LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Engineering Science
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KNOWLEDGE MANAGEMENT PRACTICES IN FINNISH RECYCLING AND WASTE MANAGEMENT COMPANIES

Master's Thesis

Examiners: Professor Ville Ojanen
Ph.D. Yan Xin

ABSTRACT

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Keywords: Knowledge management (KM), Product lifecycle management (PLM), Product-service systems (PSS), End-of-life (EOL).

Knowledge management (KM) through the entire product lifecycle (PLC) including beginning-of-life (BOL), middle-of-life (MOL), and end-of-life (EOL) is distributed to different stakeholders in product-service systems (PSS). Previous researchers have interviewed companies associated with BOL and MOL stages to investigate KM practices at these two stages under the PSS context. This thesis aims at exploring the status-quo of KM practices at the EOL stage to complete the understanding of KM status along with the entire PLC through investigating KM practices at Finnish recycling and waste management companies.

A qualitative method with semi-structured interviews and email interviews is adopted. Employees with managerial tasks were selected as targeting interviewees. In total, two recycling companies and two waste management companies participated in this study. Knowledge sharing, storing, acquiring, and reuse practices at these companies are explored and discussed by viewing them as stakeholders at the EOL stage. Companies at EOL stage practice good knowledge management skills within their companies and between companies. However, there are constraints and circumstances that make the information loop between stakeholders at EOL stage and stakeholders at BOL and MOL stages incomplete.

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To climb a mountain, the sweet victory of putting your feet finally on the mountain top is temporary. What will remain eternally, is the pain, joy, cry, rejoice, along the way. I am glad I am here now, but it can not compare to what I have learnt about life, myself, and the most high.

Thanks for my interviewees, without you this thesis would not be existed. Your help was the first step for me to climb this mountain. Then my supervisors, without your encouragements, I might have fallen on the road long ago. Thanks for all the guidance and suggestions along the way!

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Meichun Wang

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LIST OF ABBREVIATIONS

B2B	Business to business
BOL	Beginning-of-life
CEO	Chief executive officer
EOL	End-of-life
ERP	Enterprise resource planning
IC	Intellectual capital
IoT	Internet of things
IT	Information technology
KBS	Knowledge-based systems
KM	Knowledge management
KMS	Knowledge management system
MOL	Middle-of-life
PDM	Product data management
PLC	Product lifecycle
PLM	Product lifecycle management
PSS	Product-service systems
QR	Quick response
R&D	Research & development
RFID	Radio-frequency identification
RPA	Robotic process automation
RPA	Robotic process automation
SMEs	Small and medium-sized enterprises

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1 INTRODUCTION

1.1 Background

In the 21st century, industrial production is shifting from the mode of managing mass consumption towards a flexible model that could address those highly personalised needs based on individual behaviours (Morelli, 2006). Among this, a prevailing trend is the evolutionary thinking on changing the industrial offer from physical goods to a combination of goods and services, which is widely recognized in management discipline as product-service systems (PSS). As early as the 1990s, sustainability researchers raised the environmental concern of pure product-based business system. The sole focus on physical goods resulted in wasting of limited nature resources. Pollutions came from production and the product itself increased the stress on ecosystem. Shifting from physical object-focused to service-oriented business model would theoretically encourage business players to maximize the product life of the physical products, to utilize the material most effectively, and to reuse parts at the end of the product's life. As a result, the material flows could be minimized without decreasing customer satisfaction (Tukker, 2015).

The rapid development of information and communication technologies and the trend of digitalization boosted the application of information technologies in industries, such as Radio-frequency identification (RFID), sensor system, QR code, etc. An emerging product group generally named smart or intelligent products is sweeping the market. The picture of an ongoing forth industrial revolution – Industry 4.0 is filled with a network of physical objects embedded with smart technologies to exchange information via internet. Term "Internet-of-Things (IOT)" is used to describe the interaction of such network (Fakhar Manesh et al., 2021). Each single item and its surroundings in the entire product lifecycle (PLC) can be monitored through innovative features of smart technology to improve the services around the physical products, such as maintenance and repair. Further, the gathered information of the product can be utilized to optimise the whole lifecycle, including end-of-life (EOL) of a product where the information is normally missing (Kiritsis, 2011).

All these developments add challenges to the knowledge management (KM) of companies. The importance of KM for the operation of companies is not a secret in 21st century.

Intellectual capital is commonly viewed as an asset for enterprises, and it is critical in nowadays highly competitive global business environment (Petty & Guthrie, 2000). Technical tools and software bring convenience to the knowledge management activities. At the same time tremendous information and data available online bring headaches to practitioners on how to manage them. In order to utilize the available information/data/knowledge to its full strength, there is an urgent need of understanding knowledge management process within and between organizations deeply, specifically knowledge management practices such as knowledge creation, acquisition, sharing and reuse (Fakhar Manesh et al., 2021).

1.2 Research objectives

This thesis will focus on studying knowledge management practices at companies involved at product's EOL stage. Knowledge management through the entire product lifecycle (PLC) including beginning-of-life (BOL), middle-of-life (MOL) and end-of-life (EOL) is distributed to different stakeholders in product-service systems (PSS). The existing literatures are heavily emphasizing on knowledge management at BOL stage where the product design and manufacturing take place (Kiritsis et al., 2008). And the studies focus on KM at EOL stage are much less than KM studies at BOL and MOL stages.

Previous study conducted by Xin et al. (2019) investigated the knowledge management practices at BOL and MOL stages under PSS context by interviewing representatives from manufacturing and logistic companies in China. During the interview, they found out the knowledge exchange between these two phases and EOL is rare. Considering the development of recycling and waste management in China started later than European countries in general, interviews for representatives from recycling and waste management companies in Finland were designed to explore the status-quo of knowledge management practices at EOL stage. By doing so, this thesis intends to fill the vacuum of current knowledge management studies at EOL stage, and to complete the understanding of knowledge management status along the entire PLC. Further, it would potentially be helpful for studies on how to close the information loop for product lifecycle management (PLM).

In response to the discussion above, this thesis aims at investigating knowledge management practices at Finnish recycling and waste management companies. The research question is: What are the KM practices in EOL phase under PSS context?

The knowledge flow within and between stakeholders involved at EOL stage was investigated, and the links between stakeholders at BOL and MOL stages was discussed. Interviews were conducted to get qualitative insight into knowledge management practices in knowledge creation, acquisition, sharing and reuse at recycling and waste management companies in Finland. Through this, researchers and practitioners would gain knowledge about the status-quo and insights of knowledge management practices at Finnish recycling and waste management companies, and fill the knowledge gap of information flow between stakeholders in the entire PLC.

1.3 Key definitions

Some of the key definitions in this study can be defined as follows:

Knowledge management (KM) is defined as a series of knowledge handling activities includes knowledge creation, acquisition, sharing and reuse (Nonaka, 1994). Product lifecycle management (PLM) is defined as a process that supports capture, organize and reuse of knowledge throughout the entire product lifecycle (Ameri & Dutta, 2005). Product-service systems (PSS) is defined as a system consists of products, services, supporting networks and infrastructure that is designed for competitive and satisfy customers' needs with a lower environmental impact compared to traditional business models (Oksana, 2004).

1.4 Scope and limitation

This thesis is an interdisciplinary study of KM, PLM and PSS, the research area is demonstrated in **Figure 1** (see next page).

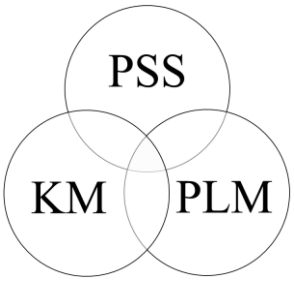

Figure 1 Research area

However, this thesis focuses on the two most striking topics among EOL activities: recycling and waste managing. Other EOL activities (such as remanufacturing) are not covered in this study. These can be areas for future research and studies.

1.5 Structure of the thesis

The **Figure 2** (see next page) summarizes the structure of this thesis. Chapter 1 explains the background, motivation, and the goal of this thesis, with defined scope and limitation. Chapter 2 will present the theoretical background of this study, the concept of KM, PLM, and PSS will be furthered discussed there, together with related theories. Chapter 3 will provide the research methodology and strategy of this thesis, and the information related to interviewees and interview questions, data collection and analyse method will be presented. The results and discussion of the interviews will be presented in Chapter 4. Conclusion of this thesis is presented in chapter 5 with detailed explanations of the limitations of this study. Future research suggestions and recommendations are made in the same chapter. Chapter 6 summarizes the whole thesis.

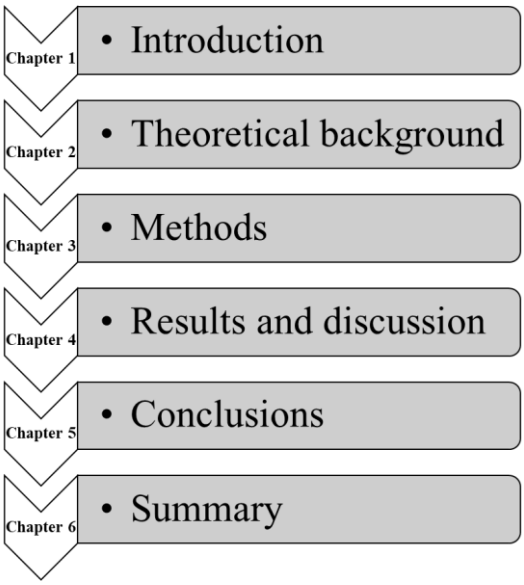

Figure 2 Structure of the thesis

2 THEORETICAL BACKGROUND

At information age, knowledge has become one of the most important assets for organizations and individuals. Effective knowledge management is one critical factor to increase organization's competitiveness. However, the word 'knowledge' has been used as a common word in literatures of different fields and in daily life. It is necessary to clarify the meaning of the term 'knowledge management' accurately. This thesis focuses on studying knowledge management from a product lifecycle management (PLM) perspective. The definition of knowledge management is adapted from Nonaka (1994) with a focus on knowledge flows and the process of knowledge creation, acquisition, sharing, and reuse. In the context of this thesis, knowledge management refers to knowledge handling activities by various stakeholders throughout the entire product lifecycle with the context of product-service systems. This chapter aims to provide an overview of the relevant theories in this thesis, as it is a cross-discipline research of KM, PSS, and PLM.

