ‘benefits and costs of interdisciplinary collaboration’; ‘types of shared knowledge and knowledge sharing channels’; ‘external actors’; ‘key person in the project’; ‘common objects’; and ‘common places’. Each theme has sub-themes, codes, and places of the data extracts within each transcript. For instance, the ‘common objects’ theme has six sub-themes and codes: ‘scanners’, ‘X-ray photographs’, ‘drawings’, ‘Dropbox and Google Docs’, ‘instruction/standards’, and ‘Gantt charts’. These six sub-themes and codes refer to different types of objects which are created and used by different knowledge communities in the project for their communications and collaborations. Each sub-theme and code is added by reference to the places of the data extracts within each transcript. For instance, the ‘scanners’ code is linked to the place of the data extracts, ‘N1, P10, L339-342’ which refers to the transcript of interviewee no. 1, page 10, and line 339-342. The data extracts of this place, N1, P10, L339-342, are as below:

> To install the scanner at the customer’s sites, during the first time we all had to go to the customer’s sites together [smiles] because each member had different jobs in the development of the scanner. We do not know which parts of the scanner would be in error [laughs lightly].

Some initial codes went to form main themes, whereas others formed sub-themes; others still needed to be coded, and some were discarded. This stage was ended by getting a collection of candidate themes, sub-themes, codes, and all extracts of data that were coded in relation to them.

iv. Reviewing themes

After a set of candidate themes was created from the previous stage, reviewing themes followed. At this stage, the set of candidate themes was reviewed and refined. To do this, the coded data extracts, codes, and sub-themes of each theme were read and considered to see whether they appeared to form a coherent pattern. If (some) candidate themes did not appear to form a coherent pattern because some of the coded data extracts within it simply did not fit, two separate themes could form one theme, or some sub-themes could become a theme, or a set of candidate themes could be reworked. For instance, a new theme was created for those extracts that did not currently work in an existing theme. Once the candidate themes adequately captured the contours of the coded data extracts or the candidate themes appeared to form a coherent pattern, the analysis process moved on to the next stage.

v. Defining and naming themes

After getting a thematic map of the data, at this stage the researcher defined the themes that would be presented for analysis, and then analysed the data within them. More specifically, the researcher identified the summary of what each theme was about. The researcher tried to describe the scope and content of each theme in a couple of sentences. To do this, the researcher considered each theme and its sub-themes. Also, the researcher created a summary in relation to the others. For instance, the 'external actors' theme was defined as 'individuals or groups of individuals from different knowledge communities outside the organisation who have an impact on the project members' actions and activities'.

Although the titles of themes were given in the previous stage, at this stage the researcher rethought about the titles or names that would be referred to in the final analysis. This was in order to give the researcher a sense of what the theme was about. As mentioned in Section 3.5.1.2, there were two phases of data collection. Figure 3.6 below presents an intermediate set of themes derived from the first phase of data collection.

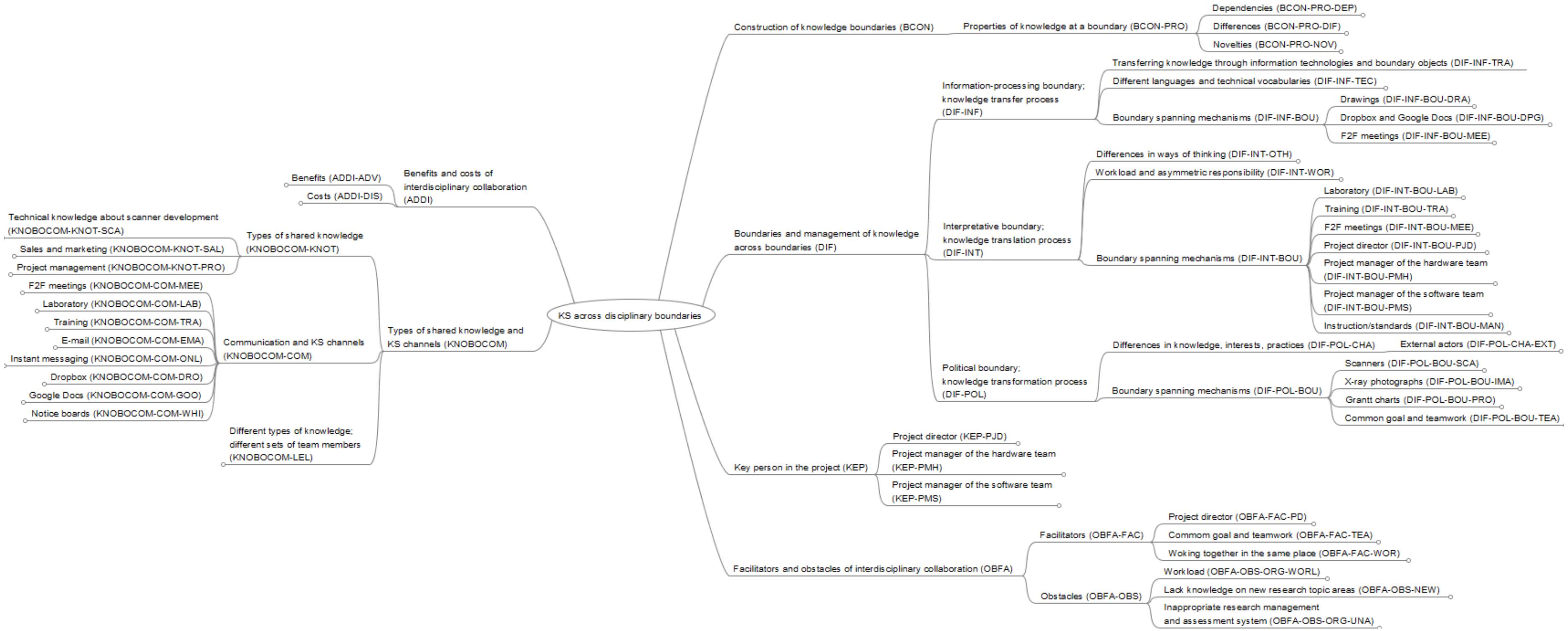


Figure 3.6 Intermediate thematic map

From Figure 3.6, there are six main themes relevant to the research objectives which derived from the first set of gathered data: ‘benefits and costs of interdisciplinary collaboration’; ‘types of shared knowledge and knowledge sharing channels’; ‘construction of knowledge boundaries’; ‘boundaries and management of knowledge across boundaries’; ‘key person in the project’; and ‘facilitators and obstacles of interdisciplinary collaboration’. Each theme has sub-themes, codes, and places of the data extracts within each transcript. The intermediate thematic map was reviewed and defined after the second phase of data collection. Figure 3.7 presents the final thematic map, showing five themes relevant to the researcher’s area of interest and the revised research objectives (see Section 1.2 for how and when the research objectives emerged, and the formulation of the research objectives). The final thematic map was developed from the two sets of gathered data.

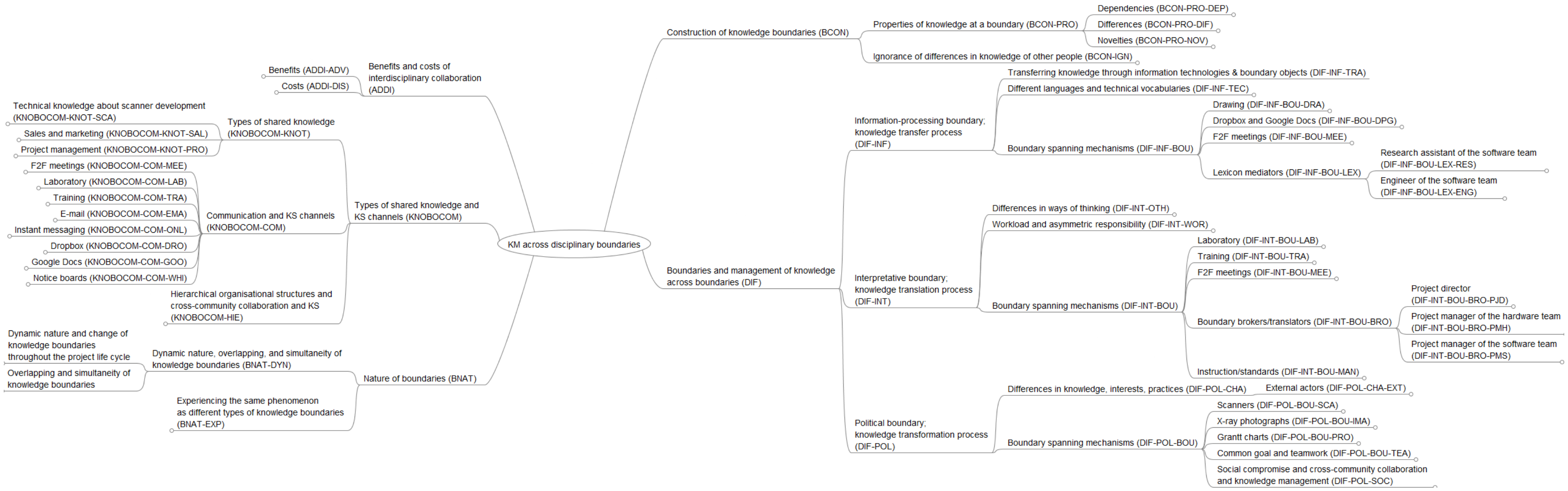


Figure 3.7 Final thematic map

From Figure 3.7, there are five main themes: ‘benefits and costs of interdisciplinary collaboration’; ‘types of shared knowledge and knowledge sharing channels’; ‘nature of boundaries’; ‘construction of knowledge boundaries’; and ‘boundaries and management of knowledge across boundaries’. Some themes and sub-themes in the intermediate thematic map were not changed in the final thematic map: ‘benefits and costs of interdisciplinary collaboration’; and ‘types of shared knowledge and knowledge sharing channels’. Some sub-themes were changed to cover the new findings. That is, sub-theme 'different types of knowledge' was changed to sub-theme 'hierarchical organisational structures and cross-community collaboration and knowledge sharing'. New themes were created from the second phase of data collection: e.g. 'nature of boundaries'. Also, some new sub-themes were added into the existing themes or sub-themes. For instance, sub-theme 'ignorance of differences in knowledge of other people' was added into theme 'construction of knowledge boundaries'; sub-theme 'lexicon mediators' was added into sub-theme 'boundary spanning mechanisms' under sub-theme 'information-processing boundary; knowledge transfer process'; and sub-theme 'social compromise and cross-community collaboration and knowledge management' was added into sub-theme 'boundary spanning mechanisms' under sub-theme 'political boundary; knowledge transformation process'. Some themes in the intermediate thematic map went to form sub-themes. For instance, theme 'key person in the project' was changed to 'boundary brokers/translators' and went to form sub-themes under 'boundary spanning mechanisms' and 'interpretative boundary; knowledge translation process' respectively.

vi. Producing the report

After getting a set of fully worked-out themes, the final stage of thematic analysis involved the final analysis and write-up of the findings and discussion (see Chapter 4 and Chapter 5).

Although the data analysis process, which was presented above, seemed to be a linear or step-by-step process, it was not a linear process. It was a more iterative process. That is, analysis involved a constant moving back and forth as needed, throughout the stages. It was a process that developed over time. Moreover, as mentioned above, data analysis occurred both during the data collection and after it. This helped to shape the direction of data collection. The researcher was thus able to consider where data collection should be focused in the future and could develop a sharper focus in relation to the research objectives. Furthermore, the researcher was able to improve the themes of the findings and the relationships between the findings. Writing was an integral part of analysis. Therefore, writing overlapped with the data collection and the data analysis process.

3.8. Ethical considerations

Due to this study involving human participants, research ethics were considered. This study received research ethics approval from the Information School Research Ethics Panel of the University of Sheffield, UK, on 3rd March 2014. It also received research ethics approval from the research setting, the Thai Committee for the Development and Encouragement of Research Ethics in Humans of the National Science and Technology Development Agency, on 5th June 2014.

This study has followed a commitment to participants' voluntary informed consent, during the data collection, data processing and storage, and data analysis and reporting stages. The participants received an information sheet and a consent form when they were invited to participate in this study. They were fully informed about the research processes and received as much information as might be needed to make an informed decision about whether or not they wished to participate. They were fully informed about: the nature of the research; the requirements of taking part; the implications of taking part and participants' rights; the use of the data collected and the way in which it would be reported; and a person to contact if there were any questions about the research. Before collecting data, each participant was asked to sign a consent form and give permission to record their voice and take photographs. Although the participants consented to participate in the study, they still had the right to decline to answer a question(s), to record any of their responses, to be observed in particular circumstances and to withdraw from the study at any time without any effects. The interviews and observation were conducted at convenient times and in natural environments for the participants such as in their offices and research laboratories. Therefore, no personal safety issues were involved. Confidentiality was ensured by conducting the interviews on an individual basis and in the interviewees' offices, as well as through data anonymisation. Each participant's name was anonymised by using a unique identification number which was only known by the research team of this study. Data were stored on the researcher's password protected computer equipment and remained secure throughout the duration of the study. Data were only accessible to the research team for academic purposes.

3.9. Reflection

3.9.1. Case study research strategy

As Section 3.3 showed, this study selected a case study approach to examine the nature of boundaries and how people manage knowledge across boundaries. Due to the small number of cases, the case study approach is frequently open to the question that its findings are not easily generalisable or transferable to other settings (Thomas, 2011; Gerring, 2007). Thus, it is difficult to know how the findings from the case study approach can provide a generalising conclusion to other settings (Bryman, 2012; Thomas, 2011; Gerring, 2007). A widely held view, among both quantitative and qualitative researchers, is that there are two main approaches for generalisation in social research (Yin, 2009). Yin (2009) called these two approaches statistical generalisation and analytic generalisation.

Statistical generalisation draws conclusions from a sample to the broader population by using a statistical method (Robson, 2011; Yin, 2009). By contrast, analytic generalisation draws conclusions by comparing the findings of the case study to previous theory (Yin, 2009). That is, analytic generalisation is generalisation to a theory of the phenomenon being studied; this theory may have much broader applicability than the case studied (Yin, 2009). Yin (2009) argued that analytic generalisation is the appropriate form of generalisation for case study research. A key feature of doing a case study is to expand and generalise theories (analytic generalisation) rather than to enumerate frequencies as statistical generalisation (Yin, 2009). The findings of case study research are generalisable to a theoretical proposition (analytical generalisation) rather than to populations (statistical generalisation) (Bryman, 2012; Thomas, 2011; Yin, 2009). The case study looks at something from many aspects of its particular features in order to obtain a rich picture and analytical insights from it (Yin, 2009). Case study research does not think that a case study is a sample of one (Bryman, 2012, p.70). This study compared the empirical findings of the case study to the existing literature and models, especially the three-tier model for managing knowledge across boundaries, on cross-community collaboration and knowledge management. These literature and models have been discussed and mentioned in several organisational and knowledge management studies. A key feature of undertaking this case study was to expand and generalise theories on cross-community collaboration and knowledge management (analytical generalisation) not to enumerate frequencies (statistical generalisation).

3.9.2. Qualitative research evaluation

This study used a qualitative approach due to the research objectives (see Section 3.4 for qualitative approach). To establish and assess the quality of qualitative research, Guba and Lincoln as cited in Bryman (2012, p.390) suggested four criteria for ensuring reliability and validity in relation to qualitative research. The four criteria are credibility, transferability, dependability, and confirmability. These criteria are comparable to the criteria used in quantitative research.

i. Credibility

Credibility, which parallels the internal validity criteria used in quantitative research, is involved in establishing that the findings of the research are believable. This study ensured credibility through two main approaches: triangulation; and member checks or respondent validation.

Firstly, triangulation refers to the use of more than one theoretical perspective, methodology, or data collection method within one study in order to check the results of one and the same subject (Saunders, Lewis and Thornhill, 2015; Bryman, 2012). This study used different methods to collect data: semi-structured face-to-face interview; participant observation; and collection of documentation and other artefacts which were created and used by different knowledge communities in the research project. Also, data were collected over different periods of time.

The use of different data collection methods in concert compensated for their individual limitations and exploited their respective benefits (see Section 3.6 for data collection methods). For instance, interviews helped to capture different ways of thinking and tensions between members from different knowledge communities in cross-collaboration working. Such data were rarely found through observation of the interaction between the communities because of the seniority culture as well as being afraid of offending, criticising, and making other people lose respect and so losing face. Interviews were cross-checked by observation to determine whether they might or might not be reported or detailed by interviewees. For instance, differences in interpretations of the same thing among project members, such as the hazard level of the repeated radiological radiation exposure in patients, which was captured during project meeting observation. Furthermore, this study interviewed participants from different professions and functions in a cross-community research project:

these included both senior and junior researchers, research assistants, engineers, and project analysts. They were also in different levels or positions in the organisational structure. The project director, project managers, and other project members were at the top, the middle, and the bottom of the pyramid of the project respectively. Hence individual perspectives, perceptions, and experiences in cross-community collaboration could be verified against others. A rich picture of the perspectives, experiences, and behaviour of cross-community collaboration could thus be constructed based on the contributions of a range of participants.

Secondly, member checks or respondent validation was another strategy used to build credibility in this study (Saunders, Lewis and Thornhill, 2015; Bryman, 2012; Shenton, 2004). That is, this study provided the participants with an account of what he or she had said in an interview. The participants were asked to read the transcripts of their interviews; they were therefore able to consider whether their words matched what they actually intended. This strategy helped to seek confirmation that the findings and impressions accurately reflect the views of the participants (Bryman, 2012, p.391). It also helped to seek out areas in which there was a lack of correspondence and the reasons for it (Bryman, 2012, p.391).

ii. Transferability

Transferability parallels the external validity criteria in quantitative research (Bryman, 2012). It is involved in establishing that the findings of one study can be transferable to other settings (Saunders, Lewis and Thornhill, 2015; Bryman, 2012). Since the findings of qualitative research are specific to a small number of particular environments, it has to be questioned whether the findings and conclusions are applicable to other contexts (Bryman, 2012; Shenton, 2004). The generalisation of the case study research strategy is presented in Section 3.9.1. Furthermore, this study built up transferability through the concept of thick description which was produced by Clifford Greetz (Ponterotto, 2006). Thick description refers to detailed accounts of a social context and culture of the phenomenon being studied (Bryman, 2012). It not only captures what individuals are doing, but also provides rich accounts of the details of the culture and setting of the phenomenon being studied in which they live (Shenton, 2004). Bryman (2012), and Ponterotto (2006) argued that a thick description can be used as a reference point for other researchers for making judgements about possible transferability.

To enable readers to make such a transfer, this study provided contextual information about the research setting and the research case study (see Section 3.5 for research setting). This contextual information was provided to readers in order to help them have a proper understanding of the phenomena which were investigated. Consequently, readers could compare the instances of the phenomena described in this study with those that they have seen emerge in their own situations. Readers could determine how far they can be confident in transferring the findings and conclusions presented in this study to other situations. Example contextual information was given in this study: the nature of the research setting and the research case study which was investigated in the study; the number and demographic data of the participants involved in the study; the data collection methods that were employed; the number and length of the data collection sessions; and the time period over which the data were collected (see Section 3.5 and Section 3.6 for research setting and data collection methods respectively).

iii. Dependability

Dependability, which parallels the reliability criteria in quantitative research, is defined as the stability of data over time and over conditions (Bryman, 2012). This study ensured dependability by adopting an auditing approach, although it has not become a popular approach to enhancing the dependability of qualitative research (Bryman, 2012). That is, records were kept of all phases of the research process such as the research design and its implementation, the selection of the research setting and participants, the operational detail of data gathering, fieldwork notes, interview audio records and transcripts, and photographs from interviewees and observation. This allows peers and readers to assess the extent to which proper research practices are being and have been followed (Bryman, 2012; Shenton, 2004).

iv. Confirmability

Confirmability parallels the objectivity criteria in quantitative research (Bryman, 2012). It involves ensuring that the findings from qualitative research are the result of the experiences and ideas of the informants, rather than the characteristics, perspectives, and preferences of the researcher (Shenton, 2004). In this study, confirmability was built up through reflexivity, self-awareness, and an awareness of the relationship between the researcher and the research environment (Lamb and Huttlinger as cited in Dowling, 2006).

The researcher used epistemological reflexivity to reflect upon the assumptions and values (about the social world) that were made in the course of the research, which helped the researcher to think about the implications of such assumptions for the research and its findings (see Section 3.1 for research philosophy). The researcher engaged in self-critique and self-appraisal, and explained how her own experience had not influenced the stages of the research process (Koch and Harrington, 1998) (see Section 3.9.3 for reflection on researcher reflexivity and research setting). This study also reflected the use of different types of data collection methods to provide more effective and impartial findings and analysis (see Section 3.6 for data collection methods and Section 3.9.4 for reflection on data collection methods). Furthermore, the confirmability of this study was built up through triangulation which was presented above. That is, use of different data collection methods, different groups of informants, and different periods of time to collect data could help to reduce the effect of researcher bias and cross-examine the integrity of participants' responses (Shenton, 2004).

3.9.3. Researcher reflexivity and research setting

Being an insider researcher, or carrying out a study directly concerned with the research setting in which the researcher worked and was already a member, provided many advantages for undertaking research and the validity of the research. That is, the researcher was native to the research setting and so had knowledge, experience, and pre-understanding about the research setting. The researcher knew the organisation's everyday life, agency, politics and atmospheres, including the legitimate and taboo phenomena of what should be asked and talked and what should not. The researcher knew the critical events and what they mean within the organisation such as the influence of the project director's power on the project members' attitude and behaviour in undertaking the research project. Moreover, the researcher knew where to locate the case study and the participants of the study as well as how to approach people in the organisation.

Becoming familiar with the context of the research setting enabled the researcher to drill down into the context and circumstances concerning cross-community collaboration and knowledge management. When there were questions or unclear points, the researcher could draw on her own knowledge, experience, and pre-understanding in asking questions, interviewing, and observation. This helped to reduce misunderstandings. For instance, there were more than one project managers because of project and human resource management within the organisation. Being an insider researcher, the researcher could appear in the collaborations of project members to observe their actions and interactions as well as could participate less without drawing attention and creating suspicion, especially in the research organisation which tends to be concerned with leakage of its research output and intellectual property. The researcher could short-circuit the lengthy process of the development of trust. Those factors helped the researcher to obtain rich and in-depth data as well as to interpret and understand meanings of the actions of the social actors and the phenomena of the subject of the study, including the nature of the context of the study.

However, being familiar with the research setting of an insider researcher could lead to questions. For instance, the researcher is perceived to be too close to the research setting and thus not attaining the relationship, the distance, and the objectivity necessary for the validity of the data and research (Brannick and Coghlan, 2007; Marty, 2015). When the researcher is too close to his/her research setting, the researcher is blind to many features (Marty, 2015). Moreover, an insider researcher has a personal stake and substantive emotional investment in the setting. The researcher may assume too much and so not probe as much as if he/she is an outsider researcher (Brannick and Coghlan, 2007). Delbridge and Kirkpatrick as cited in Saunders, Lewis and Thornhill (2015, p. 297) argued that researchers cannot isolate themselves from the social world and the social actors they are studying; the researcher is part of them. Researchers cannot avoid relying on their own common sense of knowledge and experience when trying to interpret the social world and social actors. However, the researcher was not complacent in assuming that the absence of bias and the collection and interpretation of data would be unaffected by the researcher's knowledge which had developed through experiences in the case study. To minimise the researcher's native situation and the risk of assuming too much, seven strategies were adopted as follows.

i. This study adopted different qualitative data collection methods and employed multiple sources of data. The use of multiple data collection methods and sources of data helped to cross-check the collected data from each method and source. Also, the comparison of the findings from different data collection methods and sources helped to circumvent the personal biases of the researcher This could help to ensure the validation of the data.
ii. The researcher asked participants to clarify whenever their answers contradicted what the researcher knew or believed. For instance, the researcher asked the project manager of the software group to clarify why the hardware engineer must belong to the software group and work in the software group's laboratory rather than the hardware group and work in the hardware group's office. The researcher became aware of the many moments when the researcher need to wait or require interviewees to complete sentences, thoughts, or descriptions because the researcher knew implicitly what they were referring to in response to a particular line of questioning. Each time a participant knowingly implied that the researcher knew

what they were talking about, the researcher would ask them to clarify or elaborate. For instance, participants would sometimes report issues in which the project suffered from workload and staff shortages, especially staff who had knowledge and experience in business management. Often, however, the participant would slough off the issue with a comment such as: “You know how much work each member has” and “You know how hard it is to get more members.” Instead of acknowledging the comment with a knowing affirmation, the researcher would instead ask the participant to elaborate, as in “Well, could you describe that…how many projects and tasks does that project member have to handle?” and “Well, could you describe that…how hard is it when the project suffers from getting a new member?”. This type of clarifying probe uncovered richer and more intricate analyses than those elicited through presumptive approaches.

iii. As in Section 3.6.3.2, there are different roles for the participant observer; this study selected ‘an observer as a participant’. ‘An observer as a participant’ helped to reduce significant observer bias because of a lower degree of involvement and the lower influence of the researcher on the group of people being researched.

iv. Data collection was carried out at different times over 6 months. Participants were also interviewed and observed at different times over 6 months. For instance, the hardware and software groups had different interpretations about the setting of an X-ray detector system and the quality of X-ray photographs. Also, the new requirements of external actors, more specifically customers and markets, were a major source of novelty in the project. Project members had to change their current knowledge, practices, and interests to meet the new requirements of external actors.

v. The researcher decided to transcribe everything on the audio recordings of the interviews. Consequently, the researcher had transcripts to help her to recall the interview process and interviewees’ statements. Also, this helped to avoid bias in the researcher’s judgement about what constituted important or relevant information.

vi. The researcher did not work in the participants’ environment all the time. Also, the researcher did not think and behave all the time as a member of the organisation. That is, during collecting data in the organisation, the researcher divided her time into two parts: work time in the organisation for data collection; and research at home. The researcher spent similar amounts of time working in the participants’ environment as she did writing up her research at home. After the data collection process, the researcher distanced herself from the participants and the organisation.

The researcher also spent time interpreting and analysing the collected data and findings in the very different environment of the Information School at the University of Sheffield in the UK. Thus, there was distance from the participants and the organisation.

vii. The researcher recognised the role of being a researcher. That is, the researcher recognised that the role of the researcher is not to change the behaviour, actions, interactions, activities, and perspectives of participants but rather to find out what is happening, how, and why. The researcher collected data without twisting the reaction of participants. The researcher let participants speak for themselves as much as possible. The researcher did not lead participants but also did not let them waffle. Participants were not patronised, nourished, bullied, coerced, or led unduly. Moreover, interviewees' non-verbal reactions and feelings during interviewing were recorded to help the researcher understand interviewees' meanings.

3.9.4. Data collection methods

The use of multi-qualitative data collection methods: semi-structured face-to-face interview; observation; and the collection of documentation and other artefacts, was appropriate for this study for three major reasons. First, it helped to capture and map statements, feelings, non-verbal cues, actions and contexts, including social relationships and scenes of social actors about cross-community collaboration in their real-social setting. The interviews helped to capture participants' viewpoints, perceptions, feelings, and non-verbal cues to explore their experiences and perspectives about cross-community collaboration in their own terms. Rich data about differences in knowledge, skills, and ways in thinking as well as dependencies between members from different knowledge communities in the project were mainly captured though interviews. To supplement this data, differences and dependencies in knowledge, and given tasks between different knowledge communities could be captured through observing the interactions between the communities. Observation helped the researcher to gain understanding of how social actors act and interact with others for cross-community working in the real-social context. The research project documentation and artefacts helped to capture the content of communication and collaboration among project members. All data enabled the researcher to develop a holistic view of differences and dependencies in knowledge and given tasks between interacting members from different knowledge communities in the project. Such differences led to discontinuities in collaboration between interacting members of different disciplines in the research project and led to boundaries. That is, the data collection methods used in this study enabled examining the nature and social construction of boundaries in its empirical context. Moreover, the combination of multiple types of data helped to identify the complexity and nuances involved in processes and boundary-spanning mechanisms for managing knowledge across boundaries which enabled the research to extend the theorisation of boundaries (see Chapter 5 for discussion). All data help to develop a rich picture of cross-community collaboration in the case in order to gain a better understanding of the subject.

Second, using different data collection methods helped to sequence the data collection process for a holistic view of the subject. For instance, the researcher first studied information about the research project from project proposals to gain an understanding of the background and to explore activities between different knowledge communities in the project before interviews and observation. Subsequently, after observing monthly project meetings some key (new) informants were interviewed to explore the causes behind junior project members' absence from the meetings and its effects on knowledge sharing activities among the project members.

Finally, the integration of data collection methods helped to fill gaps in each method and to corroborate findings from various sources. Interviewees gained opportunities to describe participants' experiences and perspectives about cross-community collaboration through their own eyes and in their own words. For instance, a participant from the hardware group talked about different ways of thinking between the two groups, and then criticised the other team's approach to solving blurred X-ray photographs. Such types of view were rarely found through observation of the interaction between the two groups because the project members seemed afraid and avoided criticising another member's thoughts and performances in front of them. The interviews also helped to follow-up and clarify unclear points found in observation and documentation. For instance, details of the hierarchy of project members and the types of knowledge shared among project members. Observation helped to check between what people actually do and what they say they do in the interviews, such as the collaboration between members from different groups to resolve blurred X-ray photographs in a hospital.

However, there were challenges to the use of the different data collection methods described here. One major challenge was the organisation and integration of different sources of data for data collection. To address this, before and during the data collection process the researcher considered the objectives of the study to decide which, when, and how appropriate different data collection methods would be used to meet the objectives. For instance, at the initial stage of the data collection process, interviews were conducted with some key informants, such as the project managers of both groups, to gain an overview of the collaborations. Observation was used later to corroborate the interviewees' statements and capture specific events such as the collaboration of both groups to fix X-ray delay in the laboratory. During the data collection process, data collected through different methods were integrated and analysed in parallel. This helped to understand the relationship between different datasets and the analytic findings. Moreover, it helped to determine the direction for further data collection. Therefore, a well-planned data collection process and understanding the relationship between different data collection methods, datasets, and analytic findings, needs to be considered.

3.10. Summary

This chapter focused on explaining the research methodology. The research philosophy and research approach were discussed first. This research adopted the interpretive epistemology and constructivist ontology, as well as the inductive research approach.

Section 3.3 then discussed different types of research strategies or research designs, from which the case study design was selected. This is because of the research aim and objectives, the philosophical underpinnings, and the amount of time available. The case study design allows the in-depth exploration of a complex phenomenon of the subject of the study within its real-life context (Bryman, 2012; Yin, 2009). It helped the researcher to collect rich and in-depth data (Yin, 2009). It also allowed the researcher to look at the subject from many aspects to obtain a rich picture and gain insights from it (Thomas, 2011). The concept of how to undertake the case study was explained.

The following section, Section 3.5, depicted the research setting and the reasons behind selecting an interdisciplinary research project that was set up to develop CT and DR scanners in a governmental research organisation in Thailand. This research setting was selected because it was relevant to, and enabled the researcher to meet, the research objectives. That is, it is a joint project between two different disciplinary knowledge communities. It is considered successful in terms of interdisciplinary collaboration. It is an ongoing project and thus could yield relatively rich data. Furthermore, it was selected because the researcher was already a member of the organisation. Thus, it seemed more feasible to locate the case study and participants of the study within the organisation to collect data. Being already a participant of the organisation, the researcher had pre-understanding and experience about it. The researcher could gain access and drill down into the context and circumstances concerning the subject of the study. This helped the researcher to gaining a better understanding of social actors' actions and phenomena in their natural setting.

Section 3.6 then discussed data collection methods. According to the research aim and objectives, the nature of the subject of the study, and the appropriateness of data collection methods: semi-structured face-to-face interview; participant observation; and collection of documentation and other artefacts, were selected to collect data. A rigid structured methodology such as questionnaires was not selected because it was not appropriate to reveal alternative explanations of phenomena in the real-social setting (Boeije, 2010; Thomas, 2011). A focus group method, which has been employed in previous research, was not selected because it was difficult to find mutually-convenient times to invite participants to participate with others. Also, there was the issue of Thai culture, especially the strong seniority culture, taking another person's feelings into account, and saving face (Sinthavalai, 2008; Yodwisitsak, 2004). Consequently, some participants might feel uncomfortable in stating their opinions freely in group interviews.

Section 3.6 also described the data collection process. Data were collected from April 2014 to June 2014 and from January 2015 to April 2015. Different data collection methods were used to collect data parallel. Within the two phases of the data collection process the researcher conducted interviews a total of 21 times with 14 participants over approximately 17 hours. The researcher observed the activities and interactions of project members 12 times for 31 hours. The researcher also collected data from the collections of documentation and other artefacts, which were created and used by different knowledge communities in the project. They contained the content of cross-community communication and collaboration between different knowledge communities. All data were analysed through thematic analysis. The data analysis process was described in Section 3.7.

The final section, Section 3.9, presented a reflection of the case study research strategy, qualitative research approach, researcher reflexivity and research setting, and data collection methods which were selected. Having explained how the data were collected and analysed, the next chapter, Chapter 4, will present the findings in depth.

4. Findings

4.1. Introduction

This chapter presents key findings from this study. The chapter consists of five main sections. The first two sections provide more context and background about cross-community collaboration and knowledge management activities which were found from the case study. This is to create a better understanding about cross-community collaboration and knowledge management activities in the case study of this thesis. The last three sections present the significant findings associated with the research objectives. Some findings in the last three sections relate to the findings in the first two sections.

The first section suggests the benefits and costs of interdisciplinary research and collaboration from the perspectives of the participants of this case. The second section suggests the types of knowledge that were shared as well as communication and knowledge sharing channels that were used to share the knowledge found in this case. Then, in the third section, it presents grey areas about the nature of boundaries. Following that, the fourth section presents grey areas about the construction of knowledge boundaries. These two sections are presented to suggest that knowledge management across boundaries is more complex than the existing literature on cross-community collaboration and knowledge management suggests. In the final section, the content is narrowed to the different types of knowledge boundaries that can emerge in interactions between different knowledge communities and processes to manage knowledge across them.

4.2. Benefits and costs of interdisciplinary collaboration

According to the interviews, two major broad benefits of an interdisciplinary research project and collaboration were suggested: opening knowledge sharing and learning opportunities to project members; and supporting the development of complex and advanced products to meet the complex requirements of customers and markets. However, an interdisciplinary research project and collaboration could increase workload and require more time being spent collaborating than working with members of the same discipline.

4.2.1. Benefits of interdisciplinary collaboration

A majority of participants suggested that interdisciplinary collaboration offers opportunities for knowledge sharing and learning to gain new and necessary knowledge and skills. During the development of the Computerised Tomography (CT) and Digital X-Ray (DR) scanners, the members of the hardware and software groups shared and learned knowledge with each other. For instance, one participant from the software group suggested that: “I have just learnt new things about a setting of a collimator and scattered radiation from the hardware group” [N1, P13, L453]. Similarly, one participant from the hardware group suggested that there is new knowledge learning between the two groups through coordination:

> We [the members of the hardware group] get new knowledge that we have not known yet through working with the different centre [the software group from the National Electronics and Computer Technology Center]. Because if we only work in our centre [the National Metal and Materials Technology Center], we will only get the same knowledge [N9, P9, L308-310].

There were knowledge sharing and learning activities between the hardware and software groups to improve the knowledge of each other to form common knowledge and understandings. For instance, the software group set up training to transfer its knowledge about the development, components, and functions of software, the components and functions of X-ray technologies, and the use of the software group’s viewer and planning software to the hardware group. This activity was used to improve the hardware group knowledge and understandings about the software group’s tasks and the dependencies between the two groups [N1, P9, L290-293]. Similarly, during observation of a dental CT scanner version 2 in a laboratory, one engineer from the hardware group explained the nature, behaviour, and image shooting process of an X-ray detector system to the software group members to improve their knowledge and understandings about a problem of X-ray delay [O9, P2, L41-46]. These situations tended to arise because of differences in types of knowledge between members of different groups. That is, from the examples above the hardware group had no knowledge about the components, characteristics, functions, and operations of software. By contrast, the software group had no knowledge about the nature, behaviour, and image shooting process of an X-ray detector system of hardware. To support cross-community collaboration, one group needed to learn knowledge in fields that they were not familiar with from the other group to develop common knowledge through different knowledge sharing and learning activities such as training and working together in the same place.

From interview data, during the development of the scanners the project members learned and integrated their knowledge with external actors who were members of different knowledge communities such as consultants. The project members learned the theories, concepts, operations, and technical vocabularies of an X-ray detector system and radiation from an external consultant in the scanner concept design stage. They gained knowledge on those issues from an external consultant to design and develop their scanners. For instance, one participant from the hardware group talked about gaining new knowledge from the consultant in the following way:

> The hardware group members did not know X-ray technical vocabularies. They needed to be explained what this was or what that was [smiles]. Because actually some parameters were affected by the hardware part, so we [the hardware group members] should know about them too. This was the cause of an external consultant invitation to explain about X-ray to the project members [N5, P7, L222-225].

This suggested that there is a lack of some required knowledge by some project members. Those project members wanted to gain such required knowledge to handle their parts which connected with and influenced the other parts. Thus, they needed to interact with an external knowledge source such as an external consultant to gain the required knowledge from the consultant. Knowledge sharing and learning occurred when the project members interacted with the consultant.

Similarly, the project members needed to learn new knowledge about ISO 13485 and risk management from another external consultant at the end of the development of a dental CT scanner version 1 project. They required such knowledge to improve their production processes to meet the requirement of the Food and Drug Administration of Thailand and for customers to be allowed to market their scanners. For example, one participant from the hardware group talked about the learning of project members from an external consultant as follows:

> At the beginning each project member did not have knowledge about this [ISO 13485 and risk management]. We got training from the consultant [...]. The consultant taught us what ISO 13485 was including its regulations and requirements. After the training, we needed to practice and implement ISO into our work processes. The

> consultant suggested everything about ISO to us. He helped us to create standards documents too [N3, P1, L13-24].

This suggested that there is new knowledge learning by the project members, which includes members of different knowledge communities, about ISO 13485 and risk management. Learning occurred through training and practice. From observation data, the ISO consultant gave suggestions to the project members for creating procedural documents and improving their work processes [O11, P1-3].

The project members did not learn the new and necessary knowledge just from members of another different knowledge community in the project and the external actors. They also had to study the literature and locate new knowledge in their field to improve their body of knowledge and performance for the scanner development. This was to meet customers' requirements and to compete with other scanner manufacturers. For instance, one participant from the software group suggested that project members need to study and develop new algorithms and techniques to increase X-ray doses and radiation to develop high-resolution photographs to meet customers' requirements [N12, P11, L378-415]. Similarly, another participant from the software group talked about the necessity of new knowledge learning in a research project area such as an X-ray detector system because:

> I have no sufficient knowledge and understandings about an X-ray detector system. I must learn. I must read, study, and find out more knowledge about the system such as the different ways of X-ray settings and their effects. Also, I must look at markets, commercial issues, and scanner specifications. I have learnt quite a lot from the tasks [N1, P9, L295-298].

This suggested that based on their own types and depth of knowledge, the participants had to study new and different areas to support their tasks for doing the research project. They were not only gaining new and required knowledge from the other project members and external actors, but also from self-study.

From the findings mentioned above, it suggested that an interdisciplinary research project and collaboration encourages project members to share and learn new and different required knowledge. The project members represented and transferred their knowledge to the other project members. They also learnt new and different required knowledge from the other project members and external actors. Knowledge sharing and learning activities could occur in many ways such as through training, working together, and consultation. Knowledge sharing and learning activities were necessary to develop new and required knowledge, skills, and techniques in project members' territories and in their assigned tasks. They were also necessary to develop common knowledge and understandings for communication and collaboration among the project members. This was to improve the project members' performance and output both as individuals and groups of individuals to achieve the tasks of the interdisciplinary research project and collaboration.

Another major broad benefit of an interdisciplinary research project and collaboration was the development of complex and advanced products to meet the complex requirements of customers and markets. From the documentation of this case, more specifically a project presentation, the hardware and software groups collaborated to develop a cone-beam X-ray technique and a flat panel detector to generate patients' 3D X-ray photographs [D7]. Working together, they could develop the first Thai dental CT prototype scanner, called DentiiScan. The project dental CT scanners version 1 are in use in both public and private hospitals in Thailand. Furthermore, the project gained subsidies of 16 million baht or around 29 hundred thousand pounds from the Thailand Center of Excellence for Life Sciences (TCELS) to produce four dental CT scanners version 2 [O2, P1, L3]. One participant from the hardware group suggested that:

> I think we get a bigger project and deliver more efficient products which meet the markets' requirements because we have more partners and more important components for production. Today the requirements of customers are more difficult and complex. Customers need efficient products or processes which are not reliant on a single discipline normally [N5, P8, L260-268].

It is suggested that the requirements of customers and markets are more difficult and complex. They require a wide range of knowledge and skills. Single individuals or disciplines rarely possess all the required knowledge and skills. Thus, interdisciplinary collaboration was required because it helps to acquire different and required knowledge from different disciplines to develop services and products which meet customers' needs.

According to the interviews and observation, the development of the CT and DR scanners was difficult and complex [O3, O5, O9, O10]. It required more than one type of knowledge from the collaboration of two or more different knowledge communities. In this case, there were two major different groups: the hardware and software groups. Both groups had different knowledge and skills, so they carried out different tasks in the development of the scanners. However, they could not develop the scanners on their own. They required the knowledge, skills, and output of each other to fulfil their parts and to reach the common goal of the project together. That is, the hardware group had knowledge in electrical and mechanical engineering to develop the body of the scanner for recording raw patients' X-ray photographs. By contrast, the software group had knowledge in computer science and electrical engineering such as signal processing, image processing, computer programs, computer databases, and statistical reconstruction (see Table 3.2 for knowledge backgrounds of participants from both groups). The software group required raw patients' X-ray photographs and data from the hardware group to create reconstructive photographs for diagnosis and operational planning through the software group's planning software. As one participant from the software group said, "we [the members of the software group] are not able to develop engines and machines but they [the members of the hardware group] can do that" [N12, P14, L474-477]. Meanwhile, the hardware group required knowledge and suggestions about the setting of an X-ray detector system and the quality and accuracy of X-ray photographs from the software group. This suggested that the development of the scanners demanded more than one type of knowledge and skills. No single group possessed all the required knowledge and skills to develop the scanners. Therefore, the collaboration of members from different knowledge communities was required, even while remaining anchored in their own fields.

4.2.2. Costs of interdisciplinary collaboration

Although the participants recognised the great benefits of interdisciplinary collaboration, most participants perceived that interdisciplinary collaboration was very difficult. From the interviews, cross-community collaboration increased workload and required more time being spent collaborating than working with members of the same discipline to achieve a common goal together. For instance, one participant from the software group burst out that working with the members of different disciplines is "tiring" and "gruelling" [N1, P9/12, L305/410]. According to the interviews, the tiring nature and difficulties of an interdisciplinary research project and collaboration could come from three major causes: (i.) the differences in knowledge of members from different groups; (ii.) the dependencies in knowledge of members from different groups; and (iii.) a lack of types and amount of knowledge in a research project area of project members.

In the interviews, members of the hardware and software groups stated that they are from different subject-fields. They had differences in many aspects such as knowledge, skills, perspectives, values, and cultures of thought which were shaped by their subject-fields (see

Section 4.5.1, more specifically i. Difference). For instance, one participant from the hardware group said:

> The software group seems to think that 0 is always 0, while the hardware group thinks that it is impossible to be 0. This is because it must have some mechanical errors. The software group often tells the hardware group that the setting of the X-ray detector system and the scanner must be like this or that. However, in practice sometimes the hardware group cannot do like the software group's concepts [N8, P1-2, L27-38].