2.1 Knowledge management (KM)

2.1.1 Concept of KM

Knowledge as a broad and abstract notion, has raised many epistemological debates within western philosophers since Ancient Greek time until now (Ameri & Dutta, 2005; Alavi & Leidner, 2001). The term of knowledge has been probed, questioned, or reframed by ancient and modern philosophers to discover the universal truth. However, practitioners and researchers are not interested to apply such understanding of knowledge to build knowledge-based theory of the firm and to apply it for organizational knowledge management (Alavi & Leidner, 2001).

The concept of data, information and knowledge are interacting with each other sometime. There are some distinctions between them. Data is defined as facts that are unorganized and unprocessed. Information is regarded as the aggregation of processed data that supports decision-making. Knowledge is limited to the specific information that is needed to solve a problem (Ameri & Dutta, 2005).

Knowledge management (KM) as a discipline has emerged first as a pursuit for managing big organizations, later developed as a topic of academic studies. Knowledge has always been managed implicitly with a long history. However, systematic KM for business purposes has only become explicit no longer than three decades ago (Wiig, 1997). In the early 1990s, the growing interest in treating knowledge as a significant organizational resource was driven by the confluence and natural evolution of several factors (Alavi & Leidner, 2001; Wiig, 2000). Individual practitioners in big companies initiated the needs to explore and implement approaches to manage knowledge. For them, the necessity of KM was driven by the forces of competition, market demands, and new business and management practices (Wiig, 2000).

Wiig (1997) stated that the objectives of knowledge management are enabling the enterprise to act as intelligently as possible to ensure its business sustainability and success, and to realize the best value of its knowledge assets in other ways. He concluded that "the overall purpose of KM is to maximize the enterprise's knowledge-related effectiveness and returns from its knowledge asset and to renew them constantly" (Wiig, 1997). Nowadays knowledge management as a management discipline is often referred as the tool or process to get the right knowledge from the right place for the right person at the right time (Hajric, 2018).

2.1.2 Knowledge typologies

While the knowledge management theories were developing, researchers found the importance of defining and understand knowledge types. The distinction among the different types of knowledge impacted the knowledge management system design (Alavi & Leidner, 2001). However, nowadays research on strategic organizational knowledge management is influenced heavily by the theory of defining knowledge as explicit and tacit (Loebbecke et al., 2016).

According to Nonaka (1994), knowledge in organizations can be viewed as tacit or explicit, individual or collective, see **Table 1** below. The tacit knowledge is comprised of both cognitive and technical knowledge aspects. The cognitive aspect of tacit knowledge involves individual's mental maps, paradigms, and opinions. And the technical aspect of tacit

knowledge refers to expertise that includes know-how, crafts, and skills in certain area (Nonaka,1994). The explicit knowledge is articulated, codified, and communicated in symbolic form or natural language, for example product manuals and production handbooks (Nonaka,1994). The individual knowledge is viewed as knowledge existing in individuals and is created by individuals. Relatively, collective/social knowledge is created by and inherent in the collective actions of a group (Nonaka,1994).

Other than Nonaka's four most common knowledge typologies, Alavi and Leidner (2001) classified knowledge as declarative (know-about), procedural (know-how), casual (know-why), conditional (know-when), and relational (know-with) with the aim of explaining the interrelationships among various knowledge types. Furthermore, there is another pragmatic approach which only identifying types of knowledge that are useful for an organization, such as knowledge about customers, products, processes, and competitors. The name of these knowledge is often referred as best practices, know-how, rules, patterns, project experiences, technical details, business process and so on (KPMG, 1998).

Table 1. Four basic knowledge types and their examples (adapted from Alavi & Leidner, 2001)

Knowledge types	**Definitions**	**Examples**
Tacit:	Knowledge is rooted in actions. experience, and involvement in specific context	Best ways of dealing with different customers.
Cognitive tacit	Mental models	Individual's belief on cause-effect relationships.
Technical tacit	Know-how applicable to specific work	Welding skills.
Explicit	Articulated, generalized knowledge	Knowledge of major customers in a region.
Individual	Created by and inherent in the individual	Insights gained from completed project.
Collective	Created by and inherent in collective actions of a group	Norms for inter-group communication.

2.1.3 Alternative approaches of KM

At the early development stage of knowledge management theories, several diverging and isolated notions were advanced without any general approach of managing knowledge be accepted (Wiig, 1997). The first notion took technical approaches to deal with management of explicit knowledge, and the primary focus was on the data stored in computer and IT systems. The second notion centered on management of intellectual capital mainly formed by structural capital and human capital. The third notion encompassed the first and second notions to include all relevant knowledge-related practices and activities of the enterprise that is critical for the company (Wiig, 1997).

According to the literature review conducted by Alavi and Leidner (2001), knowledge can be viewed as (a) Knowledge vis-a- vis data and information, (b) a state of mind, (c) an object, (d) a process, (e) a condition of having access to information, or (f) a capability. Different views of knowledge lead to different perceptions of knowledge management and different emphasis on Knowledge management system (KMS) design (Alavi & Leidner, 2001).

The perspective on knowledge as data and information focuses on exposing individuals to potentially useful information and facilitating assimilation of information. The focus of the KMS design of it is on data collection and storage which is not very different from existing information management system. However, the goal of enabling employees to assimilate information effectively is not found in pure information management system.

The second perspective on knowledge as a state of mind aims at expanding individual's personal knowledge and apply it for the benefit of the organization. The implication of KM includes enhancing individual's learning and understanding through provision of information. The role of IT is mainly to enable the accessibility of the sources of knowledge rather than knowledge itself because knowledge is viewed as state of knowing and understanding in human brain (Alavi & Leidner, 2001).

The third view of knowledge regards knowledge as an object that can be stored and manipulated. Therefore, the knowledge management of it focuses on building and managing knowledge stocks and IT is used as tool to gather, store and transfer knowledge.

The fourth view of knowledge is to view it as a process of acting. It is a series of activities related to creation, sharing, and storing of the knowledge with the goal of using one's expertise for solving problems and benefit the company. Therefore, the knowledge management focus is on knowledge flow and the processes of creating, acquiring, sharing, and distributing the knowledge. The role of IT is to provide link among sources of knowledge to create a fluent channel for knowledge flow (Alavi & Leidner, 2001).

The fifth view of knowledge is a condition of access to information, where KM focus is on access and retrieval of content. The accessibility of the knowledge is emphasized. The role of IT is for effectively search and retrieval to locate needed information.

Finally, knowledge is viewed as a capability that has potential impact on actions. The capacity of using information, learning and experience for decision making is regarded as core competencies. KM focuses on building these core competencies, understanding strategic know-how, and further creating intellectual capital. The role of IT is to support the development of individual and organizational competencies and increase intellectual capital of the firm (Alavi & Leidner, 2001).

Table 2 below summarized the various approaches of knowledge management and their implications for the knowledge management system design. Each perspective suggests a

different strategy for managing the knowledge and offers a different angle of knowledge management system design. However, modern enterprises adopt several approaches of KM into their knowledge management system design to achieve their goals. The perspective relied upon heavily in this thesis is to view knowledge as a process and object, closely related to the perspective of knowledge as data and information. The implication for it is to focus on the gather, storing and transfer the knowledge, and the knowledge flow between stakeholders.

Table 2. Different perspectives of knowledge and their implications (adapted from Alavi & Leidner, 2001)

Perspectives		**Implications for knowledge management (KM)**	**Implications for knowledge management systems (KMS)**
Knowledge vis-a- vis data and information	Data is facts, raw numbers. Information is processed/ interpreted data. Knowledge is personalized information.	KM focuses on ex-posing individuals to potentially useful information and facilitating assimilation of information	KMS will not appear radically different from existing information management system, but will be extended toward helping in user assimilation of information
State of mind	Knowledge is the state of knowing and understanding.	KM involves enhancing individual's learning and understanding through provision of information	Role of IT is to provide access to sources of knowledge rather than knowledge itself
Object	Knowledge is an object to be stored and manipulated.	Key KM issue is building and managing knowledge stocks	Role of IT involves gathering, storing, and transferring knowledge
Process	Knowledge is a process of applying expertise.	KM focus is on knowledge flows and the process of creation, sharing, and distributing knowledge	Role of IT is to provide link among sources of knowledge to create wider breadth and depth of knowledge flows
Access to information	Knowledge is a condition of access to information.	KM focus is organized access to and retrieval of content	Role of IT is to provide effective search and retrieval mechanisms for locating relevant information
Capability	Knowledge is the potential to influence action.	KM is about building core competencies and understanding strategic know-how	Role of IT is to enhance intellectual capital by sup-porting development of individual and organizational competencies

2.1.4 Knowledge management practices

Knowledge creation

One of the most influential knowledge creation theory is Nonaka's SECI model. It is a knowledge sharing model that describes the conversion mechanism of tacit and explicit knowledge into organizational knowledge. It is a spiral shape of interactions between explicit and tacit knowledge, and Nonaka believed that new knowledge is created during such process, see **Figure 3** below. The process of turning different types of knowledge, such as best practices, know-how, personal experiences into knowledge that can be used by an organization is continuous (Nonaka & Konno, 1998).

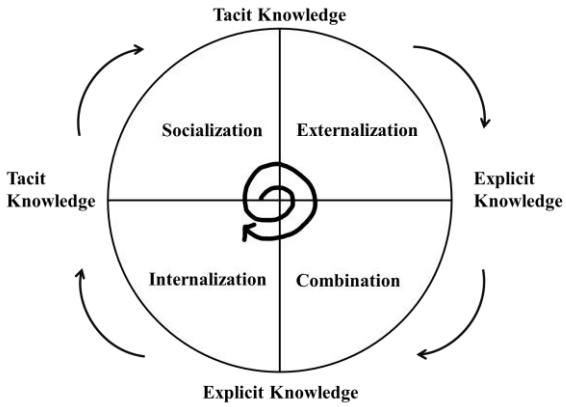

Figure 3 The SCEI model (adapted from Nonaka & Konno, 1998)

Most of the researchers have utilized the SECI models in knowledge creation related studies (Grimsdottir et al., 2019). The matter of knowledge creation has been important for organizations and enterprises, which is often discussed and studied under the title of "innovation management" (Hajric, 2010). Knowledge creation as a process is naturally linked with knowledge sharing activity. It occurs via education, training, collaborations, and communications. The types of created knowledge various, and the created knowledge can support the decision-making regards to the way of creating new knowledge (Hajric, 2010).