This suggested that members from different knowledge communities tended to have different ways of thinking in the same thing which come from the nature of their communities. Concepts or theories of one community might not be used in or suitable for another different community. Consequently, tension and conflicts between different groups could occur. For instance, one participant from the software group complained of the hardware group's performance: "it is not as we [the software group members] wish. Hardware should be designed like this" [N1, P9, L308]. This suggested that there were differences in perspectives in the same thing between different groups. Therefore, there were challenges to develop common knowledge and understandings as well as an accepted view-point between different groups to reach a common goal for coordination. The development of common knowledge and understandings between different groups for cross-community collaboration tended to take more time. Two participants from the hardware group talked about this issue, saying that:

> If a project is conducted by members from many and various disciplines, there are too many cooks spoiling the broth sometimes [laugh], waste time to quarrel awhile [N5, P8, L270-274].

> People who have the same knowledge background understand each other very fast. But if they are from different fields, they have to spend much time to communicate to understand each other. They have to talk several times [laughs] [N13, P10, L323-326].

The second cause of the tiring nature and difficulties of an interdisciplinary research project and collaboration was dependencies in knowledge and tasks between members from different groups. The two participants of the software group talked about this point:

> Tired [laughs], so so tired, it is more difficult because different groups must go together. Sometimes hardware has not been finished yet but software has to be started. It reaches a deadline but hardware has not been finished yet. So, we [the software group members] have to change our plan by doing other things first during waiting for hardware. It must be waiting for each other [N1, P9, L305-308].

> The machine has not been finished yet, so we [the software group members] cannot test anything. We have to wait for the hardware group [N2, P6, L185-188].

This suggested that all research project members had to work and walk together. Actions of members from separate groups in the research project had effects on each other. Sometimes one group had to wait for the other group to integrate their parts or to get results from the other group for doing other subsequent parts. If one group was delayed, the other group would be delayed too or had to change its plans. The project could thus be delayed.

Finally, the tiring nature and difficulties of an interdisciplinary research project and collaboration could come from a lack of types and amount of knowledge in a research project area of project members. In the interviews, some participants from the hardware and software groups suggested that the scanner development is a new and complex thing for most project members. Most project members had never been involved in the development of the scanners. For instance, two participants from the hardware group suggested that "it is a new subject for the group [the hardware group]; there are many complexities" [N7, P3, L78-79], "I had no knowledge about X-ray in an earlier stage" [N7, P3, L104-105] and "I had never developed a CT scanner [laughs]" [N9, P4, L139-140/144].

Some participants also suggested that many project members, especially the members of the hardware group, lacked knowledge and experience in the development of the scanners, especially an X-ray detector system. For instance, the participant from the hardware group talked about differences in amount of knowledge in a research project area between the hardware and software groups:

> The software group has more basic knowledge about X-ray technologies than the hardware group. The software project manager graduated in this area directly. Some software group members have such knowledge through doing their theses about X-ray, while the hardware group has no X-ray knowledge [N5, P2, L86-88].

Similarly, some participants of the software group mentioned that most members of the hardware group lacked knowledge and understandings about the physical character and operation of X-ray and a detector [N1, P3/5, L100-105/152-153]. Moreover, most members of the hardware group lacked understandings about the relationships between the hardware and software aspects [N1, P4, L132-135].

As both groups had to work and walk together, lack of knowledge and experience in a research project area of one group affected the other group. One participant from the software group, for instance, talked about lack of knowledge in a research project area of the hardware group and the effects of this issue on the software group and the research project in general:

> They [the hardware group members] may not understand some things about the physical [aspect] of X-ray of a CT scanner. It is not just the development of machines in the case of the scanner […]. They must understand X-ray, a detector, and the effects of their actions on software and X-ray photographs […]. For example, a head support for patients, it had been changed many times because it did not work and it hit a detector. Finally, we [the hardware and software groups] had to change the head support to the chin and forehead rest to fix the problem [N1, P5, L152-161].

4.3. Types of shared knowledge and knowledge sharing channels

As the beginning of Section 4.2 mentioned, an interdisciplinary research project and collaboration opens knowledge sharing and learning opportunities to project members. Thus, this section presents an overall picture of the types of knowledge that were shared as well as communication and knowledge sharing channels that were used to share the knowledge found in this case. Especially, it presents the participants' perspectives on the relation between a hierarchical organisational structure in the research project and the different types of knowledge that were shared among the project members. In this case, the participants perceived that it is appropriate to share different types of knowledge with different levels of members in the research project. It was related to task allocation based on the authority and responsibility of the project members.

4.3.1. Types of shared knowledge and knowledge sharing channels

According to the interviews, observation, and documentation, more specifically project proposals and scanner user guides, knowledge which was shared among members in the research project as well as between the members and the external actors could be grouped into three main types as follows: technical knowledge on the scanner development; sales and marketing; and project management. They were shared through different channels.

Technical knowledge, in this case, covered knowledge about the development of CT and DR scanners. Some of these types of knowledge were highly theoretical and generalised knowledge, while part of another type of knowledge included logs and notes of empirical work, as follows:

i. theories, characteristics, components, and operations of an X-ray detector system and radiation;
ii. parameters of X-ray detector setting;
iii. concept designs, drawings, components, specifications, and characteristics of the scanners;
iv. radiation and electrical safety tests;
v. technical vocabularies of an X-ray detector system and radiation;
vi. technical problems of scanner development;
vii. technologies and applications of an X-ray detector system and the scanners;
viii. components and operations of software;
ix. log files of software development;
x. results of fieldwork tests; and
xi. records and notes of scanner maintenance.

Technical knowledge was shared through various channels using both face-to-face communication and technology such as face-to-face meetings, working together in the same place, e-mail, instant messaging, and Dropbox. However, according to the interviews and observation, face-to-face communication and social interaction such as project meetings and working together in the same place were key channels for sharing technical knowledge [O1, O3-O6, O12]. Project members normally had differences in knowledge and worked in different buildings. Face-to-face communication and social interaction offered opportunities to project members to meet, share, discuss, and tune their different knowledge and perspectives with the other project members directly. This was to develop common knowledge and understandings among the project members.

The content below presents various communication and knowledge sharing channels that were used to share technical knowledge in the case under study. Those channels were ordered by importance and were often suggested by the participants: face-to-face meetings; working together in the same place such as a laboratory; e-mail; instant messaging; Dropbox; and a notice board.

In this case, there were monthly project meetings. They were where project members bring their progress reports and issues about the scanner development to report and discuss with the other members directly, especially with key decision makers such as the project director and project managers. According to observation of the monthly project meetings, the reconsideration of existing knowledge and the gaining of new knowledge of project members happened during the meetings and discussions. For instance, project members shared their knowledge and perspectives about the adaptation of the project mobile CT scanner to diagnose and operate on cleft lip and cleft palate in children [O6, P1, L6-12]. As another example, project members discussed factors which could be the causes of blurred X-ray photographs of the project dental CT scanners to find solutions together [O1, P3].

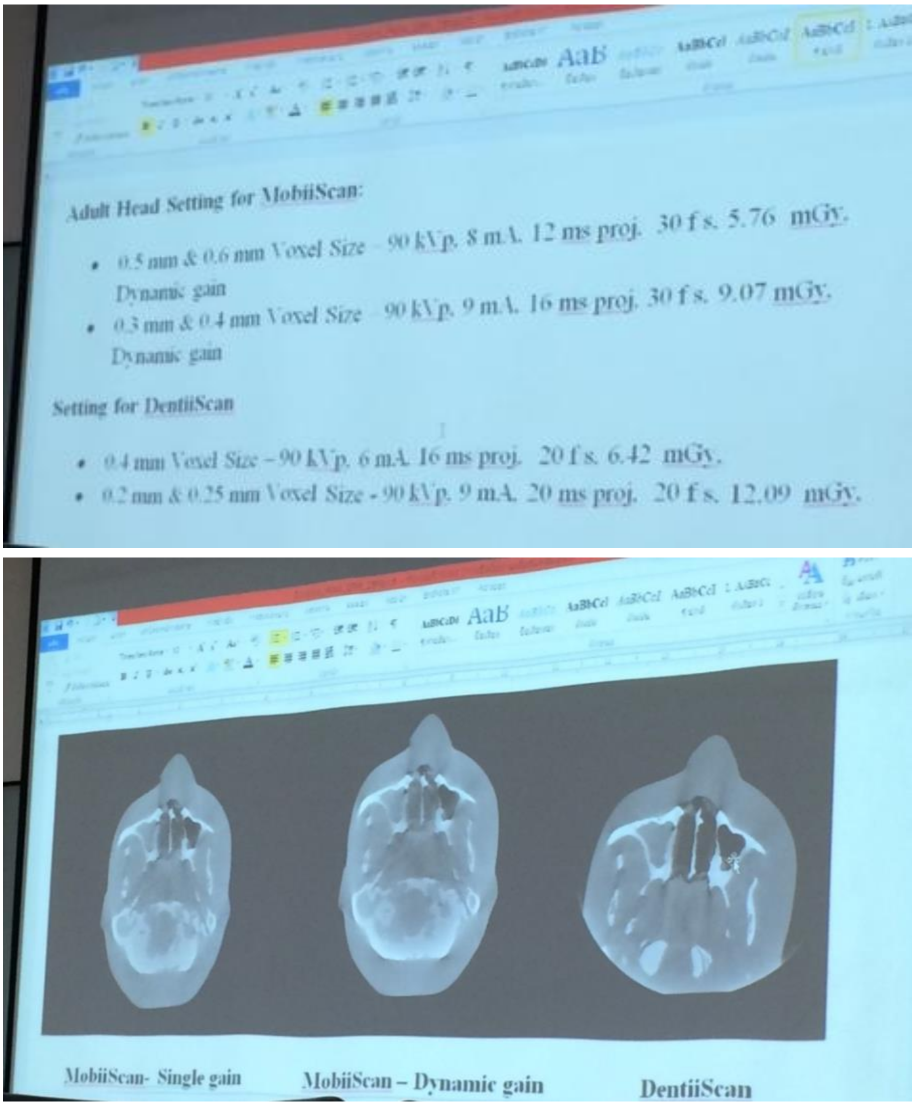


Figure 4.1 Example of technical knowledge shared in a monthly meeting

Figure 4.1 above presents an example of technical knowledge sharing by the software project manager to the other project members during the monthly project meeting. More specifically, the software project manager shared knowledge about improved parameters to set mobile and dental CT scanners [the top picture] and testing results from the improved parameters [the bottom picture] with the other project members. This was to improve the performance and output of the project mobile and dental CT scanners [O12, P5-6].

Working together in the same place was another key knowledge sharing channel which was often suggested by most participants. Most participants suggested that working together in the same place such as a laboratory is convenient for project members to point out and discuss the technical issues of the scanner development with the other project members directly at where the scanners were developed. For instance, one participant from the hardware group suggested that: “we [the hardware and software groups] work together in a laboratory; we can discuss problems at the site directly" [N7, P2, L47-48]. Working together in the same place helped project members to create a better understanding among them by providing more opportunities to project members to talk, discuss, and learn with the other project members. For instance, one participant from the software group talked about the benefit of working together in a laboratory to develop common understandings among the project members:

> I think it is going better because of working together in the same place, especially in the lab. Everyone has to come in and work in the lab. If we work in the same place, it works because we can talk with the other project members and understand tasks better. It does not work for working separately and integrating later because some things need to be discussed with other project members. The more people talk, the more people understand [N1, P5, L170-172].

Also, working together in the same place supported knowledge creation and knowledge acquisition because project members could work and learn by doing things at the same time. According to observation, members of the different groups shared their technical knowledge with each other to develop common knowledge among them. For instance, one hardware engineer explained the behaviour of an X-ray detector, the X-ray shooting, and the rising time of X-ray shooting to some software group members during resolving X-ray delay with a dental CT scanner version 2 together in a laboratory [O9, P2, L41-16].

Not only face-to-face communication and knowledge sharing channels but also non-face-to-face communication and knowledge sharing channels were used to share technical knowledge. In this case, project members mainly used technology such as e-mail and instant messaging to report progress and share technical issues about the scanner development, especially during field work, with the other project members. This was because of convenience for sending and receiving the knowledge. For instance, the hardware group sent drawings of a gantry between an X-ray source and a detector as well as photographs of gantry simulation to the software group through e-mail and instant messaging to consider for accuracy and to inform the progress of hardware development [N12, P6, L184-189]. One participant from the hardware group, for example, talked about the benefit of using instant messaging to share photographs of the scanner development:

> LINE [one application for instant messaging] is quite fast. While we [the hardware group members] are testing or maintaining a scanner in the laboratory, field trials, or customers' sites, we can send parameters, results, and photographs about the set-up

> and operation of the scanner to the other project members immediately. This is to inform and update the other project members about the work being done [N13, P5, L142-145].

Furthermore, sharing knowledge through technology such as instant messaging offered opportunities to project members to follow up and learn through the tasks of the other project members. One participant from the software group mentioned that:

> I developed software but I knew the results of the project dental CT scanner safety and electromagnetic compatibility testing of the PTEC [Electrical and Electronic Products Testing Center]. This was because the hardware group shared the results with the other project members through instant messaging. The project members who did not participate with the testing could catch up with the hardware group's tasks through this way. I got some useful points for the DR scanner development. It helped me to improve my knowledge [N2, P13, L433-444].

Moreover, the project members used storage and retrieval technologies such as Dropbox to store and share documents relating to the scanner development such as technical manuals, radiation and safety testing, and scanner maintenance. According to observation, a notice board in a laboratory was another tool used for: sharing technical knowledge, especially procedure; for reminding project members of key points about the scanner development such as notes for preparation for using a prototype CT scanner; key feedback from customers to improve the project dental CT scanner version 1; and a backlog to develop the project dental CT scanner version 2 [O3, P4-9]. Figure 4.2 below presents how technical knowledge, the parameters of X-ray detector setting for a mobile CT scanner, was shared among the project members in a laboratory to remind them about the scanner setting.

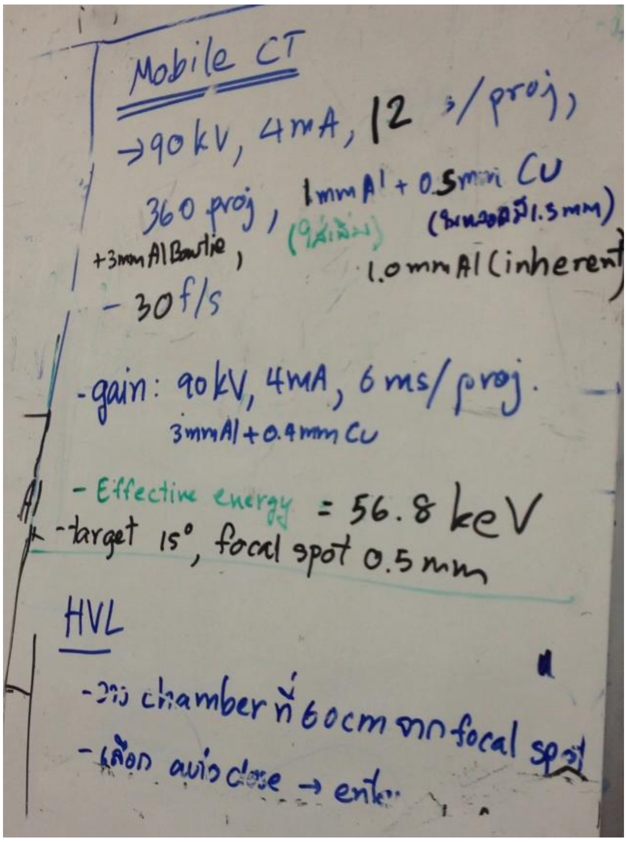


Figure 4.2 Example of technical knowledge shared on a notice board in a laboratory

As mentioned above, it is suggested that some technical knowledge of this case can be considered as explicit knowledge. That is, knowledge could be captured and presented in a visual format such as words, photographs, and drawings as well as sent through technology such as e-mail, instant messaging, and storage and retrieval technologies. The knowledge recipient(s) was able to use and understand the knowledge without social interaction with the knowledge holder.

Sales and marketing knowledge was the second main type of knowledge that was shared in this case. According to the interviews, observation, and documentation, sales and marketing knowledge covered marketing, business plans and strategies [O4, P2], the requirements and feedback of customers and markets [O1, P3] [D1], and competitor analysis including customer details and contact records [D2]. Business plans and strategies tended to be shared through the monthly project meetings because they needed to be considered by the project key decision makers such as the project director and project managers [O4, P2]. For instance, from observation data some project members presented the strengths and weaknesses of the project's and competitors' dental CT scanners to the other project members in the project monthly meeting [O4, P3, L57-63]. This was to discuss and find solutions to improve the project scanner development and marketing strategies to compete with other scanner manufacturers. To resolve the issue of sales volumes, the project director shared the concept of Alibaba.com by raising the idea of website development to offer dental CT scanner services and products within the marketplace. Moreover, the project director suggested ways to compete with another scanner manufacturer by offering a 10% discount and 2-year warranty for the project dental CT scanner [O4, P2, L42-47]. Sales and marketing documentation was stored and shared among project members through storage and retrieval technologies. For instance, the requirements, information, and contact records of customers were stored and shared through Dropbox and Google Docs; project members could access it at anytime and anywhere [D2].

The final type of shared knowledge in this case was about project management. It covered policies and plans, budget, Gantt charts, and team management including the implementation of ISO 13485 and risk management. According to the interviews, the plans, strategies, and budget of the project were heavily mentioned at the beginning of the project. They were mainly shared through face-to-face meetings. This was because they needed to be communicated and required decisions from the project director and managers to the other project members as part of the chain of command of the hierarchical organisational structure found in the case. The Gantt charts of the project, team management, and the implementation of ISO 13485 and risk management were mentioned during the course of the project through meetings, training, e-mail, Google Docs, and Dropbox. This suggested that different types of knowledge were shared, depending on the project life cycle and the work that has to be done. Figure 4.3 below, for instance, was captured during the meeting with an external consultant for ISO 13485 and some project members. They were considering the implementation of ISO into sales and marketing processes. The consultant [standing] was checking the procedural documents of one project member [red shirt] and made suggestions to improve the documents and operations. The other two project members were editing their documents after getting the consultant's comments. The consultant gave knowledge about the development of procedural documents and the improvement of operations in sales and marketing to the project members such as the standard forms and procedures of customer orders and customer complaints and feedback [O11].

Figure 4.3 Meeting of the project members and the external consultant for the implementation of ISO 13485

In this case, there were research collaborations through co-authorship between the hardware and software groups such as user manuals and research reports. However, each group wrote its part independently within a template provided. Then all content was gathered and combined together.

Table 4.1 below summarizes the different types of knowledge that were shared in this case which are matched with different knowledge sharing and communication channels.

Types of knowledge and knowledge sharing channels		Face-to-face meetings	Laboratory	Training	e-mail	Instant messaging	Dropbox	Google	Notice boards
Technical knowledge on the development of the scanners	Theories, characteristics, components, and operations of an X-ray detector system and radiation	/	/	/					
	Parameters of X-ray detector setting	/	/		/		/	/	/
	Concept designs, drawings, components, specifications, and characteristics of scanners	/			/				
	Radiation and electrical safety tests					/	/		
	Technical vocabularies of an X-ray detector system and radiation	/	/	/					
	Technical problems of scanner development	/	/						
	Technologies and applications of an X-ray detector system and the scanners	/							
	Components and operations of software	/		/			/		
	Log files of software developments						/	/	
	Results of fieldwork tests	/				/	/		
	Records and notes of scanner maintenance						/		/
Sales and marketing	Sales, marketing, business plans, and strategies	/							
	Customer details	/					/	/	
	Customer contact records	/						/	

Types of knowledge and knowledge sharing channels		Face-to-face meetings	Laboratory	Training	e-mail	Instant messaging	Dropbox	Google	Notice boards
	Feedback, complaints, and requirements of customers	/					/	/	/
	Competitor analysis	/							
Project management	Policies and plans of the project	/							
	Proposals of the project and budget documents	/			/				
	Timetables of the project	/							/
	Team management	/							
	Implementation of ISO 13485 and risk management	/		/	/		/		

Table 4.1 Different types of shared knowledge and knowledge sharing channels in the case study

4.3.2. Hierarchical organisational structures and cross-community collaboration and knowledge sharing

According to meeting observation, it suggested that there are different sets and levels of members in this case. Those sets and levels of project members discussed different issues and shared different types of knowledge [O1, P2-3]. This was confirmed by some key project members. For instance, the software group's project manager talked about this issue as follows:

> When we talk about the types of knowledge that are shared within the project, we have to consider the levels of project members. If there are sales and marketing or other issues at a higher level, they will be discussed among the project managers and senior project members at the higher level. If the topics are technical issues, they will be discussed among members at a lower level [N1, P7, L239-241].

From interview and observation data, project members in this case could be grouped into four different sets and levels as follows: the project director; project managers; senior project members; and junior project members of the hardware and software groups [O1, P4]. Project members at the higher levels were perceived as possessing more knowledge and experience than the other project members at the lower levels, especially project management. Thus, they were often invited to discuss major and broad issues such as plans and strategies. Figure 4.4 below illustrates different sets and levels of project members which are matched with different types of knowledge that they share.

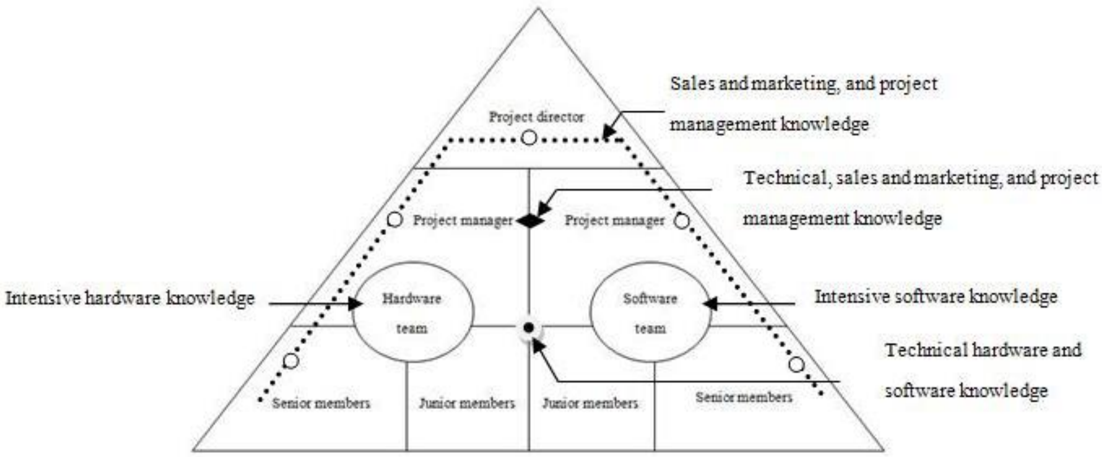


Figure 4.4 Different sets and levels of project members in this case study

As shown above, at the bottom and the middle of the pyramid the project managers and members of both groups shared technical knowledge and perspectives on the scanner development of both hardware and software with each other. The technical knowledge of the scanner development was rarely shared with the project director because he mainly looked after the overall picture of the project [N1, P11, L353-354]. The project director tends to have a more general overview. For instance, one participant from the software group suggested that “the project director looks at plans; he does not know about bugs in software or where to buy this hardware” [N2, P9, L297-300]. Intensive technical hardware and software issues were discussed among the project members of each group [N1, P6, L207]. In the software group, the software project members were divided into different sub-groups based on their knowledge and responsibilities in the group [N1, P13, L413-418]. For instance, the sub-group concerned with viewer development focused on computer programs, while the sub-group concerned with reconstruction focused on mathematical theories and algorithms. If there were issues about algorithms to reconstruct photographs, the software project manager tended to discuss them with the reconstruction group. Sales and marketing and project management issues, especially strategies and plans, were discussed among the project director, project managers, senior project members and some relevant junior project members.

According to observation, not all junior project members attended the monthly meetings or some junior project members did not attend the meetings throughout [O1]. From interview data, junior project members tended to attend the meetings which had relevance to their tasks. They absented themselves from some meetings because they had to clear up their backlogs and they perceived that the meetings were not relevant to their tasks. If there were important issues raised, those issues were briefed to the junior project members by the project managers later [N1, P11, L353-374]. The software project manager talked about the project members’ absence from meeting and a mechanism for sending and receiving information that:

> Not everyone meets up with the project director […]. Important issues, which have effects on members at the bottom level, are told to those members by me [the project manager]. I also try to ask the other project members to record meeting minutes for transferring information in meetings to the other project members [N1, P12, L384-388].

Similarly, decisions on different types of issues in the project were made by different sets and levels of project members. Decisions on plans and strategies were shaped and made by the project director, project managers, and senior project members respectively. Decisions on technical issues on the scanner development were shaped and made by the project managers and members of the two groups. Decisions on intensive hardware and software technical issues were shaped and made by the project manager and members of each group. Two participants from the hardware and software groups talked about decision-making among the project members by using the hierarchical organisational structures that:

> The project director is a key decision maker […] but he does not make decisions in minor issues. He looks at a direction and strategy […]. If there are technical problems about the scanners, each group will look at the problems [N4, P4, L127-137].

> For the software group, if there are problems about plans, the project manager will make decisions. If there are problems about programming, the front-line members will make decisions. However, we [the project manager and members of the software group] will talk to each other again to discuss about solutions [N2, P8, L253-256].

The management of different types of knowledge for sharing and making decisions mentioned above was based on the project members' authority, abilities, and responsibilities. Most participants suggested that it is appropriate to share different types of knowledge and discuss different topics with different sets and levels of members in the project. One participant from the software group, for example, talked about this issue, saying that:

> All project members are part of the jigsaw puzzle and every piece of the puzzle has its importance. One project member carries out the development of hardware or software, so he has to do his best. By contrast, the project director is well-known and has many connections, so he takes responsibility as a project coordinator and a facilitator. He does not need to look after other technical details. If everyone does everything, it does not work and takes much time […] try to allocate tasks among project members [N1, P11, L362-373].

However, one participant suggested that a hierarchical organisation structure slowed down communication and decision-making among project members. This participant stated that:

> Quite difficult because of coordinating with many people […] and different levels is quite difficult [N4, P7, L235-237]. Members who are situated on the top level have the

authority of decision-making. Sometimes we contact with and ask some members to do something but they have no authority to make decisions to do that. Consequently, they must ask their managers first [N4, P7, L245-247].

4.4. Nature of boundaries

As mentioned in the literature review in Chapter 2, more specifically in Section 2.5, boundaries are invisible, dynamic, fluid, and changeable. The findings from this case suggested that boundaries are dynamic and tend to change throughout the project life cycle depending on the work that has to be done and issues of interactions between different knowledge communities. Especially, there was co-existence, simultaneity, and overlapping of boundaries. Therefore, the identification of where one type of knowledge boundary ended and another began was not often easily identified. Furthermore, the findings suggested that when different actors face the same phenomenon, they could experience and perceive it as different types of knowledge boundaries. Therefore, the categorisation of knowledge boundaries was not often easily made. These findings argued that knowledge management across boundaries is more complex and challenging than suggested in the existing literature.

4.4.1. Dynamic nature, overlapping, and simultaneity of knowledge boundaries

According to the interviews, observation, and documentation, more specifically a project proposal [D5], the development of the scanners in this case could be categorised into three major stages: (i.) the planning and design stage covered project concept design, hardware and software design and hardware procurement; (ii.) the development and manufacturing stage covered hardware and software development; and (iii.) the testing and implementation stage covered quality and safety testing, hardware and software improvement, scanner installation in customers' sites, user training, scanner implementation with patients, scanner improvement and maintenance (see Figure 4.5 below for processes of the development of the scanners in this case). Although the project life cycle was clearly categorised into three stages, more than one stage could occur at the same time. For instance, while the project members were procuring some machines, they were also developing and assembling other machines.

i. Planning and design stage

From the interviews data it seemed that a political boundary (which was named as a pragmatic boundary by Carlile (2004, 2002) and an assembly practice by Kellogg, Orlikowski and Yates (2006)), or where interests are different and in conflict between different individuals or groups of individuals, was stronger at the beginning of the project. For instance, a participant from the hardware group perceived that he had to change his current knowledge, interest, and attention to join in this project. This participant said that:

> Actually, I did not know about it [X-ray technologies] [laughs] because my background was in chemical and materials engineering. At the beginning, I was actually uninterested in [laughs] and I seldom agreed with this project [laughs] because I thought that CT [Computerised Tomography] would be too far for Thailand. To conduct this project, it had to pull in many and various resources, otherwise this project would be a failure. However, when the research unit decided to do it, I had to help the unit to make it successful [N5, P7, L229-232].

This suggested that before starting this project there were different viewpoints and conflicts between this participant and his research unit. This example related to a political boundary because novelties in a research area of this project generated different interests between this participant and his research unit that had to be resolved. The research unit wanted to conduct this project, while this individual participant was uninterested in it and disagreed with the research unit. However, this participant had to change his mind to join in this project as a requirement and political influence of the research unit. Due to novelties and differences in types of knowledge in a research project area, as well as the political influences of the research unit, this participant perceived that there were costs in changing his current knowledge and interests in a way that supported the conduct of this project.

Not only political boundaries occurred at the beginning of the project but also interpretative and information-processing boundaries occurred at this stage. Interpretative boundaries (which were named as semantic boundaries by Carlile (2004, 2002) and representation practices by Kellogg, Orlikowski and Yates (2006)), where different individuals or groups of individuals have different interpretations of the same things and phenomena, and the knowledge translation process, occurred when the two groups discussed the concepts of the scanner development together. For instance, a participant from the hardware group talked about a need to discuss and tune different ideas and unclear points about the concepts of the scanner development between the two groups: “How do the operations of a scanner work? What are the components of a scanner? We [the hardware and software groups] discuss about that in meetings. We bring everything about that into meetings to fine-tune with each other” [N7, P2, L57-59]. This suggested that the two groups had to develop common interpretations and understandings in the development of the scanners at the planning and design stage. Information-processing boundaries (which were named as syntactic boundaries by Carlile (2004, 2002) and display practices by Kellogg, Orlikowski and Yates (2006)) and an information-processing process occurred when the two groups sent and received knowledge about project planning, scanner development procedures and drawings across the groups through information technologies, boundary objects, and face-to-face communication. The two groups were able to send and receive this knowledge because they had some common engineering language and knowledge. Also, this knowledge was low in novelty for the two groups.

ii. Scanner development and manufacturing stage

An information-processing and an interpretative boundary were two types of knowledge boundaries which were mainly found in this stage. Due to the two groups having different knowledge backgrounds and specialisations, they tended to perceive the same things and situations in the development and manufacture of the scanners differently depending on theories and concepts of their groups. Consequently, different interpretations and interpretative boundaries occurred. According to the interviews, the two groups had some different perspectives about the scanner development such as the setting of an X-ray detector system and the quality of X-ray photographs. These differences created interpretative boundaries as well as difficulties and discontinuities in collaboration. Participants from the hardware group, for example, talked about differences in ways of thinking and understandings about the setting of an X-ray detector system and the turning of a gantry in relation to a detector between the two groups:

> The two groups have different perspectives about the setting of the X-ray detector system and the quality of X-ray photographs. The software group perceives and wants to get some things but we [the hardware group members] do not understand why these things must be like the software group's requirements. The software group must explain principles why the things must be like this or like that […]. For example, we want to set a gantry of a detector away from a patient's shoulders to avoid it crashing into the patient's shoulders, while the software group wants to set the gantry close to a patient's face to take clear patients' oral cavity photographs as the theory of image processing requires [N5, P6, L189-191].

This example suggested that members of different groups look at the same things but perceived them differently. As in the example mentioned above, the two groups saw the resolution of X-ray photographs and the setting of a detector but perceived them differently depending on the theories, concepts, and contexts of their groups. Furthermore, this example suggested that members of different groups seem to lack a full understanding that these differences exist and are not aware of how other people are, act, or think. Consequently, there were criticisms in collaboration between different groups. To resolve this issue, there was a need for interaction and knowledge translation capacity of different groups to develop common meanings and understandings. For instance, two participants from the two groups talked about a need for social interaction and communication between the two groups. This was in order to develop common understandings about differences and dependencies in knowledge and tasks between the two groups:

> The precision of the X-ray detector system setting normally was about 0.3 mm […]. However, the software group thought that it must be 0 mm. The hardware group argued with the software group that there were standard errors of hardware and the X-ray detector system. So, it was impossible and inessential to set the precision of the system at 0 mm. Sometimes we [the hardware group members] have to clarify the operation of hardware to the software group that we are only able to this or that because of today's technology [N7, P4, L125-134].

> We [the software group members] explained and set training for the hardware group [smile] to make them understand how software is developed, the components of software and the functions of each component, the components and functions of X-ray technologies, and the use of the software group's viewer and planning software. Working together needs participation and getting involved between the two groups. Then, the two groups will begin to understand the effects of one part and one group on the other parts and the other groups [N1, P9, L290-293].

In addition, in this stage information-processing boundaries were found. For instance, the hardware group sent photographs of machine simulation and drawings of a gantry between an X-ray source and a detector to the other project members through e-mail and instant messaging to present the progress of hardware development and to consider the accuracy of hardware development [N12, P6, L184-189].

iii. Scanner testing and implementation stage

This was the final stage of the scanner development of this project. There was a knowledge transfer process at an information-processing boundary about the testing of the scanners between the two groups. For example, in the interviews the hardware group reported progress and sent photographs of scanner testing in field work to the other project members through instant messaging and e-mail. Furthermore, in observation of the monthly meetings the hardware project manager reported the progress of the IEC 60601 (a series of technical standards for the safety and effectiveness of medical electrical equipment) testing of the dental CT scanner version 2 to the other project members [O12, P1, L30-31]. Similarly, the software group reported progress of the field trial of the mobile CT scanner and the clinical test of the DR scanner in field work to the other project members. This suggested that there is the transfer of technical knowledge about the testing of the scanners between the different groups through information technologies and face-to-face communication. The knowledge could be transferred across the two groups because they had some common engineering knowledge and knew the transferred knowledge beforehand from the prior stages.

In this stage political boundaries occurred when the project members interacted with external actors who were members of different knowledge communities such as doctors. The project members had to interact with doctors to implement their scanners with patients in hospitals. New requirements from the doctors affected the current knowledge, skills, interests, and practices of the project members. Consequently, the project members had to be willing to change their current knowledge, skills, interests, and practices to develop the scanners in order to meet the doctors' requirements. For instance, the project members stopped creating low-resolution images at 0.4 mm and started to create high-resolution images at 0.2 mm to meet the doctors' requirements. To do this, the project members had to change current techniques and algorithms as well as acquire new knowledge to develop new techniques and algorithms for developing high-resolution images [N12, P11, L378-415]. This suggested that knowledge and interests of one group affected current knowledge and interests of other groups; the knowledge transformation process at a political boundary then arose.

This stage also covered marketing, commercial matters and a conversion of the scanners to commercialisation. There were many situations suggesting that the project members had to change their current knowledge, skills, interests, and practices to compete with other scanner manufacturers for their survival. For instance, the project members had to change their current knowledge and practice as well as invest their materials and efforts to develop a new version of a dental CT scanner. This was to compete with other scanner manufacturers. Another example; project members had to implement ISO 13485 and risk management into the project. This was to improve their performance in order to increase credibility to their scanners, to be able to sell the project scanners in the broader marketplace and to compete with other scanner manufacturers. When the novelty of implementations of ISO arose, it created different interests among the project members. That is, some project members were reluctant to implement ISO because they perceived that it had costs in terms of their time and tasks. Thus, there were costs of the development of common interests and the willingness of project members to change their attitudes and interests to participate in the implementation of ISO. This had the character of a political boundary.

In addition, when customers in the marketplace changed their requirements for the scanners because of other scanner manufacturers' innovation, the project members had to (be prepared to) change their knowledge and practices about sales and marketing. This was to develop new business strategies to increase their sales volumes. For instance, the project was trying to initiate the concept of a dental service industry to sell dental services and dental CT scanners instead of just dental CT scanners as in the past. Consequently, some project members had to change their current concepts and ways of selling scanners in the marketplace [O4, P2, L42-47].

As the findings and examples mentioned above show, it suggested that boundaries are dynamic and tend to evolve and change throughout the project life cycle depending on the work that has to be done and issues of interactions between different knowledge communities. The findings from this study also suggested that more than one type of knowledge boundaries could overlap with another and could occur simultaneously.

In the first example, observed in a meeting of an implementation ISO 13485 and risk management, there were concurrent information-processing and interpretative boundaries. In the meeting, the hardware and software groups discussed the hazards and processes of the scanner development which should be assessed for risk management [O8, P1-3, L1-28]. While the two groups were discussing the types of hazards, some project members of both groups were confused about the difference between 'hazard' and 'harm' as well as 'user error' and 'knowledge error'. To make these terms clear among the project members, one project member from the hardware group accessed a risk management manual, which was stored and shared in Dropbox, to find the definition and scope of these terms [O8, P4, L31-33]. In addition, during the meeting the project members of both groups had an unclear point about risk criteria. One hardware group member asked the other project members: "What is a hazard level of repeated radiological radiation exposure in patients?" A few members of the software group suggested that it was trivial and easy to recuperate from. So, it was classified into the first level of hazards. However, the other project members from both groups suggested that it was difficult to identify the level of hazard for this issue. These project members suggested that it was not possible to see the effects of repeated radiological radiation exposure in patients immediately. Thus, this issue should be classified into another level of hazard. While the project members were disputing risk criteria, one project member of the hardware group suggested that a definition and scope of each hazard level could be modified by the project members based on the contexts and processes of scanner development [O8, P4, L34-39].

In the circumstance mentioned above, a process of knowledge transfer and information processing between the two groups at an information-processing boundary occurred when they were jointly able to send and receive knowledge about the types of hazards and the risk assessment of the scanner development. The two groups were able to send and receive this knowledge because they had and knew this knowledge beforehand from an external consultant. However, when some unclear vocabularies about risk management occurred, communication and conversation among the project members could not flow smoothly. A risk management manual was used as a common reference point of knowledge by providing shared definitions about risk assessment to project members. It could help to develop common language in risk assessment among the project members for sending and receiving knowledge about it. In the same situation, an information-processing boundary moved to an interpretative boundary when the project members interpreted the same thing, the hazard level of the repeated radiological radiation exposure in patients, differently. Consequently, the development of common meanings and understandings among the project members was required for collaboration. Primarily, the social interaction of project members to modify risk criteria and hazard level together was suggested by one member from the hardware group. This was in order to reduce different interpretations and misunderstandings about risk criteria and hazard level among the project members.

Another example; there were simultaneous interpretative and political boundaries. One participant from the hardware group mentioned that the software group complained that hardware errors had effects on the quality of reconstructed X-ray photographs of the software group. To resolve this problem, the hardware group set up a meeting and invited some software project members to share and discuss image processing concepts as well as the quality of required and acceptable X-ray photographs with the hardware group. At the same time, the hardware group shared and discussed the standard tolerances and errors of hardware with the software group [N9, P4, L117-120].

The situation mentioned above related to an interpretative boundary. This was because the members of the two groups had different interpretations and understandings of the same things such as the X-ray photographs and the setting of hardware. That is, the software wanted to get contrasty X-ray photographs to generate high quality reconstructive X-ray photographs as image processing concepts. Thus, the software group asked the hardware group to set an X-ray detector system as an image processing concept. However, such concepts might not be fully known or be easy to do in the hardware setting. The hardware group tended to set up the X-ray detector system and generate the required X-ray photographs based on its context which had standard errors and tolerances. These errors and tolerances might not be fully known by the software group. The two groups interpreted and understood the quality of X-ray photographs and the setting of the X-ray detector system differently based on their practice and setting. Consequently, difficulty in cross-community collaboration between the two groups occurred. To resolve this problem, social interaction; more specifically face-to-face meeting and discussion, was used to specify and learn about differences and dependencies in knowledge and tasks between the two groups. This was in order to develop common meanings and understandings between the two groups about the quality of X-ray photographs and the setting of the X-ray detector system.

The situation mentioned above also related to a political boundary and a knowledge transformation process. This was because during social interaction and joint problem-solving between the two groups, these members interacted with the novelties and differences in knowledge of each other which might have effects on their current knowledge and practices. That is, in the meeting to find a jointly acceptable quality level of the photographs for both groups, the hardware group interacted with different knowledge about image processing and the quality of the photographs of the software group. Similarly, the software group interacted with different knowledge about the hardware standard tolerances and errors of the hardware group. The software group's requirements might have effects on the hardware group's current knowledge and practices. That is, the hardware group members might need to change their current knowledge and practices to develop hardware to meet the software group's requirements as much as they could.

The final example; there were simultaneous political and two other knowledge boundaries among the project members and between the project members and a consultant. A political boundary occurred when some project members seemed to be in conflict with the implementation of ISO 13485. They perceived that the implementation of ISO was a waste of time and would generate negative consequences in their lives. Consequently, they did not want to give their attention to this activity or want to be involved it. However, they had to change their mind to join in the implementation of ISO because of a political effort by the other project members who had more authority. More specifically, they were asked to join in the implementation of ISO to help the project to have more opportunities to sell the project scanners in the marketplace [N3, P9, L290-306]. This situation related to a political boundary because a new thing such as the implementation of ISO affected interests among the project members differently. This situation also related to a political boundary because there was use of political efforts to develop common interests among the project members to participate in the implementation of ISO.

The situation mentioned above also related to the other types of knowledge boundaries. That is, due to most project members having no knowledge and experience about ISO, an external consultant was hired to help them to implement ISO. The novelties and differences in types of knowledge of the consultant made it necessary for the project members to make sense of the consultant's knowledge. Thus, there was a need for the creation of common languages and meanings at an information-processing and an interpretative boundary between the project members and the consultant to communicate and interact with each other. For instance, in a meeting between the project members and the consultant some types of knowledge of the consultant could be transferred to the project members. This was because of the low novelty of this knowledge such as the formats and processes of customer services. However, when higher-level novelties of knowledge from the consultant occurred, the project members and the consultant needed to develop common languages for transferring knowledge. For instance, one project member asked the consultant to explain the term "Non-Conformance Report (NCR)" [O7, P4, L44]. Furthermore, the consultant suggested the project members create different sets and levels of customer services: silver; gold; and platinum levels to provide customers with optimal choice of services [O7, P4, L58-59]. This idea was new for the project members. Consequently, the consultant had to clarify these services to the project members for developing common understandings at an interpretative boundary.

4.4.2. Facing the same phenomenon, but experiencing it as different types of knowledge boundaries

The findings from this case suggested that, when facing the same phenomenon, different actors experience and perceive it as different types of knowledge boundaries depending on what types and amount of knowledge that they have for the phenomenon, how they are affected by it, and how much change they feel is involved for them. According to the interviews, for instance, a participant from the hardware group perceived that he had to change his current knowledge and interests to participate in this project. This participant mentioned that he had a knowledge background in chemical and material engineering, engineering design, material selection methodology and design methodology. He had no knowledge background and experience about this project which mainly involved X-ray technologies. This participant also mentioned that he had no interest in this project as he disagreed with his research unit being involved it. However, he had to change his mind to participate in this project because his research unit decided to commit to it [N5, P7, L229-232] (see the interviewee's statement on p.188).

However, another participant from the same group, who had knowledge in mechatronics and electricity, perceived that participation in this research was just learning or gaining new knowledge. This participant explained that:

> I did not change anything. The development of CT and DR scanners involves electricity and I have knowledge and experience about electricity already. I just improve knowledge and techniques about radiation such as the theories, the movements, the characteristics, and the components of radiation. Doing this project makes me feel like…I gain more knowledge. I just improve my knowledge rather than change my knowledge and my way [N8, P4, L117-119].