The knowledge creation in SMEs (Small and Medium-sized Enterprises) and larger companies are different in many ways. The differences in financial, technical, and human

resources are decisive for their capabilities of creating knowledge, thus defined the preferable methods of knowledge creating (Grimsdottir et al., 2019). There are advantages and disadvantages in different sizes of the companies. In generally, management methods in SMEs are more of the owner's governing style than formal company rules. The working process can be more simple and less bureaucratic, and the cooperation between workers are tighter compared to in large enterprise (Yew Wong & Aspinwall, 2004). Large companies have the advantage in the abundant resource, and some researchers came to conclude that these resources make large companies in a better ground of knowledge creating and innovating (Grimsdottir et al., 2019).

Knowledge acquisition

The concept of knowledge acquisition was emerged in 1980s, and it was considered as a tool that could contribute to the development of knowledge-based systems (KBS) (Boose & Gaines, 1989). The focus was on the knowledge acquisition of the computer, and how to make the information input to a computer system more effective (Motoda et al., 1991). Nowadays, knowledge acquisition often refers to the process of obtaining knowledge from outside of a company or an organization (Hajric, 2010a). Every stakeholder in the value chain can become the external source of knowledge, for example partners, customers, suppliers, services providers, government, educational institutions, etc (Hajric, 2010a). Furthermore, third party institutions can also become one knowledge source even though it is not directly linked to the supply chain.

Knowledge acquisition is regarded as important activities for a company. The ability of acquiring necessary knowledge is directly linked to its competitiveness in nowadays knowledge-intensive business environment (Xie et al., 2018) as the needed knowledge for innovation might be found outside of a firm (Segarra-Ciprés et al., 2014). The knowledge acquisition between organizations can be carried out in different modes, such as sourcing, technical supports, strategic cooperation, etc (Xie et al., 2018). In internet era, the channel of knowledge acquisition can be very creative and convenient.

Knowledge sharing

Knowledge sharing is an important subject for enterprises, it is proven to be beneficial and bring positive impact to individuals, teams and organizations (Ahmad & Karim, 2019). Knowledge sharing refers to the exchange process of knowledge between two or more parties (Sharratt & Usoro, 2003). Knowledge sharing is described as the act of push and pull to transfer knowledge between two parties, and it is often depending on each party's willingness and motivation to seek and receive the knowledge (Hajric, 2010c). Therefore, creating a friendly atmosphere for knowledge sharing in the company and industry can increase such interactions (Ni et al., 2018).

The knowledge that are shared can be tacit or explicit at two different levels: inter-organisational and intra-organizational (includes intra-project, inter-project and project-external) (Ahmad & Karim, 2019). For intra-organizational sharing, the organization structure plays an important role. The strict hierarchical structure may result in lack of social interactions between departments (Tsai, 2002). Furthermore, employees may regard their knowledge as a competitiveness factor which leads to less willingness to share under an intensive internal competition system (Menon & Pfeffer, 2003). In addition to that, knowledge sharing demands resource from an employee such as time and effort, therefore it is recommended to reward knowledge sharing activities within an organization (Davenport & Prusak, 1998). Many researchers focus on the design of an incentive system to reward employee's knowledge sharing activities in a company (Lee & Ahn, 2007).

Though competition issues are also a concern in the inter-organizational sharing, the interest of enabling effective knowledge sharing between companies along the value chain has been growing. Researchers have focused on how to facilitate inter-organizational knowledge sharing and platforms design (Chen et al., 2014). It is necessary for firms involved in inter-organizational knowledge sharing to have competence of understanding and handling complex knowledge from outside of the firm (Loebbecke et al., 2016). The inter-organizational knowledge sharing can be unilateral or bilateral, depending on the purpose and intension of the knowledge sharing. Usually, absolute unilateral knowledge sharing is not so common in current business world. Rather, knowledge sharing from both sides is needed for business operation. Especially in the context of company cooperation, the knowledge sharing is often bilateral. In some cases, knowledge sharing is reciprocal, means

that is for the benefit of both sides. For example, the collaboration between R&D units of different companies in the form of a joint investments to develop products and manufacturing process is beneficial for all the companies involved (Loebbecke et al., 2016).

Knowledge reuse

Knowledge reuse describes the action of utilizing the knowledge that was created in the past. It is a process that contains stages of knowledge management practices including capturing and documenting knowledge, organizing knowledge for reuse, distributing, or disseminating the knowledge for reuse, and reusing knowledge. Three roles can be identified in the knowledge reuse activity: the original producer of the knowledge, the intermediator who organize the knowledge to be stored, retrieved, and shared, and the user of the knowledge. These three roles can be performed by different people or even only one person, and the process includes the capturing, storing, and sharing of the knowledge (Markus, 2001). The knowledge reuse mentioned in this thesis has a focus on three roles that are performed by different people.

2.2 Product lifecycle management (PLM)

2.2.1 Concept of PLM

The concept of PLM is inextricable linked with Product Data Management (PDM) systems, which were first appeared in 1980s to serve the purpose of controlling and managing product information. At that time, the increasing sources of information raised the need of an effective and secure platform for each party to share and store information. Therefore, the early PDM systems had put an emphasize on the function of allowing each user to access the required data, keep updating the data and setting data creation/modification rules for everyone (Ameri & Dutta, 2005).

In 1990’s, since the enterprises were expanding and internationalised, knowledge sharing and storing inside and between each section of the business operation became more and more challenging than a simple structured enterprise. Furthermore, researchers and practitioners

tended to extend PDM's focus on design and manufacturing and turn it to a management method that has a "cradle to the grave" oriented view of a product. Then, the concept of product lifecycle management (PLM) was generated to build a platform for sharing product related information in its lifetime within an extended enterprise. The aim was to address all the stakeholders throughout the entire product lifecycle, and to connect the business processes and product development processes better in an enterprise (Ameri & Dutta, 2005).

Therefore, in the early development stage of the concept of PLM, data/information management played a big role. Ameri and Dutta (2005) concluded that the core of PLM is "a process which supports capture, organize and reuse of knowledge throughout the product lifecycle".

2.2.2 Three phases of PLM

Product lifecycle, means the "cradle to the grave" of a product's life, is categorised into three different phases, see **Figure 4** below.

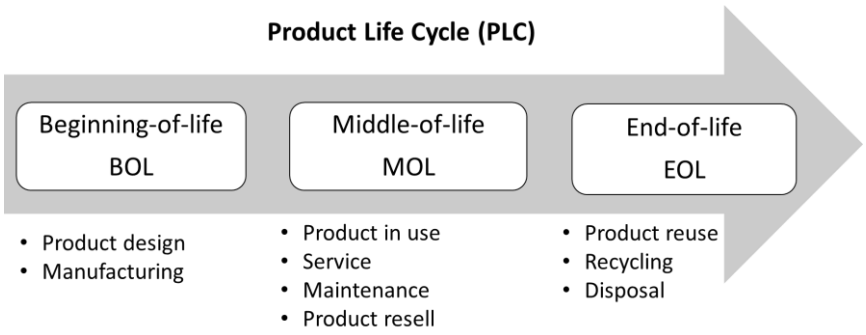

Figure 4 Three phases of PLC (Terzi et al., 2010)

a) Beginning-of-life (BOL)

This phase refers to the period before the product is ready to use, which includes the product design, development, and manufacturing process. The product concept is generated, and the prototype may be realised. Various tools and expertise are used by designers, planners and engineers to develop the product and its production process. Furthermore, the production

facilities and suppliers are planned at this stage (Terzi et al., 2010). At this phase, the product still belongs to the manufacturer, or any other company that is involved at its initiating stage.

b) Middle-of-life (MOL)

MOL phase includes any external logistic, use and services. The product has been distributed, used, repaired, and maintained by customers and service providers. An up-to-date report about the product history can be created to file the product's distribution routes, usage conditions, failures, and maintenance notes (Terzi et al., 2010).

c) End-of-life (EOL)

In the EOL phase, the product is retired from its service life, i.e. it cannot satisfy its users (initial and second-hand owners) anymore. The product is collected, disassembled, refurbished, recycled, reassembled, reused or disposed at this stage (Terzi et al., 2010). Normally, the product's original company or a third-party collector collects the retired product and proceeds it to the next procedure. The popular term 'reverse logistic' means the retired product is recollected by its original producing company to be recycled (disassembled, remanufactured, reused, etc.) or disposed. It is often discussed that the data/information of the product from its original manufacturers regards to the product materials and components should be shared to the recyclers, reusers and disposers in order to make their procedure more effective.

2.2.3 Closed-loop PLM

As discussed in **2.2.1 Concept of PLM**, PLM aimed to expand Product Data Management (PDM)'s function to a whole product life data management so that more product's information can be provided to different departments/sections within an extended enterprise. Nowadays, the scope of PLM is not only to provide product-related information for the development of one company, but more to optimize the entire supply chain including bring environmental benefits (Borsato, 2014).

Data, information and knowledge are created in all the three phases of PLM with different emphasises and purposes, that is why different kinds of tools have been developed for

capturing, storing and sharing the data/information/knowledge at different PLM stages (Kiritsis et al., 2008). However, heavy emphasizes have been put to BOL stage. Digital tools and software for BOL phase have been most researched, such as Computer Aid Design (CAD), Computer Aided Manufacturing (CAM) and Product Data Management (PDM) systems.

Recent years, the interest of servitization has been escalated among industrial practitioners and researchers (Mastrogiacomo et al., 2020). Together with the development of other digital technology such as Radio-frequency identification (RFID), Quick Response (QR) code and sensor technology, a trend named Industry 4.0 is rising and bringing a vision of a fully automatized and intelligent industrial world (Xu et al., 2018). Thus, more attention has been paid to MOL stage, with the purpose of improving customer satisfaction and product performance. Digital tools have been invented to track and monitor the real-time location and condition of the product, and to supply customers quick access to product maintenance and repair (Kohtamäki et al., 2019).

The development of tools for capturing, storing and sharing the data/information/knowledge at EOL phase is the latest improvement, since it received the least attention from past. However, the increasing concerns and awareness of the global environmental issues brings the demand of managing and recycling wastes effectively, which results in full blooming of the recycling and waste management industry (Favi et al., 2016).

The data/information/knowledge flow among the BOL, MOL and EOL phase does not fulfil the needs in current situation, even though various knowledge management tools and methods have been advanced for each PLM phase. Practitioners and researchers identified such gap and proposed a concept named Closed-loop PLM (Jun et al., 2007). It means that the information flow between different PLM stages can be fluent and complete, data/information/knowledge generated from each stage should be shared with stakeholders involved at other stages to benefit the operations at the entire phase (Kiritsis et al., 2008).