The perspective of the first participant reflected a political boundary focusing on a change of current knowledge and interests to develop common interests between actors. This was because this participant perceived that his knowledge background in chemical and materials engineering was totally different from the research area of this project, X-ray technologies. Also, this participant had no interest in participating in this project. Thus, he disagreed with his research unit conducting this project. This suggested that the novelty of the research area of this project generated different interests, and then created conflicts between this participant and his research unit. However, this participant had to change his mind and participate in this project as his research unit had decided to join it and it was thus a requirement for him. This situation presented processes that deal with different interests and political approaches between this participant and the research unit. Therefore, this participant perceived that the novelty of a research area of this project affected him and had cost implications for his current knowledge and interests.

However, the second participant perceived there was no need to change his own knowledge to participate in this project. This was because this participant had knowledge in mechatronics and electricity which related to, and could apply to, it. Consequently, he perceived the novelty of a research area of this project had no effect on his knowledge. There were no conflicts in interests between this participant and participating in the project. Thus, he perceived that participation in this project was just learning new knowledge rather than changing his own knowledge or crossing a political boundary.

4.5. Construction of knowledge boundaries

The findings from this study were in line with the theorisation of boundaries. In that different degrees or levels of the properties of knowledge at a boundary: difference, dependency and novelty, lead to the development of knowledge boundaries, as will be explained in Section 4.6. The findings from this case argued that knowledge boundaries could occur because of ignorance and not having enough understanding about differences in knowledge and disciplinary perceptions between members from different knowledge communities.

4.5.1. Properties of knowledge at a boundary

According to the literature in Chapter 2, Section 2.7, there were three properties of knowledge at a boundary: difference, dependency, and novelty. Different levels of these properties could create different types of knowledge boundaries (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Feng, Ye and Pan, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Thus, this sub-section presents these three properties of knowledge at a boundary by giving examples found from this case.

i. Difference

Difference in knowledge referred to differences in the amount and types of knowledge of different actors. When differences in the amount and/or types of knowledge between actors increased, the amount of effort to manage each other's knowledge also increased (Carlile, 2002). In this case, most participants perceived that there were differences in types of knowledge backgrounds and skills that had been acquired from study by the hardware and software groups. For example, the participants from both groups talked about this:

> Absolutely, there are differences in knowledge about hardware and software [N2, P5, L170].

> It is definitely different because each group lives in different fields [N8, P1, L27].

> Each person has differences, differences about knowledge, expertise or collected skills. For instance, the hardware team has knowledge and skills about machine design, while the software team has knowledge about computer programs [N3, P6, L198-200].

According to the interviews, most members in this case had knowledge backgrounds in engineering; however, there were differences in the branches of engineering (see Table 3.2 that summarises the knowledge backgrounds and skills of project members in the case study). The members in this project could be divided into two main knowledge communities based on their knowledge backgrounds and skills: the software group (software engineers) and the hardware group (mechanical and mechatronics engineers). Most software group members had knowledge backgrounds and skills in electrical engineering and computer science, such as signal processing, image processing, electronics and computer systems, computer graphics and visualisations, computer programs and databases, software control, and statistic reconstruction. By contrast, most hardware group members had knowledge backgrounds in electrical engineering (such as control systems engineering), chemical engineering, mechanical engineering (such as design, industrial, manufacturing, and production), biomedical engineering (such as implant and medical devices), and mechatronics. Also, they specialised in computer-aided design and manufacturing, machine design, computer numerical control, advanced manufacturing, rapid prototyping, 3D printing, biomedical engineering, and production manufacturing. This suggested that members of different groups tended to have differences in types of knowledge and skills. For instance, three participants from the software group talked about this:

> Hardware is able to be touched and easy to see, while sometimes software is embedded in a scanner and cannot be seen [N1, P1, L9-10].

> The hardware group tends to look at a structure and rarely concerns details, while software has many details and the software team have to check every single line of source codes which must not be faulty [N2, P1, L12-16].

> The nature of software tasks often works with computers and seems to be ideal. Once some software group's concepts meet with hardware group's practices and limitations, there are conflicts about acceptable errors between the two groups such as the setting of a screen for taking photographs [N12, P13, L445-464].

Moreover, members of different groups tended to have differences in the nature of tasks and ways of thinking based on what they had studied and been trained in from their groups. The nature of tasks and the ways of thinking of one group might not be known and recognised by members of another different group. They might also not have worked in the different practices and contexts of another different group. Members from the two groups perceived that members of the other different group seemed to lack understanding of the nature and difficulties of the tasks of each other. Consequently, conflicts and difficulties in collaboration between different groups could occur. Some participants from the two groups talked about this point, commenting that:

> No one can make machines at 0.00001 and no errors […]. Machines consist of many components and each component has its tolerances […]. So, I believe that problems must be fixed by software at the end. Blurred X-ray photographs should be calibrated and compensated by software rather than hardware [N6, P10-11, L345-351/360-363].

> Both groups did not know each other. [...] I view that my tasks are difficult but the other group thinks that my tasks are easy [N8, P1, L26-29].

> Sometimes they [the hardware group members] may perceive that we [the software group members] do not do anything. They may perceive that changing software is very easy because they have a lack of understanding of the nature of the software group's tasks [N1, P1, L12-13].

> Sometimes the development of some software features takes much time but other people may not see these features. If other people do not really understand how such features are difficult to develop, they may view that the software group did not do anything. They may view that it is very easy to change software [N1, P1, L9-14].

> Supposing that there are unclear X-ray photographs from the scanners, the hardware group may state that such photographs should be fixed by the software group because it is difficult to change hardware. It is better to change software [laughs] [N2, P1, L18-20].

Those examples suggested that members from different groups perceived that members from different groups did not know and understand differences and difficulties in the tasks of each other. They tended to perceive that their tasks were more difficult than the tasks of other different groups. Therefore, when problems in an overlapping area of different groups occurred, they tended to ask other groups to change to solve the problems.

Furthermore, different groups tended to have differences in languages. Some of the vocabulary of one group might not be known by members of other different groups. Such situations made communication between different groups difficult. For instance, one participant from the software group suggested that the hardware group members lacked knowledge and understating of some technical vocabularies about an X-ray detector system such as collimator, amorphous silicon, calibration, and gain collection [N1, P8, L282-285]. To resolve the problem, it required effort from members in different groups to explain and develop a common language between different groups.

In this case there were not only differences in types of knowledge backgrounds and skills but also differences in the amount of knowledge in an overlapping area of the research project between the two groups. Some participants from the two groups suggested that the software group seemed to have more relevant knowledge on the research project than the hardware group. Normally the hardware group conducted research in other different fields by focusing on computer-aided design and manufacturing, computer numerical control, biomedical devices, rapid prototyping, and 3D printing. Also, the hardware group had never developed CT and DR scanners. Thus, the development of CT and DR scanners was new for the hardware group [N7, P3, L104-105; N9, P4, L139-140/144].

By contrast, the software group normally conducted research about X-ray CT. Moreover, some software group members had completed Ph.D. theses about CT scanners and X-ray radiation. Thus, the software group had more relevant knowledge on the research project than the hardware group [N5, P2, L86-88] (see the interviewee's statement on p.173). According to the interviews, there were difficulties in collaboration between the two groups because of differences in the amount of knowledge of an X-ray detector system between the two groups.

For instance, the hardware group did not develop a gantry for an X-ray phantom head used to calibrate an X-ray detector. This is because the hardware group did not understand the relationship between an X-ray detector system, calibration and the quality of X-ray photographs. Consequently, the software group could not take patients' 3D X-ray photographs.

To resolve the problem mentioned above, the software group had to find and use a temporary stand to put an X-ray phantom head on to calibrate an X-ray detector for taking patients' 3D X-ray photographs. After that, the software group had to clarify the concept of an X-ray detector system, calibration, and quality of X-ray photographs to the hardware group for improving the hardware group's knowledge and understanding for their collaboration [N1, P4, L108-121]. This suggested that there were discontinuities in collaboration between different groups because of differences in the amount of knowledge in an overlapping area of collaboration between different groups. When differences in the amount of knowledge occurred between different groups, considerable effort from the different groups was required to develop common knowledge between the different groups.

ii. Dependency

The differences between members from different groups mentioned above were unimportant, until dependencies were also taken into account. Dependencies referred to conditions where different groups must take each other into consideration to reach common goals together.

In this case, dependencies between the hardware and software groups in the development of the scanners were clearly shown. The hardware group required knowledge about the setting of an X-ray detector system and the quality of X-ray photographs from the software group to develop effective scanners for taking patients' X-ray photographs; this included source-detector separation distance, scan time, and calibration. The software group required those raw patients' X-ray photographs and data from the hardware group to create reconstructive 3D X-ray photographs for diagnosis and operational planning through the software group's planning software.

According to the interviews, observation, documentation, and more specifically project proposals [D3-6], the development of the scanners in this case consisted of 11 main processes:

1. project concept design;

2. hardware design and software design;

3. hardware procurement;

4. hardware development (this included the development of the hardware structure and control systems of the scanners) and software development (this included the development of algorithms for calibration and artifact reduction, image reconstruction, viewer software, user interfaces, and patient databases of the scanners);

5. quality testing (this included testing of the quality and accuracy of both hardware and software);

6. dose and safety testing;

7. hardware and software improvement;

8. scanner installation in hospitals or other customers' sites;

9. user training;

10. implementation of the scanners with patients; and

11. improvement and maintenance.

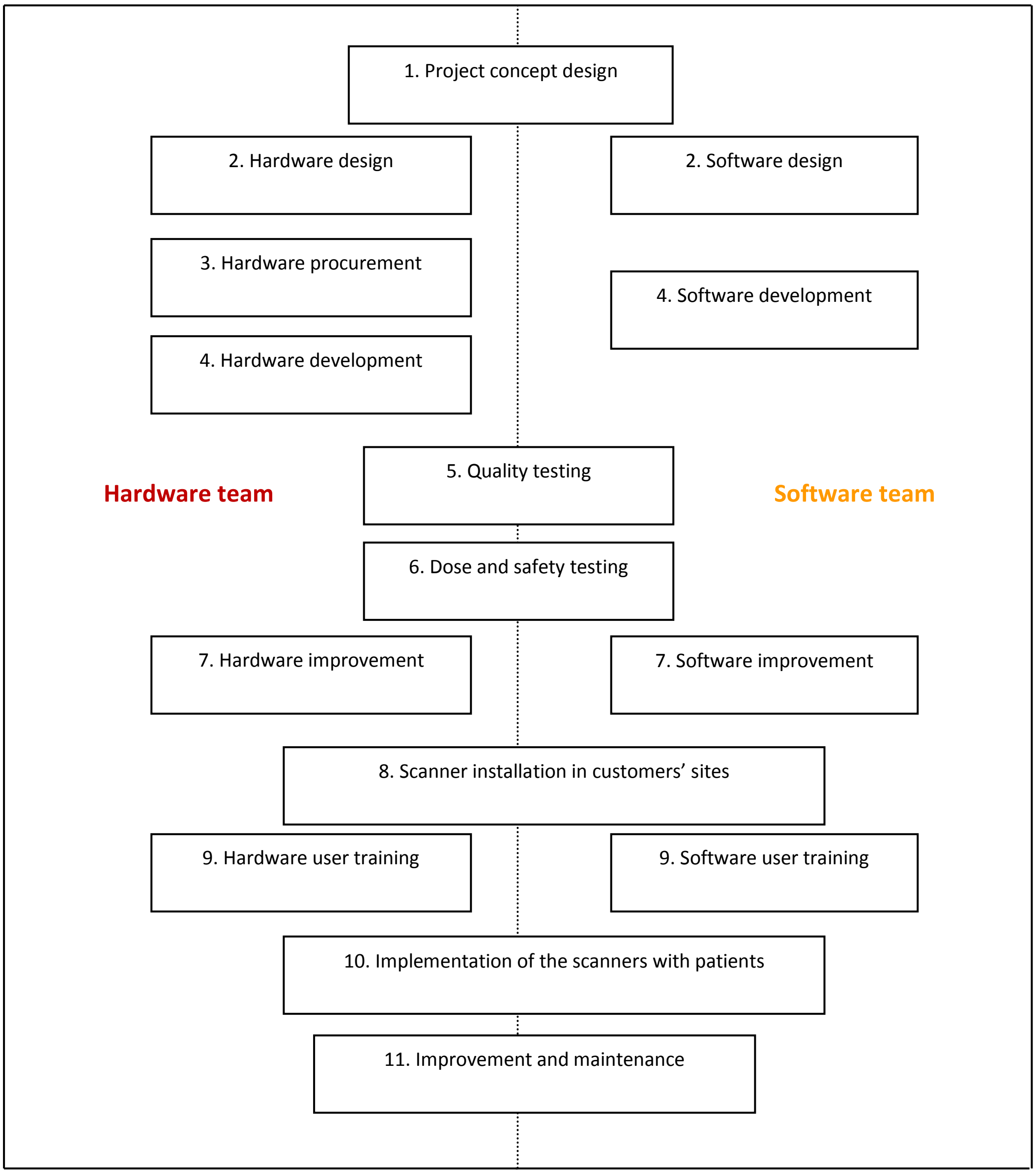


Figure 4.5 Processes of the development of the scanners

Figure 4.5 above presents processes of the development of the scanners in this case which were conducted separately or were conducted together by the hardware and software groups. The hardware group mainly focused on the development of mechanical and electronic aspects to create the structure and body of the scanners. More specifically, the hardware group's tasks covered finding new technologies and collecting the requirements of customers and markets to design the hardware of the scanners. Then, the hardware group handled hardware procurement to support the design. Moreover, the major tasks of the hardware group were the development, assembly, and improvement of mechanical and electronic aspect of the scanners. The hardware group also trained users to use the scanners.

The software group focused on the development of software for the scanners. It mainly covered the following: collecting requirements of customers and markets to design software; software design; the development of algorithms for calibration and reconstruction, viewer software, patient databases, and user interfaces; and the improvement of software. The software group also trained users to use its developed software.

Some processes of the development of the scanners were conducted in parallel. For instance, during waiting for the procurement of some hardware components, the hardware group was developing and assembling other parts of the scanners. Similarly, during the hardware and software development, there were quality and safety tests of some hardware and software parts.

Some processes mentioned above were conducted jointly by the two groups. For instance, one participant from the hardware group suggested that: "we [the hardware and software groups] determine concepts and design together, and then we separate to do our own parts. Finally, we have to compound all parts together" [N6, P6, L187-188]. Similarly, another participant from the hardware group suggested that: "the main concept of the scanners has to be discussed by both groups because there are relationships between hardware and software" [N5, P3, L100]. According to the interviews and observation, both groups co-developed the concepts of the scanner development. They worked together to test the quality and accuracy as well as the dose and safety of the scanners. Once the scanners were assembled and passed the tests, both groups collaborated to present and install the scanners in customers' sites as well as to implement the scanners with patients in customers' sites [O3, P1-3] [O5, P1-4]. They collaborated to improve and maintain the scanners to meet the requirements of customers and markets. For instance, the participants of the two groups talked about dependency and collaboration between the two groups to analyse and solve technical problems of scanner development:

> The hardware group has to take data from the software group such as parameters to control the operation of the scanners. We [the hardware group members] have to create X-ray photographs which can be processed by the software group later [N13, P4, L115-121].
>
> When we [the hardware and software groups] meet problems, we will brainstorm. If photographs blur, we will analyse them together because the blurry photographs can come from hardware or software errors [N5, P5, L173-177].

If hardware problems occur, they will be discussed within the hardware group first. Then, some key members of the software group may be asked to join in hardware group's meetings to give their views [N5, P3, L103-105].

Those statements suggested that there are dependencies and collaborations between different groups in the project, even while remaining anchored in their own groups. The different groups conferred with each other during doing their own tasks to reach the common goals of the project.

Figure 4.6 Collaboration between members from different knowledge communities

Figure 4.6 above shows collaboration between the hardware and software groups to solve blurred X-ray photographs of the project dental CT scanner in the Health Care Service Center of Thammasat University Hospital. The figure shows that there are four project members. The picture at the top left hand shows the discussion between two software group members who had knowledge and skills in image processing and reconstruction. They were discussing the operation of an X-ray detector system which may establish the causes of blurred X-ray photographs. The picture at the top right hand shows the hardware design engineer at work. He was trying to reset some hardware parts to test and improve the operation of the scanner. During the resetting of the hardware parts the project members calibrated an X-ray detector system and tested the operation of the scanner by scanning a 3D head phantom [the picture at the top right hand]. Then, the other software member collected the raw X-ray photographs to generate reconstructive X-ray photographs through the software developed by the software group [the pictures at the bottom] for checking the accuracy and quality of the X-ray photographs [O5, P2-4, L6-15]. This presented the situation of the different groups working together to investigate the causes of the problem in order to solve the problem to meet the customers' requirement. The two groups mainly focused on the testing and improvement of the quality and accuracy of their parts. However, they relied on and combined with each other to run and check their parts in order to evaluate an entire system of the scanner together.

iii. Novelty

Another property of knowledge at a boundary was novelty which referred to new needs that generate new requirements for actors' knowledge. The major sources of novelty in interdisciplinary research and collaboration, in this case, were the new requirements of customers and markets as well as the innovation of another scanner manufacturer. They affected the current knowledge, skills, practices, and interests of project members. For instance, the project members had to change the development of a dental CT scanner from two legs to one leg. This change was to reduce the size of the scanner and space required for installation as well as to reduce the cost of operation in order to reduce the selling price and compete with another scanner manufacturer [N6, P2, L43-49]. Similarly, the project members had to create high-resolution photographs at 0.2 mm instead of 0.4 mm after receiving customers' complaints [N12, P11, L378-415]. New requirements and complaints by the customers had costs in terms of knowledge, skills, practices, and interests of the project members in scanner development by the project members. They rendered the current practices of the project members obsolete in respect of the development of a smaller and cheaper scanner, and the creation of high-resolution X-ray photographs. The project members needed to improve or change their own current knowledge, skills, and practices. Also, they needed to acquire or develop new knowledge, practices, and techniques to re-design and develop the new version of the scanner which was more complex than the old version. They needed to acquire or develop new knowledge to develop new algorithms and techniques for the scanner to generate high-resolution photographs to meet the customers' requirements and to compete with other scanner manufacturers [N12, P11, L378-415].

The sources of novelty between different groups in the project could be new needs in the scanner development of each group to develop its parts. These generated new requirements for members of the other group relating to their current knowledge and skills. For instance, the software group asked the hardware group to generate raw X-ray photographs with higher quality and accuracy. To do this the software group sent new and important parameters for X-ray detector setting and calibration to the hardware group. The hardware group had to assess and learn from these parameters to develop effective scanners able to generate the software group's required photographs for further processing [O12, P4-6, 98-103] (see Figure 4.1 for an example of technical knowledge shared in a monthly meeting). Thus, there were novelties to manage knowledge between the two groups.

4.5.2. Ignorance of differences in knowledge of other people

The findings from this study suggested that knowledge boundaries not only mainly occurred because of differences in knowledge between different knowledge communities. The findings suggested that knowledge boundaries also occurred because of lack of a full understanding and awareness of differences in knowledge and disciplinary perceptions of things and situations between different knowledge communities.

As mentioned in the previous section, members of different knowledge communities tended to perceive the same things and situations through the theories and concepts of their groups. For instance, one participant from the hardware group talked about differences in ways of thinking about the same thing between the two groups in that:

> The software group asked the hardware group to create a head support for patients while the patients were being scanned. The hardware group thought about the beauty, fineness, and safety of the head support, while the software group thought about the effects of the head support on image processing and X-ray photographs [N13, P3-4, L92-110].

Furthermore, the findings from this case suggested that the members of different knowledge communities seem to lack a full understanding and awareness of differences in knowledge and disciplinary perceptions of other different knowledge communities. According to the interviews, for instance, some participants from the hardware group perceived that the software group required precise parameters to set an X-ray detector system and a scanner. Such parameters came from software concepts and theories. However, the hardware group thought that it was impossible to develop and set hardware with these precise parameters. This was because there were standard hardware tolerances and errors. One participant from the hardware group explained that:

> Most electrical and software tasks are controlled by numeric values. If we [hardware group members] use such values to control hardware, we may not get results as required by the software group precisely. Each hardware component has standard errors [N7, P1, L14-24].

> When we [the hardware and software groups] connected software and electricity together, at the beginning we had some conflicts because we did not understand what each other group was. For instance, there were hardware standard errors and tolerances. Thus, it was unnecessary and impossible to set or assemble hardware as precise as the concepts of the software group [N7, P3-4, L105-110].

This example suggested that the members of different groups have differences in concepts, theories, perspectives, and ways of thinking based on their knowledge communities. The concepts, theories, ways of thinking, tasks, and requirements of one knowledge community might not be known, understood or practiced by other different communities. Consequently, disapproval, tension, conflicts, and difficulties in collaboration between different knowledge communities occurred. For instance, two participants from the hardware group referred to the different ways of thinking, the lack of full understandings, and tension between the two groups about the setting of hardware:

> There were conflicts between the two groups because our team [the hardware group] did not understand what the other team [the software group] was. Similarly, they [the software group members] did not understand what we [the hardware group members] were too [N7, P3, L105].

> It is crazy to do this [...]. I believe that no-one can develop hardware with the high level of precision at 0.1 micron […]. However, the software group still dreams and requests arcminute or arcsecond [smile]. Machines consist of many components and each component has its standard tolerances and errors. The hardware group tries to meet the software group’s requirements but it hit the hardware group’s ceiling [N6, P10-11, L342-368].

Due to lack of a full understanding and awareness of how other groups work, in this case the members of the two groups tended to think that their tasks were more difficult than those of the other different group. Consequently, when problems between the two groups occurred, each group tended to dispute with the other group to solve the problems. Both groups tended to lack willingness to engage in joint problem solving with the other group. This situation could affect collaboration and learning between different knowledge communities. For instance, according to the interviews, the two groups had tension about the fixing of blurred X-ray photographs. That is, the software group asked the hardware group to improve the alignment of an X-ray detector system and the accuracy of hardware assembly for solving oblique and blurred X-ray photographs. However, the hardware group retorted to the software group that it was difficult to do this; other companies used software to solve problems with the photographs. Also, the hardware group agued to the software group that the software group knew about parameters to set an X-ray detector system, so why did the software group did not fix the photographs by developing algorithms to rotate the photographs. The software group argued that hardware was the origin of X-ray photographs. If the hardware failed, the software group could not do anything to improve things. Moreover, the software group argued with the hardware group that the rotation of all oblique X-ray photographs by software could increase image processing time unnecessarily. Using software to interpolate X-ray photographs could also drop the quality of the photographs [N2, P7-8, L230-253].

The example mentioned above suggested that members from different knowledge communities tend to see the same things and phenomena differently based on the concepts, theories, ways of thinking, practices, and settings of their communities. Equally importantly, they seemed to lack a full understanding and ignored differences in knowledge and disciplinary perceptions, nature, practices, and settings of other different knowledge communities. They tended to ignore differences, especially the differences which had costs in terms of their time, tasks, and willingness to change their current knowledge and practices in a way that supported cross-community collaboration. They tended to avoid entering into (some) territories in which they were unfamiliar. Consequently, discontinuity of action or interaction between different knowledge communities or boundaries could occur.

The next section is narrowed to types of knowledge boundaries that were found in collaboration and interaction between different knowledge communities. It also presents processes to overcome these boundaries for management knowledge across them.

4.6. Boundaries and management of knowledge across boundaries

The main findings from this study were in line with the theorisation of boundaries. In that, based on the different levels of difference, dependency, and novelty in knowledge between different knowledge communities, there are three increasingly complex knowledge boundaries. These three knowledge boundaries required different processes to overcome them and to manage knowledge across them (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates; 2006; Carlile, 2004). The three knowledge boundaries were labelled differently, but they referred to similar concepts to Carlile's (2004, 2002) theorisation of boundaries. Carlile labelled the three knowledge boundaries as syntactic, semantic, and pragmatic boundaries. These three knowledge boundaries are labelled in this study as information-processing, interpretative, and political boundaries. The theorisation of boundaries also suggested three processes to overcome these three boundaries to manage knowledge across them: transfer, translation, and transformation (see Section 2.7 for a model to manage knowledge across boundaries).

This section depicts the construction and characteristics of the three knowledge boundaries as well as processes and mechanisms to overcome these boundaries for managing knowledge across them. There are some novel findings about the construction and characteristics of the three knowledge boundaries and mechanisms to overcome them found in this case.

4.6.1. Information-processing boundary; knowledge transfer process

According to the theorisation of boundaries, based on degrees of complexity for managing knowledge across boundaries, an information-processing boundary was the first type of knowledge boundary. At an information-processing boundary, differences and dependencies in knowledge between members from different groups were known. Thus, this boundary focused on knowledge transfer or information processing between different groups through technology and boundary objects.

In this case, the project members who were knowledge holders codified some of their knowledge about: scanner development; ISO 13485 and risk management implementation; and sales and marketing, into media. After that, they stored and transferred the knowledge to the other project members who were knowledge recipients, through information technologies such as e-mail, instant messaging, Dropbox, and Google Docs. The knowledge recipients were able to retrieve and use the shared knowledge independently because differences and dependencies in the knowledge between members from different groups were known. For instance, the results of the scanner safety tests and the photographs of the scanner development in a laboratory and field work were sent from the hardware group members to the other project members through instant messaging and e-mail. Consequently, the other project members who did not join the tests, work in the laboratory and participate in the field work, could access that knowledge in their regular place of work.

Figure 4.7 below illustrates encodable knowledge, more specifically technical knowledge, about the development of software and computer programming. This knowledge was captured and codified into media as documentation (e.g. programming guides) by the software group. Then, it was transferred to the other project members through storage and retrieval technologies such as Dropbox to assist the other project members.

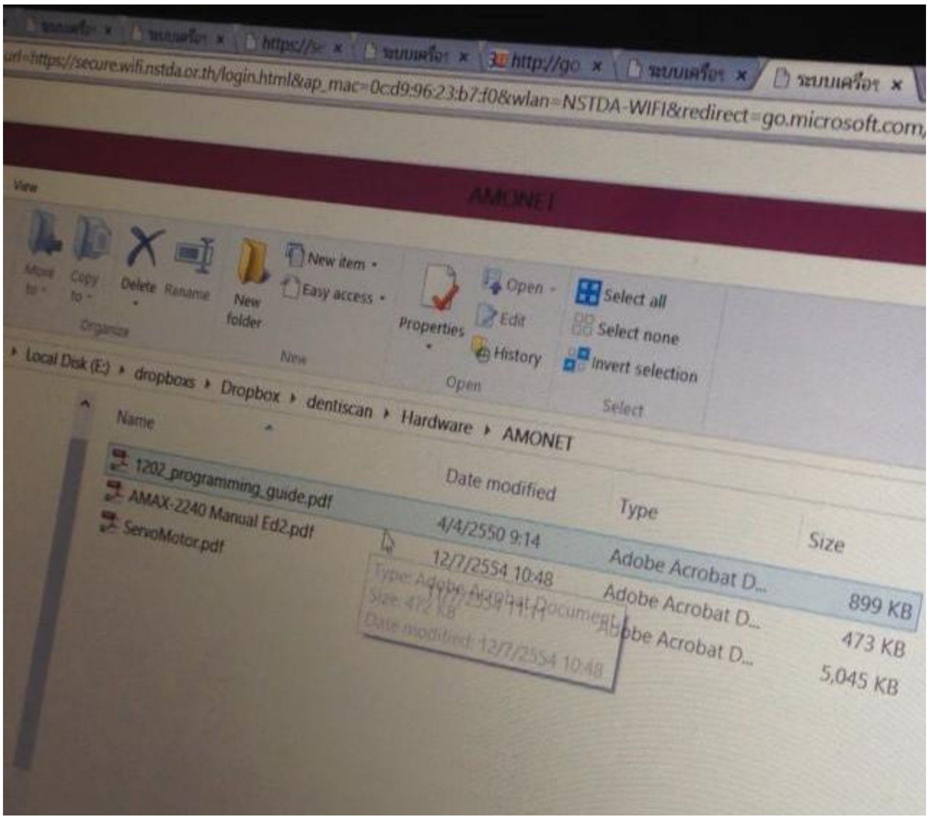


Figure 4.7 Example of codified knowledge

At an information-processing boundary, in this case project members could capture, codify, store, and transfer some of their knowledge about scanner development to the other project members through explicit forms and technologies. This was because some differences and dependencies in the knowledge among the project members were known. The project members had some common knowledge and language in engineering from their knowledge background that is sufficient to transfer knowledge at a boundary. Thus, they could rely on explicit forms and information technologies for transferring their knowledge. This stems from the statement of one participant from the hardware group, for example: “we [the hardware and software groups] have the same knowledge backgrounds in engineering, so we are likely able to talk and understand each other” [N5, P7, L221-222].

Moreover, a boundary object, which established a shared language to transfer knowledge at a boundary between the different groups, was found in this case. For instance, the hardware group sent the assembly drawings of a gantry of an X-ray detector system to the software group via e-mail to check and confirm the accuracy of the system. These drawings could be considered as a boundary object because they were created and used by the two groups in the course of their coordination. The drawings had different meanings in the different groups. They were flexible enough to allow the different groups to attach localised meanings to them. For the hardware group, the drawings represented critical tolerances and functional specifications. For the software group, the drawings provided a three-dimensional representation of the orientation of parts and critical issues for scanner assembly and testing. However, the drawings were common enough to the two groups to make them recognisable and function as a means of communication and coordination between the two groups. They provided a shared language for the two groups to represent their knowledge.

Furthermore, as mentioned above, some types of knowledge were codified and transferred from one group to the other group through storage and retrieval technologies such as Dropbox. For example: parameters for the setting of an X-ray detector and a scanner; procedures for scanner development; technical tests; customer requirements; and implementation documents for ISO 13485 and risk management. Dropbox could be considered as another boundary object at this boundary; more specifically, repositories. This was because Dropbox supplied a common reference point of knowledge across the two groups enabling the two groups to represent and transfer their knowledge to the other group. It provided shared definitions and values for better understanding and coordination between the two groups.

In this case, at an information-processing boundary knowledge was not only transferred from one group to the other group through technology and boundary objects as in Carlile’s (2004, 2002) theorisation of boundaries. Knowledge was also transferred through face-to-face communication such as in monthly meetings. The project director often used a monthly meeting as a main channel to communicate with the other project members as well as to follow up and monitor the project progress. Thus, project members were often asked (by the project director) to report progress and issues of their tasks to the project director and the other project members through face-to-face communication in the meetings. Instead of sending e-mails back and forth, the project members could talk through details of any issues in one pass through face-to-face communication. Face-to-face communication also minimised the risk of misreading compared to e-mail and instant messaging. For instance, one participant from the hardware group talked about communication and transferring knowledge from one member to another via e-mail and instant messaging saying it was “back and forth […] no endpoints” [N3, P8, L253-254] and “some members did not read messages and did not open e-mail or Google Docs” [N3, P8, L285-286]. Many topics and different types of knowledge (technical knowledge, ISO 13485 and risk management implementation, and sales and marketing) were transferred through face-to-face meetings. For instance, the results of a field trial of a mobile CT scanner, the clinical test of a DR scanner, the issues of the development of DR scanner user interfaces, the business models, and the feedback of customers were transferred through face-to-face monthly meetings [O1, O4, O6, O12]. Also, the project members transferred their knowledge to the other project members through face-to-face communication in a laboratory. For instance, the software project manager talked to hardware project members about processes and activities of mobile CT scanner testing to diagnose and operate on cleft lip and cleft palate in children in the Prince of Songkla University [O10, P1-5, L1-30].

This case found some difficulties of knowledge transfer between different groups because of differences in the amount of knowledge in a research project area and an overlapping area of the different groups. For instance, the software group transferred technical knowledge with technical vocabularies about an X-ray detector system to the hardware group. The hardware group did not know the meaning of some technical vocabularies and misunderstood knowledge that was sent. Consequently, there were difficulties in communication and knowledge transfer between the two groups at an information-processing boundary. A participant from the hardware group talked about such difficulties, saying that:

> There were some difficulties about language such as the definition of a collimator. At the beginning, I did not understand what a collimator was until the software group explained that it was a device to narrow a beam of waves [N11, P12, L409-419].

To resolve the problem, it required effort by project members to develop a common language in such areas for transferring knowledge at a boundary. The interviews helped to identify two project members who were asked to act as lexicon mediators. These two project members were software group members. They seemed to have more knowledge and experience about an X-ray detector system and a CT scanner, both of hardware and software parts, than the other project members. Also, they were more widely known and more approachable by the other project members. These two project members were able to explain technical vocabularies and some elements of one group into the language of the other group. This was to make sure that the different groups could understand what they communicated and transferred to each other.

As the previous paragraph shows, one of the lexicon mediators was the software group's research assistant. From interview data, he could cross the boundaries between the two groups because he had a direct knowledge background and skills in the project area; more specifically, an X-ray detector system and a CT scanner. He had studied CT scanners quite a lot because he wrote his Master's dissertation and Ph.D. thesis on CT scanners focusing on image processing and metal artefact reduction. Also, at the beginning of the project, he had been a member of the hardware group for two years. He helped the hardware group to develop electronic and control systems. He worked with the hardware group closely. After that, he took responsibility for software development and image quality improvement in the software group. He had a small turntable from a CT scanner in his office to study the CT scanner and an X-ray detector system in order to communicate the parameters of scanner setting to the hardware group. Thus, he seemed to know and understand an overlapping area between the two groups. One participant from the hardware group, for example, talked about the ability of this research assistant to explain technical vocabularies across groups:

> He knows both hardware and software of the development of CT scanners. He can answer questions of both sides. He can answer questions about software and coordinate with the hardware […]. He explained to me about millisievert and differences between effective dose and absorbed dose. Also, he explained to me about software source codes and parameters which were converted by the hardware group for pivoting the X-ray detector system [N3, P18-19, L610-652].

This suggested that this project member seemed to have better knowledge and understanding about the development of the scanners both in terms of hardware and software. Also, he seemed to have a better capacity as a sender and receiver, as well as actig as a lexicon mediator in an overlapping area of the two groups able to translate things into the language of the hardware group. He was able to answer questions and explain issues about software to the hardware group members. He facilitated communication and collaboration between the two groups through lexical translation.

The other project member who acted as a lexicon mediator was the hardware design engineer of the software group. He had a knowledge background in mechanical engineering and was an expert in machine design. In the project he took responsibility for hardware design and development. Although he worked with the hardware part, he was a member of the software group because of human resource management issues. He sat in the software group's laboratory. Consequently, he had more opportunities to see and absorb what the software group did or discussed. This helped him to get a better understanding of the software side. He seemed to have a better capacity to digest and translate the technical vocabularies of machines and electronics to the software group in order to make it easier for the software group to understand those vocabularies.

There were different sources of knowledge between those two lexicon mediators that helped them to be able to stand at a boundary between the different groups. For the research assistant, the sources of his knowledge came from his pre-existing knowledge as well as being a member of the hardware group and working within the hardware context. Also, in the project he took responsibility for an overlapping area between the two groups such as for an X-ray detector system and X-ray photographs. On the other side, for the hardware design engineer, the sources of his knowledge came from being located in the software context. Consequently, he had opportunities to see and absorb the software group's knowledge and practice. Such phenomena helped him to improve his understanding of the software side as well as helped him to develop common language in machines and electronics between the two groups.

According to the findings about lexicon mediators mentioned above, there were differences between the findings from this study and the theorisation of boundaries. That is, for instance, Carlile (2004, 2002) suggested transferring knowledge at an information-processing boundary through technology and boundary objects. Also, he talked about boundary brokers and (understanding) translators at an interpretative boundary which was another type of boundary (see Section 4.6.2). However, in the findings from this study, (lexicon) translators were found at an information-processing boundary because members from different groups needed to develop a common language for transferring their knowledge to the other members.

4.6.2. Interpretative boundary; knowledge translation process

According to the interviews, the two groups had differences in perspectives and ways of thinking about the same things and situations with the scanner development. These differences were mainly based on concepts, theories, methods, and techniques arising from different knowledge communities. A common language, which was developed at an information-processing boundary, was not sufficient to solve this issue and manage knowledge across boundaries. Consequently, another type of boundary, known as an interpretative boundary, and another process to manage knowledge across boundaries, known as knowledge translation, were found.

The first example of different interpretations between the two groups concerned the precision of an X-ray detector system setting. According to the interviews, the participants from the hardware group criticised the software group for seeming to think that the setting of an X-ray detector system must be as precise as 0. However, the hardware group argued that it is impossible because there are normally errors with hardware. The participants from the hardware group talked about this issue:

> The precision of the X-ray detector system setting normally was about 0.3 mm […]. However, the software group thought that it must be 0 mm. The hardware group argued with the software group that there were standard errors of hardware and the X-ray detector system. So, it was impossible and inessential to set the precision of the system at 0 mm. Sometimes we [the hardware group members] have to clarify the operation of hardware to the software group that we are able to this or that only because of today's technology [N7, P4, L125-134].

> It is crazy to do this [...]. I believe that no one can develop hardware with the high level of precision at 0.1 micron […]. However, the software group still dreams and requests arcminute or arcsecond [smile]. Machines consist of many components and each component has its standard tolerances and errors. The hardware group tries to meet the software group's requirements but it hit the hardware group's ceiling [N6, P10-11, L342-368].

> The software group told the hardware group that the setting of the X-ray detector

> system must be as precise as square or at 90 degrees. However, for hardware engineers it was impossible […] [N12, P5, L156-166].

Another example was the turning of a gantry in relation to a detector. The participants from the hardware group mentioned that the hardware group wants to set a gantry away from shoulders of patients to avoid it hitting their shoulders. However, the software group wanted to get the gantry close to a patient's face to take clearer patient oral cavity photographs as implied in the concept of image processing [N5, P6, L189-191]. Moreover, for the software group, the turning of a scanner should be through a full circle; while for the hardware group it was very difficult to achieve that [N7, P2, L40-48].

These examples suggested that members from different groups tend to interpret the same things based on the concepts and theories of their groups which tend to be different from other different groups. Moreover, they might not consider that other different groups might not know and understand their differences. They might not consider that the concepts and perspectives of one group might not be considered possible or essential to the other different groups. Consequently, difficulties in cross-community collaboration could occur.

Moreover, interpretative boundaries occurred when novelty of a research area generated some unclear dependencies between the two groups – different interpretations and understandings occurred. For instance, one participant from the software group mentioned unclear dependencies in the scanner development between the two groups:

> It is not just telling the other group [the software group] that I [referring to the hardware group] have finished my part, and then send and throw everything over to the software group. We [the hardware and software groups] work together and have effects on each other [N1, P2, L57-59].

This state was agreed by one participant of the hardware group:

> It looks like that the scanners are developed by the hardware group already. After this it is a task and responsibility of the software group [smiles] [N3, P14, L486].

To reconcile discrepancies in interpretations and understandings between the two groups at an interpretative boundary, in this case boundary interactions and boundary brokers were two main tools involved. Boundary interactions or the co-engagements of different groups in collective activities helped to overcome interpretative boundaries by offering opportunities to the groups to identify and learn differences and dependencies between them through the metaphor of "let's do it together" (Matthew, Hawkins and Rezazade, 2012, p.1806). Boundary interactions helped to share (tacit or know-how) knowledge that cannot be codified and transferred from one group to another group through media easily or different groups did not fully understand (Nonaka, 1994). Boundary interactions, in this case, mainly covered face-to-face meetings, working together in the same place, and training.

Face-to-face meetings offered opportunities to members of the different groups to represent, discuss, and learn about differences and dependencies in knowledge and tasks with the other group. This helped to develop common interpretations and understandings as well as to form acceptable points for coordination. For instance, two participants from the hardware group suggested:

> How do the operations of a scanner work? What are the components of a scanner? We [the hardware and software groups] discuss that in meetings. We bring everything about that into meetings to fine-tune with each other [N7, P2, L57-59].

> There are discussions about how the necessary requirements of one group relate to the other group and how the capabilities of one group meet the requirements of the other group [N8, P3, L73-75].

This suggested that face-to-face meetings are an essential place where the two groups are able to share, discuss, and learn differences and dependencies in knowledge, perspectives, tasks, and requirements of each other. This was in order to develop common understandings about the differences and dependencies between the two groups for their collaboration.

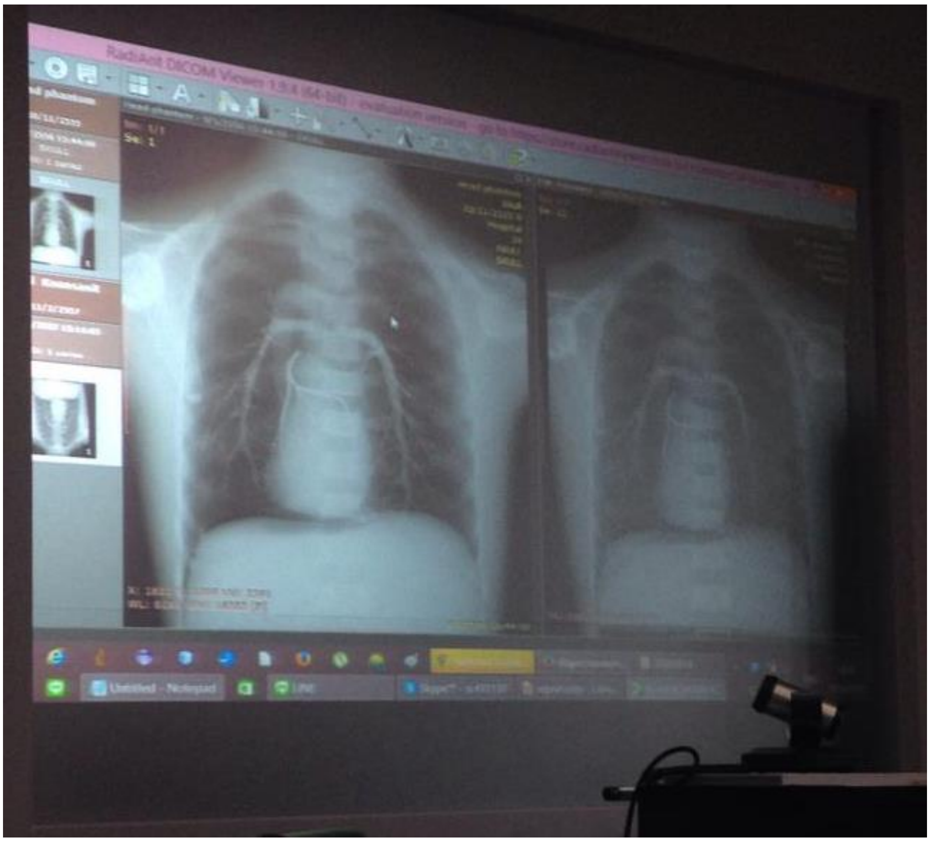


Figure 4.8 Comparison of the quality of X-ray photographs

Figure 4.8 above illustrates an example of a technical issue about the scanner development which was discussed by project members within the monthly meeting [O1, P3, L30-33]. It was a comparison of the quality of X-ray photographs between the two dental CT scanners of the project. These scanners were used in different sites: at the Thammasat University Hospital and the Suthasinee Dental Center (SDC). Some doctors at the hospital complained that the scanner in the SDC generated more contrasty X-ray photographs than the scanner in the hospital. Then, the doctors asked the project members to improve the performance of the scanner in the hospital. Consequently, the project members shared their knowledge and perspectives as well as discussed the causes and solutions of the issue in the monthly meeting together. Initially, the software group assumed that the problem occurred because of resolution, contrast, and X-ray scatter. Thus, the software group suggested increasing the dose of radiation, the development of new algorithms and the re-setting of an anti-scatter grid. By contrast, the hardware group suggested the development of X-ray shooting. This suggested that when novelty such as blurred X-ray photographs occurs, different interpretations between the two groups exist. The two groups interpreted the same thing differently depending on their different knowledge and perspectives. They had different ways of thinking about how and where the causes of the problem arose and how to fix it. The meeting facilitated knowledge sharing, discussion, and learning differences in knowledge, perspectives, and understandings between the two groups and then can lead to the development of common interpretations and understandings.