Kiritsis (2011) believed that these flows are usually interrupted at the point of products sales, and the feedback (data, information and knowledge) from the service, maintenance and recycling experts is isolated from designers and manufacturers. Design for X methodologies such as design-for-use, design-for-manufacturing, design-for-assembly, design-for-service, design-for-environment, design-for-recycling and design-for-disassembly indicates the high

dependency upon reversed information flows in order to design competitive and sustainable products (Kiritsis, 2011).

Practitioners who work for companies associated at the EOL phase require data/information/knowledge from BOL and MOL stage to improve their services and operation (Favi et al., 2016). And the efficiency of waste collection and recycling can be improved with the knowledge acquired from original producers of the product. Kiritsis (2011) assumed that many stakeholders along the product supply and value chain which including designers, manufacturers, users, service and maintenance operators, and recyclers desire a seamless flow to track and update the product information between them.

Figure 5 below represents an example illustration of a closed-loop PLM. Blue dash lines show the information flow, and black thick lines demonstrate the material flow. It is adapted from Kiritsis (2011) with few changes. The information flow between stakeholders at three PLM phases is more emphasized, and the feedback mechanism of information sharing is taken into consideration.

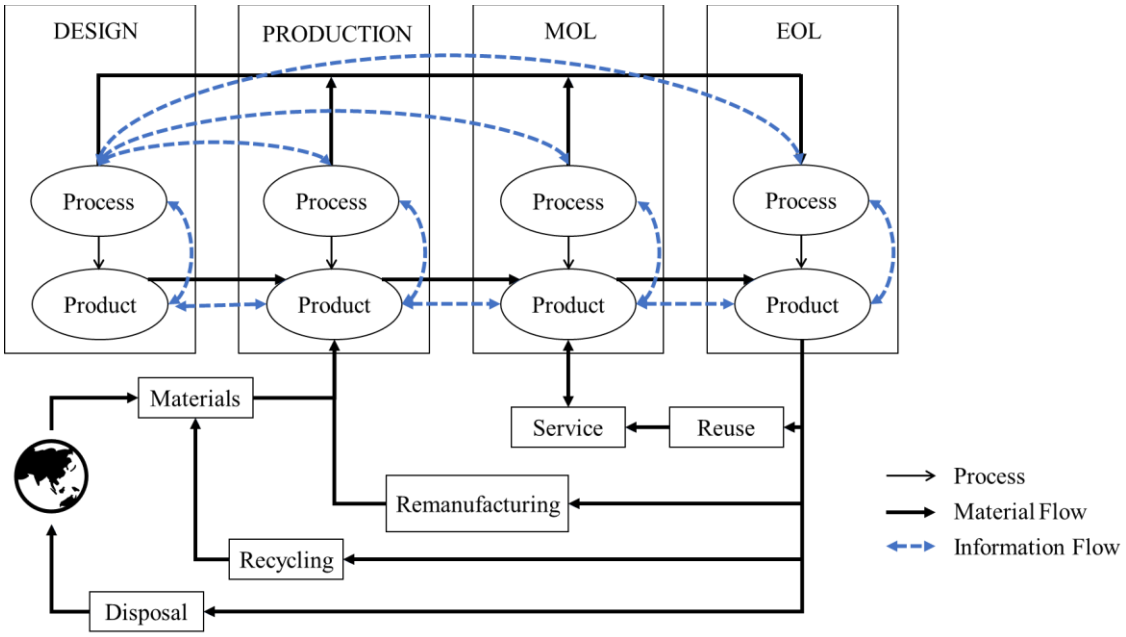

Figure 5 A Closed-loop PLM scenario (adapted from Kiritsis, 2011)

As it is shown in **Figure 5**, EOL activities play a big role in a closed-loop PLM scenario.

In summary, the benefit of closing the PLM information loop includes but not limited to (Kiritsis, 2011):

a) Designers could utilize expertise and know-how from stakeholders of the entire product life cycle, to improve the competitiveness and sustainability of the product design.
b) Manufacturers could acquire the data of the product usage mode, duration, retirement condition and disposal information from stakeholders from MOL and EOL phase.
c) Service and maintenance providers could get assistant information for their work: up-to-date status report of the product, real-time technical support from players at BOL stage, and usage history.
d) Recyclers and reusers could get the accurate information about the quantity and quality of the incoming valuable material from players at MOL and BOL stage.

2.3 Product-service systems (PSS)

2.3.1 Concept of PSS

The concept of PSS was raised with the rising concerns of global environmental issues such as shortage of resources and waste disposal. It aimed at transforming the current system that concentrates on trading physical objects towards a service-centred system, i.e. shifting the focus from physical/tangible products towards the intangible products that is services (Annarelli et al., 2016). Mont (2002) determined that a PSS should consist of the following elements: a combination of eco-designed products; designed product services at different stages of a product's life cycle; different concepts of the product use (use or result-oriented); and close involvement of final consumers and actors in the system. However, the process of achieving the consistency of the definition of PSS has been long, and different scholars have improvised their own opinion on PSS. **Table 3** below presents a few examples.

Table 3 Definition of PSS (adapted from Tukker, 2015)

Author	**Definition of PSS**
Mont (2004)	a system consists of products, services, supporting networks and infrastructure that is designed for competitive and satisfy customers' needs with a lower environmental impact compared to traditional business models.
Brezet et al. (2001)	Eco-efficient services are systems of products and services which are developed to cause a minimum environmental impact with a maximum added value.
Manzini et al. (2003) Halen et al. (2005)	A product-service systems can be defined as the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands
Hockerts & Weaver (2002)	A pure product system is one in which all property rights are transferred from the product provider to the client on the point of sale. A pure service system is one in which all property rights remain with the service provider, and the clients obtain no other right besides consuming the service. A product-service systems is a mixture of the above. It requires that property rights remain distributed between client and provider, requiring more or less interaction over the lifetime of the PSS
Tukker (2006)	A product-service systems consists of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling specific needs of customers

This thesis adapts definition from Mont (2004), because it provides image of a value chain among different stakeholders which can be related to the product lifecycle (PLC) stages.

2.3.2 Types of PSS

Though there are various definitions of PSS in literatures, it is now generally accepted to divide PSS into the following three distinctive types according to its characteristics (see **Figure 6** below):

Figure 6 Subcategories of PSS (Mont, 2002)

a) Product-oriented PSS

The physical product is still the focus point, and service is existing just to support the use of the product. Service may cover the whole phases of a product lifecycle that may include product maintenance, supply of spare parts, and a take-back agreement when the product reaches its end of life (Tukker, 2004).

b) Use-oriented PSS

The sales of the physical product are insignificant. Instead, product renting becomes a form of doing the business. The ownership of the product remains the same during its lifecycle, and the owner takes responsibility for its maintenance, repair and waste disposal. Customers pay for the times or durations of using the product.

c) Result-oriented PSS

The focus is totally shifted from the physical product to the service. The Customer pays for the service, and the physical products that are used to deliver result is insignificant for them.

The owner of the physical product involved in the delivery process of the service and the service deliverer are not necessary the same party. One example is outsourcing, in which part of a company's activities is outsourced to the third party with a contract that includes performance indicators for controlling of the service quality (Tukker, 2004).

2.4 KM studies at end-of-life stage under PSS context

2.4.1 Knowledge management at end-of-Life stage

Knowledge management studies targeted at EOL stage are rare, and the focus is usually on how to manage knowledge in order to empower reverse logistics (Skapa, 2015; Wadhwa & Madaan, 2007). Reverse logistics is described by Hawks (2006) as "the process of moving goods from their typical destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics." It covers most of the EOL phase activities, but not all.

Researchers found there is a positive relationship between knowledge creations with reverse logistics for organization (Mihi-Ramirez & Girdauskiene, 2013). In the empirical study conducted by Skapa (2015), knowledge management was proven to be an influencing factor of effectiveness of reverse logistics. Adequate knowledge management through all the phases of product returning effectively solve problems generated in the reverse logistics processes (Wadhwa & Madaan, 2007). Furthermore, knowledge management system could accelerate the agility and innovativeness of reverse logistics processes. The knowledge management system with a focus on activities that are not limited within companies can improve reverse logistics (Skapa, 2015).

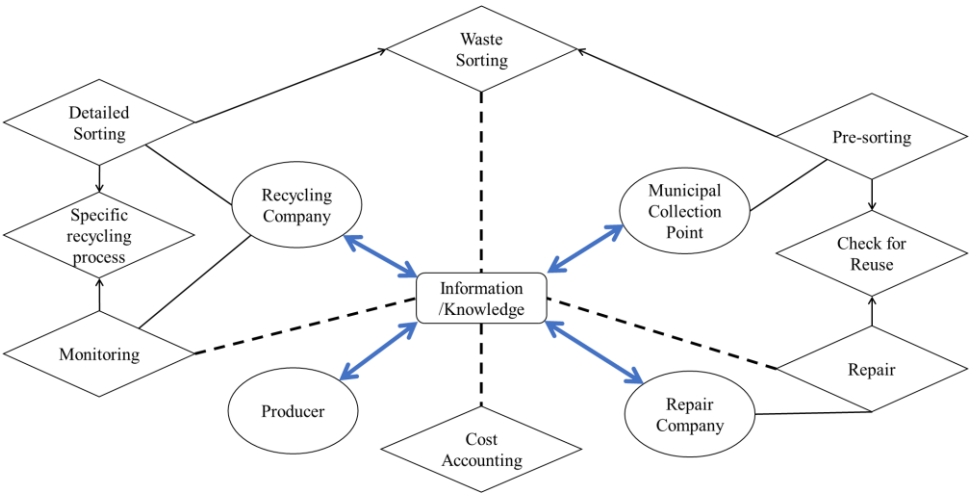

Figure 7 Information system for recycling (adapted from Thoroe et al., 2011)

Information/knowledge provided by four main stakeholders as shown in the **Figure 7** above supports the other activities at the EOL stage. For example, authorized repair services can access to manufacturer's product information system to achieve best efficiency of repairing. By including check-for-reuse to municipal collection points' pre-sorting procedure, products or its parts could be repaired or recycled in disposal phase (Thoroe et al., 2011).

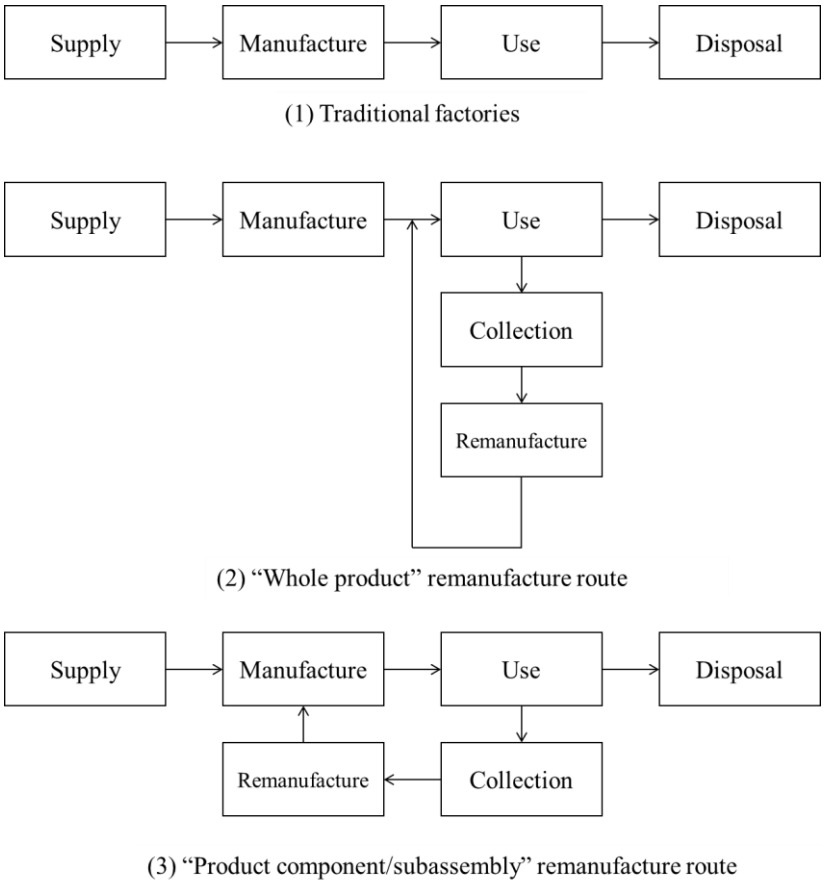

Figure 8 Information flow for varying methods of remanufacture (Rosamond, 2010)

Rosamond (2010) listed three routes to demonstrate the flow of product and information in different remanufacturing scenarios. The first route shows a liner flow in traditional factories without remanufacturing planning. The second and third flow give two examples on how remanufactured product or equivalent sub assembly/components re-enter the traditional manufacturing route at different stages (See **Figure 8** above).

Further, E-technologies can be used for knowledge management activities at EOL stage such as interaction, collaboration and knowledge exchange between stakeholders which is the

same idea as the closed-loop PLM (Skapa, 2015). Thoroe et al. (2011) proposed a RFID-based Individualized EPR and Recycling System for WEEE (waste electrical and electronic equipment) in their paper. The aim was to utilize object-related information to improve the product recycling. The detailed suggestion was to attach RFID-transponders on all the electric appliances in the BOL stage and create a network of data collection points in the EOL stage.

2.4.2 Green design of a PSS from an end-of-life perspective

The concept of product life cycle (PLC) and product lifecyle management (PLM) has existed in literatures longer time than PSS. Scientists want to use the concept of PSS to solve current environmental issues and improve the sustainability of industries. Circular economy has emerged in recent years as a theory that can bring positive environmental impact to the society. In this kind of trend, PSS theories are developing towards the direction with clearer environmental focuses. Product-service lifecycle management is one of the examples which aims at combing the concept of PLM and PSS to structure a platform that supports PLM under PSS concept. Therefore, some people say that product/service lifecycle management is the extension of PLM. Based on that, a theory named Smart-circular PSS was developed by Alcayaga et al. (2019), see **Figure 9** below.

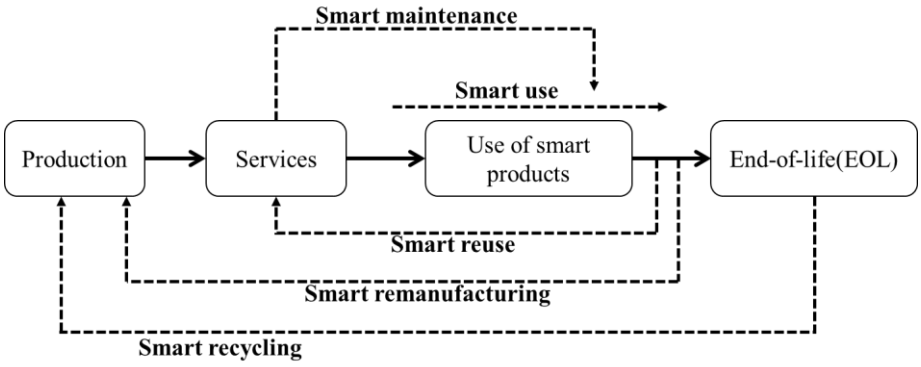

Figure 9 Smart-Circular PSS (adapted from Alcayaga et al., 2019)

Information technologies are used to support these PSS model. The recorded details of product information and its real-time situation facilitate its maintenance and adaptations. Predictive maintenance is also achievable due to the real-time condition tracking. In addition, active tracking of used products, parts and materials supports product reuse and remanufacturing activities, and gives a better estimation of its remaining lifetime (Ingemarsdotter et al., 2020).

To achieve the ecological goal of PSS, multiple areas need to be considerate already at the design stage of the PSS. From an end-of-life perspective, the following points should be considered (Szafraniec, 2017):

1) prioritize usage of recycled and recyclable materials in tangible products and its packaging.

2) minimize material consumption in both tangible and intangible products.

3) design-for-recycling: maximize the recycling rate of the entire system with optimized design of the tangible and intangible products.

4) optimize the design of product service to enhance product durability. Required information/data: database of parameters of available recycled and recyclable materials; environmental impacts at all the stages of product-service lifecycle (BOL, MOL and EOL).

Since knowledge management theory has been widely applied to information system developments, researchers from recycling and waste management field also paid attention to applying KM to enhance information flow for reverse logistics. Rosamond (2010) developed a theory that include requirement of a successful information and knowledge management system, for the purpose of supporting remanufacturing and PSS activities:

1) be able to monitor customers' use or abuse of the product, to track the location of the products, to predict failure, to schedule maintenance, and to drive the procurement and material management process.

2) be able to manage the complete core remanufacturing process flow and finished stock levels, to link products, business, and customer together carefully, to identify customer and production needs and manage required data.

3) be able to manage supplier/customer details, specific information of individual product, product remanufacturing/material process information, and information about EOL disposal/recycling routines.

3 METHODS

3.1 Introduction

In this chapter, research philosophy is clarified to help readers to understand the logics and motivations of this research. The research methods are then introduced, along with the reason of choosing it. Next are the issues related to data collection, including the consideration on sampling and a brief profile of the interviewed companies and interviewees. Finally, the technique and steps of data analysis is discussed, as well as the digital tool utilized for data analysis.

3.2 Research philosophy

Ontology is used as a concept of philosophical discipline to describe the nature and structure of the reality (Staab & Studer, 2010). Ontology considers the ideas of the existence and relationship of things in the world in general (Eriksson & Kovalainen, 2015). Epistemology is defined as a philosophical study of the nature, origin, and limits of human knowledge (Stroll, 2005). The discussion surround it is normally about what the knowledge is and what the sources and limits of knowledge are? (Eriksson & Kovalainen, 2015). Epistemology defines what kind of knowledge is available and the limitation of it in scientific research (Eriksson & Kovalainen, 2015). Axiology is the philosophical study of the nature and classification of values. Specifically in research philosophy, it is kind of assessment of the position of researcher's own value reflected on his/her research activities (Business Research Methodology, 2020). In practice, ontology, epistemology, and axiology forms research philosophy, and it is about three questions: what the nature of reality is, how can we know about this reality, and the specific method through which we create knowledge (Business Research Methodology, 2020).

There are two major philosophies in nowadays scientific research: positivism and interpretivism. This research is a positivistic thesis because the author adopts a view of positivism. Positivist researchers believe that the truth can be learned only through science, and interpretivist researchers assume that the reality is studies only through social

interactions. (Business Research Methodology, 2020) Interpretivism was developed regards to the criticism of positivism in social science, and interpretivist researchers might emphasize qualitative over quantitative research method. (Business Research Methodology, 2020) The differences of positivism and interpretivism in ontology, epistemology and axiology is shown in the **Table 4** below.

Table 4 Differences of positivism and interpretivism in ontology, epistemology, and axiology (adapted from Carson et al., 2001)

		Positivist	**Interpretivist**
Ontology	Nature of the world About reality	Have direct access to real world. Single external reality.	No direct access to real world. No single external reality.
Epistemology	'Grounds' of knowledge Relationship between reality and research	Possible to obtain hard, secure objective knowledge. Research focus on generalization and abstraction. Thought governed by hypotheses and stated theories	Understood through 'perceived' knowledge. Research focuses on the specific and concrete. Seeking to understand specific context.
Axiology	Focus of the research Role of the researcher	Detached, external observer. Clear distinction between reason and feelings. Seek to maintain clear distinction between facts and value judgments. Distinction between science and personal experience.	Researchers want to experience what they are studying about. Allow feeling and reason to govern actions. Distinction between facts and value judgments less clear. Accept influence from both science and personal experience.

Deduction and induction are two basic models of research in social science. In deductive model, researchers carry the research begin with the theory as the first source of knowledge, then deduce one or more hypothesis based on the known theory, and the hypothesis shall be tested through empirical study and end with an empirical analysis. The strict deductive model is considered as inappropriate for most of the qualitative business research. Induction is the research model that emerges theories out from empirical studies. The research process goes from empirical studies to theoretical results (Eriksson & Kovalainen, 2015). However, in practice the pure induction is uncommon, since most of the researchers raise research ideas from existing theories and literatures. There is a third research model called abduction which combines deduction and induction approach in one project, since many researchers utilize both during the actual research process. Abduction is considered as the process of transferring the knowledge or meanings that is referred in daily life by people into concepts that will give understanding or explanation to the studied phenomenon. (Eriksson & Kovalainen, 2015) The research method of this study is more of inductive approach. But as it is mentioned above, pure inductive studies are rare in business research, this study more or less contains perspectives from deduction as well.

3.3 Research strategy

As mentioned in the previous section, a positivistic view of the world and knowledge was adapted for this thesis. Inductive approach was selected since previous research has only shed lights on knowledge management practices at BOL and MOL stages (Xin et al., 2019a). However, it was hard to find research on knowledge management practices at EOL stage. Therefore, inductive research was necessary for exploring this blue ocean. Qualitative research method was more suitable than quantitative method due to its research nature. Compared to quantitative approach, qualitative approach allowed a more holistic view for answering the research question of this thesis.