Working together in the same place such as a laboratory was another key boundary interaction. It offered opportunities to project members to share, discuss, fine-tune, and learn differences and dependencies in their knowledge and tasks with each other. This was in order to reconcile different interpretations and understandings about what they were trying to do and how it might be achieved. A participant from the software project, for example, talked about the advantage of working together in the same place to gain a better understanding:

> I think, it is going better because of working together in the same place, especially in the lab. Everyone has to come in and work in the lab. If we work in the same place, it works because we can talk with the other project members and understand tasks better. It does not work for working separately and integrating later because some things need a lot of discussion. The more people talk, the more people understand [N1, P5, L170-172].

This statement pointed out the importance of having a common workplace such as a laboratory where project members from different groups could share and discuss their knowledge and tasks with the other project members during working together to develop mutual understandings. Working together in the same place tended to offer a better result than working in different places and only coming together to provide individual findings for integration at the end. Figure 4.9 below illustrates collaboration between the hardware group members [that sat within the safety room] and the software group members [that sat at the front of the room] to improve the image quality of a DR X-ray scanner together in a laboratory. They discussed and checked the parameters to set an X-ray detector system for improving the image quality of the scanner.

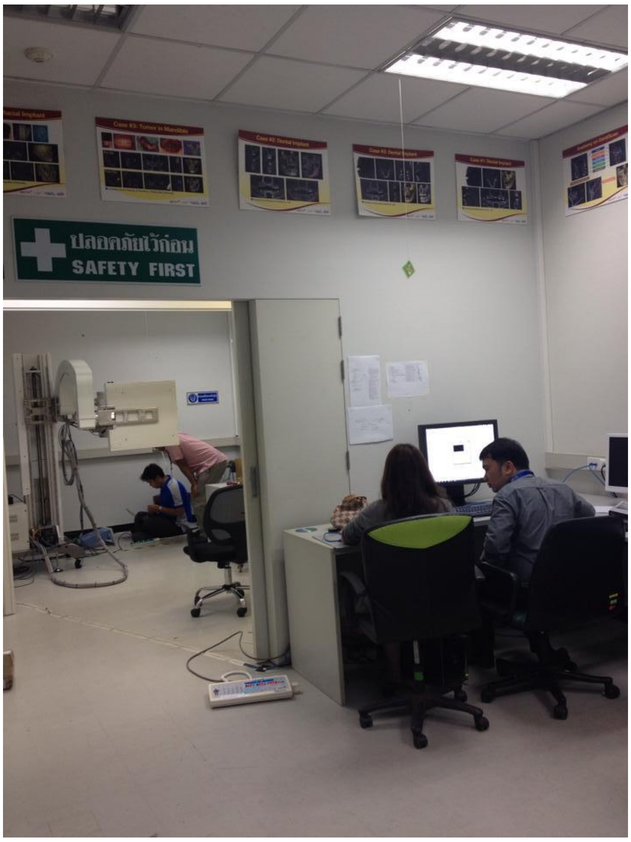


Figure 4.9 Collaboration of members from different knowledge communities

Furthermore, working together in the same place helped in sharing tacit knowledge that cannot be expressed easily or one group did not fully understand. For instance, according to the observation of collaboration between the hardware and software groups in a laboratory, while the software group was testing a dental CT scanner version 2, there was a problem about X-ray delay. One hardware group member shared his knowledge about X-ray detector system operation with the software group members. The hardware group's engineer clarified the operations of electrical systems and controllers, the behaviour of an X-ray detector system and X-ray shooting to the software group. Especially, the hardware engineer clarified differences between theory and practice in the operation of an X-ray detector system and X-ray shooting for taking X-ray photographs to the software group. That is, he explained that in theory a detector might take an electrical signal and then take X-ray photographs after 10 to 20 milliseconds. However, in practice a detector might take the signal and take the photographs after 12 to 18 milliseconds. Thus, before taking X-ray photographs the software group had to wait for an X-ray detector system turn-on [O9, P2, L41-46].

In this case, training was another form of boundary interaction between the different groups. Training helped to develop common interpretations and understandings between the different groups. For instance, the software group set up training about the components and functions of software and X-ray technologies as well as the use of the software group's developed software [N1, P9, L290-293] (see the interviewee's statement on p.190). Such training was created to develop the hardware group's understanding about software as well as to clarify differences and dependencies in knowledge and tasks between the two groups. In training the two groups could meet, share, discuss and learn knowledge used by, and tasks carried out by, the other group to work effectively together. Thus, training became a mechanism through which the gap between different groups could be bridged.

There were some project members who facilitated collaborations between the different groups by working in different roles as a coordinator, a facilitator, a representative, and an understanding translator. Some of them acted in more than one of those roles. For a coordinator and facilitator, according to the interviews and observation, the project director was the most important person in the project. The project director facilitated and coordinated collaboration between the two groups as well as between the project members and external actors [O12]. One participant from the hardware group, for instance, suggested: "there are not any other strong points in this project besides the project director [smiles]" [N9, P10, L321]. The project director pulled human resources from different groups to conduct this project together. He handled meetings to offer opportunities to members from different groups to share knowledge and viewpoints as well as to discuss unclear points for developing common understandings in coordination. Also, he was able to enter into the discussions between different groups by offering ideas to promote tacit knowledge sharing and learning, develop common understandings, encourage coordination, and facilitate problem solving between different groups. Moreover, he developed and maintained the environment of collaboration and the sense of commitment between different groups. It allowed members from different groups to collaborate and share their knowledge with the other members.

According to the interviews and documentation, and more specifically a project proposal and presentation [D5, D7], the project director was a senior researcher and top executive. He used his knowledge, experience, and power to pull and motivate human resources from different groups under NSTDA to conduct this project together. One participant from the hardware group, for instance, expressed: "He motivated people to work together. He was an attractive magnet for setting-up this project" [N6, P1, L12-13]. Similarly, the other participant from the hardware group expressed his perspective about the influence of the project director's knowledge and power on the participation of project members in the project, saying that:

> The director is a powerful and senior actor. He has a lot of knowledge and experience in research [...]. It is not easy to set up a big project like this, but he could pull resources to set up and support it. So, it is a good opportunity for me to join in this project [N11, P1, L56-63].

The project director created a common area where different groups could share, identify, inquire, and learn about differences and dependencies in their knowledge and tasks to develop common understandings. The common area was monthly meetings. Many topics were shared and discussed among project members in monthly meetings: the scanner development (such as the precision of X-ray detector setting, the improvement of image processing speed, the quality of X-ray photographs, and the schedule of scanner development); and the plans and strategies of sales and marketing (such as market strategies to compete with another scanner manufacturer by increasing discount and warranty, and the presentations of the project which would be presented to the National Health Security Office of Thailand to ask for subsidies).

The project director had accumulated knowledge related to digital signal processing and CT scanners for over three decades since he had become a university lecturer. Thus, he was able to enter into practice between the different groups to encourage knowledge sharing and learning as well as to facilitate problem solving through framing knowledge between the groups. For instance, the two groups were discussing causes and solutions to improve the quality and accuracy of X-ray photographs in the monthly meeting. They had unclear points about where the causes of the problem arose and how to fix them. The project director suggested both groups consider the alliance and alignment of a detector gantry with the X-ray photographs. He also suggested both groups create checkpoints to help them track the causes of problems [O12, P6, L104-110]. Another example; in the monthly meeting the project director asked and discussed with the project members, especially the project managers, the application of the project mobile CT scanner to diagnose and operate on cleft lip and cleft palate in children. The project members of both groups, and especially the project managers, shared their views about the possibilities of the development with the project director and the other project members. At the end of the meeting, the project director assigned both groups to study the age and height ranges of children to identify how the scanner could be used with children [O6, P1, L6-12].

The project director had authority and good connections both inside and outside the organisation. Thus, he was able to pull and connect human resources from other different functions and fields both inside and outside the organisation to collaborate with the project members to conduct this project. For instance, the project director asked researchers from a different group, the Wireless Information Security and Eco-Electronics Research Unit, to co-develop a DR scanner with members in the project [O12, P2, L49-52]. Similarly, he asked the members of the Business Development Unit to share their knowledge and experience about business development for research projects with the project members [O12, P2, L34-44]. This was in order to develop an effective project business plan. From interview data, the project members suffered from organisational research assessments. That is, the project members perceived that this project was an interdisciplinary research project. It was a big, difficult, and complex project as well as creating high social impact. However, the organisation seemed to assess large or small and simple or complex research projects as the same thing. Thus, the project members perceived that the organisation should use different criteria to assess different types of research projects [N1, P14, L474-476]. To resolve this problem, the project director invited the deputy executive director of the National Center, which the software group was under, to join the project meeting. This was to hear and discuss the issue with the project members [O12, P3, L69-88]. This suggested that the project director created connections between members of different fields and functions. He provided opportunities to members from different knowledge communities to share and learn knowledge and perspectives, and to discuss unclear points for developing common understandings among them.

In addition, the project director created a sense of commitment between members from different groups in the project; it allowed the members to share their knowledge with each other. For instance, one participant from the software group suggested that:

> If the project director did not push forward this project, we could not really pull human resources to work together and get commitments of the project members to complete the tasks [N1, P2, L43-44/53-58].

According to the interviews, there were two other project members, the hardware and software project managers, who acted as facilitators between the two groups. The project managers facilitated knowledge sharing and learning as well as the development of mutual understandings between the two groups. Also, they developed and maintained awareness and the environment for collaboration between the two groups. For instance, the hardware project manager reconciled the attitudes and criticisms of the hardware group about the software group to manage the relationships between the two groups:

> Some members of my group [the hardware group] criticised the software group that the software group should do like this or that, it was very easy. But I told them that it looked easy for us because we did not do it and we were outsiders […]. I had to explain to my members and make them understand that what the software group made may look easy in our eyes but the software group had to fix many things to reach our requirements [N5, P7, L236-242].

This suggested that members of one group might not fully understand the nature and tasks of other different groups. They seemed to look at the same situation based only on their perspectives. This might affect collaboration between different groups. The hardware project manager could be considered as a facilitator between the two groups because he explained differences and dependencies in tasks between the two groups to the hardware group members. Doing this helped to reconcile discrepancies and negative attitudes, to develop understandings and to maintain relationships between the two groups by asking members to put themselves in the other members' shoes.

According to observation of monthly meetings, the project managers also acted as a representative or a person who spoke and acted officially for their groups. They presented the work, viewpoints, and interests of their groups to the project director and the other project members in the meetings. Also, they were key contact points and informants of their groups [O12, P3-6, L96-103].

There were some types of documentation that could be considered as a boundary object at an interpretative boundary between the two groups, such as the checklists of the scanner development [D1], and the detector and scanner user's manuals [D8]. Such objects were boundary objects because they provided methods of common communication and collaboration across different groups. Also, they provided concrete means for the two groups to specify and learn differences and dependencies in knowledge and tasks. For instance, according to observation of cross-community collaboration to resolve X-ray delay of a dental CT scanner version 2 in a laboratory, both groups checked an operating instruction for a detector to re-check the detector setting [O9, P2, L59] (see Figure 4.10 below). The instruction coulds be considered as a boundary object because it was used by the two groups and facilitated communication between the two groups. That is, the instructions were a reference document or a focal point of both groups to answer questions about the detector setting and the X-ray detector system operation. It provided a concrete means for communication and working together between the two groups in the development of the scanners. Furthermore, the project members were trying to create standard forms and documents in the development of the scanners to provide a common way to communicate and coordinate across different groups.

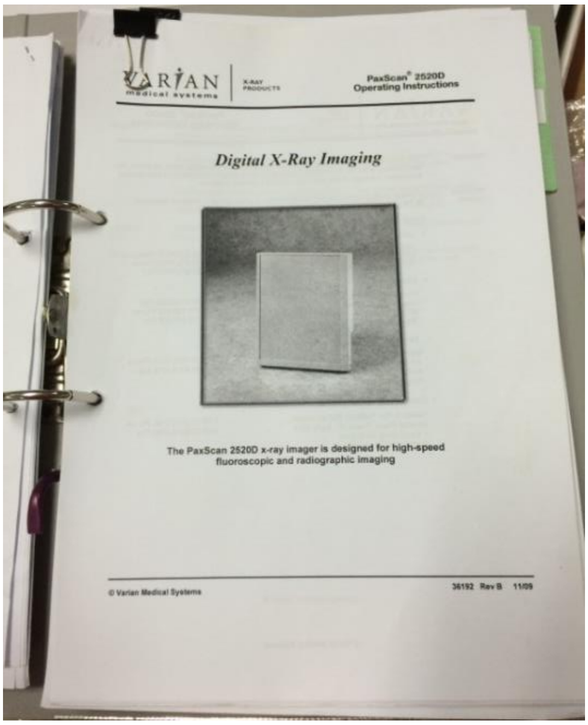


Figure 4.10 Operating instructions for a detector

Moreover, there were the efforts of the hardware project manager to develop a standard protocol for cross-community collaboration to reduce the risks of different interpretations and conflicts. According to the hardware project manager, the scanner development in this case consisted of three different sub-groups: the mechanical, electrical, and software groups. At the beginning of the scanner development these sub-groups discussed an overall specification for final output together with a sub-specification for the output of each sub-group. Each sub-group must create and deliver output as a promise and commitment. For instance, a mechanical group must create and deliver output 'A' to an electrical group. The electrical group knows that it must take output 'A' to create and deliver output 'B' to a software group. The software group must know that it must develop software to correspond with output 'B' in order to deliver output as promised as well [N6, P4, L120-125]. This standard protocol could provide a concrete way to communicate and coordinate among different groups and functional settings. Also, it was a shared understanding about what they were trying to do and how it might be achieved.

The findings from this study suggested that the workload of project members influenced their willingness and possibility to participate and share knowledge with the other project members to develop common understandings. This project consisted of four sub-projects: the development of a dental CT scanner; a mobile CT scanner; a mini CT scanner; and a DR scanner. These four sub-projects had different knowledge challenges. For instance, there were differences in the size and shape of each scanner as well as parts of patients' body for X-ray scanning. These sub-projects were conducted in parallel [D1, F8]. Also, project members were assigned to participate in more than one sub-project. Some researchers and engineers in the project not only researched and developed the scanners but also sold the scanners because of a lack of the required human resources. One participant from the hardware group, for instance, expressed the negative impact of multiple roles of project members on their operation that:

> I have to do everything by myself. I work like all-in-1. I do not want to work like this. Research and technical staff have to design, develop, assemble, and find customers by themselves [N6, P8, L269].

According to the interviews, most project members had to conduct other research projects and some of these projects did not relate to CT and DR scanners. Thus, most project members complained about their asymmetric responsibilities and workloads. For instance, the software and hardware project managers expressed that:

> We have many parallel projects, but there is a limit on the number of project members. So, [taking a deep breath] the project members are tired [N1, P12, L405-406].

> I am very tired [laughs]. I would like to have time to look at each scanner because some scanners have not been completed yet and need to be improved further, but they must wait [N1, P12, L410-411].

Some participants talked about the negative impact of workload on the project members' competitive capability in the scanner development that:

> We are not able to catch up with the launch of new models of another scanner manufacturer because we are limited by the number of project members. The hardware project members have other jobs which are not related to the development of CT scanners. We are very slow to develop a dental CT scanner version 2; while companies might spend six months or one year to develop it [N5, P7, L220-223].

> Our researchers must invent, manufacture, and assemble the scanners by themselves. So, they may work slower than companies [N4, P3, L82].

From observation, some junior project members did not attend the monthly meetings throughout. They absented themselves from some meetings and agendas because they thought that they were not relevant to them and they had to clear up their backlogs [O1]. Consequently, social interaction, knowledge sharing, and learning activities between theses project members and the other project members could be hindered. One participant from the hardware group talked about this issue mentioning that there are efforts made by project managers to ask hardware group members to document what they did to share with the other project members. However, those members were very busy. They did not have time to record what they did. Although those members suggested videoing what they did during the scanner assembly, they also never had time to do it. As one interviewee from the hardware group stated:

> The project managers and senior researchers of the two groups made efforts to encourage project members to record what they did in documentation for sharing their knowledge with the other project members. However, the project members were very busy. Consequently, they did not have time to record what they did in documentation […]. Some hardware group senior researchers suggested the hardware project members record what they did during the scanner assembly on video. However, these members never started to record what they did because of lack of time [N11, P14, L469-482].

This situation affected knowledge sharing, and then created tension and discontinuities in collaboration among the project members. For instance, one participant from the software group talked about this issue, saying that:

> The hardware group members did not often create documents to record what they did. If one of the members leaves, the project lost their knowledge. Consequently, the existing or new project members did not have documentation to refer to. They thus

> had to waste resources and time to restart the scanner development [N1, P8, L270-271].

To solve this issue, primarily the project was trying to use the benefits from the implementation of ISO 13485 as a tool to encourage project members to record and document their tasks.

4.6.3. Political boundary; knowledge transformation process

In this case, the new requirements of customers and markets, as well as the innovation of another scanner manufacturer, were the major sources of novelty. They affected the current knowledge, practices, interests, and agendas in the development of the scanners of project members. The project members needed to change their current knowledge, practices, interests, and agendas in order to meet the requirements of customers and to compete with another scanner manufacturer.

Most customers of this project were doctors who were members of different knowledge communities. When the project members interacted with the new requirements of customers, they tended to interact with novelty of knowledge. There were needs for compromise and transformation in the current knowledge, practices, interests, and agendas in the scanner development of the project members in a way that supported the customers' requirements for continuation of the project. For example, the customers and the project members had different perspectives and interests in image resolution of X-ray photographs. Two participants from the software group told the story that:

> The software group was satisfied with the creation of image resolution at 0.4 mm […]. However, in the real world many big hospitals used dental CT scanners […] which created high-resolution images at 0.25 mm. The issue occurred when doctors at the Thammasat University Hospital compared the performance of the project scanner with the J. Morita Company. Then, they complained that the project scanner generated blurred photographs, there was much noise on the photographs, and the view sizes of photographs were small […]. After receiving the complaints, we interpreted the meaning of the doctors' complaints. Consequently, we stopped creating low-resolution images at 0.4 mm and started to create high-resolution images at 0.2 mm. We researched and developed new algorithms and techniques to increase X-ray doses and radiation to develop high-resolution photographs. During

> the improvement, I compared the results of our scanner with the J. Morita all the time. We tried to answer every question of the doctors. However, those complaints were motivations [N12, P11, L378-415].

> Doctors requested us [the project members] to reduce image-processing time of the project DR scanner from 19 seconds to 5 seconds. They also asked us to connect the scanner to the PACS [the Picture Archiving and Communication System] of a hospital. This system was a new thing for us. To meet the requirements of the doctors, we had to research and develop new algorithms and techniques to reduce the image-processing time of our scanner. Also, we had to study and find out ways to connect the scanner to the hospital's system [N2, P1, L11-28].

According to the examples mentioned above, the new requirements and complaints of the customers and the capabilities of another scanner manufacture or competitors, were sources of novelty for the project members. They affected the current knowledge, practices, interests, and agendas in the scanner development of the project members. That is, the project members were satisfied with the creation of image resolution at 0.4 mm. However, they had to stop work and start trying to create high-resolution images at 0.2 mm as per the customers' requirements. Similarly, the project members could generate patients' 3D X-ray photographs from the project DR scanner in 19 seconds. However, they had to reduce the image-processing time of the scanner and generate the photographs within 5 seconds. The current practices and techniques were no longer sufficient. Consequently, they needed to invest resource and effort to change their current knowledge and practices. Also, they needed to create new knowledge and practices to develop new algorithms and techniques to increase contrast on photographs and to reduce image-processing time of the scanner. Furthermore, they needed to go into a new and an unfamiliar area, and then learn about it, such as the Picture Archiving and Communication System (PACS) of a hospital. This is in order to meet the customers' requirements.

Focusing on the effects of innovations of another scanner manufacturer on the current knowledge and practices of the project members, the participants from both groups spoke about the project dental CT scanner and its competitors:

> Customers seem to give more satisfaction to another company's CT scanner. We still follow another company. Another company goes forward with both the quality of X-ray photographs and the body of the scanners. The scanner of this project is big and

> bulky, while the scanners of another company are smaller and lighter. The scanners of competitors are 3-in-1 [panoramic, cephalometric, and 3D/CT] and generate high-resolution photographs, while our scanners are just 3D/CT. The price of competitors' scanners is cheaper than us. So, customers seem interested in the competitors' scanners […]. Consequently, the project members have to research and develop new techniques and technologies to improve the scanner to compete [N4, P2-3, L59-74].

> In a very competitive marketplace, most competitors reduce the size and costs of a detector. The price of a scanner in the marketplace is reduced from 10 million baht [around 185,400 pounds] to 3.5 million baht [around 64,900 pounds], while our cost is still 3 million baht [around 56,000 pounds]. Now I press the project members to develop a one leg dental CT scanner and cut its cost to 1 million baht [around 18,540 pounds] [N6, P2, L43-49].

From the examples mentioned above, they suggested that new innovation of competitors, which covered new knowledge, processes, technologies, and products, rendered knowledge, practices, technologies, and products of the project members obsolete. The project members had to change their current knowledge, practices, and technologies. They had to invest resources and effort to develop a new version of the scanner such as changing from two legs to a one leg scanner and reducing the size and costs of a detector. This was in order to compete with competitors in the marketplace. During the interview, one participant seemed to be afraid of talking about a comparison between the project's scanners and another scanner manufacturer's scanner. This interviewee said: "I can talk about that, right?" [N4, P2, L59].

One participant from the hardware group talked about the effects of changing from two legs to a one leg scanner on his current tasks, saying that:

> There are effects of changing from two legs to one leg dental CT scanner. It is easier to work with a bigger scanner because a two leg scanner has more stability than a one leg scanner [...]. A one leg scanner has more difficulties for engineering. There are many parameters that must be controlled for the production [N13, P8, L252-267].

Furthermore, the innovation of competitors created conflicts and political boundaries among the project members in the same group. According to the interview, the hardware project manager told the project members that he wanted to halve the cost of hardware to compete with other competitors in the marketplaces. However, the members in the hardware design group told the manager that they could not do that. The hardware project member talked about this issue:

> I told the hardware group members that I wanted to cut in half the cost of the hardware to compete with another competitor in the market. The members from the hardware design team told me that they could not do that, but I retorted that I do not care and you must cut the cost [N6, P9, L294-308].

This suggested that there are different interests between members of the same group in the same thing such as the cost reduction and hardware development needed to increase opportunities to compete with other competitors. When interests were in conflict, the interests of the hardware project manager generated consequences in terms of knowledge, practices, and interests of the hardware design group. The hardware design group was reluctant to change because it was costly to change their current knowledge and practices. However, they needed to change their knowledge and practices to develop hardware as required by the hardware project manager because of the hardware project manager's political influence.

Due to the case of this study being a research project in a governmental research organisation, the new requirements of stakeholders was another major source of novelty. The requirements and interests of stakeholders from various parties had effects on current knowledge, practices, interests, and agendas in the development of the scanners of the project members. For instance, external funding agencies asked the project members to adapt the project scanners as they wanted to set subsidies for the project [O4, P3, L63-65]. This suggested that the project members have to face novelty which comes from the new requirements and different interests of external funding agencies. It had cost implications for the current knowledge, interests, practices, and agendas of the project members. They had to change their practices and agendas as well as improve their current knowledge and practices in some new areas to develop the scanners for different settings. This was in order to meet the requirements of the offer from the funding agencies.

To meet the requirements of the customers and stakeholders as well as to compete with other scanner manufactures, the project members needed to interact with other external actors as consultants. This was to gain new and required knowledge for the scanner development from consultants. When the project members interacted with consultants, it could relate to a political boundary. This was because they interacted with the novelties and differences in knowledge of consultants who were members of different knowledge communities. The novelties and differences of knowledge of consultants generated consequences in terms of current knowledge of the project members. That is, there were costs of learning about what was new and changing current knowledge. It was necessary for the project members to make sense of the knowledge of consultants as well as knowledge integration between the project members and consultants. For instance, the Food and Drug Administration of Thailand (FDA) asked the project members to get ISO 13485 certification to be able to sell the project scanners in the marketplace. Also, the project members wanted to get the certificate to increase the credibility of their products with customers to compete with competitors. The interviews suggested that most project members did not know about ISO. Thus, they hired an external consultant to provide knowledge about ISO [N10, P9, L312-318].

The situation mentioned above implied that the requirement of external actors such as the FDA and customers affected the project members. The project members had to invest resources and effort to implement ISO and develop solutions to meet the requirements of the FDA and customers. The solutions had costs in terms of the project members' current knowledge and practices because they needed to interact with novelties and differences in knowledge of a consultant. The project members gained and integrated new knowledge about the implementation of ISO from the consultant to improve some of their work processes and to create procedure documents in order to improve their performance. When they integrated the new and different knowledge from the consultant, they were in the process of knowledge transformation at a political boundary where they must prepare to change their current knowledge and practices.

Particularly, at the beginning of the implementation of ISO into the project, there were differences in attitude of some project members. One participant from the hardware group said that:

> The most difficult thing was about changing the attitude of some project members to accept the implementation of ISO because when they heard about ISO they shook their heads immediately. They thought that it was documents, burdens, and retardation […]. If they resisted it, they would not do and go along with it immediately [N3, P9, L290-306].

This suggested that when novelty arises, there is a lack of common interests among the project members to implement ISO. New knowledge in one different group, such as from the consultant for ISO, generates consequences for the project members. That is, some project members were reluctant to implement ISO because they perceived that it had costs in terms of their time and tasks. They did not want to be forced to do something that seemed a waste of time. Furthermore, as the dialogue presented above shows, "if they resisted it, they would not do and go along with it immediately". This suggested that when the interests and attitudes of project members are different and in conflict, it could create barriers for collaboration and hinder knowledge management across boundaries. Therefore, there were costs of willingness of project members to change their interests and attitudes to adopt and implement ISO into their work processes.

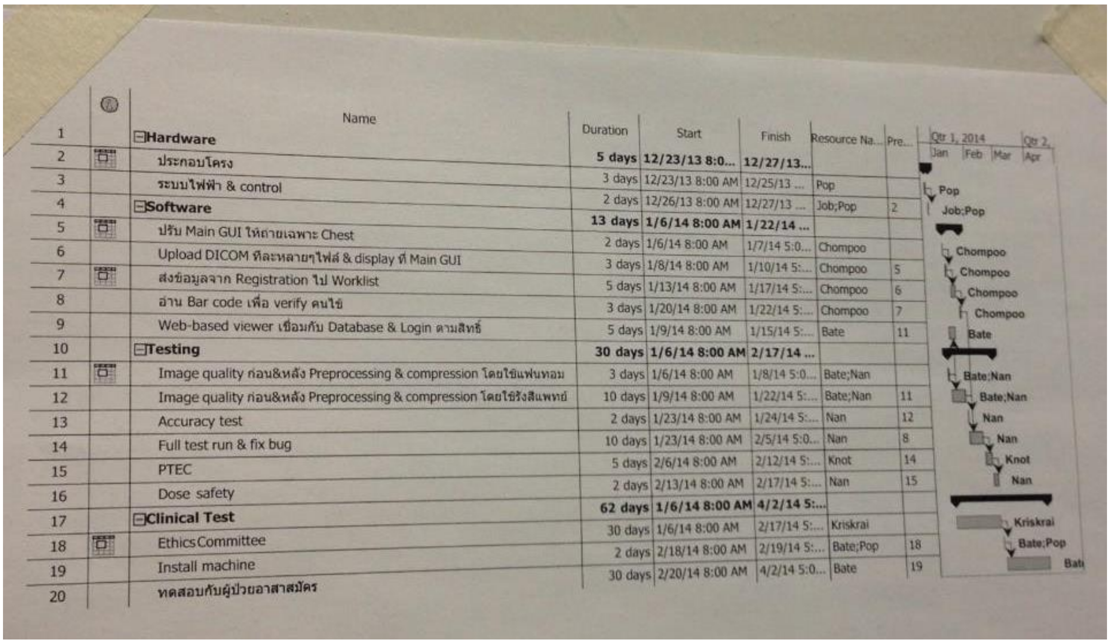
In this study, there were three main boundary objects facilitating knowledge transformation among the project members and between the project members and external actors at a political boundary. Three boundary objects were: CT and DR scanners; X-ray photographs; and project Gantt charts.

CT and DR scanners were co-developed and used by members of the hardware and software groups in the course of their interaction and collaboration. They were shared and shareable across different groups and contexts. The scanners' structure meanings were common enough to the two groups to make them recognisable and function as a means of communication and collaboration, although they had different meanings in different groups. They were strongly structured in each group and weakly structured in common use in the two groups. Moreover, they helped to clarify differences and dependencies in knowledge and tasks that existed between the two groups. For instance, the hardware group focused on the development of the hardware and body of a scanner as well as the generation of raw X-ray photographs. The software group focused on the development of software and programming as well as the generation of reconstructive X-ray photographs. The software group required raw data and raw X-ray photographs from the hardware to generate patients' 3D X-ray photographs. Similarly, the hardware group needed to coordinate with the software group to set an X-ray detector system to generate the required data and X-ray photographs.

The scanners facilitated communication, interaction, and knowledge transformation between the project members and external actors such as customers and stakeholders. That is, the scanners were the project's final output. The project members needed to present and sell the scanners to external actors. Moreover, many situations mentioned above suggested that the project members need to take in the external actors' requirements to improve their scanners in order to meet the external actors' requirements for the selling of their scanners. This suggested that there are dependencies between the project members and external actors on the scanners. Moreover, the requirements of the external actors encouraged communication, interaction, and collaboration between the hardware and software groups to develop the scanners to meet the requirements.

In the same way, X-ray photographs from the scanners were a shared object between the two groups. They sat in the middle between the two groups. Both groups needed to communicate, interact, and coordinate with each other to generate high-quality reconstructed photographs. Similarly, the external actors commented on and fed back the quality and performance of the project scanners through X-ray photographs. This suggested that X-ray photographs are common to both the project members and external actors, who tended to be members of different groups, to make them recognisable and function as a means of communication and interaction.

Another boundary object at a political boundary was a project Gantt chart. It consisted of work tasks involved in the project, work flow, start and finish dates of the summary elements of the project, and who would be responsible for each task. It helped to clarify differences and dependencies in knowledge and given tasks that exist between the hardware and software groups. Therefore, it offered, in effect, a map of boundaries to clarify differences, dependencies, and boundaries that exist between the two groups, as shown in Figure 4.11 below.



	Name	Duration	Start	Finish	Resource Na...	Pre...
1	**Hardware**	**5 days**	**12/23/13 8:0...**	**12/27/13...**		
2	ประกอบโครง	3 days	12/23/13 8:00 AM	12/25/13 ...	Pop	
3	ระบบไฟฟ้า & control	2 days	12/26/13 8:00 AM	12/27/13 ...	Job;Pop	2
4	**Software**	**13 days**	**1/6/14 8:00 AM**	**1/22/14 ...**		
5	ปรับ Main GUI ให้ถ่ายเฉพาะ Chest	2 days	1/6/14 8:00 AM	1/7/14 5:0...	Chompoo	
6	Upload DICOM ทีละหลายๆไฟล์ & display ที่ Main GUI	3 days	1/8/14 8:00 AM	1/10/14 5:...	Chompoo	5
7	ส่งข้อมูลจาก Registration ไป Worklist	5 days	1/13/14 8:00 AM	1/17/14 5:...	Chompoo	6
8	อ่าน Bar code เพื่อ verify คนไข้	3 days	1/20/14 8:00 AM	1/22/14 5:...	Chompoo	7
9	Web-based viewer เชื่อมกับ Database & Login ตามสิทธิ์	5 days	1/9/14 8:00 AM	1/15/14 5:...	Bate	11
10	**Testing**	**30 days**	**1/6/14 8:00 AM**	**2/17/14 ...**		
11	Image quality ก่อน&หลัง Preprocessing & compression โดยใช้แฟนทอม	3 days	1/6/14 8:00 AM	1/8/14 5:0...	Bate;Nan	
12	Image quality ก่อน&หลัง Preprocessing & compression โดยใช้รังสีแพทย์	10 days	1/9/14 8:00 AM	1/22/14 5:...	Bate;Nan	11
13	Accuracy test	2 days	1/23/14 8:00 AM	1/24/14 5:...	Nan	12
14	Full test run & fix bug	10 days	1/23/14 8:00 AM	2/5/14 5:0...	Nan	8
15	PTEC	5 days	2/6/14 8:00 AM	2/12/14 5:...	Knot	14
16	Dose safety	2 days	2/13/14 8:00 AM	2/17/14 5:...	Nan	15
17	**Clinical Test**	**62 days**	**1/6/14 8:00 AM**	**4/2/14 5:...**		
18	Ethics Committee	30 days	1/6/14 8:00 AM	2/17/14 5:...	Kriskrai	
19	Install machine	2 days	2/18/14 8:00 AM	2/19/14 5:...	Bate;Pop	18
20	ทดสอบกับผู้ป่วยอาสาสมัคร	30 days	2/20/14 8:00 AM	4/2/14 5:0...	Bate	19

Figure 4.11 Project Gantt chart for the development of the scanners

According to the interviews, common goals, teamwork, and being willing to change by project members had positive effects on knowledge transformation at a political boundary. Having a common goal for project members facilitated cross-community collaboration and helped to overcome political boundaries. This was because a common goal is regarded as a direction of thoughts and actions of members from different groups in the project. Although the two groups took on different responsibilities and had different goals in their groups, they had dependencies in knowledge and tasks to reach a common goal of the project together. They tried to help each other to reach the common goal together. For instance, two participants from the software and hardware groups suggested that:

> We [the hardware and software groups] are like partners, so we go towards a goal together. We are bound together. We have a same goal. That is, Hey! Brother [it refers to the hardware project manager], why is it slow, something like that. When problems occur, we will help each other to solve the problems together [N1, P5, L146-147/149-150].
>
> We [the hardware and software groups] have the same goal which is the development of a prototype of the scanners and transfer technology for commercialisation [N3, P11, L384].

This suggested that the participant perceives members of the other different group in the project as having the same goal and working together as partners. Both groups were likely to cooperate and help each other to reach the project goal together. Similarly, one participant from the hardware group suggested that: “because we have known each other for a while, so it seems like…we are able to talk to each other and we are friends” [N3, P11, L374]. This suggested that there is a sense of close relationship and teamwork between members of different groups in the project which was influenced by the time of working together. According to the project presentation document, the project members have co-developed the scanners together since 2007 [D7]. The sense of close relationship and familiarity of the project members had positive effects on communication and collaboration among the project members.

Another facilitator was being willing to change the current knowledge, interests, and practices of project members. According to the situations mentioned at a political boundary, there were many new requirements and complaints from the external actors on the project scanners. Although solutions affected the current knowledge, practices, and interests of project members, they recognised and were willing to change their current knowledge, practices, and interests to meet the external actors' requirements. For instance, during talking about the complaints of some doctors on the project dental CT scanner version 1, one participant from the software group said: "However those complaints were motivations" [N12, P11, L415] (see the interviewee's statement on p.230). This suggested that although complaints and solutions have costs and effects on this participant's current knowledge, practices, and interests, he had enthusiasm for dealing with those complaints. Having a positive attitude to change and being willing to change supported knowledge transformation at a political boundary.

In addition, the findings suggested that some Thai cultural traits such as 'Kren jai' which can be found through saving face helps to reduce conflicts among project members. This stems from the statement of one participant from the software group, for example: "the hardware and software groups rarely have conflicts because Thais compromise" [N2, P11, L379].

4.7. Summary

This chapter presents the findings about cross-community collaboration and knowledge management, in the context of an interdisciplinary research project in a governmental research organisation which has received little attention from the existing literature. Based on the perspectives of the participants in this case, interdisciplinary collaboration opened knowledge sharing and learning opportunities to project members for both internal and external learning or learning between members from different groups in a project and the learning of the project members with external actors. Also, it supported the development of complex and advanced products to meet the complex requirements of customers and markets. This is because no single individual or group could possess all the required knowledge and skills to develop complex and advanced products such as the CT and DR scanners. However, interdisciplinary collaboration could increase workload and required more time being spent collaborating than working with members of the same disciplines to reach a common goal together.

There were different types of knowledge which were shared among project members through both face-to-face and non-face-to-face communication and knowledge sharing channels depending on the characteristics of the knowledge and the qualities of the channels. Moreover, this case suggested that different types of knowledge are shared with different sets and levels of members in the project depending on the project members' authority, abilities, and responsibilities in the project. Most participants from this case perceived that it is appropriate to share knowledge with different sets and levels of members in the project because of time and task allocation. In this case there were no negative effects of a hierarchical organisational structure and knowledge sharing, excepting that this organisational structure slowed down communication and decision-making among project members.

The findings from this case argued that knowledge management across boundaries is more complex and challenging than suggested in the existing literature because of the nature and construction of knowledge boundaries. For the nature of knowledge boundaries, the findings from this case argued that boundaries tended to change throughout the project life cycle based on the work that has to be done and issues of interactions between members from different knowledge communities. There were simultaneous and overlapping knowledge boundaries. Thus, the identification of where one type of knowledge boundary ended and another began was not often easily identified. Another point; for the nature of knowledge boundaries, the findings suggested that when different actors look at the same phenomena, they could perceive them as different types of knowledge boundaries. This was according to the types and amount of knowledge relating to the phenomena owned by different actors and how they were affected by them. Therefore, the categorisation of knowledge boundaries was not often easily made.

Furthermore, the findings from this case argued that knowledge boundaries arise because of lack of a full understanding and awareness of differences in knowledge and disciplinary perceptions between members from different groups. Due to lack of a full understanding and awareness of these differences, the members of different groups tended to think that their tasks were more difficult than the tasks of another group. When problems between different groups occurred, each group tended to dispute with another to solve the problems rather than engage in joint problem solving. Such situations could affect cross-community interaction, collaboration, and learning.

To manage knowledge across boundaries, the main findings from this study substantiated the existing theorisation of boundaries in that there are three increasingly complex knowledge boundaries: information-processing, interpretative, and political boundaries; and three increasingly complex processes for managing knowledge across these boundaries: transfer, translation, and transformation. This case suggested some differences in the contexts of knowledge boundaries and boundary-spanning mechanisms to overcome the boundaries.

At an information-processing boundary, the findings suggested that (explicit) knowledge is not only transferred from one group to anther through technology and boundary objects, but also through face-to-face communication. This was because of the limitations of technology and the activity of some influential project members. Moreover, a lexicon mediator was required at this boundary to develop a common language for transferring knowledge between different groups.

Having only a common language was not sufficient to manage knowledge across boundaries. This is because members from different groups tended to interpret the same things and situations in different ways based on what they had studied and were trained for in their groups. Therefore, an information-processing boundary moved to an interpretative boundary. In this case, two major tools for the development of common interpretations and understandings between different groups were boundary interactions and boundary brokers. Face-to-face meeting and discussion, working together in the same place, and training were examples of boundary interactions found in this case. They helped to identify and learn differences and dependencies in (tacit or know-how) knowledge that cannot be codified and transferred from one group to another through media and technology easily or that one group did not fully understand. Boundary brokers were another tool to develop common meanings and understandings between different groups. For instance, they offered opportunities to project members to share and learn knowledge and to discuss unclear points as well as develop the environment of collaboration and the sense of commitment between different groups.

An interpretative boundary moved to a political boundary when the knowledge and interests of one actor or group affected the knowledge and interests of another. Consequently, they must be prepared to change their own knowledge and interests to resolve consequences required across boundaries. In this case, project members needed to change their current knowledge, practices, interests, and agendas in the scanner development to meet the requirements of customers, stakeholders from various parties and markets. Also, they needed to change their current knowledge, practices, interests, and agendas in the scanner development to compete with another scanner manufacturer for their survival. Furthermore, in this case, the innovation of another scanner manufacturer created political boundaries between members in the same group. To overcome a political boundary, political effort, and influence was required to develop common interests among interacting actors in the project. Objects that help to clarify differences and dependencies in knowledge and given tasks that exist between different groups were used to overcome a political boundary such as project Gantt charts, X-ray photographs, and the scanners. Moreover, common goal, teamwork, and willingness to change of project members had positive effects on knowledge transformation at a political boundary by working as a direction of thoughts and actions of project members as well as encouraging collaboration between different groups.

The next chapter, the discussion chapter, will present explanations and comparisons between the findings from this study and the existing literature on knowledge management and boundary spanning. Also, it will present a framework for managing knowledge across boundaries that emerges from this study.

5. Synthesis and discussion of the findings

5.1. Introduction

The aim of this chapter is to discuss the findings found from this study, which have been presented in Chapter 4, against the existing literature on cross-community collaboration and knowledge management. This, it is argued, provides a richer understanding of the similarities and differences between the findings and model stemming from the existing literature and the findings and framework that emerges from this study. Some of the relevant literature, which was presented in Chapter 2, is referred to again in this chapter. Other further literature is presented to contextualise and substantiate the findings in Section 5.2 to 5.5. The content in this chapter is structured based on the research objectives.

As mentioned in Chapter 2, Section 2.11, there are some major gaps about cross-community collaboration and knowledge management in the existing literature which should be explored to get better understandings on cross-community collaboration and knowledge management. Firstly, the nature of boundaries has been little explored and depicted in the literature; boundaries are dynamic, fluid, changeable, and invisible. Secondly, most existing studies have suggested that knowledge boundaries mainly arise because of differences in knowledge and disciplinary perceptions between interacting actors from different knowledge communities. Finally, the existing models of knowledge management across boundaries have predominantly developed from, and have been used in, particular contexts; especially for new product development in the industrial context. It seems that the existing literature has given less attention to how context can influence its model and findings such as boundary-spanning mechanisms to manage knowledge across boundaries. Moreover, the influential model for managing knowledge across boundaries, more specifically Carlile's three-tier model (2004, 2002), has been commented on that there is little knowledge about the dynamics of knowledge boundaries.

In this context, this thesis aims to explore the nature of boundaries and how knowledge is managed across them, particularly in a public sector context. This aim led to the development of four research objectives: (i.) to explore the nature of boundaries; (ii.) to explore why knowledge boundaries arise; (iii.) to explore how people manage knowledge across boundaries; and (iv.) to develop a framework for managing knowledge across boundaries. The research setting of this thesis was the development of Computerised Tomography (CT) and

Digital X-Ray (DR) scanners in the National Science and Technology Development Agency (NSTDA), a governmental research organisation in Thailand. The background of the case was presented in Chapter 3, Section 3.5.

5.2. Nature of boundaries

5.2.1. Dynamics, overlapping, and simultaneity of knowledge boundaries

The literature, presented in Chapter 2, Section 2.5, depicted boundaries are regularly conceptualised as between two (or more) actors or groups of actors from different communities (Wenger, 2000). Similarly, Stokols, Hall, Taylor and Moser (2008) suggest that boundaries are to some extent arbitrarily defined and agreed upon by knowledge communities. Boundaries are not something that people can see or grasp easily (Hawkins and Rezazade, 2012; Adam as cited in Hoffmann, 2012; Carlile, 2004; Wenger, 2000). Similarly, the interview data from this study suggested that interacting actors can perceive boundaries differently. That is, in this case there are not only knowledge boundaries between the hardware and software groups as most participants normally perceive and report or found from observation. The interview data suggests that there are other boundaries between members in the same group. For instance, a boundary between the hardware project manager and the hardware design team is found when the hardware project manager talks about conflicts and different interests between the hardware project manager and the hardware design team about the cutting of hardware production cost to compete with another scanner manufacturer in the market [N6, P9, L294-308] (see the interviewee's statement on p.232). Another example; the hardware project manager reports that there are three different groups: the mechanical, electrical, and software groups, involved in the development of the scanners [N6, P4, L120-125] (see the interviewee's statement on p.227).