Considering the above-mentioned research question was “what are the KM practices in EOL phase under PSS context?”, the present work aims at exploring the status quo of knowledge management practices at Finnish recycling and waste management companies to gain insights into the knowledge management practices in the EOL phase under the context of

product-service systems. In this context, semi-structured interview has been selected to gain insights from employees at these companies since it allows to discover their common working practices related to knowledge management at their companies. Email interview has been selected as an alternative method provided to the interviewees because it requires less time engagement from them.

Via email, participants responded to the same initial open-ended interview questions related to the knowledge management practices at their company. And subsequent interview questions and additional exploratory questions were asked based on the initial responses to elicit further details. Walker (2013) stated that a major advantage of the email interview is its convenience and practicality to overcome geographical and financial issues that hinder face-to-face interviews. Even though telephone and video interviews have the same advantage in this aspect, what distinct email interview from these is its ability to conduct asynchronous interviews (Hawkins, 2018). The unique asynchronous nature of email interviews allows participants to decide their level of participation. As participants have the access to control the amount of time spent in the interview, it encourages a greater participation of working adults.(Fritz & Vandermause, 2018; Hawkins, 2018) In this study, the scheduling advantages of email interview helped me find more targeting participants, i.e. employees from companies.

Based on the research philosophy, research question and research approach, qualitative research was chosen as research method for this thesis. Semi-structured interviews and email interviews were utilized for the empirical study.

3.4 Data collection

3.4.1 Sampling

The primary data was collected through semi-structured interviews and email interviews. The interviewees were selected among Finnish recycling companies and waste management companies, because these two types of companies are the essential stakeholders of a product’s EOL stage. Tens of interview requests had been sent to different employees from around 20 recycling and waste management companies at the beginning of the research and

along the studies. The targeting interviewees were limited to the people with managerial tasks in order to better reflect issues related the knowledge management practices. In the end, four employees from four different companies had committed to this study which include single-category and multi-category products recycling companies, municipal waste collection company, and private environmental management company. Among them, two interviewees came from recycling companies, and the other two came from waste management companies. The details of the profile of the interviewees and their companies are presented in the table below.

Equal number of interviewees from recycling company and waste management company gave a holistic view of the knowledge management practices in different segmentations of EOL stage. There were interviewees from both large and small size enterprise for recycling company and waste management company. This provided insights into the operational differences due to differences in size.

Table 5 Profile of the company and interviewees

Company	Sector	Size	Interviewee	Interview type
R1	Recycling	Micro (0-9)	CEO	Face to Face
R2	Recycling	Large (250+)	R&D Manager	Via Skype
W1	Waste Management	Small (10-49)	Customer Service and Communication Manager	Email
W2	Waste Management	Large (250+)	Facility Chief	Email

3.4.2 Interview questions

The same interview questions were asked to all the interviewees. It consisted of four major sections: type of knowledge used, knowledge sharing, knowledge reuse and impact of digitalization. These questions followed the structural guideline from Xin et al., (2019) on knowledge management practices at BOL and MOL stages and applied it at EOL stage. This consistency makes it convenient for future comparisons of knowledge management at different product lifecycle stages. The interview questions are listed below (Xin et al., 2019):

a) Type of used knowledge

- Which type of knowledge is most important/useful from your point of view?
- Which source of knowledge is most important/useful from your point of view?

- How do you get them? Are they difficult to get?
- What other types/sources of knowledge are also needed but you do not have?
- If there is such knowledge, is it because of not knowing where the knowledge is, or due to the difficulty of accessing and acquiring it?
- If you are informed where the knowledge is, do you know how to access and acquire it?

b) Knowledge sharing

- Have you shared knowledge only within your department or across the company? Why and how (for instance, codification or personalization)?
- Have you shared knowledge with other companies? If yes, why and how?
- Is knowledge sharing useful/effective in the current situation? Why?
- What factors have motivated you to share knowledge or prevented you from sharing knowledge?
- Which department/company is the one that you want to share the most and least? Why?

c) Knowledge reuse

- Have you reused knowledge from previous products/projects? Why and how?
- Do you want to reuse more in the future? Why?
- If you want to reuse more, what knowledge will be the most important one from your point of view?

d) Impact of digitalization

- How digitalization affected knowledge management in your company? Why and how?
- How do you see the future of this industry, what would be the biggest driver for this industry in your opinion?

3.4.3 Research ethics

The face-to-face and skype interviews were recorded with interviewee's permissions, and it would be used only for the purpose of the data analysis of this thesis. The study was anonymous, and it was done by removing names and any other identifying information when the recording was transcribed (typed out into a document from the audio recording). Details

of any third parties, such as people or organizations that the interviewees may talk about were anonymized as well. Interviewees were notified about the anonymity of this study. Any commercially sensitive information was treated as confidential. With the interviewee's permission, the title, size of the company and type of the company were mentioned in the thesis. Detailed information on the company's operational field were not disclosed and analyzed in the thesis. A copy of the thesis would be sent to all the interviewees before submission to ensure that their privacy/confidentiality requirements are met.

3.5 Data analysis

Framework analysis is a data analysis method that is commonly used in qualitative research. It has similarities with grounded theory and content analysis. Framework analysis works in the research with specific questions, a pre/designed sample and a priori issues. (Srivastava & Thomson, 2009) The primary concern of framework analysis method is to describe and interpret the happenings under certain circumstances. (Ritchie & Spencer, 2002) The most important characteristic of framework analysis is that the original data is reduced by summarization and synthesis, and the analysis try to retain the links to the original data to analysis it in respect to the 'reality' (Research Methods and Statistics, 2016).

Framework analysis involves five stages (Ritchie & Spencer, 2002):

1) familiarization of the collected data – to have an overview of the data, and to form ideas about the key issues and themes.
2) identifying a thematic framework – to continue the process of abstracting and conceptualizing the data.
3) indexing(coding) – to apply the thematic framework to the data systematically.
4) charting/summarizing – to select data from its original context and put it under suitable theme.
5) mapping and interpretation – to "define concepts, mapping range and nature of phenomena, creating typologies, finding associations, providing explanations, developing strategies, etc" (Ritchie & Spencer, 2002).

Framework analysis technique was used for analyzing all the interview data because it was the most suitable method based on the research philosophy, research question and research

approach. The interviews were categorized by the type of the company. Recycling companies were labeled as R1 and R2, and waste management companies were labeled as W1 and W2, see **Table 5**. NVivo12 software program was used as data analysis tool. Transcript of two semi-structured interviews and two email interview files were imported to NVivo12, with two representing recycling companies (R1 and R2) and two representing waste management companies (W1 and W2). After the first familiarization step, the interview data of W1 and W2 were first analyzed and coded together while the data of R1 and R2 were handled at one place. Such arrangement is because their similarity form of data and type of company. The first level of the node/code was knowledge requirement, knowledge reuse, knowledge sharing, impact of digitalization and future scope, and a few more levels of nodes/codes were made to summarize the original data. After the preliminary result from these two analyses was accomplished, a third analysis was conducted to compare and combine the data from all the companies. The data was rearranged, and codes were adjusted at this stage. The last step was summarizing and interpreting the data.

3.6 Summary

In summary, this thesis mainly adopted inductive research approach. The research method is qualitative method with semi-structured interview and email interview. Data collection concentrated on Finnish recycling company and waste management company to represent essential stakeholders at EOL stage. Employees with managerial tasks were selected as targeting interviewees. In total, one micro recycling company, one large recycling company, one small waste management company and one large waste management company participated in the study. The variety of the size and type of the company provided a possibility to compare different knowledge management practices at Finnish recycling and waste management company.

4 RESULTS AND DISCUSSION

This chapter will present the key findings from all the interviews. It is categorized based on the interview questions and qualitative analysis techniques mentioned chapter **3.4 Data collection**. The result of required knowledge types and source is showed under section **4.1 Knowledge requirements**. Section **4.2 Knowledge sharing** will demonstrate current knowledge sharing scope in these companies including objects and channels of knowledge sharing as well as the effectiveness and motivation of it. Knowledge reuse related result will be given in 4.3. The influence of digitalization and the result related to sustainability will be presented in the following sections 4.4 and 4.5.

4.1 Knowledge requirements

4.1.1 Knowledge types

Based on where the knowledge may be found, the knowledge types are categorized into external and internal groups. **Table 6** (next page) summarizes all the required knowledge types mentioned in the interviews. As shown in the table, the external group has most of the knowledge types mentioned in the interviews. Legislations and incoming recycling materials knowledge are required for all four companies. Consumer market knowledge and recycled products market knowledge are more meaningful for recycling companies than waste management companies because of the business nature of the recycling company.

Table 6 Types of required knowledge

	Knowledge types	**R1**	**R2**	**W1**	**W2**
External	Consumer market knowledge	x	x		
	Recycled products market knowledge	x	x		
	Incoming recycling materials knowledge	x	x	x	x
	Equipment and treatment knowledge	x	x	x	
	Legislations	x	x	x	x
	Customer information	x	x	x	
Internal	Personal experiences	x	x		x
	Company's rules and practices	x	x		x
	Production data	x	x		x

Information about the market change was commented as vital by both interviewees from two different recycling companies. The market change is one of the external factors that will affect their business, and the company itself is influenced by many external factors as well. The consumer market determines what and how much will the recycling company get as their raw materials. Incoming recycling materials and the recycled product's market define what and how much they can sell for revenue. Recyclers need to follow the market price of certain raw materials that they produce. This is especially true for those recyclers whose main business is based on buying post-consumer wastes from waste collectors and then selling recycled raw materials to the B2B market. It was mentioned that certain post-consumer waste collectors check the market price of the raw materials frequently and make their selling decisions based on it. In such situation, the amount of incoming raw materials that recyclers may acquire does not only depend on the number of end-of-life products from the consumer market, but rather a dual mechanism that is combined with the consumer market and recycled products market. Therefore, understanding the market from each side is essential for the recycling business.

The knowledge of incoming materials was mentioned in all the interviews as one of the most important types of knowledge. The quality and quantity of incoming waste are considered as imperative knowledge for both recycling and waste management companies. The operations of recycling companies and waste management companies often include a series of complex procedures such as disassemble, dismantle, distill, filter, etc. More data and information on the incoming waste means more controllability they can have over the production. With the information on hand, companies can make their plan to reach the maximum efficiency of material handling.

The knowledge of equipment and treatment was mentioned by two recycling company interviewees and one waste management company interviewee. The expertise of the treatment plants and methods is highly important for their business because the core competitiveness of the recycling company and waste management company is the material handling efficiency and recycling rate. Scientific research of the newest material handling methods and process planning is essential of this field, as well as the development made by equipment suppliers.

Legislations are the key knowledge for all the companies. It is also one of the biggest external factors and drivers for their business. Essentially, the recycling and waste management business is built based on the laws and regulations related to environmental issues. The rising concern of environmental issues pushed authorities to legislate decrees and regulations related to wastes and recycle materials management. Changes in regulations and laws have a direct effect on the business of both recycling companies and waste management company, in terms of market, operation methods, and business model.

Customer information was mentioned by most interviewees as the knowledge that they require. For waste management companies, customer information, including customer's location is regarded as one of the most important knowledge. For recycling company R2, the customer needs and feedbacks are valuable for improving their services. The relationship between customers and recycling/waste management companies has similarities but also significant differences with companies associated at BOL and MOL stages. Conventional manufacturers can somehow be the pure product-oriented business. However, service is an indispensable part of the business of companies associated at the EOL stage. For example,

for recycling companies, “buying” is also a service for their “suppliers”, no matter it is to deal with pre-consumer wastes for manufacturers or buying post-consumer wastes from waste collectors. Service always means more than the product itself for this industry. Furthermore, waste management companies provide purely services to their customers. It is not hard to understand why customer information is critical.

The above-mentioned knowledge types belong to the external group. For internal group, knowledge types that are needed are personal experiences, the company’s rules and practices, and production data. These are common knowledge types that are also needed in companies associated with BOL and MOL stages. Personal experiences are one type of knowledge found to be very important for both recycling companies and one waste management company. Especially for the micro-sized recycling company R1, personal experiences are *undocumented* expertise for their production. Besides, the interviewee from the large-sized recycling company R2 mentioned that the personnel findings and experiences - “the sort of silent knowledge” of the production workers are important. Experiential knowledge often represents expertise that is kept within the company, it is one kind of intellectual asset for the company. Therefore, the resignment of experienced employees may incur losses to the company. The company’s internal rules and practices normally are made based on know-how and best practices knowledge. Recycling companies with their R&D department produce such knowledge to support decision-making on their practices. It was mentioned that production data obtained from the production line, inventory value, weight, and quality of the outgoing products are required.

4.1.2 Knowledge source and availability

Different sources of knowledge mentioned during the interview are represented in the **Table 7** (next page). To the question “Which source of knowledge is most important/useful from your point of view?”, interviewees from different firms gave various answers. The interviewee from the W1 answered authorities, seminars/education, lobbying organizations, customer contacts, registers, and cooperation partners. The regional facility chief from W2 listed the state’s official knowledge-sharing pages, internal file server, and individual’s own archiving from email. Customers, suppliers, and the pricing of recycled material getting from a third-party website were responded to be the most important/useful knowledge source by

the CEO of R1. Different from others, the R&D manager from the R2 accentuated their research department as one of the most important knowledge sources in addition to other sources like equipment suppliers, manufacturers, customers, and government. Other sources of knowledge were identified by the author through analysis of the interviews.

Table 7 Source of required knowledge

	Knowledge source	**R1**	**R2**	**W1**	**W2**
External	Cooperation partners	x	x	x	
	Customers	x	x	x	
	Government	x	x	x	x
	Third-party	x	x	x	
Internal	Intranet		x		x
	Employees own archiving	x	x		x
External & Internal	Experts from inside and outside of the company	x	x	x	

The third-party includes recycled materials exchange markets, producer responsibility organizations, and lobbying organizations. The way of getting needed information can be through websites and personal contacts. Experts from inside and outside of the company include experts from the production and R&D department and researchers in educational institutions. The contact to experts within the company is normally done through personal contact or via the intranet. For experts outside of the company, personal contact is one way, and another way is to browse scientific literature, or order industry magazines. Cooperation partners include equipment manufacturers, manufacturers that produce pre-and post-consumer wastes, and municipal waste management companies for recycling companies. The channel of acquiring knowledge from equipment manufacturers is available and accessible. However, cooperation between recyclers and the original manufacturers is mainly limited to pre-consumer wastes handling, which means recyclers help manufactures deal with the industrial waste produced during the production. It is convenient for recyclers to receive required knowledge such as the quantity and quality of the incoming products from their industrial partners because the material flow is relatively steady. However, for

post-consumer wastes, the channel of acquiring knowledge from original manufacturers is available only if the recyclers and waste management companies have collaboration with them. The R&D manager from R2 shared that in order to get the needed knowledge of those post-consumer wastes, the company's research center not only conducts continuous research and creates knowledge about it on their own, but also cooperates with the product manufacturers.

All the interviewees believe most of the necessary knowledge is accessible, legislation information is accessed through governmental websites. Big companies are more likely to use the intranet as a source of knowledge. Small companies rely on employees' own archiving. Communication between companies and their customers is good because they usually can get the needed information. Two interviewees referred that required knowledge is not difficult to get, but they must be active in acquiring the knowledge. Active discussions with different stakeholders are needed. Communication between each party involved in the EOL stage seems to be fluent except between competitors, all of them confirmed that required knowledge usually can be found in one way or another. The ways of knowledge sharing between each party will be discussed further in section 4.2 knowledge sharing. In general, interviewees from recycling and waste management companies approved the current knowledge available at their positions.

The interviewee from W1 indicated that some information is not free. Further, the R&D manager from R2 mentioned that they do not have access to all scientific databases. Charge for knowledge increases the cost of accessing useful information. Market knowledge is one type of knowledge that is difficult to acquire because of its attribute of uncertainty. Some future trends could be predicted if the influencing factors are simple and known. Nevertheless, if in case such as fluctuation in prices is caused by complicated reasons, it is challenging to interpret the situation. CEO of R1 referred that nobody could answer why the prices go up and down, but only speculate if it is the world politics or other factors that affect.

The facility chief of W2 mentioned that some knowledge from the competitors cannot be shared. Therefore, to get such knowledge, someone must collect the data by themselves or ask around for experiential knowledge. The R&D manager from R2 shared that they need sufficient resources to follow the newest scientific publications about recycling actively.

Their solution is to collaborate with different research centers such as universities to have new knowledge in the scientific field. And these connections with academics have become one of the channels for them to access required knowledge.

The customer service and communication manager from W1 answered that the reason for missing knowledge possibly due to authorized permissions are not available. In short, all the interviewees believe if they are informed where the required knowledge is, they would know how to access and acquire it. Using digital tools is not challenging for them either.

4.2 Knowledge sharing

4.2.1 Knowledge sharing scope

Both recycling companies and waste management companies share their knowledge within their companies and with other stakeholders actively (as shown in **Table 8**). Companies that are involved in the EOL stage have different stakeholders from those associated companies at BOL and MOL stage. For recycling companies and waste management companies, some stakeholders are the same and some are different. Furthermore, for R2, their cooperative industrial customers are simultaneously their suppliers. Normally, there is a cooperation between recycling companies and waste management companies, and it can be seen from the interviews. Both interviewed recycling companies and waste management companies listed the counterpart as an object of knowledge sharing.

Table 8 Targets of knowledge sharing

	Objects of knowledge sharing	**R1**	**R2**	**W1**	**W2**
External	Competitor				
	Suppliers	x	x		
	Customers	x	x		
	Cooperation partners	x	x	x	x
	Third-party		x		
Internal	Colleagues	x	x	x	x

Most of the interviewees indicated that competitors are the least wanted knowledge-sharing object. Some interviewees mentioned that knowledge sharing between them and companies with similar operations is existing, but only limited to those companies without direct competition with them. However, the R&D manager from R2 acknowledged that they do share knowledge with their competitors in the case of issues that are concerned of the whole industry, for example, regarding legal requirements of different wastes. Under these circumstances, they could have cooperated and shared knowledge even with competitors.

The R&D manager from R2 emphasized that the goal of the R&D department is to create the information and knowledge for other departments of their company, and the information/knowledge acquired from other departments is utilized for improving their work. The interviewee thought knowledge sharing within the company is the most important thing they do, and intensive knowledge sharing is demanded between the R&D department and other departments.

Different from large companies, micro-companies might not have departments in the organization. Knowledge sharing within the company is carried among individual employees. The demand for knowledge sharing within the company is at the same level as large companies but tends to have a more flexible sharing mode. It is found from the interview with R1 that information is stored and carried by individuals and knowledge retrievals are mostly done through person-to-person interactions. Such mode saves the time and effort of dealing with documentation. However, the CEO of R1 also agreed that the resignation of an employee can cause trouble because knowledge is stored in individuals.

It was discovered from the interviews that recycling companies have mutual knowledge sharing with equipment suppliers. Keep contact with their equipment suppliers was regarded as important by interviewees from both recycling companies. Recycling companies get knowledge from equipment manufacturers on the production and maintenance of their machines, and equipment suppliers could receive feedback and insights to improve their products. The CEO from R1 mentioned that knowledge sharing with their customers and suppliers is equally important due to the chain effect of the company's operation for example purchase of incoming materials, production, and sales. The interviewee concluded that everything is important, everyone needs to know something or to share the knowledge with somebody.

4.2.2 Knowledge sharing channels

Digital tools are generally used for communication at both recycling companies and waste management companies with different scenarios at different companies, as shown in **Table 9**. In general, multiple tools are involved in daily knowledge-sharing activities. Furthermore, person-to-person communication in various ways is found to be the most common way of

knowledge sharing. CEO of R1 proved that personal sharing takes the biggest part in their knowledge-sharing activities. Phone calls are used frequently for sharing knowledge with waste collectors, customers, and colleagues. Face-to-face discussions take place in their daily operations for sharing knowledge between workers within R1. Emails are utilized for keeping in contact with the equipment supplier. Social media applications such as WhatsApp and Skype serve the purpose of communicating with their customers within Finland and abroad. CEO of R1 shared that some customers use WhatsApp if they expect prompt response.

Table 9 Channels of knowledge sharing

Channels of knowledge sharing	**R1**	**R2**	**W1**	**W2**
Intranet		x		x
Social media	x	x		
Person to person	x	x		
Phone call	x			
Email	x			x

R2 is a bigger recycling company in comparison to R1. Thus, applications for project work are more likely adapted for daily operation. The R&D manager from R2 shared that they have applications and tools for project work, the knowledge and data of the projects are shared within the project team. Personal discussions and applications are the channels for communication with their customers. For the interviewee's position, discussions in person take a bigger proportion than applications. Knowledge sharing channels in W1 were not mentioned in the interview.