In addition, normally the participants perceive that the hardware and the software groups are different knowledge communities. However, when they talk about interaction between the project members and customers such as doctors, who are members of another different knowledge community, they perceive that the hardware and the software groups are one knowledge community. This stems from the statements of one participant from the software group. This participant calls the hardware and software groups 'we', and calls customers as 'they' when the participant talks about the effects of the customers' requirements on the knowledge and practices of project members in the scanner development [N12, P11, L378-415] (see the interviewee's statement on p.230).

The literature depicted the nature of boundaries as dynamic, fluid, changeable, and invisible (Lindberg, Walter and Raviola, 2017; Holford, 2016; Smith, 2016; Paraponaris and Sigal, 2015, Adam as cited in Hoffmann, 2012; Carlile, 2004; Stokols, Hall, Taylor and Moser, 2008; Wenger, 2000). Carlile (2004, p.560) depicted the interrelationships and transitions where one knowledge boundary ends and another begins as an iterative process related to the level of difference, dependency, and novelty of knowledge between interacting actors from different knowledge communities. He also argued that the transition where one knowledge boundary ends and another starts is not often easily identified by the interacting actors involved. The findings from this study, which have been presented in Section 4.4.1, extend the existing literature about the nature of boundaries. They argue that boundaries are dynamic and tend to evolve and change throughout the project life cycle depending on work that has to be done as well as the context and issues of the interactions between different communities and boundaries. In addition, boundaries are often co-existing and overlapping, which is discussed below.

As mentioned in Section 4.4.1, the stages of the scanner development in this case study comprised of three main stages: planning and design; development and manufacturing; and testing and implementation stages. At the first stage, the planning and design stage, political boundaries are strong because novelties in the areas of the scanner development affect pre-existing knowledge of project members. That is, by taking part in the project, project members might have to change their pre-existing knowledge and practices to respond to novelties in the areas of the project or the scanner development. Novelties in the areas of the scanner development also generate conflicts and different interests between individual project members and their research unit. For instance, one specific individual interviewee stated that he has to change his current knowledge background and his mind to join in this project because of the political influence and requirement of his research unit, although he was uninterested in doing so [N5, P7, L229-232] (see the interviewee's statement on p.188).

Due to the suggestion that members from different knowledge communities fundamentally have different knowledge bases, they tend to perceive the same things and phenomena differently based on their conceptual and theoretical lenses (Smith, 2016; Siedlok and Hibbert, 2014; Hislop, 2013; Sunmer and Tribe, 2007; Carlile, 2004; Wenger, 2000; Becher, 1994). Consequently, different interpretations of the same things and phenomena at an interpretative boundary are mainly found at the second stage which is the stage of the scanner development and manufacturing. As one key interviewee from the hardware group stated:

> The two groups have different perspectives about the setting of the X-ray detector system and the quality of X-ray photographs. The software group perceives and wants to get some things but we [the hardware group members] do not understand why these things must be like the software group's requirements. The software group must explain principles why the things must be like this or like that […]. For example, we want to set a gantry of a detector away from a patient's shoulders to avoid it crashing into the patient's shoulders; while the software group wants to set the gantry close to a patient's face to take clear patients' oral cavity photographs as the theory of image processing requires [N5, P6, L189-191].

At the same stage, the development and manufacturing stage, interpretative boundaries might transmute to political boundaries. This is because the ways of thinking, requirements, and practices of one group about the quality of X-ray photographs might affect current knowledge, practices, and agendas of the other group. Consequently, one group might need to change its current knowledge, practices, and agendas to meet the requirement of the other for generating more high quality X-ray photographs for collaboration.

Not only interpretative and political boundaries but also the knowledge transfer process at information-processing boundaries are found at the scanner development and manufacturing stage. For instance, the photographs of machine simulation and the assembly drawings of a detector gantry are sent from the hardware group to the software group via e-mail and instant messaging to inform the progress of hardware development and to check the accuracy of the drawings together [N12, P6, L184-189].

At the scanner testing and implementation stage, the final stage of the scanner development, political boundaries are strong when project members need to interact with external environments. For instance, project members have to interact with doctors, who are members of different knowledge communities, to implement the project scanners with patients in hospitals. New requirements from the doctors about the scanners and the innovations of another scanner manufacturer render project members' current knowledge and practices obsolete. It affects the sales volumes of the project scanners in the market. Consequently, project members have to change their current knowledge, practices, interests, and agendas to improve the scanners to meet the doctors' requirements and to compete with another scanner manufacturer (see examples in Section 4.6.3). As one interviewee from the software group illustrated:

> Doctors requested us to reduce image-processing time of the project DR scanner from 19 seconds to 5 seconds. They also asked us to connect the scanner to the PACS [the Picture Archiving and Communication System] of a hospital. This system was a new thing for us […]. We had to research and develop new algorithms and techniques to reduce image-processing time of our scanner. Also, we had to study and find out ways to connect the scanner to the hospital's system [N2, P1, L11-28].

This suggests that when different interests between different groups meet and the interests of one group affect knowledge bases and practices of another group, conflicts and political boundaries emerge (Carlile, 2004). To resolve the different interests at a political boundary, the lower power group may need to change its knowledge bases, practices, and agendas (Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004). That is, as in the above example, the doctors and the project members have different interests in the image-processing time of the project scanner. The interests and requirements of the doctors have effects on the current version of the project scanner as well as the current knowledge and practices of the project members. To resolve these different interests between the project members and the doctors, the lower power group seen as the project members needs to change its obsolete knowledge, practices, and agendas to create new knowledge and practices; old ones have to be changed. This is in order to improve their scanner to meet the doctors' requirements. At the testing and implementation stage of the scanners, information-processing boundaries are found as well. For instance, some software project members share the trial results of a mobile CT scanner with the other project members during a project monthly meeting [O6, P1, L1-7].

As the activities and situations mentioned above show, they suggest that boundaries tend to evolve and change throughout the project life cycle depending on work that has to be done as well as the context and issues of the interactions between interacting actors from different communities. All types of knowledge boundaries might occur at all stages of the project, although some types of knowledge boundaries seem to be mainly mentioned at different stages of the project. This is depending on work that has to be achieved as well as the context and issues of the interactions between different groups at different stages of the project. The findings from this study also suggest that more than one type of knowledge boundaries can occur at the same time, and one type of knowledge boundaries can overlap with another. This finding brings into focus the complexity and challenge of knowledge management across boundaries by addressing that sometimes knowledge boundaries cannot be categorised and compartmentalised easily at an empirical level. For instance, there are simultaneous information-processing and interpretative boundaries. In the meeting on implementation of ISO 13485 and risk management, the hardware and software groups discuss the hazards and the processes of scanner development which should be assessed for risk management. A knowledge transfer process at an information-processing boundary emerges when the two groups are jointly able to send and receive knowledge about the types of hazards and the risk assessment of scanner development [O8, P1-3, L1-28]. They are able to do that because they have some common knowledge about them from an external consultant. However, difficulty in the knowledge transfer process occurs when some unclear vocabularies about risk management occur among project members. That is, some project members of both groups are confused about the difference between 'hazard' and 'harm' as well as between 'user error' and 'knowledge error'. To resolve the information-processing boundary, one hardware group member accesses a risk management manual to find the definition and scope of these terms, and then shares this with the other project members [O8, P4, L31-33].

From the above situation, an information-processing boundary moves to an interpretative boundary when the project members interpret the same thing, the hazard level of the repeated radiological radiation exposure in patients, differently. One hardware group member asks the other project members: "What is a hazard level of repeated radiological radiation exposure in patients?" A few members of the software group suggest that it is trivial and easy to recuperate from. So, it should be classified into the first level of hazards. However, the other project members of both groups argue that it is difficult to identify the level of hazard for this issue. This is because it is not possible to see the effects of repeated radiological radiation exposure in patients immediately. Thus, this issue could be classified into another level of hazards [O8, P4, L34-39]. From this situation, the development of common meanings and understandings is required to reduce different interpretations and misunderstandings among project members. To reconcile different interpretations, one project member of the hardware group suggested that a definition and scope of each hazard level is not static as in the manual. A definition and scope of each hazard level could be co-modified by the project members based on the contexts and processes of scanner development. That is, engagement and interaction among the project members is suggested to co-develop a definition and scope of each hazard level.

Another example; there are simultaneous information-processing and interpretative boundaries in training for the hardware group by the software group. From the interview data, the software group set up training about the development, components, and functions of software, the components and functions of X-ray technologies, and the use of the software group's viewer and planning software. This training is set up to train the hardware group for developing the hardware group's understandings about the software group's tasks and dependencies between the two groups [N1, P9, L290-293] (see the interviewee's statement on p.190). This example suggests that training is a boundary-spanning mechanism helping one group to transfer its knowledge to another. Knowledge about software operation is transferred to the hardware group. As with theorisation of boundaries, a knowledge transfer process emerges at an information-processing boundary. At the same time, training is one of the important boundary interactions helping members from different communities to share, identify, and learn differences and dependencies in knowledge and tasks with each other. The hardware group could learn differences and dependencies in knowledge and tasks between the two groups by looking at the operation of software about the development of the scanners. Therefore, the knowledge translation process as well as common meanings and understandings between different groups at an interpretative boundary could be developed. From this example, it is argued that there is overlapping between different boundaries such as information-processing and interpretative boundaries.

The findings mentioned above are similar to the findings of some current studies on cross-community collaboration and knowledge management: Lindberg, Walter and Raviola (2017), Smith (2016), and Le Dain and Merminod (2014). These studies argued that the processes of boundary work were dynamic whereby different types of knowledge boundaries are performed at the same time, and within the same process (Lindberg, Walter and Raviola, 2017; Smith, 2016; Le Dain and Merminod, 2014). Lindberg, Walter and Raviola (2017) suggested that boundary work is a dynamic process whereby different types of boundaries occurred at the time. Boundary work is built on a relationship between practice and boundaries. The emerging practice drove and constituted changes in boundaries. Similarly, Smith (2016) examined a high-novelty research and development collaboration between multiple organisations by focusing on the occurrence of knowledge boundaries and mechanisms to manage knowledge across those boundaries. Then, Smith (2016) explained a complex picture of knowledge boundaries that goes beyond a hierarchic and linear representation of boundaries as suggested by Carlile (2004, 2002). Smith (2016, p.51) argued that multiple knowledge types may exist in a project either continually or simultaneously; while Carlile's model implies that boundary emergence and spanning occur in a linear way and that only on type of knowledge boundary exists at one time. Le Dain and Merminod (2014, p.698), in another study, argued that the dynamics of knowledge sharing between customers and suppliers in new product development projects in energy and domestic appliance companies, involved in three knowledge boundaries, depending on each supplier's involvement configuration.

However, Le Dain and Merminod's (2014) study has one limitation which has been found from the findings of this thesis. The limitation is that their findings are collected from only one stage in new product development, the design stage. Consequently, their findings mainly focus on activities to develop common meanings at an interpretative boundary between different groups for co-development projects. However, the findings from this thesis are developed based on the project life cycle of the case study. Consequently, three knowledge boundaries and three knowledge processes to overcome them are suggested. They are suggested according to the context and the issues of the interactions between different groups and boundaries. No single type of knowledge boundaries and knowledge processes to overcome them is found to be the main focus.

Moreover, the other findings from this thesis, which will be presented below, provide multiple perspectives to suggest that cross-community collaboration and knowledge management are more complex than the existing literature suggests. That is, the findings suggest that cross-community collaboration and knowledge management are complex not only because of the dynamics and simultaneity of knowledge boundaries, but also because of perceiving the same phenomenon as diverse types of knowledge boundaries (see Section 5.2.2). Therefore, there are challenges about the categorisation of knowledge boundaries and the mechanisms of cross-community collaboration and knowledge management. Furthermore, the findings suggest a different perspective about the construction of knowledge boundaries. That is, the findings suggest that knowledge boundaries not only occurred because of differences in knowledge between members from different knowledge communities as many studies in the subject of the study suggest, but also occurred because of ignorance of differences in knowledge of other people (see Section 5.3.2).

In addition, the findings from this study point out the role of context on cross-community collaboration and knowledge management. Firstly, most public research and development organisations mostly often have characteristics of both government bureaucracies and private agencies. They need to retain characteristics of public service organisations to keep the privileges of public funds as well as needing to have a close relationship to their users and their market (external) funds in the private sector. Also, they need to compete with another agency, which produces and delivers the same services and products, in both the private and public sectors and at both national and international levels. This hybrid nature (Gulbrandsen, 2011) introduces tensions and challenges into the operation of public research and development organisations. The organisations must be prepared and willing to change their current knowledge, practices, interests, and agendas to account and respond to the wide range of demands (see Section 5.3.1.3). Secondly, the findings suggest that bureaucratic cultures in hierarchical organisational structures have positive impacts on cross-community collaboration and knowledge management. That is, the power of the project director, who is at the top of the pyramid of the project, helps to pull actors, who are in lower levels, from different knowledge communities to work together. Also, the power of the project director encourages social interactions between the actors to develop common understandings as well as create a sense of commitment among the actors. These help to reduce conflicts among the actors (see Section 5.3.1.2). Furthermore, the hierarchical organisational structures help to clarify differences and dependencies in knowledge and responsibility among members, create clear lines of communication, and give project members clear spokespersons. This helps overcome boundaries (see Section 5.4.2). Finally, social compromise and harmony process help to reduce conflicts in cross-community collaboration (see Section 5.4.3). These suggest that context plays a crucial role for managing knowledge across boundaries.

5.2.2. Facing the same phenomenon, but experiencing them as different types of knowledge boundaries

The findings in Section 4.4.2 suggest that when facing the same phenomenon different actors experience or perceive it as different types of knowledge boundaries in the three-tier model. This is depending on the current types and amount of knowledge that individuals have about the phenomenon, how they are affected by it, and the extent of changes that they feel the phenomenon requires. This finding extends the theorisation of knowledge management across boundaries in that the difficulty of knowledge management across boundaries is not just that members from different knowledge communities have differences in languages or terminologies, interpretations, and interests that create three types of knowledge boundaries (e.g. Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Farag, Jarvenpaa and Majchrzak, 2011; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). The difficulty is also that the same phenomena are possibly seen by the others as different types of knowledge boundaries; individuals perceive them in light of their own experience and knowledge bases.

For instance, the major research areas of this project covered X-ray technologies, radiography, and digital image processing. From the interview data, one participant from the hardware group perceived that his pre-existing knowledge in chemical and materials engineering was not compatible with the research areas of this project. Consequently, this participant perceived that to join in this project he had to change (some of) his pre-existing knowledge as well as had to study and create new knowledge in different areas. This participant, the hardware project manager, stated that:

> Actually, I did not know about it [X-ray technologies] [laughs] because my background was in chemical and materials engineering. At the beginning, I was actually uninterested in [laughs] and I seldom agreed with this project [laughs] because I thought that CT [Computerised Tomography] would be too far for Thailand. To conduct this project, it had to pull in many and various resources, otherwise this project would be a failure. However, when the research unit decided to do it, I had to help the unit to make it successful [N5, P7, L229-232].

However, another participant from the same group perceived that participation in this project involved just furthering his knowledge in the same area. This is because this participant had pre-existing knowledge in mechatronics and electricity which could be applied to use in this project directly. Consequently, this participant perceived that there was no need to change his pre-existing knowledge to participate in this project. This participant, a hardware engineer, stated that:

> I did not change anything. The development of CT and DR scanners involves electricity and I have knowledge and experience about electricity already. I just improve knowledge and techniques about radiation […]. Doing this project makes me feel like…I gain more knowledge. I just improve my knowledge rather than change my knowledge and my way [N8, P4, L117-119].

From the above example, it is suggested that the two participants have differences in types and amount of knowledge relating to the research areas of this project. The first participant has pre-existing knowledge which is different from the research project; while the second participant has pre-existing knowledge which is related to the project. Therefore, these two participants have different perspectives about how they would be affected by joining this project and how much change they feel they are involved in. That is, the first participant perceives that to join in this project he would be affected by it. This is because he has to change his pre-existing knowledge and create new knowledge in the research areas of this project. By contrast, the second participant perceived that to join in this project he would not be affected by it because he has required knowledge which is related to the research areas of this project already.

As the two participants have differences in types and amount of knowledge relating to the project and differences in perspectives on participation in the project, the two participants perceive joining in this project as different types of knowledge boundaries. The perspective of the first participant reflects a political boundary. A political boundary mainly focuses on a change of current knowledge when knowledge of one individual or group affects knowledge of another individual or group to make things work at a boundary (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). From the above example, when the novelties of the research areas of this project occurred, the first participant perceived that his pre-existing knowledge in chemical and materials engineering was different from the research areas of this project. This participant had no knowledge and experience in the project. Thus, this participant perceived that he would be affected by joining this project. Significantly, when the novelties of the research areas of this project occurred, they generated conflicts between this participant and the research unit which this participant belonged to. That is, this participant did not want to participate in this project, while his research unit was interested in and wanted to do it. Although this participant was not interested in and did not want to participate in this project, he had to change his mind to join it in order to follow the decision and requirement of the research unit. This pointed out the use of the political influence of the research unit to develop common interests between this participant and others to start the project. The political effort and influence was mentioned at a political boundary (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Thus, this participant perceived that the novelties of the research areas of this project and participation in it affected and transformed his pre-existing knowledge and interests. He had to change his pre-existing knowledge and interests.

However, the second participant perceived there was no need to change his current knowledge to participate in this project. This is because he had knowledge which related to and could be applied to this project directly. Thus, this participant perceived that there were no effects from the novelties of the research areas of this project on his pre-existing knowledge base. This participant perceived that participation in this project was just learning new knowledge or improving pre-existing knowledge rather than changing his pre-existing knowledge and interests as at a political boundary.

According to the different perspectives and experiences of the two participants mentioned above, it is argued that individuals face the same phenomenon but perceive or experience it as different types of knowledge boundaries in the three-tier model. This is depending on what types and amount of knowledge that they have for the phenomenon, how they are affected by it, and how much change they feel is involved for it.

5.3. Construction of knowledge boundaries

As regards the second research objective of this study, why knowledge boundaries arise, the main findings from this study, which have been presented in Section 4.5.1 and 4.6, substantiate the existing literature in that knowledge boundaries arise from the level of difference, dependency, and novelty of knowledge and disciplinary perceptions between interacting actors from different knowledge communities (see Section 5.3.1). Equally important, the findings, which have been presented in Section 4.5.2, argue that boundaries arise from ignorance of these differences between interacting actors from different knowledge communities (see Section 5.3.2).

5.3.1. Differences in knowledge and boundaries between interacting actors from different communities

The existing literature, presented in Chapter 2, Section 2.5, depicted boundaries as social intersection and sociocultural difference between different interacting actors (Holford, 2016; Akkerman and Bakker, 2011). The difference leads to discontinuity of action or interaction between different individuals or groups of individuals which are relevant to another individual or group of individuals in a particular way (Kotlarsky, Hooff and Houtman, 2015; Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Carlile, 2004, 2002; Wenger, 2000; Star and Griesemer, 1989). Matthew, Hawkins and Rezazade (2012, p.1802) argued that a knowledge boundary is a border of an agent's knowledge base in relation to different disciplines. Similarly, many scholars argued that each discipline provides and shares the different framework of knowledge and the different concept of theories, methods, and techniques in the discipline in which its members have studied, been trained, and carried out tasks. Consequently, members of different disciplines have fundamental differences in many aspects such as in their ways of thinking, interpretation, and use of vocabulary (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004, 2002; Wenger, 2000; Davenport and Prusak, 1998; Becher, 1994; Brown and Duguid, 1991; Star and Griesemer, 1989).

When members from different disciplines use different languages to talk about and attach different interpretations to the same things and phenomena including having different interests in a particular practice, lack of common knowledge and understandings between them occurs (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002; Bechky, 2003). This situation creates difficulties, discontinuities, and boundaries in action, interaction or collaboration between interacting actors from different knowledge communities (Abraham, Aier and Winter, 2015; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002; Bechky, 2003; Wenger, 2000; Star and Griesemer, 1989). Abraham, Aier and Winter (2015, p.5) argued that "the level of difference in knowledge, goals, and assumptions among knowledge communities can be expressed via the construction of knowledge boundaries".

The findings from this study, which have been presented in Section 4.5.1 and 4.6, substantiate the existing literature in depicting that knowledge boundaries arise because of differences, dependencies, and novelties in knowledge between interacting actors from different knowledge communities. More specifically, the different levels or degrees of differences, dependencies, and novelties in knowledge between interacting actors from different knowledge communities lead to different languages or terminologies, different interpretations and understandings, and different interests. These differences represent three increasingly complex knowledge boundaries that can emerge in cross-community collaboration and knowledge management (e.g. Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Majchrzak, More and Faraj, 2012; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002).

In this thesis, the three boundaries are named: information-processing, interpretative, and political boundaries, which Carlile (2004) called syntactic, semantic, and pragmatic boundaries; and Kellogg, Orlikowski and Yates (2006) called display, representation, and assembly practices. The nature, occurrence, and transmission of these boundaries are depicted in Section 5.3.1.1.-5.3.1.3.

5.3.1.1. Information-processing boundary

Knowledge management across boundaries initially involves information processing. As previous research has highlighted, at an information-processing boundary knowledge can be captured, codified, stored, retrieved, and sent from one individual or group to another individual or group across contexts (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004). This knowledge was labelled know-what knowledge by Brown and Duguid (1998) or explicit knowledge by Nonaka (1994). Knowledge can be transferred from one individual or group to another different individual or group because differences and dependencies in knowledge between them are known; this together with common languages between the different groups is sufficient to support knowledge transfer at a boundary (Carlile, 2004, 2002). Due to interacting actors knowing about differences and dependencies in knowledge and having common languages between them, then at this boundary the knowledge flow tends to be unidirectional and takes the form of knowledge transfer (Carlile, 2004) from a knowledge holder to a knowledge recipient(s) (Boyd, Ragsdell and Oppenheim, 2007). That is, an information-processing boundary can be mainly resolved via a knowledge transfer process (Carlile, 2004, 2002).

In this case, some theories, concepts, data, statistics, and facts about the scanner development are captured, codified, stored, retrieved, and sent from one project member to the others through media such as technical reports and manuals. For instance, the parameters, results, and photographs of the scanner set-up and operation in the laboratory, field trials, or customers' sites were sent from the hardware group members to the other project members through instant messaging [N13, P5, L142-145] (see the interviewee's statement on p.178). This knowledge could be transferred from the hardware group to the software group because the two groups had some common knowledge and language in engineering; see Table 3.2 that summarises the knowledge backgrounds and skills of project members in the case study and the interviewee's statement on p.210. In addition, differences and dependencies in knowledge between the two groups were known, see Section 4.6.1.

Difficulties and information-processing boundaries between different groups arise from incompatible codes and lack of common languages for communication between different groups (Rosenlund, Rosell and Hogland, 2017; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). For instance, one interviewee from the hardware group talked about difficulties in communication with the software group because of lack of information and understanding about software and X-ray technical vocabularies:

> There were some difficulties about language such as the definition of a collimator. At the beginning, I did not understand what a collimator was until the software group explained that it was a device to narrow a beam of waves [N11, P12, L409-419].

This suggests that knowledge cannot transfer from one group to anoother different group because of lack of common languages between two different groups. The mechanisms of the development of common languages to transfer knowledge across information-processing boundaries are presented in Section 5.4.1.1.

5.3.1.2. Interpretative boundary

Having a common language or terminology is necessary but not always enough for managing knowledge across boundaries; more specifically, interpretative and political boundaries (Carlile, 2004, 2002). The literature, presented in Chapter 2, Section 2.5 and Section 2.7, depicted members of different disciplines as having fundamental differences in many aspects such as in their ways of thinking, conceptual and methodological standards, assumptions, and values (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Becher, 1994; Star and Griesemer, 1989; Biglan, 1973a; Kuhn, 1962). When members from different disciplines attach different meanings to the same phenomena and things across practices and groups, interpretative boundaries – semantic boundaries (Carlile, 2004) or boundary about representation practices (Kellogg, Orlikowski and Yates, 2006) – emerge.

The findings from this study substantiate the existing literature (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002); interpretative boundaries emerge when members from the hardware and software groups foster different interpretations related to the scanner development across practices. Consequently, tension and misunderstandings in collaboration between the two groups occur and then make collaboration more difficult. As one participant from the hardware group illustrated:

> The precision of the X-ray detector system setting normally was about 0.3 mm […]. However, the software group thought that it must be 0 mm. The hardware group argued with the software group that there were standard errors of hardware and the X-ray detector system. So, it was impossible and inessential to set the precision of the system at 0 mm. Sometimes we [the hardware group members] have to clarify the operation of hardware to the software group that we are able to this or that only because of today's technology [N7, P4, L125-134].

What transpires from the above example is that members from different knowledge communities live in different thought-worlds (Smith, 2016; Dougherty, 1992). They fundamentally have differences in their ways of thinking and ideas for solutions (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Siedlok and Hibbert, 2014; Hislop, 2013; Sumner and Tribe, 2007; Carlile, 2004; Wenger, 2000; Becher, 1994; Brown and Duguid, 1991). They tend to use their knowledge and expertise within the particular contexts of action and give meanings in their practices to the same things and phenomena across different knowledge communities (Smith, 2016; Dougherty, 1992). The ways of thinking and key ideas in one knowledge community may be considered uninteresting, irrelevant, inessential or impossible in another different knowledge community. Consequently, different understandings in the same things and phenomena between different knowledge communities occur. Then, tension and difficulties in working together between different knowledge communities happen (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Hislop, 2013; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). The mechanisms of the development of common interpretations between different knowledge communities is discussed below (see Section 5.4.1.2).

5.3.1.3. Political boundary

To manage knowledge across boundaries, it is not enough just to understand differences in languages and meanings between interacting actors from different knowledge communities; the interacting actors must also be prepared to change their current knowledge (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Fellows and Liu, 2012; Majchrzak, More and

Faraj, 2012; Farag, Jarvenpaa, and Majchrzak, 2011; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). The literature, presented in Chapter 2, Section 2.7, depicted that political boundaries are the result of different knowledge and interests between different knowledge communities. That is, the knowledge of one community affects the knowledge of another different community (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). The findings from this study suggest some differences about the construction of political boundaries due to the different context of the study, more specifically a governmental research organisation, which is discussed below.

A number of studies have examined public and private sector management (e.g. Helden and Reichard, 2016; Meier and O'Toole, 2011; Rainey and Chun, 2009). These studies have suggested that the public sector is different from the private sector and has some unique features of its own; especially ownership, source of financial resources, and social control. Firstly, most public organisations are owned by governments and their ownership rights are transferred with difficulty; while private organisations are owned by shareholders, who can transfer their rights easily (Helden and Reichard, 2016; Meier and O'Toole, 2011). Secondly, public organisations are largely funded from taxes; while private organisations are funded by the income earned by selling services and products into the market. Also, there is a link between resource generation and resource consumption in private organisations (Helden and Reichard, 2016; Meier and O'Toole, 2011). Thirdly, public organisations take a stakeholder-dependent approach or are controlled by multiple stakeholders at different levels of a politically constituted hierarchy. Stakeholders are various parties such as citizens, the state, local governments, organisations of the private sector and lobby groups. That is, all policy decision-making, considerations, activities, services, and products of most public sector organisations should be accountable to stakeholders. By contrast, private organisations take a shareholder-dependent approach or are controlled by shareholders (owners). That is, private sector organisations mainly respond to their shareholders by providing returns on investments to them. Also, private sector organisations are controlled by the market through selling services and products, and receiving the sales incomes (Helden and Reichard, 2016; Amayah, 2013; Jahn, Bergmann and Keil, 2012; Meier and O'Toole, 2011; Adel and Shaghayegh, 2010; Seba and Rowley, 2010; Rainey and Chun, 2009; Willem and Buelens, 2007; Yao, Kam and Chan, 2007; Cong and Pandya, 2003). However, Helden and Reichard (2016) argued that differences between public and private management have decreased. For instance, successful performance management in the private sector needs to emphasise multiple goals, dimensions, and parties. Private sector performance management thus becomes more multidimensional. In addition, cost consciousness has become significant in the public sector.

The case of this thesis is a research project in a governmental research organisation; it has some unique aspects of management. Firstly, it is owned and controlled by the government. Secondly, it is largely funded through taxes as well as by funding, subsidies, and incomes earned by selling its services and products to the funding agencies, subsidiaries, and the market. Consequently, thirdly, this case study is influenced by multiple stakeholders from various parties at different levels of a politically constituted hierarchy such as governments, citizens, funding agencies, subsidiaries, customers, and markets. All policy decision-making, considerations, activities, services, and products of this case study should be accountable to multiple stakeholders. Furthermore, this case study has to compete with other private and public organisations delivering similar services and products. This suggests that this case is complex and challenging.

Being accountable to stakeholders, operating with dependence on political authorities and responding to their multiple requirements, are an overwhelming pressure on the knowledge transformation of project members in this case study. This is because project members must be prepared and willing to change their current knowledge, practices, interests, and agendas in scanner development constantly to take account of, and respond to, a diversity of stakeholders' requirements for their survival and success. Moreover, they must be prepared and willing to constantly change their current knowledge, practices, interests, and agendas in scanner development to compete with competitors or other organisations delivering similar services and products in the market. This argues that knowledge management across boundaries in public organisations; more specifically governmental research organisations, could be difficult and complex to cope with.

One interviewee from the software group, for instance, talked about the effects of customers' new requirements for the image quality of X-ray photographs on the current knowledge, practices, and agendas of project members:

> The software group was satisfied with the creation of image resolution at 0.4 mm […]. However, in the real world many big hospitals used the dental CT scanners […] which created high-resolution images at 0.25 mm. The issue occurred when doctors at the Thammasat University Hospital compared the performance of the project scanner

> with the J. Morita Company. Then, they complained that the project scanner generated blurred photographs, there was much noise on the photographs and the view sizes of photographs were small […]. After receiving the complaints, we interpreted the meanings of the doctors' complaints. Consequently, we stopped creating low-resolution images at 0.4 mm and started to create high-resolution images at 0.2 mm. We researched and developed new algorithms and techniques to increase X-ray doses and radiation to develop high-resolution photographs. During the improvement, I compared the results of our scanner with the J. Morita all the time. We tried to answer every question of the doctors. However, those complaints were motivations [N12, P11, L378-415].

What transpires from the statement above is that this participant perceives that there are other different communities involved by using 'they', 'we', and 'the other scanner manufacturer'. That is, members from the hardware and software groups in the project, which are normally perceived as different communities, are perceived as the one community by using 'we'. By contrast, doctors or customers, and other scanner manufacturers are perceived as the other different community by using 'they' and 'the other scanner manufacturer' respectively. This suggests that boundaries are always conceptualised as between different communities (Wenger, 2000).

The example above also depicts that project members face strong expectations for efficient performance. The complaints of customers and the innovations of competitors or another scanner manufacture generate different interests and create conflicts between project members and customers. That is, the requirements, interests, or complaints of customers and the innovation of competitors affect the current knowledge, practices, interests, and agendas of project members. The project members need to recognise that their current knowledge and practices have to be changed: to create new knowledge and practices, obsolete ones have to be changed, to resolve the consequences required at a boundary between the project members and the customers (Carlile, 2004, p.559). As the interviewee states, the project members stopped creating low-resolution X-ray photographs at 0.4 mm and started to create high-resolution X-ray photographs at 0.2 mm. To do this, they had to research and develop new algorithms and techniques to increase X-ray doses and radiation to develop the required high-resolution X-ray photographs. The quotation, as shown above, states that "we tried to answer every question of the doctors"; this explicitly shows that the agency of customers has an effect on the current knowledge, practices, and agendas of project members.

Rainey and Chun (2009) argued that public management depends on political authority for authorisation of activities and for funding of them. Therefore, public management faces a very different operating environment. Likewise, in this case study the new requirements of funding agencies and subsidies affect the current knowledge, practices, and agendas of project members. For instance, project members have to develop their current (or create new) knowledge and practices to adapt the project mobile CT scanner to diagnose and operate on cleft lip and cleft palate in children. That is, at the beginning of the development of the project mobile CT scanner, the scanner was developed to diagnose and operate on adult patients. However, the agenda of scanner development was changed during the technical testing because one funding agency asked the project director to develop the scanner to diagnose and operate on cleft lip and palate in children [O6, P1, L6-12]. The development of the scanner for the adult and child patients had different challenges such as differences in physical and radiological absorption between adult and child patients.

These above examples suggest the diversity and intensity of external political influences on the decisions and activities of public organisations (Rainey and Chun, 2009). Public sector organisations, more specifically governmental research organisations, have to interact with and respond to various parties such as customers and stakeholders which have influences on their agency. Different parties tend have different requirements. Members in governmental research organisations may have to become involved in new and different activities and practices to meet the multiple requirements of the parties for their survival and success. Involvement with these new and different activities and practices may require the willingness, ability, and skill of project members to change their current knowledge, practices, interests, and agendas.

Governmental research organisations not only have to deal with the new and different requirements of customers and stakeholders in their activities; they must also compete with competitors or (both private and public) organisations delivering similar services and products. Innovations by competitors constitute an overwhelming pressure on governmental research organisations to change their current knowledge, practices, interests, and agendas to compete with them. For example, two interviewees from the hardware and software groups talked about the influence of the better practices of another scanner manufacturer on the current knowledge and practices of project members in their scanner development:

> […] The price of a scanner in the marketplace is reduced from 10 million baht [around 185,400 pounds] to 3.5 million baht [around 64,900 pounds], while our cost is still 3

> million baht [around 56,000 pounds]. Now I press the project members to develop a one leg dental CT scanner and cut its cost to 1 million baht [around 18,540 pounds] [N6, P2, L43-49].
>
> Customers seem to give more satisfactions to another company's CT scanner. We still follow another company. Another company goes forward with both the quality of X-ray photographs and the body of the scanners. The scanner of this project is big and bulky, while the scanners of another company are smaller and lighter. The scanners of competitors are 3-in-1 [panoramic, cephalometric, and 3D/CT] and generate high-resolution photographs, while our scanners are just 3D/CT. The price of competitors' scanners is cheaper than us. So, customers seem interested in the competitors' scanners […]. Consequently, the project members have to research and develop new techniques and technologies to improve the scanner to compete [N4, P2-3, L59-74].

This exemplifies that the new knowledge and better practice of competitors or organisations delivering similar services and products affect the current knowledge, practices, interests, and agendas of project members. That is, competitors can develop new CT scanners with a higher performance, a smaller size, and a lower cost. This new innovation and better practice of competitors renders the current knowledge and practices of project members obsolete. Especially, it affects the sales volumes of the project scanners in the market. To resolve this issue, project members recognise that their current knowledge, practices, and agendas have to be changed. They have to create new knowledge and better practices to develop a new version of their CT scanner by changing from a two leg to a one leg scanner and using a smaller detector to cut its costs to compete with competitors.

The above interviewees' statements suggest that project members have to worry about selling their products to the public and competing with companies. This is because private sector companies are better equipped to do this type of research project in terms of the quality of X-ray photographs as well as the body size and the price of the scanners. Customers seem more satisfied with the private sector companies' scanners than the project's scanners. This affects the sales volumes of the project scanners in the marketplace. Consequently, project members have to (be prepared to) change their current knowledge and practices about sales and marketing to develop new and better business strategies and plans. For instance, the project director is trying to initiate the concept of a dental service industry to sell dental services and dental CT scanners instead of just the scanners as in the past. Moreover, some project members, who have a sales job, have to change their current knowledge and way of selling scanners in the marketplace. For instance, they cooperated with some Small and Medium-sized Enterprises (SMEs) to install and service the project scanners in high traffic places such as department stores. This is to promote and increase awareness of the project scanners in the marketplace to increase the sales volumes of the project scanners [O12, P1, L13-16].

Similarly, project members have to implement ISO 13485 and risk management into the project to improve their performance. The implementation of ISO 13485 and risk management is also to increase the credibility of products and to meet the requirements of customers including to sell products in a wider marketplace such as in the ASEAN Economic Community (AEC) [N10, P9, L3121-312]. The implementation of ISO 13485 into the project affects the current knowledge and practices of some project members because they perceive that it has costs in terms of being time-consuming. Consequently, there are costs in terms of the willingness of project members to change their perspectives and practices to adopt and implement ISO 13485 into their work processes [N3, P9, L290-306] (see the interviewee's statement on p.234).

The findings from this study also suggest that the actions of external environments create conflicts and political boundaries among internal actors who are members of the same knowledge community. One of the potential examples about the conflict between the hardware project manager and the other hardware team members was given by the hardware project manager [N6, P9, L294-308] (see the interviewee's statement on p.232). This example suggests that the actions of external environments such as another scanner manufacturer affect the current knowledge, practices, interests, and agendas in the development of the scanners of project members. The actions of external environments create different interests and conflicts between members in the same group such as the hardware project manager and the hardware design team. That is, the hardware project manager wants to cut in half the cost of the hardware to compete with another scanner manufacturer in the market, while the front-line hardware design team members reflect it seems to be impossible. To resolve this issue, the hardware project manager uses his political influence to ask the hardware design team to change their current knowledge, practices, and agendas for developing hardware as he has required. This is in order to cut the cost of the hardware to respond to another competitor in the market. This shows the use of the political influence of members at the higher levels to develop common interests among members. This situation refers to a political boundary - knowledge and practices in one community affect the knowledge and practices of the other different communities as well as the use of political effort to develop common interests among interacting actors.

As the sets of findings and examples mentioned above show, public sector organisations, more specifically governmental research organisations, have to cope with various external environments. That is, they have to be accountable and responsible to the requirements of multiple customers and stakeholders. Also, they have to deal with the innovation of competitors or other organisations delivering similar services and products. The requirements of multiple customers and stakeholders, and the innovation of competitors have effects on the current knowledge, practices, interests, and agendas of project members about the development of the scanners. Project members must be prepared and willing to constantly change their current knowledge, practices, interests, and agendas to meet the multiple customers' and stakeholders' requirements as well as to compete with competitors' innovations for their success. Much willingness of internal actors is required to change their current knowledge and practices to respond to the external environment's actions. Likewise, Rainey and Chun (2009) suggested that many public sector managers must definitely be prepared to deal with vague, multiple, and conflicting goals. Strategic decision-making processes and performance management in public organisations, more specifically governmental research organisations, can be generally similar to private organisations. However, they are more likely to be subject to interventions, interruptions, and involvements of external authorities and influent parties. As a result, it is argued that cross-community collaboration and knowledge management in governmental research organisations seems to be complex and difficult.

Knowledge boundaries are related to professional identities (Liberati, Gorli and Scaratti, 2016; Smith, 2016; Kotlarsky, Hooff and Houtman, 2015; Haland, 2012; Kellogg, Orlikowski and Yates, 2006). That is, professions are special kinds of knowledge-based occupations and the form of knowledge (Haland, 2012). Professionals from different knowledge communities develop different professional identities (Wenger, 2000). Professional identities can be broadly understood as socially constructed demarcations (Liberati, Gorli and Scaratti, 2016). They occur as people engage in practices that produce and reproduce it over time (Smith, 2016). Professional identities give rise to a specification of roles and tasks. For instance, the hardware group is in charge of the development of the hardware and body of a scanner as well as the generation of raw X-ray photographs; whereas the software group is in charge of the development of software to generate high quality reconstructive X-ray photographs.

Professional identities provide a sense of belonging, a mean for collective identity-making, or who is on the inside and who is on the outside of the profession or the group (Liberati, Gorli and Scaratti, 2016; Smith, 2016; Haland, 2012). Also, professional identities provide enhanced self-esteem to it members, and in this sense, a strong professional identity can facilitate collaboration and knowledge management among members in the same communities (Smith, 2016). However, group formations based on a collective, group, or professional identity can lead to tensions and challenges as a result of competitive behaviour toward other different communities and a lack of trust as well as perceived status inequality, suggesting that knowledge boundaries can occur between different groups due to division between different identities (Liberati, Gorli and Scaratti, 2016; Smith, 2016).

In this case, project members labelled themselves and each other according to their educational background, their role in the project, and their organisational affiliation. Categorising oneself and others to a particular group can cause prejudice among project members and consequently affect cross-community collaboration and knowledge management (Smith, 2016; Kellogg, Orlikowski and Yates, 2006). For instance, the software group members perceive a difference in the setting of an X-ray detector system and the development of a scanner and express that the hardware group members do not understand about their job. One software group member said:

> They [the hardware group members] may not understand some things about the physical [aspect] of X-ray of a CT scanner. It is not just the development of machines in the case of the scanner […]. They must understand X-ray, a detector, and the effects of their actions on software and X-ray photographs […]. For example, a head support for patients, it had been changed many times because it did not work and it hit a detector. Finally, we [the hardware and software groups] had to change the head support to the chin and forehead rest to fix the problem [N1, P5, L152-161].

The hardware group members sometimes feel that the software group sticks with its image-processing concept [N6, P10-11, L342-368] (see the interviewee's statement on p.217).

Liberati, Gorli and Scaratti (2016), who studied boundaries that affect collaboration in multidisciplinary teams among doctors and nurses, argued that knowledge boundaries are difficult to bridge because they are connected with the professional socialisation. Therefore, it is important to defining professional identities in cross-community collaboration (Liberati, Gorli and Scaratti, 2016). According to Smith (2016), a professional identity boundary is one of six major types of knowledge boundaries which challenge cross-community collaboration and knowledge management. The research objectives of this are focused on disciplinary knowledge boundaries; more specifically, information-processing, interpretative, and political boundaries. It would be interesting to carry out further investigations by focusing on the occurrence of knowledge boundaries; more specifically professional, identities and mechanisms to manage knowledge across them, as well as the relationship between different types of knowledge boundaries such as professional boundaries, disciplinary boundaries, organisational boundaries and so on.

5.3.2. Ignorance of differences in knowledge of other people

The findings from this study, which have been presented in Section 4.5.2, extend a perspective on the construction of knowledge boundaries. They argue that knowledge boundaries arise when a member(s) of one knowledge community lacks a full understanding and awareness of differences in knowledge and disciplinary perceptions of the same phenomena of another interacting knowledge community. More specifically, knowledge boundaries arise when a member(s) of one knowledge community does not really fully understand and realise that the concepts and theories of one knowledge community might not be known, adopted, or followed in different practices by another different knowledge community. Several interviewees illustrated this point:

> Most electrical and software tasks are controlled by numeric values. If we [hardware group members] use such values to control hardware, we may not get results as required by the software group precisely. Each hardware component has standard errors [N7, P1, L14-24].

> When we [the hardware and software groups] connected software and electricity together; at the beginning we had some conflicts because we did not understand what each other group was. For instance, there were hardware standard errors and tolerances. Thus, it was unnecessary and impossible to set or assemble hardware as precise as the concepts of the software group [N7, P3-4, L105-110].

> The software group seems to think that 0 is always 0, while the hardware group thinks that it is impossible to be 0. This is because it must have some mechanical errors. The software group often tells the hardware group that the setting of the X-ray detector system and the scanner must be like this or that. However, in practice sometimes the hardware group cannot match the software group's concepts [N8, P1-2, L27-38].

The other two interviewees from the hardware group referred to the software group's beliefs on precision in the setting of the X-ray detector system. This interviewee expressed that the software group seems to embrace the view that the setting of the X-ray detector system must be as precise as perpendicular, at 90 degrees, or 0 mm. However, the hardware group argued that it is impossible to do this; see the interviewee's statement [N6, P10-11, L342-368] on p.217 and the interviewee's statement [N12, P5, L156-166] on p.217.

Similarly, Kotlarsky, Hooff and Houtman (2015), and Faraj and Xiao (2006), argued that members from different professions have difficulties in communicating with their counterparts. This is because they do not have an accurate awareness of the expertise of another team member or if team members find it difficult to understand each other. For instance, one participant from the software group commented on the amount of required knowledge and expertise of the hardware group members about the scanner development, expressing that:

> They [the hardware group members] may not understand some things about the physical [aspect] of X-ray of a CT scanner. It is not just the development of machines in the case of the scanner […]. They must understand X-ray, a detector, and the effects of their actions on software and X-ray photographs […]. For example, a head support for patients, it had been changed many times because it did not work and it hit a detector. Finally, we [the hardware and software groups] had to change the head support to the chin and forehead rest to fix the problem [N1, P5, L152-161].

The findings also suggest that when members of one community have less overlapping knowledge, understanding, and awareness of differences in the knowledge and disciplinary perceptions of another different community, they tend to believe that their tasks are more difficult than another different community's tasks. This stems from the statements of interviewees from the hardware and software groups; for instance:

> Both groups did not know each other. [...] I view that my tasks are difficult but the other group thinks that my tasks are easy [N8, P1, L26-29].

> Sometimes they [the hardware group members] may perceive that we [the software group members] do not do anything. They may perceive that changing software is very easy because they have a lack of understanding of the nature of the software group's tasks [N1, P1, L12-13].

> Sometimes the development of some software features takes much time but other people may not see these features. If other people do not really understand how such features are difficult to develop, they may perceive that the software group did not do anything. They may feel it is very easy to change software [N1, P1, L9-14].

Consequently, when problems occur, members of one group tend to dispute with the other different group to solve the problems. One group perceives that the other different group has to take responsibility to solve a problem rather than join in with the other group to solve it. For instance, two interviewees, the project manager and a member of the software group, perceived that the hardware group did not fully understand the operation of software to solve blurred X-ray photographs. Thus, when the scanner generated blurred X-ray photographs the hardware group criticised and disputed this with the software group. The two interviewees stated that:

> The software group asked the hardware group to improve the alignment of the X-ray detector system and the accuracy of the hardware assembly to solve blurred X-ray photographs. However, the hardware group retorted to the software group that other companies used software to fix the problem […]. The hardware group also expressed that the software group knew parameters to set the system, so why did the software group not fix the problem by developing new algorithms to rotate the photographs. The software group argued that hardware was as a water source of the photographs [N2, P7-8, L230-253].

By contrast, a hardware project member stated that:

> […] I believe that problems must be fixed by software at the end. Blurred X-ray photographs should be calibrated and compensated by software rather than hardware [N6, P10-11, L360-363].

The example mentioned above suggests that there is tension, difficulty, discontinuity, and conflict in relation to work tasks and procedures between different knowledge communities in their collaboration. Such tension, difficulty, discontinuity, and conflict are caused by lack of a full understanding and awareness of significant differences in knowledge and disciplinary perceptions as well as work activities and tasks of the other different interacting knowledge communities. Also, the above example presents that when difference and conflict occurs, one knowledge community tends to stay in its territory instead of entering into (some) overlapping territories between different communities in which they are unfamiliar and ignorant for cross-boundary collaboration. In other words, conflict impacts on interacting actors' work engagement and cross-community collaboration.

When members of one community have less overlapping knowledge, understanding, and awareness of differences in the knowledge and disciplinary perceptions of the other, different interacting community, they tend to criticise the ways of thinking and doing of the other interacting community.

According to the findings, which were presented in Section 4.5.1 (more specifically in i. Difference), Section 4.5.2, and Section 5.3, hardware and software communities represent different knowledge communities. The two communities have differences in knowledge background and skills that had been acquired from study by the hardware and software communities. Also, the two communities have different ways of thinking, values, interests, roles, and tasks based on what they had studied and been trained for in their communities. Consequently, the two communities have differences in knowledge and understandings about the same thing, the development of scanners.

The tensions which emerged between hardware and software communities are more likely to have resulted from perceived differences. For instance, the hardware community thinks about the beauty, fineness, and safety of a head support for patients; while the software community thinks about the effects of the head support on image processing and X-ray photographs [N13, P3-4, L92-110]. Also, the software community seems to attach its theoretical ideas to scanner development; while the hardware group seems to attach its practical ideas to it. The existing literature on cross-community collaboration and knowledge management has suggested that different disciplines have differences in many aspects, such as: ontological and epistemological approaches to problem definitions; traditions and the cultures of thought; assumptions; values; interests; interpretations; conceptual and methodological standards; analytical methods and techniques; and use of language (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Becher, 1994; Star and Griesemer, 1989; Biglan, 1973a; Kuhn, 1962). Moreover, each discipline determines, provides, and shares its framework of knowledge and concepts of theories, methods, techniques, and problems, with its members. Such differences lead to discontinuity of interaction between two (or more) actors or communities from different disciplines (Kotlarsky, Hooff and Houtman, 2015; Siedlok and

Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Carlile, 2004, 2002; Wenger 2000; Star and Griesemer, 1989).

Furthermore, tensions between hardware and software communities are more likely to have resulted from: did not know, understand, and aware differences in knowledge; disciplinary perceptions; nature; and the tasks of each other. For instance, there are differences in perspectives on precision in the setting of scanners between the two groups. The software group seems to embrace the view that the setting of scanners must be as precise as perpendicular; while the hardware group perceives that it is impossible because of the standard tolerances and errors of hardware. In addition, tensions between the two communities occurred because they perceive that their tasks are more difficult than the tasks of the other different community. Consequently, when problems occur, they tend to ask the other group to change and to solve the problems rather than join in problem solving with the other group [N2, P7-8, L230-253; N6, P10-11, L360-363] (see the interviewees' statements on p.267-268).

5.4. Management of knowledge across boundaries

As regards the third research objective of this study, how people manage knowledge across boundaries, the main findings from this study are in line with the existing literature in that there are three knowledge processes to overcome the three boundaries (see Section 4.6). These processes are knowledge transfer, knowledge translation, and knowledge transformation respectively (see Section 5.4.1). However, the findings from this study suggest some different boundary-spanning mechanisms which are used to overcome the three knowledge boundaries and to manage knowledge across them, which will be depicted in Section 5.4.1. For instance, face-to-face communication is used to transfer knowledge, as well as lexicon mediators being required to develop common languages or terminologies at an information-processing boundary. Furthermore, the findings argue that bureaucratic cultures in hierarchical organisational structures, and culture or a social compromise and harmony process, help to reduce conflicts between different communities for knowledge management and collaboration across boundaries (see Section 5.4.2 and Section 5.4.3 respectively).

5.4.1. Processes and mechanisms to overcome boundaries

5.4.1.1. Information-processing boundary; knowledge transfer process

The major challenge of an information-processing boundary is an increasing of capacity to process more (explicit or knowledge-what) knowledge, as well as making work visible and accessible to others to facilitate communication and coordination across a boundary (Kellogg, Orlikowski and Yates, 2006; Carlile, 2004). To overcome this challenge, the theorisation of information processing, transferring knowledge capacity and taxonomies, including storage and retrieval technologies, are suggested (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004). According to the findings in Section 4.6.1, in this case, information technologies played key roles in transferring knowledge at a boundary. For instance, the hardware group members sent parameters, results, and photographs about the set-up and operation of the scanner in the laboratory, field trials, or customers' sites to the other project members through instant messaging to inform and update them about the work being done [N13, P5, L142-145] (see the interviewee's statement on p.178). This suggests that (explicit or knowledge-what) knowledge can be captured, codified in media, and transferred from one interacting actor or group to another different interacting actor or group across contexts through information and communication technologies, and media (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004; Brown and Duguid, 1998; Nonaka, 1994).

The finding above substantiates the knowledge management literature, especially from an information system perspective. It suggested that knowledge management is regarded as the development and utilisation of organisational knowledge through information system management practices or transferring knowledge indirectly through technology (American Productivity and Quality Center, 2013; Suresh and Mahes, 2006; Andreu and Sieber, 2005; Jashapara, 2004; Ahmed, Lim and Loh, 2002; Swan, Newell, Scarbrough, and Hislop, 1999; Davenport and Prusak, 1998).

Another solution to overcome boundaries by being able to manage knowledge across them is by what have been called boundary objects (Star and Griesemer, 1989). Carlile (2002) adapted Star and Griesemer's four categories of boundary objects: repositories, standardised forms, objects or models, and maps of boundaries. Then, Carlile (2002) identified three key characteristics of boundary objects to overcome the three knowledge boundaries (see Section 2.8.1). At an information-processing boundary, a boundary object that establishes a shared language for actors to represent their knowledge is suggested (Carlile, 2002). For instance, the hardware group sent the assembly drawings of a gantry for an X-ray detector system to the software group via e-mail and instant messaging to check the accuracy of the drawings [N12, P6, L184-189]. The drawings could be considered as a boundary object because they serve as a medium in helping transmit knowledge and perspective between the hardware and software groups. They also provide a shared language for the two groups to represent their knowledge (Gal, Yoo and Boland, 2004; Bechky, 2003; Carlile, 2002). That is, the drawings as a representation are enhanced because the two groups are familiar with them. For the hardware group, the drawings represented critical tolerances and functional specifications. For the software group, the drawings provided a three-dimensional representation of the orientation of parts and critical issues for scanner assembly and testing.

In this case, know-what and explicit knowledge was also transferred from one group to the other different group through storage and retrieval technologies such as Dropbox. Parameters for the setting of an X-ray detector system, technical tests, program guides, and scanner user manuals were examples of the knowledge which was transferred through Dropbox. Dropbox could be considered a boundary object, specifically repositories (Star and Griesemer, 1989). This is because Dropbox is a repository or database of objects which members from the two groups can access and use for their own purposes. It supplies a common reference point for data and measures across the two groups that provide shared definitions for communication (Carlile, 2002; Star and Griesemer, 1989).

Unlike the previous theorisation of boundaries (e.g. Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002), the findings from this study, which have been presented in Section 4.6.1, found that at an information-processing boundary explicit or knowledge-what knowledge is not only transferred through information technologies and boundary objects as mentioned above. Knowledge is also transferred through face-to-face communication. This is because of the limitations of information technologies and the influence of individual power boundary brokers. This stems from the interview and observation data. For instance, theories, data, measures, and facts about scanner development were transferred from one project member to the others in monthly meetings such as parameters to set up mobile and dental CT scanners [O12, P4, L98-103], the results of clinical tests of a DR scanner, and the progress of the development of DR scanner user interfaces [O6, P1, L15-30]. This finding is in line with earlier studies which depicted that knowledge is transferred by informal discussion (Fong and Lo, 2005), and training (Edenius, Keller and Lindblad, 2010, p.144; Feng, Ye and Pan, 2010, p.1509). In this study, face-to-face communication was used as a tool for transferring knowledge because it helped a sender to transmit more details to a receiver(s). It also reduced time-consuming and unnecessary back-and-forth conversion, as well as minimised the risks of misreading of some information technologies such as e-mail and instant messaging by project members. Similarly, Cummings and Kiesler (2005) stated that the use of communication technologies such as e-mail, instant messaging, telephones, and video-conferencing, encouraged too many tasks and too little intra-project sharing and learning.

As mentioned above, in this case explicit or knowledge-what knowledge was transferred from one to the other project members through face-to-face communication, especially monthly meetings, because of the influence of individual boundary brokers. The individual boundary brokers, especially the project director, asked the other project members to set up a monthly meeting. This is in order to report and give updates on what work was being done and the issues of the scanner development to the other project members. Issues needing decisions by the project director were also brought to the monthly meetings. Furthermore, the project director used the monthly meetings as a channel to track the operations of the other project members. This suggests that information technologies and boundary objects play an important role in transferring knowledge at an information-processing boundary. However, the limitations of technology and the specific organisational context, more specifically the influence of individual boundary brokers, in which members are encouraged to transfer their knowledge through face-to-face communication, should always be considered together for knowledge transfer.

As mentioned above, in Section 4.6.1 and Section 5.3.1.1, some knowledge about the scanner development could be captured, codified, stored, retrieved, and sent from one group to the other different group through information technologies and boundary objects, including face-to-face communication. This knowledge could be transferred between the different groups because these groups had some common knowledge and language in engineering. In addition, differences and dependencies in knowledge between the two groups were known (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002).

Difficulties and information-processing boundaries arise when interacting actors from different knowledge communities lack common languages for communication and knowledge transfer. For instance, the hardware group found difficulties in communication with the software group because of lack of knowledge and understanding about software technical vocabularies; the examples have been presented in Section 5.3.1.1. To resolve this issue, two software group members, who seemed to have more knowledge and experience about hardware and software operation than the other project members and who were more widely known and more approachable, were asked to explain technical vocabularies to the other project members [N3, P18-19, L610-652] (see the interviewee's statement on p.215).

The two software group members mentioned above worked as lexicon mediators. That is, they are able to answer queries from other people. Especially, they are able to translate technical vocabularies created in one group into the language of the other different group where there are no common vocabularies to make sure that the different groups can understand what they send to each other (Kim and Jarvenpaa, 2008; Maaninen-Olsson, Wismen and Carlsson, 2008). They are able to do this because they have more overlapping knowledge between different groups. Carlile (2004) talked about (understanding) translators and boundary brokers at a semantic or an interpretative boundary (see Section 5.4.1.2). However, in this study, translators, more specifically lexicon mediators, were found at an information-processing boundary. This is because members from different groups lacked common languages for transferring their knowledge to the other members at a boundary.

Similarly, in the current work, Rosenlund, Rosell and Hogland (2017) used Carlile's model (2004, 2002) and Kellogg, Orlikowski and Yates' model (2006), to explore knowledge boundaries that occur in the development of environmental science and technology research collaborations between triple helix sectors: the university, industry, company, and public sectors. The findings suggested that the transfer of academic knowledge to outside academia at syntactic boundaries (Carlile, 2004, 2002) or information process-oriented boundaries (Kellogg, Orlikowski and Yates, 2006) requires a person who can work with knowledge transfer and a person who can function as an information translator and a gatekeeper regarding communication (Rosenlund, Rosell and Hogland, 2017).

5.4.1.2. Interpretative boundary; knowledge translation process

Section 4.6.2 and Section 5.3.1.2 explained the construction of an interpretative boundary. The development of common meanings and understandings between interacting actors from different knowledge communities is one of the major challenges at an interpretative boundary (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Feng, Ye and Pan, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Fong, Srinivasan and Valerdi, 2007; Carlile, 2004, 2002). Boundary interactions are one of the boundary-spanning mechanisms that help to create common meanings and understandings between different communities at an interpretative boundary by engaging members from different knowledge communities in activities (Kotlarsky, Hooff and Houtman, 2015; Hislop, 2013; Matthew, Hawkins and Rezazade, 2012; Edenius, Keller and Lindblad, 2010; Carlile, 2004; Wenger, 2000). Engaging in activities helps in sharing knowledge that cannot be expressed easily or where one group does not understand the knowledge of another group (Matthew, Hawkins and Rezazade, 2012; Boisot, 1998). That is, engaging in activities helps in creating shared meanings and understandings (Carlile, 2004; Dougherty, 1992), or reconciling different meanings, and understandings between different knowledge communities (Nonaka and Takeuchi, 1995). Similarly, the knowledge management literature, especially from a human and organisational perspective, argued that tacit knowledge is shared through social networking and social interaction, including social and organisational learning (Suresh and Mahes, 2006; Andreu and Sieber, 2005; Jashapara, 2004; Swan, Newell, Scarbrough, and Hislop, 1999). Engaging in activities also helps in identifying and learning about differences and dependencies in knowledge and tasks between different groups through discussions to develop common meanings and understandings between the groups (Matthew, Hawkins and Rezazade, 2012). For instance, two participants from the hardware group stated that: “we [the hardware and software groups] bring everything about that [the concepts of the scanner development] into meetings to fine-tune with each other” [N7, P2, L57-59]; and “there are discussions about how the necessary requirements of one group relate to the other group and how the capabilities of one group meet the requirements of the other group” [N8, P3, L73-75].

In this case, working together in the same place, training, and face-to-face meetings are key boundary interactions to develop common meanings and understandings, as well as to move knowledge across interpretative boundaries. These boundary interactions are often mentioned by most participants. From the interviews and observation, working together in the same place (e.g. a laboratory) helps to reconcile different meanings and develop common understandings between different groups in the project. It bridges gaps by engaging members from different groups in a process of co-development of knowledge and understandings (Matthew, Hawkins and Rezazade, 2012). For instance, from the observation of cross-boundary collaboration between the hardware and software groups in a laboratory, one hardware group member shared his knowledge about X-ray detector system operation with the software group members. This was to develop common understandings of the software group members about the cause of an X-ray delay. More specifically, the hardware engineer clarified the operation of electrical systems, controllers, X-ray detector systems, and X-ray shootings to the software group members. He explained that in theory a detector might take an electrical signal and then take X-ray photographs after 10 to 20 milliseconds. However, in practice a detector might take the signal and take the photographs after 12 to 18 milliseconds. Thus, before taking X-ray photographs the software group had to wait for an X-ray detector system to turn-on [O9, P2, L41-46].

From the example mentioned above, it suggests that the hardware and software groups have differences in knowledge and understandings about X-ray detector system operation and X-ray shootings. The software group seems to attach its theoretical ideas to X-ray detector system operation; while the hardware group seems to attach its practical ideas to it. Also, the hardware group seems to have more knowledge about X-ray detector system operation than the software group. To develop common understandings on X-ray detector system operation and the cause of an X-ray delay between the two groups, the hardware group members shared his knowledge and perspectives about it with the software group during tracking and solving X-ray delay in the laboratory together. The laboratory, from this example, could be considered as a boundary object. This is because it involves an overlap of practices and consists of different knowledge communities, the hardware and software groups, which work with different internal contents, the development of hardware and software of the scanners, but have overlap with each other (Star and Griesemer, 1989).

From the interview data, training is another important boundary interaction helping members from different groups to share, identify, and learn differences and dependencies in knowledge and tasks between the groups to develop common meanings and understandings. For instance, the software project manager stated that:

> We [the software group members] explained and set training for the hardware group [smile] to make them understand how software is developed, the components of software and the functions of each component, the components and functions of X-ray technologies, and the use of the software group's viewer and planning software. Working together needs participation and getting involved between the two groups. Then, the two groups will begin to understand the effects of one part and one group on the other parts and the other groups [N1, P9, L290-293].

As the statement above exemplifies, training becomes a boundary-spanning mechanism helping one group to transfer knowledge to another different group. It also helps project members from different groups to identify and learn about differences and dependencies in knowledge and tasks between each other. Therefore, common meanings and understandings between different groups could be developed.

In this case, a boundary broker is another significant boundary-spanning mechanism used to overcome interpretative boundaries (Matthew, Hawkins and Rezazade, 2012; Carlile, 2004; Wenger, 2000). A boundary broker is defined as a human agent who has intercommunity social relationships to stay at the boundaries of different communities to translate, coordinate, and align between the knowledge and practices of the different communities (Gasson, 2005a; Brown and Duguid, 1998, p.103; Wenger, 1998). Some researchers label boundary brokers differently such as: boundary crossers (Hayes and Fitzgerald, 2009); marginal people (Star and Griesemer, 1989, p.411); knowledge brokers (Dalkir, 2005; Jashapara, 2004); or boundary spanners (Matthew, Hawkins and Rezazade, 2012, p.1803; Kim and Jarvenpaa, 2008, p.1; Levina and Vasst, 2005, p.338). The findings from this case suggest that the political influences of individual boundary brokers are important in the development of common meanings and understandings between interacting actors from different knowledge communities.

The project director and the project managers of the hardware and software groups, in this case, are powerful boundary brokers. They use their power to pull members from different groups to work together and create connections between them. They also use their power to encourage and facilitate communication and interaction between different groups to share knowledge and perspectives and to discuss unclear points for the development of common understandings between them. They build trust and improve the relationships, awareness, and environment of working between different groups. Examples and details are depicted below.

Grounded in the interview data, the project director is the most important and powerful boundary broker. As one interviewee suggested: "there are not any other strong points in this project besides the project director [smiles]" [N9, P10, L321]. From documentation [D9], the project director had a high profile. That is, the project director received his Bachelor Degree from Imperial College London and a Ph.D. degree from Cambridge University. He has been chairman and director of many organisations, both public and private. His former positions are, for example, a permanent secretary of the Ministry of Science and Technology, the president of King Mongkut's Institute of Technology Ladkrabang and the president of NSTDA from 1998 to 2004. He received Director Accreditation from the Thai Institute of Directors. He is the recipient of numerous Thai Royal decorations as well as national and international awards and honours. He has gained the confidence of the Thai Royal family as well. He has been a senior advisor and senior researcher of NSTDA since 2005. From the interview data and documentation, more specifically a project presentation [D10], this research project was started by the project director. He used his political influence and capabilities in organisational and project management as well as knowledge and skills in research project areas, especially digital signal processing to motivate and pull researchers from different disciplines together for doing this project. As one interviewee, the hardware project manager, stated:

> He motivated people to work together. He was an attractive magnet for setting-up this project [N6, P1, L12-13].

> The director is a powerful and senior actor. He has a lot of knowledge and experience in research […]. It is not easy to set up a big project like this, but he could pull resources to set up and support it. So, it is a good opportunity for me to join in this project [N11, P1, L56-63].

Due to the background of the project director and the above interviewees' statements, it suggests that the high profile, ability, and power of the individual boundary brokers in hierarchical organisational structures play an important role in cross-boundary working. It is able to attract the other individual project members' attention and admiration. It is also able to influence the behaviour and attitude of the other individual project members to participate in cross-boundary working. From the above interviewees' statements, it suggests that project members believe that their director possesses knowledge and experience which goes beyond their own capacity. Thus, they should follow their director's requirements and directions. Similarly, Sinthavalai (2008), and Yodwisitsak (2004) argued that many Thai employees usually believe that people who are in higher hierarchical levels possess knowledge and experience more than those who are in lower levels. Thus, they should follow such people's guidance and instructions. The project members also trust the project director, and then agree to participate in the project. This suggests that interpersonal trust between project members and the project director plays a crucial role in shaping project members' motivation, attitude, and willingness to participate in cross-community collaboration. Relatedly, Matthew, Hawkins and Rezazade (2012, p.1803) stated that boundary brokers possess personality, political skills, and cognitive capabilities that enable them to succeed despite legitimacy, trust, and membership issues.

From the interview and observation data, the project director uses his power and project management capability to facilitate and coordinate communication and collaboration between different communities of both internal and external actors to support this project. That is, he facilitates and coordinates communication and collaboration between the hardware and software groups in the project. He also facilitates and coordinates communication and collaboration between the two groups and other different groups both inside and outside the organisation. For instance, the project director uses his power to request monthly and other meetings between the hardware and software groups to keep informed about work progress and to discuss issues about the development of the scanners [O1, O4, O6, O12]. Also, he stays at a boundary of the two groups to encourage and engage in sharing elements of practices by handling meetings. In one monthly meeting, for instance, the software group shared knowledge about parameters and new algorithms for setting a mobile and a dental CT scanner with the other project members; more specifically, the accuracy of hardware setting and the quality of X-ray photographs from the scanners [O12, P4, L98-103]. The knowledge was shared to develop the common knowledge and understandings of the project members, especially the hardware group members. A meeting is as a common place where members from different groups could share, identify, inquire, and learn differences and dependencies in knowledge and tasks from each other to develop common knowledge and understandings in the same phenomena and things (Gasson, 2005a; Carlile, 2004; Wenger, 2000; Star and Griesemer, 1989).

In addition, the project director creates a sense of commitment between the hardware and software groups which allows them to share their knowledge and perspectives with each other. Then, it helps to maintain the balance and manage the relationships between the two groups (Kimble, Grenier and Goglio-Primard, 2010). For instance, from the observation data, in a monthly meeting the project director asked and discussed with the project members, especially the project managers, about the application of the project mobile CT scanner to diagnose and operate on cleft lip and cleft palate in children. The project managers and members of both groups shared viewpoints about the possibilities of the scanner development with the project director and the other project members. Specifically, they discussed the modes of taking X-ray photographs, the physical characteristics of children and the scanner, and the possibilities of the use of the project mobile CT scanner on children. After the meeting, the two groups were assigned by the project director to study and report about the age and height ranges of children to identify where the scanner could be used with different child groups [O6, P1, L6-12]. Without the project director's power, proactively encouraging interaction and communication, and creating a sense of commitment between different groups, collaboration across groups is difficult. As one interviewee from the software group stated:

> If the project director did not push forward this project, we could not really pull human resources to work together and get commitments from project members to complete their tasks [N1, P2, L43-44/53-58].

Also, the project director uses his power to connect external actors from different knowledge communities and functions to share knowledge and perspectives with project members. This is in order to develop knowledge and understandings for coordination and support the project. For instance, the project director asked the members of the Business Development Unit to share knowledge and perspectives about the business development of the research project with project members to develop a more effective business plan for it [O12, P2, L34-44]. This suggests that the project director creates connections not only between members from different groups in the project, but also between these project members and members of other different groups and functions. He also engages in the knowledge sharing phenomenon between different groups.

The project director uses his power to connect external actors from different groups and functions to discuss unclear points with project members in order to develop common understandings and reduce conflicts. For instance, the project director invited the deputy executive director of National Electronics and Computer Technology Center (NECTEC), which the software group was under, to discuss the organisational research assessment system with project members. That is, project members perceived that this project was large, difficult, and complex as well as creating high social impact. However, the organisation assessed small or large and low or high impact research projects with the same criteria. Consequently, project members perceived and complained that the research assessment system was not appropriate and should be revised. At the end of the meeting, the deputy executive director stated that he would discuss this issue with the board of the organisation to find solutions [O12, P3, L69-88]. This suggests that the project director creates connections and facilitates communication between project members and members from other different groups and functions. He also stays at a boundary between different groups to encourage and engage in sharing different perspectives on the same thing in order to develop common understandings among them to foster coordination

From the example mentioned above, the development of common understandings between members from different knowledge communities is an activity at an interpretative boundary – a semantic boundary (Carlile, 2004, 2002) or representation practices (Kellogg, Orlikowski and Yates, 2006). However, using the political influence of boundary brokers such as the project director to ask members from different knowledge communities to discuss unclear points, especially to consider their actions which have effects on the other groups' actions and practices to reduce conflicts or disagreements, is related to the other type of knowledge boundary; a political boundary – a pragmatic boundary (Carlile, 2004, 2002) or assembly practices (Kellogg, Orlikowski and Yates, 2006). Thus, it is argued that there is overlapping between different knowledge boundaries (see Section 5.2.1).

The other boundary brokers of this case are the project managers of the two groups. They create connections as well as encourage and facilitate cross-community communication and collaboration between the two groups to develop common knowledge and understandings. For instance, from observation data the software project manager asked an engineer of the hardware group to come into the laboratory to investigate and solve the problem of X-ray delay with the software group. In the laboratory, the hardware engineer shared his knowledge and clarified the operations of electrical systems, controllers, and X-ray shooting with the software group to develop common understandings about the cause of X-ray delay [O9, P2, L41-46] (see the full observation notes on p.221).

The project managers also work as pairs (Wenger, 2000) to improve and maintain relationships and collaborations between the two groups. They reconcile negative attitudes and criticisms of members from one group about the other group that can create conflicts between them. This helps to improve awareness and the environment of collaboration between the two groups. As one interviewee, the hardware project manager, illustrated:

> Some members of my group [the hardware group] criticised the software group that the software group should do like this or that, it was very easy. But I told them that it looked easy for us because we did not do it and we were outsiders […]. I had to explain to my members and make them understand that what the software group made may look easy in our eyes but the software group had to fix many things to reach our requirements [N5, P7, L236-242].

This suggests that members from different groups have different perspectives and ways of thinking about the same things and phenomena (Wannenmacher and Antonie, 2016; Siedlok and Hibbert, 2014; Hislop, 2013; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Becher, 1994). They also tend to attach their different perspectives and ways of thinking to the same things and phenomena across groups and practices (Dougherty, 1992). Such different perspectives and ways of thinking of one group may not be known, understood, and considered by members of other different groups. Consequently, misunderstandings and conflicts in collaboration between different groups occur. To resolve this issue, in this case, a boundary broker identifies differences and dependencies in knowledge and tasks between different groups to encourage project members to learn and give attention to these differences and dependencies. This is in order to develop common understandings and reconcile the negative perspectives of members of one group about the other different group. Doing this can lead to improvement of the relationships, as well as the awareness and environment of coordination between different groups.

As the sets of findings and the examples mentioned above show, the project director and the project managers are powerful boundary brokers in this case. They use their knowledge and capability, including political influence in hierarchical structures to play significant roles to bridge gaps between different communities. It is argued that the political influences of individual boundary brokers have a great impact on the development of common understandings between different communities. Due to the knowledge, capability, and strong political influence exhibited by the individual boundary brokers to act as bridges across boundaries mentioned above, political boundaries, which will be depicted further in Section 5.4.1.3, between different communities are reduced as well. That is, when different perspectives between interacting actors from different communities are identified, learnt, and acknowledged, when mutual understandings between them are being developed, when negotiations tend to be built, and when conflicts between them are reduced, political boundaries or different interests are reduced. This finding argues that the agency of individual powerful boundary brokers has effects on the shifting of knowledge boundaries. Knowledge boundaries and processes to overcome the boundaries can be affected by the role and degree of political influence that the individual boundary brokers have and perform. Therefore, the importance of the political influence of individual boundary brokers on knowledge boundary shifts should be the object of more careful/greater consideration.

Moreover, the findings from this case, which have been presented in Section 4.6.2, suggest that enormous and asymmetric responsibility, which tends to be found in public sector organisations (Mares, 2013; Adel and Shaghayegh, 2010; Cong and Pandya, 2003), affect involvement in the social interactions and the community of practice of project members. The social interactions and the community of practice is a major solution for sharing tacit knowledge (Nonaka, 1994), and a major mechanism for developing common understandings between actors from different communities at an interpretative boundary (Carlile, 2004). For instance, from the interview and observation data, some project members left monthly meetings. This is because they thought that they had other important and urgent tasks as well as a backlog of work to do [O1] (see p.185). This suggests that these project members pay less attention to participating in social interactions with the other project members for sharing and learning knowledge because of workloads. Similarly, Riege (2005) argued that people normally focus on the tasks that are more beneficial to them. Time limitations and workloads can be a reason why people may potentially ignore spending time to share their knowledge with others (Riege, 2005).

From the interview data, there was a comparison of responsibility and output between governmental research organisations and companies delivering similar services and products. Members in a governmental research organisation, from the participants' perspectives, tended to do their jobs slower than members in a company. This is because members in a governmental research organisation had many parallel jobs to do, and had workload and asymmetric responsibility. By contrast, members in a company seemed to be assigned to focus on specific jobs; a company also tended to have a large number of members. Consequently, companies tended to be able to deliver their services or products faster than governmental research organisations. For instance, two interviewees from the two groups talked about asymmetric responsibilities in the project:

> Our researchers must invent, manufacture, and assemble the scanners by themselves. So, they may work slower than companies [N4, P3, L82].

> We are not able to catch up with the launch of new models of another scanner manufacturer because we are limited by the number of project members. The hardware project members have other jobs which are not related to the development of CT scanners. We are very slow to develop a dental CT scanner version 2; while companies might spend six months or one year to develop it [N5, P7, L220-223].

Similarly, some scholars argued that responsibilities in the government sector can be enormous and tend to be asymmetric; while responsibilities in private sector organisations are more clearly balanced (Mares, 2013; Adel and Shaghayegh, 2010; Cong and Pandya, 2003).

From the interview and observation data including a project presentation [D7], this project consisted of four parallel sub-projects. Most project members were assigned to participate in more than one sub-project. Also, some researchers and engineers in the project had not only a scientific role, but also a sales role because of a limit on the number of project members. Moreover, most hardware group members had to conduct other projects which were not related to this project. Many participants from both groups complained about their asymmetric responsibilities and a limit on the number of project members which prevented prompt action and had effects on their feeling in their tasks:

> I have to do everything by myself. I work like all-in-1. I do not want to work like this. Research and technical staff have to design, develop, assemble, and find out customers by themselves [N6, P8, L269].

> I am very tired [laughs]. I would like to have time to look at each scanner because some scanners have not been completed yet and need to be improved further, but they must wait [N1, P12, L410-411].

Due to the asymmetric responsibilities and workloads of project members, as noted from the interview data, project members lacked time to share knowledge with the other project members. Consequently, the other project members had limited access to the knowledge for learning and developing common knowledge and understandings among them [N11, P14, L469-482] (see the interviewee's statement on p.229).

This suggests that lack of time and the workloads of project members have effects on the provision of means to make some tacit knowledge explicit to allow the other project members access to that knowledge. Lack of time and the workloads of project members thus affected project members' eagerness and willingness to share their knowledge with the other project members. Project members may want to access that knowledge to develop their common knowledge and understandings. Similarly, Riege (2005), and Lilleoere and Hansen (2011) argued that time limitations could be a reason why people might potentially keep their knowledge to themselves rather than spend time to share knowledge with others. Similarly, Maaninen-Olsson, Wismen and Carlsson (2008) argued that lack of time has effects on the willingness and possibility to understand each other's knowledge and to integrate knowledge in cross-community collaboration. Therefore, lack of time and workloads have a negative impact on an actor's attitude to sharing and integrating knowledge as well as to collaborate with others in cross-boundary working.

Furthermore, lack of time to make some tacit knowledge explicit could create tension and discontinuities in coordination among project members in cross-boundary working when project members leave the organisation. For instance, one interviewee, the software project manager, stated that:

> The hardware group members did not often create documents to record what they did. If one of the members leaves, the project lost their knowledge. Consequently, the existing or new project members did not have documentation to refer to. They thus had to waste resources and time to restart the scanner development [N1, P8, L270-271].

To resolve this issue, from the interview and observation data, the project is trying to use the implementation of ISO 13485 as a tool to encourage project members to record what they do in documentation [O11]. Some scholars argued that organisations should play a key role to resolve this issue. They suggested that leadership and organisations should allocate time and offer enough space to enhance communities of practice and social interaction among employees. This is to allow people to take time to generate, reflect, share, and integrate knowledge in cross-disciplinary collaboration (Amayah, 2013; Seba, Rowley and Delbridge, 2012; Akhavan, Hosnavi and Sanjaghi, 2009; Maaninen-Olsson, Wismen and Carlsson, 2008).

5.4.1.3. Political boundary; knowledge transformation process

According to the findings in Section 4.6.3 and the discussion on the construction of a political boundary in Section 5.3.1.3, political boundaries, in this case, mainly occurred because of different interests in the development of the scanners between project members and external actors such as customers, funding agencies, and subsidiaries. More specifically, these external actors' requirements had influences on project members' decision-making, considerations, activities, services, and products. Consequently, project members had to change their current knowledge, practices, interests, and agendas in scanner development constantly to take account of, and respond to, a diversity of external actors' requirements for their survival and success. Similarly, project members had to constantly change their current knowledge, practices, interests, and agendas in scanner development to compete with other organisations delivering similar services and products. Examples were presented in Section 4.6.3 and 5.3.1.3.

In this case study, different interests and conflicts between internal actors from different knowledge communities were mainly reduced by the agency of boundary brokers (see Section 4.6.2 and Section 5.3.1.2). Moreover, from the interview data, the political boundaries between internal actors were reduced by having common goals (Carlile, 2004). Common goals are regarded as the direction of thoughts and actions of members from different knowledge communities in the project. This stems from the statement of one interviewee from the hardware group: “we [the hardware and software groups] have the same goal which is the development of a prototype of the scanners and transfer technology for commercialisation” [N3, P11, L384]. From the interview data, common goals encourage members of one group to perceive other members from different groups in the project as working together as partners. Consequently, they are likely to cooperate and help each other to reach their common goals together. For instance, one participant from the software group suggested that:

> We [the hardware and software groups] are like partners, so we go towards a goal together. We are bound together. We have a same goal. That is, Hey! Brother [it refers to the hardware project manager], why is it slow, something like that. When problems occur, we will help each other to solve the problems together [N1, P5, L146-147/149-150].

In addition, negotiation and compromise between different groups helps to resolve conflicts and develop common interests at a political boundary (Carlile, 2004, 2002). For instance, the software group agreed with the hardware group to postpone the modification of some hardware components to improve a collimator as a requirement of the software group because of time-limitations and priorities [N13, P8, L275-280].

According to the findings in Section 4.6.3, the developed scanners, the X-ray photographs, and the project Gantt charts are the main boundary objects at a political boundary. They facilitate knowledge transformation between different groups both between the hardware and software groups as well as between these two groups and the external environment. The scanners and the X-ray photographs are created and used by different groups in the course of their collaboration. They represent different knowledge and functional interests from the different groups. Also, they represent complex relationships between different groups in a way that facilitates communication and coordination by de-personalising the discussion between them on functions, efficiencies, costs, and trade-offs (Wenger, 2000; Cook and Brown, 1999; Star and Griesemer, 1989). The project Gantt charts are the maps of boundaries (Carlile, 2004). They consist of tasks involved in the project, work flow, and start and finish dates of the summary elements of the project including who will be responsible for each task. They help to clarify differences and dependencies in knowledge and tasks between different groups in the project (Carlile, 2002). Therefore, the project Gantt charts offer, in effect, a map of boundaries to clarify differences, dependencies, and boundaries that exist between the two groups (Carlile, 2002).

Furthermore, the findings in Section 4.3.2 and 4.6.3 argue that bureaucratic cultures in hierarchical organisational structures, and culture or a social compromise and harmony process help to reduce conflicts, especially political boundaries, between different communities for knowledge management and collaboration across boundaries (see Section 5.4.2 and Section 5.4.3 respectively).

5.4.2. Hierarchical organisational structures and cross-community collaboration and knowledge sharing

As mentioned in Section 5.1, some of the existing literature on cross-community collaboration and knowledge management has addressed how knowledge is managed across boundaries, often in the context of industry (e.g. Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004, 2002). However, many studies on knowledge management have indicated that knowledge management in the public sector has some peculiar challenges. One of the well-known challenges that confront knowledge management efforts within the public sector is the bureaucratic culture found in hierarchical organisational structures (Hislop, 2013; Chong, Salleh, Ahmad and Sharifuddin, 2011; Seba and Rowley, 2010; Akhavan, Hosnavi and Sanjaghi, 2009; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Yao, Kam and Chan, 2007; O'Riordan, 2005; Syed-Ikhsan and Rowland, 2004).

Hierarchical organisational structure is defined as a system in which power, decision-making, and responsibility of members in an organisation are clearly identified and allocated to each member according to standing, status, and authority in the hierarchy (Hislop, 2013; Chong, Salleh, Ahmad and Sharifuddin, 2011; Seba and Rowley, 2010; Akhavan, Hosnavi and Sanjaghi, 2009; Rainey and Chun, 2009; Al-Alawi, Al-Marzooqi and Mohammed, 2007; Alvesson and Sveningsson, 2007; Yao, Kam and Chan, 2007; O'Riordan, 2005; Syed-Ikhsan and Rowland, 2004; Kärreman, Sveningsson and Alvesson, 2002). The basic hierarchy structure looks like a pyramid: members with a higher level or position in an organisation are in charge of the levels below and report to the levels above (Wyman, 2007). The members with a higher level also have the power to make decisions regarding the work situation of their members with a lower level (Wyman, 2007).

The case involved in this thesis is a research project in a governmental research organisation. According to the findings, which have been presented in Section 4.3.2, the case presents some characteristics which tend to be normally found in hierarchical organisational structures. That is, the project director is at the top of the pyramid of the project and has two project managers reporting to him. These two project managers are situated on the middle level of the pyramid of the project. They are the bosses of the other project members at the bottom of the pyramid. The project director creates a direction and mandates initiatives to the project managers, who then turn this direction into tasks to be carried out by the front-line project members. The project director and the project managers have power to make decisions regarding the tasks of the other project members. Moreover, the flows of decision-making and communication are vertically up and down the chain of command; the line that gives orders and makes decisions follows from top to bottom (Heathfield, 2016). Furthermore, the matters of documentation and issues of decision-making and communication tend to be defined according to standing, status, and authority in the hierarchy of member in the project (see Section 4.3.2).

The findings from this case, which have been presented in Section 4.3.2, indicate that the participants have an overall positive perception of the hierarchical organisational structure in the project. For instance, one participant from the software group talked about the positive effect of the hierarchical organisational structure on the allocation of responsibility among project members [N1, P11, L362-373] (see the interviewee's statement on p.186). This example points out the hierarchical levels of project members by comparison between the project director and the front-line or junior project members. It suggests authority, responsibilities, and job functions which are clearly defined and allocated among project members from the different levels in a hierarchy. Heathfield (2016) argued that in a hierarchy, the authority, responsibilities, and job functions of each member are clearly specified and allocated. Everyone knows exactly what his authority, responsibilities, and job functions are. Consequently, no one seems to be confused about differences, dependencies, and boundaries among project members. By contrast, confused authority, responsibilities, and roles among project members can create gaps in who is responsible for certain tasks, where no-one feels it is their job to do that task. The consequences of having gaps are blaming and fault finding. Who ought to have assigned it to someone, who should have done it without being asked or at least should have noticed it was not being done. This situation can lead to conflicts, disjointed efforts, and lack of coordination. Moreover, the above interviewee's statement suggests that project members generally accept the task allocation of the project according to standing and authority in the hierarchy. Project members are like cogs in a wheel. They have different responsibilities and job functions in the project. Each cog is essential to make the wheel turn.

Furthermore, the findings argue that members in cross-boundary working may actually desire some form of control in a hierarchy to manage authority, responsibilities, and human resources among them. This stems from the statements of two interviewees from the software group:

> If this project did not have actors in a higher level such as the project director, we have nothing to force the other group [N2, P14, L486-487].
>
> Doing a big project like this requires actors with a higher level in a position of a deputy director […]. This is because they have authority to order project members to do this or to do that as well as to manage human resources" [N1, P9, L311-314].

This suggests that the non-hierarchical nature of cross-boundary working might make this challenge more complex and difficult.

Due to different levels of authority among project members, the project director and the project managers with a higher position in the project have more power to make decisions regarding the other project members' tasks. However, in this case, the project director tends to have a more general overview. For instance, one participant from the software group suggested that "the project director looks at plans; he does not know about bugs in software or where to buy this hardware" [N2, P9, L297-300]. Therefore, the other project members with a lower position are deemed better suited to make decisions regarding the execution of their specific tasks. In this case, project members with a lower position have authority to make decisions on their specific tasks. Some interviewees illustrated the allocation of decision-making among the project members by using the hierarchical organisational structures:

> The project director is a key decision maker […] but he does not make decisions in minor issues. He looks at direction and strategy […]. If there are technical problems about the scanners, each group will look at the problems [N4, P4, L127-137].

> For the software group, if there are problems about plans, the project manager will make decisions. If there are problems about programming, the front-line members will make decisions. However, we [the project manager and members of the software group] will talk to each other again to discuss about solutions [N2, P8, L253-256].

What transpires from the examples above is that there are different levels of authority and rights to make decisions among project members in the hierarchical organisational structures. The project members with a higher position such as the project director and the project managers are key decision makers. They have power to make decisions regarding the tasks of project members but in a more general overview. The other project members with a lower position still have the rights to make decisions regarding the execution of their specific tasks. Thus, the hierarchical organisational structures, as perceived by most participants in this case, are not considered to be hampering freedom and reducing rights in decision-making among the project members. They help to allocate and manage authority and responsibilities among project members. They help to clarify differences and dependences in knowledge, authority, and responsibilities among project members.

According to the findings and examples mentioned above, it is argued that the involvement of project members in cross-boundary working should rely on a system in which the authority, responsibilities, and job functions of project members are clearly specified and allocated. This is because such systems can help to reduce confusion about authority, responsibilities, and roles among project members which can create gaps among them. Moreover, the system needs to give opportunities and rights to project members to express their perspectives and make decisions according to the execution of their specific tasks. Similarly, Castro (2015) suggested that actor members in knowledge broking activities cannot rely on a too restrictive and coercive logic. This is because it may cause a disengagement of actor members.

Dale (2011) argued that where an organisation has several layers of hierarchy the organisation also has the potential for miscommunication. However, the findings from this case argue that the hierarchical organisational structures, as perceived by most participants, are not considered to be a cause of miscommunication. They do not limit communication between project members in different levels. This might be because the project managers, who are situated on the middle level of the pyramid of the project, are able to carry messages between actors who are situated on the top and bottom levels of the pyramid. They act as a representative or a person who speaks officially for their groups' members. In addition, recorded communication is used to transfer information from one individual or group to another individual or group. For instance, the software project manager explained that:

> Not everyone meets up with the project director […]. Important issues, which have effects on members at the bottom level, are told to those members by me [the project manager]. I also try to ask the other project members to record meeting minutes for transferring information in meetings to the other project members [N1, P12, L384-388].

The hierarchical organisational structures create clear lines of communication and give project members clear spokespersons; members know who to report to and where to get knowledge and directives from. They also point to clear scopes and subjects of communication and knowledge sharing among project members based on the authority and responsibilities of project members. For instance, one participant from the software group explained that:

> When we talk about the types of knowledge that are shared within the project, we have to consider the levels of project members. If there are sales and marketing or other issues at a higher level, they will be discussed among the project managers and senior project members at the higher level. If the topics are technical issues, they will be discussed among members at a lower level [N1, P7, L239-241].

The above example suggests that there are levels of knowledge sharing within the project based on the levels of project members. Different topics or subjects are shared and discussed among different levels or sets of members in the project based on their authority and responsibilities. Project members quite clearly define types of documents and subjects which are shared and accessed among them depending on their authority and responsibilities in the project (see Section 4.3.2). For example, technical documentation about the scanner development is rarely shared with the project director because he looks after the overall picture of the project. Documents about sales and marketing are mainly shared among the project members who have a sales job in the project.

Some scholars argued that a hierarchical and bureaucratic organisational culture is negatively related to levels of knowledge dissemination within organisations (Stock, McFadden and Gowen, 2010; Seba and Rowley, 2010). However, in this case, this is not considered to be a barrier to shared and accessed knowledge among project members. Rather, it is considered to be a proper way to manage shared knowledge within the organisation which is matched with the project members' responsibilities. For instance, one participant from the software group talked about the key reason for the task allocation and sharing knowledge based on authority and responsibilities of project members as that: "[…] If everyone does everything, it does not work and takes much time […] try to allocate tasks among project members" [N1, P11, L362-373] (see the interviewee's statement on p.186).

Dale (2011), and Seba and Rowley (2010), argued that the hierarchical organisational structures inhibit or slow down most sharing practices. In this case, one interviewee from the software group indicated that the hierarchical organisational structures make work slower in terms of decision-making, communication, and taking action. This is because decisions and communications must move up and then back down the chain of command. The interviewee stated that the situation is:

> Quite difficult because of coordinating with many people […] and different levels is quite difficult [N4, P7, L235-237]. Members who are situated on the top level have the authority of decision-making. Sometimes we contact with and ask some members to do something but they have no authority to make decisions to do that. Consequently, they must ask their managers first [N4, P7, L245-247].

As mentioned above, a hierarchical organisational structure has both advantages and limitations to cross-community collaboration and knowledge management. Therefore, there is a need to consider effective organisational structures for knowledge management and collaboration across boundaries.

5.4.3. Social compromise and cross-community collaboration and knowledge management

The findings from this study, which have been presented in Section 4.6.3, extend the existing literature on cross-community collaboration and knowledge management by depicting that there is a positive relationship between some social cultures and knowledge management across boundaries. That is, the findings suggest that some Thai cultural traits such as 'Kreng jai', which can be found through compromise and saving face (Pongsakornrungsilp, 2011), help to reduce conflicts between actors at a political boundary. This stems from the statement of one interviewee from the software group: "the hardware and software groups rarely have conflicts because Thais compromise" [N2, P11, L379]. Kreng jai or being afraid of offending is one aspect of Thai culture. It is defined as the situation where there is the potential for discomfort or conflict but an individual tries to take another person's feelings into account (Pongsakornrungsilp, 2011; Holmes and Tantongavy, 1996). It is considered as a social harmony process where Thais are always concerned about the feelings of other people (Pongsakornrungsilp, 2011). For instance, one interviewee from the software group seemed to be afraid of talking about a comparison between the quality of the project's scanners and another scanner manufacturer's scanner. This interviewee said that "I can talk about that, right?" [N4, P2, L59]. This suggests that this interviewee was afraid to offend her colleagues in the project by saying that the scanners of another scanner manufacturer are better than the scanners of the project. Kreng jai tends to be strongly found in the network where there are strong relationships or social ties among members (Pongsakornrungsilp, 2011; Yodwisitsak, 2004).

Another example, from the observation data; the project had been suffering from the inaccurate setting of the gantry and the resulting oblique X-ray photographs. To resolve these issues, the project director asked the other project members to focus on the gantry setting, especially the alignment of the gantry, the detector, and the X-ray photographs. The project director also suggested that the project members should have hardware checkpoints to examine the hardware operation. Then, the software project manager expressed some disagreement with the operations of the hardware group by saying that "looking at X-ray photographs in a final stage of the scanner development is too late". However, the hardware project manager just replied that "we lacked knowledge about the different accuracy degrees of the gantry setting which could create the different quality levels of the X-ray photographs". That is, the software group seemed to blame the gantry setting of a detector and the generation of X-ray photographs on the hardware group. By contrast, the hardware group argued that this problem occurred because of lack of accurate parameters for the gantry setting from the software group [O12, P6, L104-110].

What transpires from the above situation is that there is conflict in coordination between the two groups about the inaccurate setting of the gantry. It affects raw X-ray photographs which are an input of the software group. However, both groups try to keep quiet rather than argue; they avoid criticism, and just make a few comments on the issue for finding solutions. This is because the two groups are afraid to offend and make their partners lose respect and lose face in the meeting. This is due to cultural concerns about losing face. Pongsakornrungsilp

(2011), and Yodwisitsak (2004) argued that Thais are always concerned about taking another person's feelings into account. They were always afraid of offending other individuals or parties. They usually avoided making any criticism because the person who had been criticised would have been perceived as losing face. Consequently, the conflict between the two groups is not escalated. The conflict is resolved by the two groups, which are perceived as partners, through a culture of compromise to reach their common goals together. However, Kreng jai or being afraid of offending may obstruct the learning process. This is because it may effect both interaction and conversation among members who have different knowledge and perspectives (Pongsakornrungsilp, 2011; Holmes and Tangtongtavy, 1997). It may inhibit or decrease sharing different knowledge and perspectives of different groups.

5.5. Framework for managing knowledge across boundaries

As stated by the findings from this study which are compared with the literature on knowledge management and boundary spanning, Figure 5.1 below illustrates types of knowledge boundaries that can emerge at interactions between members from different knowledge communities. It also presents knowledge processes to deal with these boundaries for managing knowledge across them in order to explain how knowledge can be managed in such contexts.

In Figure 5.1 there are three increasingly complex knowledge boundaries that can occur at interactions between members from different knowledge communities: namely, information-processing, interpretative, and political boundaries. Moreover, there are three increasingly complex knowledge processes that are used to manage knowledge across these boundaries: knowledge transfer, knowledge translation, and knowledge transformation. Each type of boundary is categorised, showing the interrelated complexity of a boundary according to the relational properties of knowledge between different knowledge communities at a boundary, as: differences, dependencies, and novelties (Carlile, 2004, 2002) (see Section 5.3.1 for types of knowledge boundaries and Section 5.4.1 for knowledge processes and mechanisms to overcome the boundaries). When novelty increases the diagram spreads, scaling the increasing complexity and the amount of effort required to manage knowledge across boundaries. As a boundary moves up in complexity, the process and capacity at a more complex boundary still requires the processes and capacities of those below it. The linear Venn diagram is used in this framework to present relationships between knowledge boundaries and processes to overcome them.

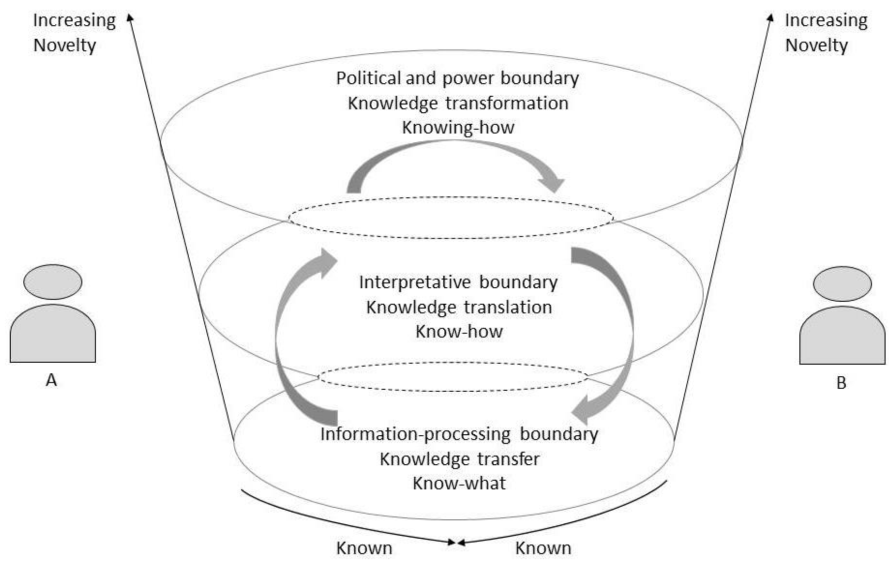


Figure 5.1 Framework for managing knowledge across boundaries

The findings from this study suggest that boundaries are dynamic and tend to evolve and change throughout the project life cycle, depending on the work that has to be done as well as the context and issues of interactions between interacting actors' different knowledge communities and boundaries (see Section 5.2.1). Thus, the circular arrows are applied among the three knowledge boundaries to represent this. Moreover, the dashed lines between knowledge boundaries are used in this framework to represent that the transition of boundaries, or where one boundary ends and another begins, is not clearly and easily identified. Boundaries are blurred and often co-existing and overlapping (see Section 5.2.1). The dynamics and simultaneity of knowledge boundaries have been suggested by the following recent studies in the subject area of this study: Lindberg, Walter and Raviola (2017); Smith (2016); and Le Dain and Merminod (2014). The dashed lines between knowledge boundaries are also used in this framework to represent that sometimes the categorisation of knowledge boundaries is not often easily made because different actors face the same phenomenon but perceive them as different types of knowledge boundaries in the three-tier model (see Section 5.2.2). This finding extends the theorisation of knowledge management across boundaries in that the difficulty of knowledge management across boundaries is not just that members from different disciplines have differences in languages, interpretations, and interests that create knowledge boundaries (e.g. Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Farag, Jarvenpaa and Majchrzak, 2011; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). The difficulty is also that the same phenomena are possibly seen by others as different types of knowledge boundaries; individuals perceive them in the light of their own experience and knowledge bases.

To explain the transition of knowledge boundaries in Figure 5.1, briefly, an information-processing boundary is placed at the bottom of the diagram. It emerges when dependencies and differences in knowledge between interacting actors from different knowledge communities are known and when common languages are developed that are sufficient to manage knowledge at a boundary (Rosenlund, Rosell and Hogland, 2017; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Thus, an information-processing boundary focuses on a process of knowledge transfer (Rosenlund, Rosell and Hogland, 2017; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004). The theorisation of information processing, transferring knowledge capacity, taxonomies, information technologies, and storage and retrieval technologies are suggested to overcome the challenge at this boundary (Rosenlund, Rosell and Hogland, 2017; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002).

The findings from this study extend the theorisation of boundaries by suggesting that (explicit or know-what) knowledge at an information-processing boundary is not only transferred through information technologies and boundary objects. The knowledge is also transferred through face-to-face communication. This is because of the limitations of information technologies and the political influence of individual boundary brokers in the case study. This suggests that technology and boundary objects play an important role in transferring knowledge at this boundary. However, the limitations of information technologies and the organisational context as the political influence of individual boundary brokers encourage actors to transfer their knowledge through face-to-face communication.

The findings from this study also suggest that difficulties and information-processing boundaries arise or increase from lack of common languages for communication and transferring knowledge between interacting actors from different knowledge communities. To resolve this issue, lexicon mediators are required. Lexicon mediators are individuals who have more overlapping knowledge between different knowledge communities and who are able to answer the queries of other people. Especially, lexicon mediators are individuals who have the ability to translate vocabularies created in one group into the language of another different group to make sure that the different knowledge communities can understand what they have sent to each other. Carlile's (2004, 2002) theorisation of boundaries talked about translators; more specifically understanding translators, and boundary brokers at another boundary. In this study, translators; more specifically, lexicon mediators, were found at an information-processing boundary. This is because members from different knowledge communities need bridges to develop common languages for communication and transferring their knowledge to another member at a boundary (an information-processing boundary and a knowledge transfer process; see Section 5.3.1.1 and Section 5.4.1.1 respectively).

The transition from an information-processing boundary to an interpretative boundary occurs when the degree of novelty of knowledge between interacting actors from different knowledge communities arises. Novelty generates different interpretations of the same things and phenomena between interacting actors from different knowledge communities (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Therefore, an interpretative boundary focuses on a process of knowledge translation (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). Making (tacit or knowledge-how) knowledge explicit to create common interpretations and understandings between different knowledge communities is one of the major challenges at this boundary (Carlile, 2004, 2002) (an interpretative boundary and a knowledge translation process; see Section 5.3.1.2 and Section 5.4.1.2 respectively).

The findings from this study suggest that the enormous and asymmetric responsibility, which tends to be found in public organisations (Mares, 2013; Adel and Shaghayegh, 2010; Cong and Pandya, 2003), affects the provision of means to make some tacit knowledge explicit among project members. That is, the enormous and asymmetric responsibility affects participation among project members to allow them to share their knowledge with another for developing common knowledge and understandings. Project members mainly focus on the tasks that are more beneficial to them. Therefore, they do not potentially give their attention to joining in social interactions for sharing their knowledge with the other project members. They do not potentially give their attention to converting some of their tacit knowledge into media (see Section 5.4.1.2).

The transition from an interpretative boundary to a political boundary occurs when the further increasing novelty of knowledge between members from different knowledge communities results in different interests – conflicts thus emerge (Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). To manage knowledge across boundaries it is not enough just to understand differences between different knowledge communities. Individuals and groups must also be prepared to change their own knowledge, practices, and interests when the knowledge of one individual and knowledge community affects the knowledge of another (Carlile, 2004, 2002). The findings suggest that, due to the strong political influences of boundary brokers in the development of common understandings among internal actors, political boundaries between internal actors are reduced. In this case study, political boundaries mainly occur from different interests between internal actors and external environments (a political boundary and a knowledge transformation process; see Section 5.3.1.3 and Section 5.4.1.3 respectively).

The findings argue that knowledge management across boundaries; more specifically at a political boundary, in public organisations seems to be difficult and complex to deal with. This is because most public sector organisations have to respond to the requirements of multiple parties as stakeholders. Therefore, the members of the public sector organisations must be prepared and willing to change their current knowledge, practices, interests, and agendas to account and respond to their stakeholders' requirements for their existence. At the same time, some public sector organisations such as governmental research organisations must compete with competitors or organisations delivering similar services and products. Innovations by competitors constitute an overwhelming pressure on governmental research organisations to change and improve their knowledge and practices to compete with them. Furthermore, the actions of external environments can create different interests and political boundaries among internal actors in the same knowledge communities (see Section 5.3.1.3).

The findings from this study extend the literature on knowledge management across boundaries by paying attention to the importance of organisational and cultural contexts in cross-boundary knowledge management and collaboration. They suggest that there is a positive relationship between Thai culture as 'Kreng jai' or being afraid of offending and knowledge management across boundaries. 'Kreng jai' can be found through saving face (Pongsakornrungsilp, 2011; Yodwisitsak, 2004). It is considered as a social harmony process where Thais are afraid to offend, criticise, and make other people lose respect and lose face (Pongsakornrungsilp, 2011). Consequently, conflicts between interacting actors from different knowledge communities in the project, which are perceived as partners, are not escalated. The conflicts are reduced and resolved by different knowledge communities through a culture of compromise and harmony. However, this culture may inhibit the learning and sharing knowledge process by limiting action and conversation among members who have different knowledge and perspectives (Pongsakornrungsilp, 2011; Holmes and Tangtongtavy, 1997) (see Section 5.4.3).

For boundary objects to manage knowledge across a political boundary, boundary objects which facilitate the knowledge transformation process are required (Carlile, 2004). That is, boundary objects which provide a means for interacting actors to specify and learn about differences and dependencies in knowledge between different knowledge communities as well as to transform knowledge used by another different community in a way that supports coordination between different communities, are required (Carlile, 2004, Star and Griesemer, 1989). The developed scanners, the X-ray photographs, and the project Gantt charts are example of boundary objects at this boundary (see Section 5.4.1.3).

Table 5.1 below presents a comparative summary of the three types of knowledge boundaries as well as knowledge processes and boundary-spanning mechanisms to manage knowledge across them. Those where this study extends the existing literature on the subject are indicated by plus signs (+).

<table>
<tr><th></th><th>Information-processing boundary</th><th>Interpretative boundary</th><th>Political boundary</th></tr>
<tr><td>Defining situation</td><td>• Differences and dependencies in knowledge between actors are known
• Common language is developed that is sufficient to transfer knowledge at a boundary

+ Novelty generates different languages that are unknown</td><td>• Novelty creates differences and dependencies in knowledge between actors that are unclear – different interpretations emerge</td><td>• Novelty creates different interests and agendas in knowledge and tasks between actors (among internal actors or between internal and external actors) that hinder their ability to manage knowledge and collaborate across a boundary
• Knowledge and interests in one actor affect another</td></tr>
<tr><td>Focus</td><td>• An effective transmission of knowledge</td><td>• Developing common meanings and understandings</td><td>• Discovering differences and dependencies between actors and changing the current knowledge and creating new knowledge to resolve consequences required at a boundary</td></tr>
<tr><td rowspan="2">Solution</td><td>• Knowledge transfer
• Transferring knowledge capacity
• Boundary objects (e.g. taxonomies and storage and retrieval technologies)

+ Face-to-face communication
+ Lexicon mediators</td><td>• Knowledge translation
• Translating knowledge capacity
• Boundary objects (e.g. standard forms and methods)
• Boundary interactions (e.g. meetings, work in the same place, and training)
• Boundary brokers (e.g. brokers and pairs)</td><td>• Knowledge transformation
• Transforming knowledge capacity
• Boundary objects (e.g. maps or prototyping)

+ Culture or a social compromise and harmony process</td></tr>
<tr><td colspan="3">+ The role and degree of actions and political influences of individual boundary brokers</td></tr>
</table>

	Information-processing boundary	Interpretative boundary	Political boundary
Challenge	+ The limitations of technologies to transfer knowledge at a boundary + Developing common languages • Increasing capacity to transfer more explicit knowledge • A common language is necessary but not always sufficient to manage knowledge across a boundary	+ Asymmetric responsibility reduces the social interactions of one member with another and the sharing of knowledge • Making tacit knowledge explicit • The creation of common meanings to manage knowledge across a boundary often requires the creation of new agreements	• Changing knowledge • The creation of common interests to manage knowledge across a boundary often requires practical and political effort and investment in time and compromises in valued community practices and interests + Culture or a social compromise and harmony process may obstruct the learning process
	+ The dynamic, simultaneity, and overlapping of knowledge boundaries + Looking at the same things and phenomena but perceiving them as different types of knowledge boundaries + Lacking a full understanding and awareness of differences in knowledge between interacting actors from different knowledge communities		

Table 5.1 Comparative summary of boundaries

Interdisciplinary research and development organisations can be considered as key tools for the convergence of researchers and scientists from different scientific backgrounds and the advancement of integrated scientific and technical knowledge (Avila-Robinson and Sengoku, 2017). However, members of different disciplines have fundamental differences in many aspects such as the framework of knowledge, the traditions and the cultures of thought, assumptions, values, interests, interpretations, standards, analytical methods and techniques, including the use of language, which their members have studied, been trained in, and performed tasks in (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Ylijoki, 2000; Davenport and Prusak, 1998; Becher, 1994; Star and Griesemer, 1989; Biglan, 1973a; Kuhn, 1962). This points out tensions and challenges in collaboration and knowledge management in interdisciplinary research and development organisations. Three types of knowledge boundaries can occur in collaboration and knowledge management between members from different disciplines in the organisations. These three boundaries are named in this thesis as information-processing, interpretative, and political boundaries. They occur because of lack of common languages, understandings, and interests in communication and collaboration between members of different disciplines respectively.

The findings from this study depict a complex picture of collaboration and knowledge management in interdisciplinary research projects in (interdisciplinary) research and development organisations. They suggest that different types of knowledge boundaries can occur in a project consecutively, overlapping, or simultaneously. Different practices and interactions between actors from different disciplines in a project determine which boundaries emerge (Lindberg, Walter and Raviola, 2017; Smith, 2016). Also, they highlight that people can perceive the same things and phenomena as different types of knowledge boundaries in the three-tier model. This highlights that multiple knowledge boundary types and multiple boundary-spanning mechanisms can exist and are required at the same process or same stage in a project simultaneously. Furthermore, a complex picture of collaboration and knowledge management in interdisciplinary research projects in (interdisciplinary) research and development organisations is depicted by indicating the construction of knowledge boundaries as a result of ignorance of differences in knowledge and perspectives of other different people.

Collaboration and knowledge management in interdisciplinary research and development organisations involves converging different knowledge, disciplinary perceptions, ways of thinking, and ideas for solutions from two or more disciplines. Integration is identified as a key characteristic of interdisciplinary collaboration (Alexarje, 2012; Pratt, 2012; Stock and Burton, 2011; Russell, Wickson and Carew, 2008; Russell, Wickson and Carew, 2008; Sumner and Tribe, 2007; Rogerson and Strean, 2006). It involves the (re-)combination of knowledge from different disciplines through processes of knowledge transfer, knowledge translation, and knowledge transformation (Carlile, 2004, 2002). Knowledge transfer, translation, and transformation play important roles in the knowledge management process and collaboration of interdisciplinary research and development teams. This is because interdisciplinary researchers need to send and receive knowledge across boundaries, develop accurate understandings for sharing knowledge across boundaries, and change the current knowledge and create new knowledge to resolve the consequences required in collaboration. To improve the degree of knowledge transfer, translation, and transformation, boundary objects, boundary brokers, and boundary interactions are suggested. They facilitate communication, collaboration, and knowledge management between members from different disciplines in interdisciplinary collaboration in (interdisciplinary) research and development organisations (Holford, 2016; Abraham, Aier and Winter, 2015; Hislop, 2013; Hoffmann, 2012; Akkerman and Bakker, 2011; Kimble, Grenier and Goglio-Primard, 2010; Kim and Jarvenpaa, 2008; Maaninen-Olsson, Wismen and Carlsson, 2008; Fong, Srinivasan and Valerdi, 2007; Carlile, 2004; Wenger, 2000; Davenport and Prusak, 1998; Star and Griesemer, 1989).

Organisational and social culture and context play a key role in the development of boundary-spanning mechanisms and solutions to manage knowledge across boundaries and to reduce tensions in collaboration in interdisciplinary research projects in (interdisciplinary) research and development organisations. More specifically, in this case, there is: the impact of bureaucratic cultures in hierarchical organisational structures; the power of individual boundary brokers, who are at the top of the pyramid of a project; and social compromise and harmony process, on the effectiveness of collaboration and knowledge management across disciplinary boundaries. The framework for managing knowledge across boundaries was thus developed (see Figure 5.1 and Table 5.1).

5.6. Summary

This chapter discusses the findings from this study against the existing literature on knowledge management and boundary spanning. Some of the findings substantiate the existing literature on the subject in that there are three increasingly complex knowledge boundaries: namely, information-processing, interpretative, and political boundaries; and three processes to overcome them: knowledge transfer, translation, and transformation (Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). In addition, the findings are similar to the current literature on the subject in that boundaries are dynamic - different types of knowledge boundaries are performed at the same time, and within the same process (Lindberg, Walter and Raviola, 2017; Smith, 2016; Le Dain and Merminod, 2014).

The evaluation in Section 5.2.2 to 5.5 argues that the findings from this study provide a more nuanced and granular view of boundaries in interdisciplinary collaboration than what is suggested by the literature review by bringing a multiple perspective lens to the subject. The findings argue that knowledge management and collaboration across boundaries is more complex to deal with than suggested in the literature. They suggest: differences in individuals' perceptions and experiences of what types of knowledge boundaries occur; and the construction of knowledge boundaries arises from ignorance of differences in knowledge and disciplinary perceptions between interacting actors from different knowledge communities. They suggest the influence of organisational and cultural contexts; more specifically, bureaucratic cultures in hierarchical structures and a social compromise and harmony process, on cross-community collaboration and knowledge management. Also, they suggest the tensions and challenges of the operation of organisations and the knowledge management across boundaries; more specifically, knowledge transformation, due to the hybrid nature (Gulbrandsen, 2011) of the organisations.

Firstly, for three progressively complex knowledge boundaries and knowledge processes to manage knowledge across them, the findings argue that at an information-processing boundary knowledge is not only transferred through information technologies and boundary objects but also through face-to-face communication. This is because the limitations of information technologies and the political influence of individual boundary brokers encourage the use of face-to-face communication to transfer knowledge at a boundary. In addition, the previous studies suggested that the existence of common languages and storage and retrieval technologies were enough for transferring knowledge at this boundary. This is because differences and dependencies in knowledge between different communities had been known. However, this thesis argues that when novelty generates different languages that are unknown, lexicon mediators are required to develop common languages between different communities for transferring knowledge at a boundary.

At an interpretative boundary the findings argue that the political influences of individual boundary brokers have a significant impact on the development of common meanings and understandings between different communities. Furthermore, the agency of powerful boundary brokers influences the shifting of knowledge boundaries. The capability to be a bridge across communities and the strong political influence of boundary brokers helps: to create connections; to develop common understandings; to keep a balance; to manage relationships; to build trust; and to improve awareness and create a good working environment among interacting actors. Consequently, conflicts at another boundary, a political boundary, are reduced. At an interpretative boundary, asymmetric responsibility, which tends to be found in governmental organisations, hinders the participation of interacting actors in social interactions and knowledge sharing activities. It reduces opportunities for interacting actors to share and access the knowledge of another actor for developing common meanings and understanding among them.

The findings argue that a political boundary tends to be more complex and occur more often in public sector organisations than in private sector organisations. This is because public sector organisations have to account and respond to multiple stakeholders in both the public and private sectors. They must also compete with other organisations delivering similar services and products. Responses to the requirements of stakeholders and innovations by the other organisations are an overwhelming pressure on the knowledge transformation of members in public organisations. They have to (be prepared to) change their current knowledge, practices, and agendas to account and respond to the stakeholders' requirements, and to compete with the other organisations.

Secondly, the findings argue that the nature of boundaries is dynamic and tends to evolve and change throughout the project life cycle, depending on the work that has to be done, as well as the context and issues of the interactions between interacting actors from different knowledge communities. Boundaries are often co-exiting and overlapping (Lindberg, Walter and Raviola, 2017; Smith, 2016; Le Dain and Merminod, 2014). This makes knowledge management across boundaries more laborious than is depicted in the literature.

Thirdly, the difficulties of knowledge management across boundaries not only arise from crossing or overcoming different types of knowledge boundaries. The difficulties of this subject also arise from different actors facing the same things and phenomena but perceiving them as different types of knowledge boundaries, depending on what types and amount of knowledge that they have for the phenomena, how they are affected by them, and how much change they feel is involved for them.

Fourthly, knowledge boundaries arise not just from differences in knowledge and disciplinary perceptions between interacting actors from different knowledge communities. Equally importantly, they arise from lack of a full understanding and awareness of these differences between interacting actors. Due to lack of a full understanding and awareness of the differences, the members of different knowledge communities think that their tasks are more difficult than those of another community. When problems occur, they tend to dispute with another community to solve the problems rather than solve the problems together. This situation affects the learning process and coordination across boundaries.

Fifthly, there is a positive relationship between Thai culture as 'Kreng jai' or being afraid of offending and a reduction in conflicts between interacting actors from different knowledge communities, especially at a political boundary. This suggests that culture or a social compromise and harmony process might shape interacting actors' attitudes and behaviour in interaction with others in cross-community collaboration, especially knowledge transformation at a political boundary. However, this culture may obstruct the learning process by limiting different perspectives from others.

Finally, the findings argue that bureaucratic cultures in hierarchical organisational structures in governmental organisations have positive effects on knowledge management and collaboration across boundaries. A clear authority and responsibility of each member of the hierarchical structures help to reduce confusion among members in their coordination. Confused authority and responsibilities can lead to disjointed efforts and lack of coordination. Clear lines of communication and giving members clear spokespersons within the hierarchical structures help members know who to report to and where to get information from. As advantages of the hierarchical structures, they, as seen by most members in the case study, are not considered to be hampering freedom and creating miscommunication. They are not considered to be a barrier to communication between members in different levels. This opens up the thought of the hierarchical structures as something that might be desired by workers in cross-boundary working.

The purpose of the next and final chapter (Chapter 6: Conclusions) is to draw out how this study can increase theoretical and practical knowledge.

6. Conclusions

6.1. Contributions to knowledge and theoretical implications

The concept of knowledge boundaries is one of the key concepts in the organisational and knowledge management field. The importance of cross-boundary collaboration has been recognised in this field since the early 1990s. This is because the creation of most new knowledge leading to innovation, which is regarded as a central resource of organisations to succeed in the knowledge economy and globalisation, often occurs at a boundary between different disciplines or knowledge communities (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Mailhot, Gagnon, Langley and Binette, 2016; Smith, 2016; Wannenmacher and Antonie, 2016; Scarbrough, Panourgias and Nandhakumar, 2015; Siedlok and Hibbert, 2014; Jahn, Bergmann and Keil, 2012; Akkerman and Bakker, 2011; Edenius, Keller and Lindblad, 2010; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Russell, Wickson and Carew, 2008; Cummings and Kiesler, 2005; Carlile, 2004; Bronstein, 2003; Tranfield, 2002; Davenport and Prusak, 1998; Katz and Martin, 1997; Star and Griesemer, 1989). Innovation can be new ideas, new methods, new ways of doing things, advanced services and products, new technologies, and new artefacts. It can also be a recombination of old ideas (Edenius, Keller and Lindblad, 2010). Moreover, most organisations face multifaceted issues that are part of an increasingly complex business environment such as: crises in energy and food production; the progress of technology which is playing a more important role in economic and social development; and changes in global trade rules and regulations which affect commerce (Maglaughlin and Sonnenwald, 2005; Bronstein, 2003). Connecting and integrating knowledge from different disciplines is necessary to gain a better understanding of the complex and interconnected nature of the issues for the development of more comprehensive and effective solutions (Jahn, Bergmann and Keil, 2012). In addition, no single individual will possess all required knowledge, skills, and techniques to make contributions in more than a very narrow area of work or inquiry (Katz and Martin, 1997). Consequently, there is an emphasis on seeking for connections and collaborations across disciplines to reduce the limiting effects of specialisation and fragmentation of knowledge of individuals (Hislop, 2013; Akkerman and Bakker, 2011; Wenger, 2000; Katz and Martin, 1997).

Many authors have studied knowledge management across boundaries. However, they have predominantly focused their studies on particular contexts, especially new product development and information technology in private sector organisations (e.g. Holford, 2016; Kotlarsky, Hooff and Houtman, 2015; Scarbrough, Panourgias and Nandhakumar, 2015; Hsu, Chu, Lin and Lo, 2014; Le Dain and Merminod, 2014; Kimble, Grenier and Goglio-Primard, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Carlile, 2004, 2002). Much of the previous work has adopted the linear three-tier model for managing knowledge across boundaries (e.g. Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Mailhot, Gagnon, Langley and Binette, 2016; Smith, 2016; Wannenmacher and Antoine, 2016; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Tortoriello, Reagans and McEvily, 2012; Farag, Jarvenpaa, and Majchrzak, 2011; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). There are different labels for the three levels of knowledge boundaries used in the model; however, there is a strong similarity in what the levels are. Carlile (2004, 2002) named the three boundaries: syntactic, semantic, and pragmatic boundaries. Many other scholars have used these labels (e.g. Lindberg, Walter and Raviola, 2017; Smith, 2016; Kotlarsky, Hooff and Houtman, 2015; Le Dain and Merminod, 2014; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Tortoriello, Reagans and McEvily, 2012; Farag, Jarvenpaa, and Majchrzak, 2011; Yates and Paquette, 2011; Edenius, Keller and Lindblad, 2010; Maaninen-Olsson, Wismen and Carlsson, 2008; Fong, Srinivasan and Valerdi, 2007). These three boundaries are named: display, representation, and assembly practices by Kellogg, Orlikowski and Yates (2006). They are named: information process-oriented, cultural, and political boundaries by Rosenlund, Rosell and Hogland (2017). Edenius, Keller and Lindblad (2010, p.136), and Kellogg, Orlikowski and Yates (2006, p.23) argued that the organisational literature on knowledge management and coordination across boundaries can be understood in terms of three primary perspectives: (i.) the information-processing aspects, the information-processing perspective, or the information-processing orientation; (ii.) the cultural aspects; and (iii.) the political aspects or the political and power perspectives.

As well as not agreeing a settled terminology, it does not seem that the existing studies have yet arrived at a consensus as to how different contexts can influence the linear three-tier model; more specifically: the construction of knowledge boundaries; the processes of knowledge management across boundaries; and mechanisms for managing knowledge and collaboration across disciplinary boundaries. Yet assessing the model in different contexts makes it not only possible to identify similarities and differences but also to open a broad perspective and to create an understanding of the subject. A rigorous debate about the challenges that can occur and to develop guidance for knowledge management across boundaries is needed.

Furthermore, the existing studies have only suggested the transition of the three levels of knowledge boundaries, or where one boundary ends and another begins. It does not seem that they have yet depicted the dynamic nature, co-existence, and simultaneity of the three levels of knowledge boundaries in the model. In the current studies, Le Dain and Merminod (2014) argued that Carlile's three-tier model for managing knowledge across boundaries (2004, 2002) explains the transition of the three knowledge boundaries as an iterative process related to the level of novelty of knowledge between interacting actors. However, the model did not consider the relative intensity of each boundary and knowledge process according to the activity of the interactions between interacting actors. Lindberg, Walter and Raviola (2017) and Smith (2016), argued that the model explains boundary emergence and spanning occurrence as a static construct and in a linear way and that only one type of knowledge boundary exists at any one time. Lindberg, Walter and Raviola (2017) and Smith (2016), argued that the processes of boundary work are dynamic whereby different types of knowledge boundaries occur at the same time, and within the same process. In addition, the existing studies have mainly depicted that knowledge boundaries arise from differences in knowledge backgrounds and terminologies, including differences in interpretations and interests in the same things and phenomena between interacting actors from different knowledge communities.

Given the rather limited range of contexts in which the model has been assessed to date and how the nature, construction, and dynamics of its boundaries have been depicted, the aim of this thesis was to explore the nature of boundaries and how knowledge is managed across them, particularly in a public sector setting. This aim was translated into the following four research objectives:

i. To explore the nature of boundaries;
ii. To explore why knowledge boundaries arise;
iii. To explore how people manage knowledge across boundaries; and
iv. To develop a framework for managing knowledge across boundaries.

In order to answer these research objectives, a case study research approach was selected, together with an interdisciplinary research project to develop Computerised Tomography (CT) and Digital X-Ray (DR) scanners in a governmental research organisation, the National Science and Technology Development Agency (NSTDA), in Thailand. This research project was an ongoing joint project between two different knowledge communities from different disciplines and from different national research centres under NSTDA; more specifically, between electronics and computer technology, and metal and materials technology. This research project is one large and well-known project of NSTDA. It is considered successful in terms of interdisciplinary collaboration because it proposed the first development of the cone-beam CT scanner in Thailand, called DentiiScan. The dental CT scanners, version 1, of this project have been used in both public and private hospitals in Thailand. The project scanners have created social impact on Thais' health, well-being, and social care (see Section 3.5.2 for research case study).

An interpretative methodology was adopted as a research framework because it enabled the researcher to explore multiple viewpoints and meanings that actors attach to complex situations of the subject of the study (Saunders, Lewis and Thornhill, 2015; Matthews and Ross, 2010) (see Section 3.1 for research philosophy). In accord with the aim and objectives of the thesis, a multi-method qualitative approach; semi-structured face-to-face interview; participant observation; and collection of documentation and other artefacts, was selected to collect data (see Section 3.6 for data collection methods). Data were analysed through thematic analysis (see Section 3.7 for data analysis).

The contributions of this study to the knowledge management area; more specifically, knowledge management across boundaries, are grouped into four points as follows.

6.1.1. Nature of boundaries

This research looked at the subject of the study by adding consideration to the details of activities, actions, and interactions between interacting actors at each type of knowledge boundary. In regard to research objective one, the findings contribute knowledge to the theorisation of boundaries and the three-tier model by suggesting that boundaries are more complex than usually thought. The findings give a more complex picture of the nature of boundaries. Paying attention to the detail of activities, issues, and contexts in interactions between interacting actors from different knowledge communities, helps to specify the complex nature of boundaries. That is, the nature of boundaries is dynamic and tends to evolve and change throughout the project life cycle depending on the work that has to be done as well as the context and issues of interactions between interacting actors from different knowledge communities. There is co-existence, simultaneity, and overlapping of boundaries. This is by contrast to the existing literature and the three-tier model which mainly illustrate the transition from one type or level of knowledge boundary to another as an iterative and linear process related to the level of novelty in knowledge between interacting actors from different knowledge communities. Consequently, the challenges of the nature, categorisation, fluidity, and management of knowledge boundaries are not fully captured in previous work. Thus, this thesis contributes to the theorisation of boundaries and the three-tier model. It suggests that studies on cross-community knowledge management and the three-tier model need to look at the detail of activities, issues, and contexts in interactions between interacting actors from different knowledge communities related to each type or level of knowledge boundary. This is in order to get a better understanding of the knowledge management in such contexts; especially the nature, categorisation, fluidity, and management of knowledge boundaries which are dynamic, blurred, and complex. This contribution is similar to the findings which have been presented in some recent studies, more specifically Lindberg, Walter and Raviola (2017) and Smith (2016). These studies argued that the processes of boundary work were dynamic; different types of knowledge boundaries are performed at the same time, and within the same process.

The findings from this thesis provide more a more nuanced and granular view as well as depicting multiple perspectives on knowledge management and collaboration across boundaries compared to the concepts and the findings identified from the existing literature. The findings from this thesis suggest that knowledge management across boundaries is more complex than the existing literature suggests. This is because, faced with the same phenomenon, different individuals experience it as different types of knowledge boundaries in the three-tier model. This depends on the current knowledge that individuals have of the phenomenon, how they are affected by it, and the extent of changes that they feel the phenomenon requires. Previous studies have not identified this point yet. Differences in individuals' perceptions and experiences of the same phenomenon as different types of knowledge boundaries in the three-tier model make cross-community collaboration and knowledge management even more difficult. Sometimes boundaries are not easily compartmentalised. Similarly, different knowledge processes and boundary-spanning mechanisms might be required at the same time to overcome different knowledge boundaries. This suggests that studies on cross-community collaboration and knowledge management, and the three-tier model, need to take account of other different levels, especially at an individual level, and individuals' perceptions of knowledge boundaries, to gain a better understanding of the phenomenon of knowledge management and collaboration across boundaries.

6.1.2. Construction of knowledge boundaries

The findings confirm the usefulness of the three-tier model for clarifying and gaining understanding on cross-community collaboration and knowledge management in an interdisciplinary research project in a governmental research organisation. That is, in response to research objective two, relating the findings to the existing literature, it was found that there are three increasingly complex knowledge boundaries that exist in interactions between interacting actors from different knowledge communities (Lindberg, Walter and Raviola, 2017; Rosenlund, Rosell and Hogland, 2017; Smith, 2016; Fellows and Liu, 2012; Majchrzak, More and Faraj, 2012; Farag, Jarvenpaa, and Majchrzak, 2011; Yates and Paquette, 2011; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004, 2002). These three boundaries, identified in this thesis, are named as information-processing, interpretative, and political boundaries. They are distinguished through the increasing magnitude of difference, dependence, and novelty in knowledge between individuals or groups of individuals from different knowledge communities (Carlile, 2004, 2002).

An information-processing boundary occurs when differences and dependencies in knowledge between interacting actors from different communities are known. Also, interacting actors from different knowledge communities share the same stable terminology. Consequently, (know-what or explicit) knowledge can be transferred from one actor or group of actors to another different actor or group through information technology and boundary objects at a boundary (American Productivity and Quality Center, 2013; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Suresh and Mahes, 2006; Andreu and Sieber, 2005; Carlile, 2004; Jashapara, 2004; Ahmed, Lim and Loh, 2002; Brown and Duguid, 1998; Davenport and Prusak, 1998; Nonaka, 1994). Difficulties arise when interacting actors from different communities do not have common terminology for sending and receiving knowledge; knowledge could not then be transferred at a boundary. Thus, the development of common terminology is required.

Having only common terminology is not sufficient to manage knowledge across the other boundaries; interpretative and political boundaries. This is because members from different communities tend to interpret and understand the same things and phenomena in different ways based on what they were trained for (Siedlok and Hibbert, 2014; Akkerman and Bakker, 2011; Sumner and Tribe, 2007; Hislop, 2005; Carlile, 2004; Wenger, 2000; Becher, 1994). Therefore, an interpretative boundary, the second knowledge boundary, occurs; the knowledge translation process and the development of common interpretations and understandings are required to manage knowledge at such a boundary (Matthew, Hawkins and Rezazade, 2012; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004; Wenger, 2000; Dougherty, 1992).

Just having common languages and interpretations is not sufficient to manage knowledge across boundaries. This is because the novelty of knowledge generates different interests and political boundaries, the third knowledge boundary, between interacting actors from different knowledge communities (Kellogg, Orlikowski and Yates, 2006; Carlile, 2004). A political boundary occurs when knowledge in one knowledge community affects knowledge in another different community. The knowledge transformation process, or changes in the current knowledge and practice of interacting actors, has to be used to develop common interests between different communities to manage knowledge at this point (Carlile, 2004).

Due to the consideration of the influence of context on the construction of knowledge boundaries, the findings from this thesis suggest that the hybrid nature of public research and development organisations introduces challenges in relation to the occurrence of knowledge boundaries, especially political boundaries. That is, public research and development organisations require funding and resources to support their work from government and external agencies both in the private and public sectors. Consequently, they need to find a way to respond to the various requirements of both government and external agencies in the decision-making processes and activities. The new requirements of customers and stakeholders from various parties in both the private and public sectors, including markets, render the current knowledge and practices of project members obsolete. It affects the sales volumes of the project scanners in the market. To resolve this issue, the obsolete knowledge and practices of project members have to be changed: to create new knowledge and practices, old ones have to be changed. Furthermore, a wide range of demands from customers and stakeholders, including markets, challenge members in public research and development organisations to build and maintain a balance and the relationship between those groups. This can impact on the change of current knowledge and interests of members in public research and development organisations at a political boundary. As mentioned above, the influence of context on the construction of knowledge management across boundaries needed to be considered.

The findings give a different view of the construction of knowledge boundaries. The findings suggest that knowledge boundaries are also constructed from lack of a full understanding and awareness about differences in knowledge and disciplinary perceptions between interacting actors from different knowledge communities. Interacting actors from different communities tend to look at the same things and phenomena through their own conceptual lenses. They tend to use their knowledge and skills within particular contexts of action and give meanings in their practices to the same things and phenomena across different communities (Dougherty, 1992). The ways of thinking and key ideas in one community may not be understood or may be considered unimportant in another different community. Due to ignorance about these differences, interacting actors from different communities do not exercise enough care to collaborate with other different communities. They also do not pay attention to learning about the differences between each other in order to develop common knowledge and understandings. This inhibited learning, collaboration, and boundary-spanning activities between different communities. Tension, difficulties, and boundaries in cross-community collaboration occur.

As mentioned above, the findings contribute knowledge to the theorisation of boundaries and the three-tier model by suggesting that the construction of boundaries needs to be looked at in detail and perceived within a mental, cognitive, or intangible dimension. Difficulties in cross-community collaboration and knowledge boundaries can occur when an individual is unable or unwilling to see the relevance of others' work and knowledge to their own work and knowledge. This is by contrast to the existing studies and the three-tier model identified in the literature review which generally have suggested that knowledge boundaries mainly arise because interacting actors from different knowledge communities have fundamental differences in knowledge, disciplinary perceptions, ways of thinking, and ideas for solutions (Siedlok and Hibbert, 2014; Hislop, 2013; Sumner and Tribe, 2007; Carlile, 2004; Wenger, 2000; Becher, 1994; Brown and Duguid, 1991). More specifically, the three-tier model suggests that knowledge boundaries arise because of differences in terminologies, meanings, and interests between interacting actors from different communities (Carlile, 2004, 2002). Consequently, the challenges of the construction and management of knowledge boundaries are not fully captured in previous work.

6.1.3. Managing knowledge across boundaries

Relating to the construction of knowledge boundaries and research objective two, the findings confirm the usefulness of the three-tier model for clarifying and gaining understanding on processes to manage knowledge across boundaries. That is, in response to research objective three, relating the findings to the existing literature, it was found that to overcome and to manage knowledge across boundaries, three increasingly complex knowledge processes: transfer, translate, and transformation, are required (Carlile, 2004, 2002). However, looking at the subject of the study from multiple dimentions and giving consideration to the role of context, the findings suggest some areas where the model is insufficient, especially in boundary-spanning mechanisms to overcome and to manage knowledge across boundaries. These mechanisms are connected to and influenced by the context: especially, the bureaucratic cultures within the hierarchical structures of a public sector organisation; power of individual boundary brokers in hierarchical organisational structures; and social harmony process in organisational culture.

At an information-processing boundary the findings suggest that due to the limitations of information technology and the influence of individual power actors in the hierarchical organisational structures in the case such as the project director, face-to-face communication is used to transfer knowledge between different communities. Therefore, the findings suggest that, at an information-processing boundary knowledge is not only transferred through information technologies and boundary objects, but also through face-to-face communication. Furthermore, difficulties at this boundary arise when interacting actors from different knowledge communities do not have common terminology for sending and receiving knowledge; knowledge could not then be transferred at a boundary. Thus, the development of common terminology is required. The findings suggest a lexicon mediator is required to develop common terminology for transferring knowledge at a boundary. By contrast, the previous work and three-tier model suggest the use of (understanding) translators and boundary brokers at another boundary.

At an interpretative boundary, the second knowledge boundary, the knowledge translation process and the development of common meanings are required to manage knowledge at such a boundary (Matthew, Hawkins and Rezazade, 2012; Edenius, Keller and Lindblad, 2010; Kellogg, Orlikowski and Yates, 2006; Carlile, 2004; Wenger, 2000; Dougherty, 1992). Boundary interactions and boundary brokers, in this case, are major tools to develop common meanings and understandings to manage knowledge across an interpretative boundary. Boundary interactions help to develop common meanings and understandings by offering opportunities to interacting actors from different communities to share, discuss, identify, and learn differences and dependencies in their knowledge and tasks through the metaphor of working together to reconcile different interpretations (Matthew, Hawkins and Rezazade, 2012; Brown and Duguid, 2001).

The findings highlight that political influence within the hierarchy of individual boundary brokers plays an important role in managing knowledge across boundaries. For instance, project members accept the invitation of the project director to join in the research project because of the project director's political power within the hierarchy and experience. This suggests the influence of individual boundary brokers within hierarchical structures can pull actors from different communities to work together. Also, individual boundary brokers use their power to connect actors to share knowledge and discuss unclear points between them to develop common interpretations and understandings. They facilitate and coordinate collaborations between project members from different communities by developing the environment of collaboration and the sense of commitment between the project members for sharing knowledge in order to develop common understandings.

Political boundaries, in this case, mainly occur because the new requirements of customers and stakeholders from both private and public sectors, and innovations of other scanner manufacturers, render the current knowledge and practices of project members obsolete. To resolve this issue, project members have to change their obsolete knowledge and practices to new knowledge and practices to meet customers' and stakeholders' requirements and to compete with another scanner manufacturer. The findings suggest that having public authorities as a main target market makes cross-boundary collaboration more complex. This is because the requirements of stakeholders strongly influence the decision-making processes, activities, services, and products of governmental research organisations and their research projects. Stakeholders from different parties normally have different requirements. Consequently, project members have to be prepared and willing to change their current knowledge, practices, interests, and agendas in scanner development constantly to take account and respond to a diversity of stakeholders' requirements for their survival and success. Furthermore, the hybrid nature of public research and development organisations makes cross-boundary collaboration more complex. This is because public research and development organisations need to have a close relationship with their users in the private sector to support their operation, such as using them as external resources. The organisations need to retain the characteristics of public service organisations to acknowledge that they are supported from and response to their public funds. The existence of public research and development organisations on a middle point between private agencies and government bureaucracies challenges the management and change of their interests and attentions to respond to multiple sources of requirements. Also, the findings suggest that political boundaries and conflicts between project members from different knowledge communities are reduced because of the actions and power of individual boundary brokers within the hierarchical organisational structures in the development of common understandings and common goals.

As mentioned above, this thesis pays attention to the importance of organisational and cultural contexts in knowledge management and collaboration across boundaries. The findings also suggest some aspects which the three-tier model does not mention. That is, this study examined knowledge management and collaboration between interacting actors from different knowledge communities in a different context: an interdisciplinary research project in a governmental research organisation in Thailand. It looked at the subject by adding consideration of the importance of context (organisational and cultural): more specifically, the bureaucratic cultures within the hierarchical structures of a public sector organisation; the power of individual boundary brokers in hierarchical organisational structures; and the social harmony process in Thai culture, in the management of boundaries. The findings suggest that there are specific influences of organisation and culture on knowledge management and collaboration across boundaries in this context.

Firstly, hierarchical organisational structures have been identified as a factor that has a strong impact on knowledge management difficulty. For instance, Seba and Rowley (2010) argued that hierarchical organisational structures inhibit communication, cooperation, and knowledge sharing across functions in the Dubai Police Force. However, the participants in this case perceive that hierarchical organisational structures have positive effects on communication, collaboration, and knowledge sharing among interacting actors. Hierarchical structures clarify differences and dependencies in authority, knowledge, and responsibility among interacting actors. They also create clear lines of communication among interacting actors. Sharing different knowledge types with different sets and levels of project members, in this case, does not inhibit knowledge sharing and access among project members. It is considered as an appropriate organisation to manage shared knowledge which is matched with the project members' responsibilities. Further, the non-hierarchical nature of project members could make knowledge management and collaboration across boundaries more complex.

Relating to hierarchical organisational structures, the power of individual boundary brokers such as the project director, who is at the top of the pyramid of the project, has effects on cross-boundary collaboration at different levels of boundaries. As mentioned above, for instance, project members are encouraged by the project director to use face-to-face communication as another tool to transfer knowledge at an information-processing boundary. The project director uses his power and capability to develop common understandings between project members from different knowledge communities at an interpretative boundary. Also, conflicts between different knowledge communities in the project are reduced because of the political influence of the project director in the development of common goals among the project members, and Thai culture, which will be explained below.

Secondly, the findings suggest that there is a positive relationship between Thai culture, 'Kreng jai' or being afraid of offending which is considered a process of building social harmony, and a reduction in conflicts between interacting actors at a political boundary. However, this cultural factor may obstruct the learning process by limiting different perspectives from others.

Thirdly, the findings suggest that asymmetric responsibility, which tends to be found in governmental organisations (Mares, 2013; Adel and Shaghayegh, 2010; Cong and Pandya, 2003), has an influence on interacting actors' participation in communities. It limits interacting actors' opportunities to communicate and participate with others to allow them to access and share knowledge for developing common understandings at an interpretative boundary. It also limits interacting actors' efforts to transfer their knowledge into media to allow others to access the knowledge at an information processing boundary.

Finally, having public authorities as a main target market and the hybrid nature of public research and development organisations makes cross-boundary collaboration more complex. This is because the requirements of stakeholders strongly influence the decision-making processes, activities, services, and products of governmental research organisations and their research projects. Stakeholders from different parties normally have different requirements. Consequently, project members need to be prepared and willing to change their current knowledge, practices, interests, and agendas in scanner development constantly to take account of, and respond to, a diversity of stakeholders' requirements for their survival and success. The existence of public research and development organisations on a middle point between private agencies and government bureaucracies introduces challenges to the orgaisations; especially the management of their interests and attentions in response to various requirements from different sectors.

As the findings mentioned above show, organisational and cultural context have an influence on knowledge management and collaboration across boundaries. Considering a wider and a different context of cross-community collaboration can extend and differentiate perspectives about knowledge boundary construction and management. These points suggest that the theorisation of boundaries and the three-tier model need to look at more widely, both in a different context, and in multiple dimensions, in order to gain a more comprehensive understanding of the management of knowledge boundaries.

6.1.4. Framework for managing knowledge across boundaries

According to the nature and construction of knowledge boundaries, knowledge processes, and boundary-spanning mechanisms for managing knowledge across knowledge boundaries, which have been found in this case and are mentioned above, it is argued that knowledge management across boundaries is a more challenging undertaking than currently portrayed in the standard three-tier model. The model takes a simplistic view about knowledge management across boundaries. The types of gaps explored in this study show the model as inadequate to explain how knowledge boundaries are experienced in practice and thus how it has limited effectiveness at an empirical level. A framework for managing knowledge across boundaries from the findings and from the gaps which have been found in this case is developed and discussed in Section 5.5. More specifically, Figure 5.1 presents types of knowledge boundaries that can occur at interactions between interacting actors from different knowledge communities; and knowledge processes to deal with these boundaries for managing knowledge across them. It also presents the dynamic nature, blurring, fluidity, overlapping, and simultaneous character of knowledge boundaries. A comparative summary of the three types of knowledge boundaries and approaches to manage knowledge across them is presented in Table 5.1.

6.2. Practical implications

In addition to the contributions to knowledge and theoretical implications stemming from the findings, there are practical implications for actors, whether they are individuals or groups of individuals engaged in cross-community collaboration and knowledge management. More specifically, the findings have practical implications for the following stakeholders: (i.)

managers; (ii.) staff members who are involved in interdisciplinary work; and (iii.) knowledge officers and librarians.

i. Managers

Managers should be informed and trained to understand and be aware of the complex nature of boundaries, the construction and existence of boundaries, and the different types of knowledge boundaries and knowledge processes to manage knowledge across them. This is in order to help managers recognise these aspects, and then develop personal strategies for tackling them in organising and managing cross-community work.

Managers, especially those who are boundary brokers, should be informed and trained to be aware of the extension of their perspectives to understand that different individuals face the same phenomenon but perceive it as different types of knowledge boundaries. They should be trained to recognise the development of flexible and multi-dimensional perspectives to address the dynamic, blurring, and changing nature of boundaries.

As the findings suggest, boundary brokers are one of the key boundary-spanning mechanisms to manage knowledge across boundaries. Managers should find staff members who can be bridges or boundary brokers between different knowledge communities and give them training, more resources, and recognition for being effective boundary brokers. Due to the importance of boundary interactions to develop common knowledge and understandings, managers should place emphasis on the meaningfulness of the engagement of project members from different knowledge communities. Managers should provide face-to-face communication channels, tools, and spaces for members such as formal and informal meetings, workshops, seminars, and training. These channels and spaces are where members from different knowledge communities can share, identify, inquire, and learn differences and dependencies in knowledge, perspectives, and tasks with each other. They should also create activities and boundary-spanning mechanisms to encourage sharing and learning about diversity among members from different knowledge communities for increasing cognizance of differences in knowledge and disciplinary perspectives among them.

Furthermore, the findings suggest that the political power and authority of managers in hierarchical organisational structures play key roles to overcome knowledge boundaries in cross-community work. Thus, managers should consider the management of their political power and authority for managing and organising cross-community collaboration. In addition, managers should look at the structure of organisational and project management, which combines both hierarchical and flexible elements, to support and encourage cross-community work. More specifically, managers should look at the development of the organisational and project management structure and environment which clearly specifies and allocates each member's authority, responsibilities, and his/her relationships with other members. This is in order to reduce confusion over authority, roles, responsibilities, and lines of communications among organisational members. This structure and environment must also not inhibit knowledge sharing and learning, and collaboration among members.

Managers should give training to staff members to recognise that there are different types of knowledge boundaries, that boundaries are complex, and that there are challenges of cross-community collaboration. Managers should give staff members opportunities to talk about what and where boundaries they are experiencing lie to learn about the dynamic nature and change of boundaries across the project life cycle. Managers should give guidelines to staff members on how to manage knowledge and collaborate with the other staff members from different knowledge communities. More specifically, managers can use the findings to create project management manuals and best practice guidelines for cross-boundary working for staff members. The manuals and guidelines might depict boundaries as a particular type of risk or challenge and suggest a list of tips to identify where different types of knowledge boundary are being encountered and how to cope with them.

ii. Staff members

Staff members, who are involved in cross-community work, should be trained to understand different types of knowledge boundaries that can occur in cross-community collaboration and processes to overcome them. Also, they should be trained to recognise the complex nature of knowledge boundaries and the challenges of cross-community collaboration.

Staff members can use the findings as guidelines to move their knowledge and collaborate with the other members across boundaries. Such guidelines, for instance, could include: staff members should be able to change easily according to the dynamic and blurred nature of boundaries; should have flexible and multi-dimensional perspectives for addressing the shifting of boundaries, and for addressing differences in perceiving the same phenomenon as different types of knowledge boundaries; and should take a broader perspective to pay attention to and learn about differences in knowledge and disciplinary perceptions of the other different members.

iii. Knowledge officers and librarians

Knowledge officers and librarians, who manage organisational knowledge and provide information resources relating to organisational operations to another member, should develop activities to support and facilitate organisational members to move their knowledge and to collaborate across boundaries. For instance, they should (co)develop tools to create common terminology among members from different communities such as online taxonomies, ontologies, and glossaries. They should (co)develop storage and retrieval databases to transfer knowledge among members in an organisation. They should also study and suggest effective communication and collaboration tools to support cross-community communication and collaboration among members such as live video streaming.

6.3. Limitations and future research directions

The study does have a number of limitations. Firstly, the findings are based on a single case; they are affected by the context of the case and other unique factors specific to the study. That is, the findings might be context specific or only relevant to public sector organisations, more specifically governmental research organisations, and Thai culture. For instance, the influence of accountability and multiple stakeholders on the activities of project members may be context specific. Similarly, the influence of bureaucratic cultures in hierarchical organisational structures and Thai's compromise culture on relationships and collaborations between different actors could be seen as context specific. Therefore, it is not suggested that the findings derived from this case are applicable to all different research settings, although they could possibly be extrapolated to other research settings on the basis of interpreting the findings through the lens of theory. This might help to understand the pattern of the findings and facilitate extrapolation of the findings to other settings. There might be different challenges in other contexts, which need to be subject to careful consideration appropriate to the individual context. Given the important need to move towards a consensus about the nature of boundaries, construction of boundaries, types of knowledge boundaries and knowledge processes to overcome them, and boundary-spanning mechanisms to facilitate cross-community collaboration, future research could examine whether their emerging elements are fundamentally different from, or similar to, the ones identified in this study. Moreover, due to a limited number of case studies, there are reasons to believe that other different types of practices and contexts would portray different challenges and opportunities for the subject of the study. Therefore, it would be interesting to carry out further investigations in other different contexts. For instance, future research might explore knowledge management across boundaries in research projects which are considered unsuccessful in terms of interdisciplinary collaboration. Another instance; future research might explore the topic in interdisciplinary research projects which do not present the strong political influence of some project members such as the project director, and have less bureaucratic cultures in hierarchical organisational structures. This is to explore the nature of boundaries, the construction of boundaries, types of knowledge boundaries and knowledge processes to overcome them, and boundary-spanning mechanisms for managing knowledge and collaboration across boundaries. The utilisation of other strategies of inquiry, such as: What is the nature of boundaries in an unsuccessful interdisciplinary research project? Why do knowledge boundaries arise in such contexts? How do people manage knowledge and collaborate across boundaries? What are the factors that hinder cross-community collaborations and knowledge processes, and how do such factors inhibit or affect them? could also consolidate and triangulate the validation of the findings and framework from this study. They could also explore further synergies and divergences.

Secondly, due to time constraints, this study mainly focused on boundaries in knowledge and disciplinary perceptions between members from different communities. However, according to the literature review, cross-community knowledge management and collaboration encompasses an enormous variety of contexts and can involve the crossing of knowledge community, occupational, functional, organisational, and national boundaries (Hislop, 2013; Kimble, Grenier and Goglio-Primard, 2010; Cummings and Kiesler, 2005). Therefore, it would be interesting to carry out further investigations of boundaries at these levels. For instance, the study of cross-community collaboration between interacting actors who are members of different knowledge communities (knowledge boundaries); more specifically, who have different functions (functional boundaries), different occupations (occupational boundaries), and work in different organisations (organisational boundaries). This is to examine how boundaries arise, how one type of boundaries can involve or relate to another type of boundaries, and how to manage knowledge across these boundaries.

Thirdly, the case of this study is an on-going research project. It is also affected by changes; it is under constant change, mainly through the new requirements of its customers and stakeholders, including markets, as well as the innovations of other organisations delivering similar services and products. This shows that the case is continually developing. Future research might carry out a longitudinal study. A study of phenomena over an extended period of time might help researchers to look at and track changes over time and the detailed characteristics and activities of project members around the main focus of the study

(Saunders, Lewis and Thornhill, 2015; Thomas, 2011). It might help researchers to detect and gain additional insights on whether project members, activities, and issues about knowledge management and collaboration across boundaries from the inception to the transformation of technology for commercialisation which have been studied, are really changing or stay the same.

Fourthly, data in this thesis were collected by combining qualitative data collection methods: semi-structured face-to-face interview; participant observation; collection of documentation and other artefacts (see Section 3.6 for data collection methods). Further research might use other appropriate data collection methods as an adjunct to collect data. Further research might, for instance, use diaries (Snowden, 2015; Thomas, 2011; Alaszewski, 2006) as an adjunct to other data collection methods. They can be used, for instance, to collect data alongside interviews. Further research might specifically ask participants to keep diaries as a record of their actions, reactions, conversations, ideas, reflections, thoughts, feelings, emotions, and so on at any point in the collaboration across communities over a period of time. This is to capture their everyday working lives, behaviours, viewpoints, perceptions, and feelings to events and experiences in cross-community collaboration. Diaries might be a useful tool for collecting data from where participants seem to be afraid to talk about sensitive collaboration issues which might offend and make other close colleagues lose respect and lose face (Snowden, 2015; Thomas, 2011). Also, diaries might be a useful tool for collecting data from where participants were likely to experience difficulties recalling their experiences in cross-community collaboration (Snowden, 2015). Diaries might be kept in various formats, including paper diaries, e-diaries, and photographic diaries (Snowden, 2015; Thomas, 2011). However, the planning, preparation, and construction of diaries should be carefully considered and planned in terms of data collection and analysis to ensure that a diary is an appropriate tool for the research (Snowden, 2015). For instance, it requires the investment of time, resources, and effort by participants and researchers to develop a diary that is fit for the objectives of the research over a period (Snowden, 2015). Participants may become tired of keeping records and os be less thorough in their reporting. Researchers should also show concern for the potential effects on participants of keeping diaries (Snowden, 2015; Alaszewski, 2006).

As the points above exemplify, there are avenues that can be explored further based on the findings and framework from this study. As such, there are opportunities for further research within the organisational and knowledge management field, and more specifically knowledge management and collaboration across communities and boundaries.

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8. Appendices

8.1. Key factors for managing and sharing knowledge in public sector organisations

According to the review of the literature on knowledge management in the public sector, which was presented in Section 2.4.1, Table 8.1 below summarises some key factors which have influences on knowledge management and knowledge sharing in public sector organisations. These factors have been mentioned in many studies. They involve individual/human factors, organisational factors, and cultural factors.

	ICTs	**Incentives**	**Individuals' attitudes**	**Leadership**	**Management support**	**National culture**	**Organisational commitment**	**Organisational culture and structure**	**Social interaction**	**Time allocation**	**Trust**
Amayah (2013)		x	x	x	x				x		
Seba, Rowley and Delbridge (2012)			x	x		x				x	x
Chen, Sun and McQueen (2010)						x					
Seba and Rowley (2010)								x			x
Akhavan, Hosnavi and Sanjaghi (2009)	x			x	x			x			

	ICTs	Incentives	Individuals' attitudes	Leadership	Management support	National culture	Organisational commitment	Organisational culture and structure	Social interaction	Time allocation	Trust
Tong and Mitra (2009)						x					
Sinthavalai (2008)						x					
Wei, Stankosky, Calabrese and Lu (2008)			x			x	x		x		x
Al-Alawi, Al-Marzooqi and Mohammed (2007)								x			x
Willem and Buelens (2007)		x					x	x			x
Yao, Kam and Chan (2007)			x			x			x		x
Pardo, Cresswell, Thompson and Zhang (2006)		x									x
Numprasertchai and Igel (2005)	x						x		x		x
Riege (2005)											x

	ICTs	Incentives	Individuals' attitudes	Leadership	Management support	National culture	Organisational commitment	Organisational culture and structure	Social interaction	Time allocation	Trust
Syed-Ikhsan and Rowland (2004)								x			
Yodwisitsak (2004)			x			x		x	x		
Cong and Pandya (2003)	x	x		x	x			x	x		x
McAdam and Reid (2000)			x								
Newell and Swan (2000)											x

Table 8.1 Factors for managing and sharing knowledge in public sector organisations

8.2. Academic disciplines and discipline classification systems

Different disciplines have differences in many aspects such as the framework of knowledge, the traditions and the cultures of thought, assumptions, values, interests, interpretations, standards, analytical methods and techniques, including the use of language which their members have studied, been trained in, and performed tasks in (Siedlok and Hibbert, 2014; Hislop, 2013; Akkerman and Bakker, 2011; Lilleoere and Hansen, 2011; Chen, Sun and McQueen, 2010; Sumner and Tribe, 2007; Cummings and Kiesler, 2005; Carlile, 2004; Wenger, 2000; Ylijoki, 2000; Davenport and Prusak, 1998; Becher, 1994; Star and Griesemer, 1989; Biglan, 1973a; Kuhn, 1962). The study of disciplines has attracted interest since the nineteenth century (Kuhn, 1962). Three key scholars in the topic of classification of academic disciplines are likely to be cited in much of the literature. They are Kuhn (1962), Biglan (1973a), and Becher (1989).

Biglan (1973b) analysed the characteristics of different academic areas. 168 scholars at the University of Illinois and 54 scholars at a small denominational liberal arts college in the State of Washington were asked to judge similarities and differences among 36 academic subject areas through questionnaires. Biglan classified three dimensions to group academic disciplines: the existence of a single paradigm; the degree of concern with application; and the difference between biological and non-biological areas.

i. The existence of a single paradigm

According to Biglan (1973b), the level of paradigm development is the first dimension to group in academic disciplines. A paradigm refers to a basic framework of assumptions, principles, understanding, methods and techniques which is subscribed to by members of each field (Becher, 1994; Kuhn, 1962). The first paradigm development was introduced in *The Structure of Scientific Revolutions* in 1962 by Thomas Kuhn. Kuhn designates academic fields within two broad camps: paradigm sciences and non-paradigm sciences. These camps were based on the patterns of knowledge exploration and the formats of knowledge growth, as well as the main concerns and the purposes of finding (Kuhn, 1962). Kuhn's paradigm sciences and non-paradigm sciences (1962) were similar to the hard disciplines and soft disciplines suggested by Biglan (1973b), as well as to the hard pure knowledge and soft pure knowledge disciplines suggested by Becher (1989).

Paradigm sciences are the concept of development-by-addition and practice within a single paradigm (Kuhn, 1962). The main purpose of paradigm sciences is to share and convey a paradigm to fill in gaps or find a nearest solution based on basic commitments and past achievements that some communities acknowledge over a period of time. That is, present knowledge and new findings are typically generated by developing and assimilating previous knowledge in a process similar to tree branches (Becher, 1994). Thus, this camp often suppresses fundamental novelties of theory. Becher (1994) argued that members of paradigm sciences enjoy sharing the different forms of intellectual investigation and attempt to work together because they have clearly defined paradigms, consensus, and boundaries.

By contrast, non-paradigm sciences (Kuhn, 1962), soft disciplines (Biglan, 1973b) and soft pure knowledge (Becher, 1989) generally lack explicit consensus and the well-marked boundaries which exist between neighbouring disciplines (Ylijoki, 2000; Kuhn, 1962). Becher (1989) called the pattern of knowledge growth in this camp 'a meander'. Ylijoki (2000) and Kuhn (1962) explained that the indicators of consensus in a discipline are the absorption of the same technical literature, education, and professional initiation; cohesiveness in a community which promotes full communication and united professional judgments on disciplines; a shared set of goals; and the training of successors. These indicators are always found in the first camp or paradigm sciences, but have low levels in the second camp or non-paradigm sciences. The members of this camp may operate based on subject-based interest groups without constituency control (Kuhn, 1962). They were not found to share a unitary paradigm or get involved in other member's activities which are known as non-paradigmatic fields (Kuhn, 1962).

Becher (1989) and Kuhn (1962) suggested differences between the first and the second camps by focusing on the domain's content and methods to discover knowledge or solve problems. The first camp tends to focus on universals through precise measurement by seeking regularities and framing mathematical models. It is likely to break down complex ideas into simple elements. By contrast, the second camp tends to be concerned with particulars and deals with minute conceptual delineation. It lacks scopes for pattern and reproducibility. Another difference between the first and second camps is the result of the first camp's tendency to explain conjectures or discoveries because they derive from the systematic scrutiny of relationships between a few carefully controlled variables. By contrast, the results of the second camp tend to interpret or enhance understanding of discoveries or puzzles (Becher, 1989; Kuhn, 1962).

ii. The degree of concern with application

The second dimension to group disciplines focuses on the degrees of concern with applications and the purpose of findings (Becher, 1989; Biglan, 1973b). Biglan (1973b) designates academic knowledge into two broad camps as applied and pure disciplines which are similar to the hard and soft applied knowledge designed by Becher (1989). The first camp, which is labelled applied disciplines (Biglan, 1973b) and hard applied knowledge (Becher, 1989), concerns knowing what and is viewed as more concerned with the application of knowledge. By contrast, the second camp, which is labelled pure disciplines (Biglan, 1973b) and soft applied knowledge (Becher, 1989), concerns knowing how and is considered as less focused on practical application (Tranfield, 2002; Biglan, 1973b). The first camp focuses on ways of mastering the physical world. The primary results of the first camp are products and techniques. By contrast, the second camp focuses on the enhancement of [semi-] professional practices. The primary results of the second camp are protocols or procedures (Becher, 1989).

iii. Biological and non-biological areas

The third dimension to group disciplines concerns living or organic matter (Biglan, 1973a; Biglan, 1973b). Biglan grouped academic knowledge into two main groups: life sciences and non-life sciences. The life sciences consist of fields which involve the scientific study of living organisms and life processes such as cells, plants, animals and human beings. Non-life sciences, by contrast, consist of fields which involve the scientific study of non-living matter and energy, including physics and the chemistry of nature (see Table 8.2 for the grouping of academic disciplines).

All dimensions and distinctions mentioned above are comparable along the cognitive dimension (Tranfield, 2002). Another broad dimension to understanding the characteristics of disciplines is called the social organisation dimension (Tranfield, 2002; Becher, 1989). The social organisation dimension is based on the degree of encountering problems and the proportion of researchers involved with the problems (Becher, 1989; Bigland, 1973a). For the degree of encountering problems, Becher (1989) and Bigland (1973a) separated academic disciplines into two broad camps: convergent sciences and divergent sciences. Convergent sciences are likely to close down new questions and problems rather than open up new questions and problems as divergent sciences. For the proportion of researchers involved in problems, academic disciplines are designated into urban directions and rural directions (Becher, 1989; Bigland, 1973a). Urban directions have a higher people-to-problem ratio than rural fields (Bigland, 1973a). Becher (1989) indicated that urban environments might be thought of in the rush hour context with many researchers attempting to inhabit a relatively small intellectual space. Urban environments are also located in a narrower area of study. They are drawn and sharply demarcation into separate and easily definable areas and research problems which are not found in rural environments. For this reason, communication and co-operation between research groups occurs more often in urban environments than in rural environments. Overall, urban environments are often thought to be fashionable and potentially attractive to funding agencies; particularly as being able to anticipate specific deliverables that add to the knowledge stock (Becher, 1989; Bigland, 1973a).

<table>
<tr><th colspan="3">Paradigm that exists</th><th colspan="2">Practical applications</th><th>Life/Non-life</th></tr>
<tr><td>Kuhn (1962)</td><td>Biglan (1973b)</td><td>Becher (1989)</td><td>Biglan (1973b)</td><td>Becher (1989)</td><td>Biglan (1973b)</td></tr>
<tr><td>Paradigm sciences</td><td>Hard disciplines</td><td>Hard pure knowledge</td><td>Applied disciplines</td><td>Hard applied knowledge</td><td>Life systems</td></tr>
<tr><td colspan="3">Such as mathematics, physics, chemistry, and biology
Nature of knowledge: additive; tree branches; concerned with universals, quantities, and simplification; results in discovery and explanation
Nature of culture: competitive and sociable; politically well-organised; high publication rate; task-oriented</td><td colspan="2">Such as mechanical engineering and agriculture
Nature of knowledge: purposive; know-what via hard knowledge; concerned with mastery of physical environment; results in products and techniques
Nature of culture: entrepreneurial, cosmopolitan; dominated by professional values; patents substitutable for publications; role oriented</td><td>Such as biology and agriculture</td></tr>
<tr><td>Non-paradigm sciences</td><td>Soft disciplines</td><td>Soft pure knowledge</td><td>Pure disciplines</td><td>Soft applied knowledge</td><td>Non-life systems</td></tr>
<tr><td colspan="3">Such as anthropology, archaeology, economics, linguistics and history
Nature of knowledge: reiterative; river-like; concerned with particulars, qualities, complication; results in understanding and interpretation
Nature of culture: individualistic, pluralistic; loosely structured; low publication rate; person oriented</td><td colspan="2">Such as history, education, and accounting
Nature of knowledge: functional; know-how via soft knowledge; concerned with enhancement of professional practices; results in protocols and procedures
Nature of culture: outward-looking; uncertain in status; dominated by intellectual fashions; publication rates reduced by consultancies; power-oriented</td><td>Such as languages, mathematics, and physics</td></tr>
</table>

Table 8.2 Broad disciplinary grouping and characteristics

Adapted from: Becher (1994)

8.3. Interview guides in the first and second stages

8.3.1. Interview guides in the first stage

1. Could you tell me about your education background?
2. Could you tell me about your area of expertise?
3. Could you talk about your work history in NSTDA?
4. Could you talk about the story of participation in this research project?
5. What types of activities in this project?
6. What is your role in this project and what does it involve?
7. Could you tell me about the nature of project members in this project?
8. What are the differences and similarities you perceive between project members from different groups in the project?
9. Could you describe a workflow for doing this project?
10. When do project members from different groups need to work together or apart?
11. What kinds of knowledge do you share with the other project members in conducting the project and how is the knowledge shared?
12. What channels are used to communicate with the other project members?
13. How are decisions taken in the project?
14. Could you name key project members who make the decisions in the project?
15. What are factors that facilitate or obstruct communication and collaboration in this project?
16. Could you talk about difficulties you have experienced when working with project members from the other different group and different subject field?
17. What capacities are required to work with project members from different subject fields?
18. What are the advantages and disadvantages of interdisciplinary research projects and collaborations?
19. Could you name any project member who you work most closely with?

8.3.2. Interview guides in the second stage

1. Could you talk about the nature and characteristics of your group and the other group from the other different subject field?
2. Could you talk about differences and similarities you perceive in ways of thinking and looking at the scanner development between project members from different groups and different subject fields in the research project?

3. Could you tell me about differences and similarities you perceive between your group members who from different sub-subject fields?
4. Could you talk about difficulties you have experienced when working with people from different subject fields or different sub-subject fields at each stage in the conduction of the research project?
5. What capacities are required to overcome these difficulties?
6. Could you talk about disagreements, oppositions, or conflicts between project members from different groups?
7. How do project members manage those conflicts?
8. If you had to fit in with how the other different group do things, what would you have to do differently?
9. Is there any project member who acts as a coordinator or a middleman between two groups or between different members of the group?
10. What are activities and situations where this project member acts as a coordinator or a middleman in the research project?
11. What kinds of knowledge do you share with the other project members though each communication and knowledge sharing channel?
12. What are key shared objects between the two groups in the research project and how are they shared and used?
13. What are factors that facilitate or obstruct communication and collaboration in the research project and how do the factors influence communication and collaboration?
14. What are the advantages and disadvantages of the conduction of research projects with people from different subject fields?
15. What are your recommendations in conducting research projects with people from different subject fields?

8.4. Sample of observation notes

The observation of the monthly project meeting

Date: 25 March 2015 Time: 13.30-16.00 Place: Pragim 3, NECTEC, NSTDA

Participants

1. The project director
2. Software team members
    i. The project manager
    ii. Participant no. 2
    iii. Participant no. 4
    iv. Participant no. 12
3. Hardware team members
    i. The project manager
    ii. Participant no. 6
    iii. Participant no. 11
4. Others
    i. The deputy executive director of National Electronics and Computer Technology Center (NECTEC)
    ii. Two members from the Business Development Unit

Situations	Comments
1. Project members report to the project director the instalment of a dental CT scanner version 2 in the Century department store to encourage people to use the project's scanner. That is, the project gained subsidies from the Thailand Center of Excellence for Life Sciences (TCELS) of 4 million baht to develop 4 dental CT scanners. One of 4 dental CT scanners will be installed and used in a	• Project members interacts with external actors outside the organisation both in the public and private sectors such as governmental hospitals, subsidisers, companies, and testing centres. • Subsidy is one source of the project's funding. • A scanner can be considered as a boundary object between project

Situations	Comments
private sector place such as in the Century department store. The issue is project members have changed some points in the contract between the project and TCELS. More specifically, project members will deliver dental CT scanners version 2 not version 1. Also, they will deliver and install the scanners in private sector places not in governmental hospitals. Consequently, project members must revise the contract which is accepted by both the project and TCELS. The hardware project manager reports that a dental CT scanner version 2, which will be installed and used in the Century department store, is being tested to comply with IEC60601 [a series of technical standards for the safety and effectiveness of medical electrical equipment] at the Electrical and Electronic Products Testing Center (PTEC). The project director asks the hardware project manager to describe IEC60601. The hardware project manager describes IEC60601 to the other project members.	members and external actors because they are co-developed and used by them. • There is a knowledge transfer process. The hardware project manager transfers knowledge about IEC60601 to the other project members in the meeting. • Technical knowledge, more specifically IEC60601 or technical standards for the safety and effectiveness of medical electrical equipment, is transferred from the hardware project manager to the other project. • Face-to-face meeting is a tool for knowledge transfer.
2. Two members of the Business Development Unit are invited to join in the meeting to share their knowledge and perspectives about the development of business plans with project members.	• Project members interact with members from different knowledge communities and different functions inside the organisation, more specifically the

Situations	Comments
The project director suggests project members to develop marketing strategies through online media and a seminar to introduce the project and the project's scanners to customers.	members of the Business Development Unit. • There is a knowledge transfer process from the members of the Business Development Unit to project members. • Knowledge is not only transferred from one group to the other group within the project, but also from one group inside the organisation to project members. • Sales and marketing knowledge, more specifically the development of business plans, is transferred from external actors in the organisation to project members. • There is learning in different subject fields to support the project. That is, project members must learn about sales and market plans and business development which is different from their current knowledge in software or hardware engineering. • The project director uses his power to assign some project members to develop a market plan.
3. The project director asks project members to reduce the size and change the colour of the project's dental CT scanner version 2.	• There is a new requirement of the scanner development from an internal actor, the project director. This requirement might have impacts on current knowledge and practices of project members. That is, project members may have to change their current knowledge and practices to

Situations	Comments
	reduce the size and to change the colour of the scanner to meet the requirement of the project director.
4. The software project manager reports the progress of the development of a digital X-ray scanner. Firstly, a main program of a scanner could retrieve patients' data from the hospital's Picture Archiving and Communication System (PACS) to generate X-ray photographs. Doctors accepted the quality and accuracy of the X-ray photographs. Secondly, a viewer was developed and could view patients' X-ray photographs properly. However, there is a problem about image-processing time of a digital X-ray scanner. That is, the scanner spent about 19 seconds to generate X-ray photographs, while scanners of another company spent only 5 seconds for doing that. To solve this issue, project members will change a hard disk and will improve the connection between a main program and a viewer. The project director asks project members to create Gantt chart to follow up the project progress.	• Not all project members join in the meeting. Some project members, who are involved in the development of a digital X-ray scanner, have just come in to the meeting to present information about the scanner. They come in to the meeting for their agenda item only. • There is a knowledge transfer process from the software project manager to the other project members. • Technical knowledge about the scanner development is transferred, more specifically the development of a main program and a viewer, and the image-processing process. • Project members must interact with external actors as customers or doctors. Doctors have influences on the scanner development and project members' practices. That is, project members must develop a scanner to meet doctors' requirements. • The best practice of another scanner development company has impacts on the current knowledge and practices of project members. That is, project members need to change their obsolete knowledge and practices or improve their

Situations	Comments
	current knowledge and practices to develop new techniques to improve their scanners. This is in order to compete with another scanner development company.
5. The hardware project manager reports the status of the development of a mini CT scanner. Also, he says that the hardware group needs to know about DSO parameters from the software group.	• This suggests collaboration between the hardware and software groups. That is, the hardware group needs to know parameters from the software group to design and set up hardware. • Technical knowledge such as DSO parameters is sent from the software group to the hardware group.
6. The project director invites the deputy executive director of the National Electronics and Computer Technology Center (NECTEC) to join in the meeting to discuss the organisational research management and assessment strategy. The project director asks the deputy executive director to reconsider and discuss the organisational research management and assessment strategy with the organisational board. Firstly, small and big projects should be assessed separately and differently. Secondly, the organisation should look at different mechanisms to evaluate different research projects. More specifically, the organisation should not only pay most attention to research	• The project director uses his power to ask the deputy executive director to join in the meeting. • The project director uses his power to ask the deputy executive director to take into account project members' perspectives about the organisational research management and assessment. • The project director acts as a boundary broker between the organisation and project members by facilitating and coordinating the meeting to develop common understandings and common goals between the organisation and project members. • There are different perspectives, different interests, and conflicts in research management and assessment

Situations	Comments
publications. It should consider and encourage engineering excellence from research projects as well. Thirdly, the project director and the software project manager suggest that the organisation should pay attention to the measurement of the social impact of research. This is because some research projects can create high social impact. However, those projects are assessed by inappropriate research assessment criteria. The organisation should add social impact, quality of life, and social value into the research assessment criteria. The software project manager expresses that this research project is a big and complex project. Also, it creates high social impact. However, the project has been assessed and received very low research assessment scores. Project members have suffered from inappropriate research assessment. Fourthly, the project director suggests that the organisation should reconsider the Key Performance Indicators (KPI) of researchers in the organisation. Finally, the project director suggests that the organisation should develop the concept of pre-commercial to promote the organisational research output.	between the organisation and project members. • There is knowledge transfer about research management and assessment strategies between project members and the deputy executive director. • Common understandings and common goals in research management and assessment are being developed between the deputy executive director and project members. • Inappropriate research management and assessment systems in the organisation have negative impacts on project members' motivation to conduct interdisciplinary and complex research projects.

Situations	Comments
7. The hardware project manager presents a master plan of all sub-projects. [two photos of a master plan]	• A master plan could be considered as a boundary object because it presents tasks which need to be worked on together or apart between the hardware and software groups. It helps to clarify differences and dependencies in knowledge and given tasks that exist between the members of the hardware and software groups.
8. The software project manager presents technical results of X-ray setting with dynamic gain to improve the quality of X-ray photographs of a dental CT scanner version 2. She compares the quality of X-ray photographs which are created by using different techniques: single gain and dynamic gain. The setting of X-ray with dynamic gain gives a better result and a better X-ray photograph than a single gain. She also presents the technical results of the adult head setting for a mobile CT scanner [3 photographs of a presentation on X-ray setting and adult head setting].	• There is a knowledge transfer process from the software project manager to the other project members. • Technical knowledge about X-ray setting and adult head setting is transferred in the meeting. • X-ray photographs of patients can be considered as a boundary object because it is created and used by the hardware and software groups.
9. The project director expresses that the project suffered from the setting of a gantry of a detector, especially the alignment of a gantry, a detector, and X-ray photographs. Thus, he suggests project members create a list of hardware	• The project director uses his power to assign tasks to the hardware group. • The project director shares his knowledge and perspective to improve the quality of the scanner development.

Situations	Comments
checkpoints to examine hardware operation at each step of the scanner development. The software project manager agrees with the project director and expresses some disagreement with the operations of the hardware group by saying that “looking at X-ray photographs in a final stage of the scanner development is too late”. Moreover, the project director suggests project members to study about how different accuracy degrees of the gantry setting create the different quality levels of the X-ray photographs. The hardware project replies that “we lacked know-how knowledge about this”.	• Project members require technical knowledge about quality control, more specifically how different accuracy degrees of the gantry setting create the different quality levels of the X-ray photographs. • There is criticism and conflict in coordination between the different groups about the inaccurate setting of the gantry. That is, the software group seems to blame the gantry setting of a detector and the generation of X-ray photographs on the hardware group. It can be seen from the statement “looking at X-ray photographs in a final stage of the scanner development is too late”. By contrast, the hardware group argues that this problem occurred because of lack of accurate parameters for the gantry setting from the software group. However, both groups try to keep quiet rather than argue, avoid criticism, and just make a few comments on the issue. This might be because of the seniority culture, being afraid of offending, and making other people lose respect or losing face.
Others	• Meeting seating of project members in the meeting could reflect different levels of power and authority of project members.

Situations	Comments
	That is, the project director, who has the highest power in the project, sits at the head of the table. Everyone in the meeting can see the project director. Also, this seat can present the function of the project director as a facilitator and coordinator between the different groups in the project. The hardware and the software project manager sit next to the project director. The team members of each group sit next to or behind their manager. This suggests that the project managers act as a representative or gatekeeper between their team members and the other project members from different groups. • In the meeting, the discussions mainly concern the project director and the project managers. The project managers are representatives of their groups. They provide information and answer inquiries about their groups to the other project members. • In the meeting, project members seem to discuss about concepts of the scanner development rather than the details of the scanner development. This might be because of the limitation of time in the meeting. Also, the technical issues and details of the scanner development are discussed among the hardware and software group members without the

Situations	Comments
	project director being present. The project director tends to look at a more general overview of the scanner development.