4.2.3 The effectiveness and motivation of knowledge sharing

During the interviews, all the interviewees commented positively about the effectiveness/usefulness of current knowledge sharing at their company. Three out of four interviewees evaluated knowledge sharing in the current situation as very effective or useful. One mentioned that it has been effective and useful all the time, and the other one pointed

out that knowledge transmission is fast and can happen anywhere due to cloud services. One interviewee showed that share the experiences and information with others has helped them because they do not need to do all the work by themselves, and it is the biggest motivation for them to share knowledge.

There are a few points related to motivation of knowledge sharing accumulated from interviews: 1) to save time and money, 2) to learn the best practices, 3) to avoid errors and bad solutions, 4) to develop the whole industry, 5) to satisfy customers and gain their trust, and 6) to keep the operation smoothly. The biggest prevention to share knowledge is competition and confidentiality. Business secrets such as business figures, production volume (incoming volumes and outcoming products), material compounds, and specific technical issues were reflected as the knowledge that is unlikely to share with others. Non-disclosure agreements on certain issues also prevent people to share specific knowledge with others.

4.3 Knowledge reuse

All the interviewees confirmed the importance of reusing knowledge for them, and it is part of their knowledge management practices. The interviewee from W1 answered that their operations are developed based on previous knowledge and experiences. The interviewee from W2 pointed out specifically that if the knowledge from previous products and projects is relevant, they will reuse that. CEO from R1 shared that their motivation of reusing knowledge from previous products and projects is to get a better understanding of their business. The experts within the company provided knowledge from their expertise and experiences. The mindset of continuous development of their business also motivates them to reuse the knowledge in the future because it helps the improvement process, especially expertise in the technical field. The interviewee from W1 shared a similar view to this.

It was positively found that the R&D department of large recycling company R2 practices knowledge reuse actively and systematically to some extent. The R&D manager from R2 thought that one important function of knowledge reuse is to avoid duplication of works. For example, gathering past test results with different machines and equipment for the development of the recycling process is very useful for their department. It was described

that very often they need to return to some previous projects to check again the information or knowledge from it. For example, if previous studies have been done for product or business development but has not been applied in the company because of external reasons, they would like to check those result again and see whether it is applicable now since external factors are changing as time passes by. In such a way, they have been using lots of previous information, knowledge, and results. Knowledge reuse is a very common practice for them. In addition, the manager shared that reports and documents make knowledge reuse more convenient. Though the information/knowledge from past projects has been well reported and documented, there is still numerous useful tacit knowledge that is difficult to retrieve.

4.4 The impact of digitalization on knowledge management practices

There was one question asked at the end of the interview: “How digitalization affected knowledge management in your company? Why and how?”. Three interviewees have answered this question. One interviewee indicated that digitalization has advanced and accelerated the corporate culture significantly. Knowledge retrieving is faster compared to the past. In addition, people can be quickly gathered through remote meetings. The CEO of R1 agreed that digitalization has affected knowledge management in their company a lot compared to 20 years ago. He/she noticed that younger partners tend to use social media such as WhatsApp for communication, while older partners still prefer phone calls or emails. Another change is that authorities have developed various digital tools or online systems for related issues. One interviewee mentioned that the system can be complicated to use, thus it is not certain that things get easier. The R&D manager from R2 concluded that since more information is produced and available, there are more different kind of applications developed for different purposes with different databases. The amount of information has become huge nowadays and is harder to be found and managed in some cases. There is space for improvement in the knowledge and information management of their company. And the application of new digital applications for work and new ways to produce and manage the information is challenging for those older people in the company.

Furthermore, digital trends such as Robotic Process Automation (RPA) and Internet of Things (IoT) were mentioned by the interviewee from W2 as driven factors for the industry’s future. R&D manager from R2 agreed that the application of IT technologies such as IoT

and QR code that enables recyclers to get more information about product and product usage history would help them to recycle more and better. Meanwhile, the target of R2 is to recover the material more efficiently, to get safe and valuable products, and to produce less waste. However, it was found from the discussion with interviewees from both recycling companies that, the information from BOL and MOL stages of some goods consumer does not matter to their recycling process. The importance of the information from the product's BOL and MOL stages depends on the attributes of the product. In summary, for some products that information is very significant for its recycling stage, and for some other products, it is not significant.

4.5 Sustainability

Three interviewees have answered the interview question: "How do you see the future of this industry, what would be the biggest driver for this industry in your opinion?". All of them mentioned sustainability, which is not a surprise. Recycling and waste management have become the center of the public discussion regards to environmental issues including resource and energy efficiency.

Interviewees approved the potential of their business was driven by green values. People's interests and awareness of waste collecting, and recycling is one important factor that driven the development of this industry, and the legal requirements and regulations play the role of steering the whole industry in the right direction. Finland has already reached a high recycling rate on certain materials in the past 20 years with the development of the concept of sustainability. In the future the direction and value of the circular economy are expected to bring new changes to this industry, to reach the goal of responsible and sustainable global recycling.

5 CONCLUSIONS

5.1 Theoretical contributions

Companies involved at EOL stage have similar knowledge management practices to those at BOL and MOL stages. Knowledge is viewed as intellectual asset for the company. The importance of employees' personal experiences and expertise is well recognised and valued by companies at EOL stage. The importance of tacit knowledge is also recognised, and knowledge codification is practiced. Similar with other companies, the characteristic of KM practices within companies at EOL stage is determined by the size of the company. Naturally, small companies tend to have simpler KM structures and less KM tools than big companies. Usually, big companies have their own intranet and systems for acquiring, sharing, and storing knowledge. The same functions are inclined to be performed by employees at small companies. However, personal contact is still highly favoured by employees as channels for acquiring and sharing knowledge, in both big and small sized companies. In general, the knowledge sharing, acquiring, creating, storing, and reusing within companies are relatively satisfying according to the results from interviews.

Similar with companies at BOL and MOL stages, there is constant necessary communications between different departments within the company at EOL stage. Data/information from production/operation facilities are reported to offices to support customer services and sales. Knowledge creation is usually concentrated at R&D department, and knowledge sharing between R&D department and other departments is one of the most important knowledge management practices for the company.

Despite the similarities, the knowledge management practices between stakeholders at EOL stage has obvious differences with KM practices at BOL and MOL stage. The stakeholders involved at different PLC stage are different. Even at EOL stage, the stakeholders of recycling company and waste management company are slightly different. Waste management companies provide the service of collecting, sorting, and disposing products at EOL stage. Their customers can include service providers, consumers, manufacturers, and recyclers. For recyclers, their stakeholders include manufacturers, consumers, waste manager, environmental organizations, and government. The exchange of information between stakeholders seemed fluent. However, there are a few points to be addressed: 1)

knowledge sharing between stakeholders are not bilateral; 2) knowledge creation among each stakeholder is independent; 3) knowledge acquisition tools are available and people have awareness and ability of using them; 4) knowledge reuse is a common practice among stakeholders at EOL stage.

Knowledge management practices between stakeholders at EOL stage and manufacturers at BOL stage can be separated as manufacturers of the original product and manufacturers of the equipment for companies at EOL stage. Manufacturers of the original product for recyclers and waste managers can be separated as manufacturers for pre- and post-consumer wastes. Pre-consumer wastes refers to wastes generated during manufacturing of the final product while post-consumer wastes refer to wastes of the products reached its EOL. EOL products include both two categories, and from these two categories several kinds of service contracts and recycling items are produced to satisfy the customers needs from BOL and MOL stages. The links between stakeholders at these two stages and EOL stage is weak but significant. Any extra information flow would boost in the efficiency improvement and resource saving. Stakeholders at different PLC stages demand a closed information loop within the PLC. However, more insights are found during this study about the critical information loop of the stakeholders at PLC.

5.2 Practical implications and future research

The use of government and third parties is underestimated in most of the literatures regarding closed-loop PLM. To reach such goal, the role of government and third parties is not suitable to be despised. Scientists and researchers focus on the links between stakeholders at each PLC stage, but no attention has been paid to parties that are outside of the circle. Organizations that are part of people's private and business life play major roles in nowadays life planning and strategy making. Knowing the importance and power of each organization and utilize it in the right way would motivate the development of a closed-loop PLM. All the stakeholders at PLC stages are already understanding the function of third parties and governmental authorizations as the implement of a closed-loop PLM can not be made without considering their effect. However, whom to ask and what to ask is often a problem in knowledge sharing between stakeholders across industry and fields. A third party with the

function of connecting necessary stakeholders together with needed information on who are they and what can they provide would solve this issue.

From the results, information from government is shown to be very important, related policies and regulations are critical for stakeholders at EOL stage. Today, policy makers are in responsible of most of the issues in society. No doubt, many industries are built based on related policies and regulations. Standards for an industry guide the practitioners to do things within certain boundaries. Such boundaries cannot be made without the information from the existing industry and its relevant data. Policy makers are rarely persons who are unknown about how things work in one area. To be trust-worthy policy makers, more information means less chance to make major mistakes. A closed-loop information system of the industries would bring convenience for them to make better decisions. With such motivation, plans can be done for moving the closed-loop PLM forward. Practitioners should trust in the political power that is there already among them. By including them into the information loop, changes can be made in a faster way.

Information loop of EOL companies in Finland is significantly well structured. A long history of cooperation exists between recycling companies and waste management companies. The cohabitation of these two disciplines makes the waste sorting and recycling efficient and fluent. The service of recycling and waste collecting at some point is carried out by the same players. Related stakeholders are the same, and the interest is the same. EOL companies share the same goal of improving waste dealing and restoring values in used products and materials. Bring out these values requires tight connection between these stakeholders. Even though it is already a common knowledge that improving cooperation between recyclers and waste managers are beneficial for both of their business, the mode on how and why to cooperate is remain unclear for both sides. Such knowledge gap is caused by unsystematic cooperation culture and little documentation of previous projects. The result of each cooperation projects is worth of better analysing and storing. Studies should be done to fill the knowledge gap between players on what and how they could benefit each other the most. Neutral agreements should be made based on the interests of both sides so that both can benefit from it, which will promote more information exchange. Competitions are not the biggest barrier of knowledge sharing if the scheme is made suitably for both sides. The effect of a knowledge sharing platform is shown in such case. With a fair sharing

agreement and confidentiality agreement, the problem of competition can be eliminated, and players could focus on the actual knowledge sharing and its positive effect.

Afterall, the knowledge sharing between different stakeholders at EOL stage depends on the mutual interest and technical development that is vital for all of them. The fear of losing control of the most advanced technologies made them band together and actively seek help from scientific research centers. By doing so, scientists and enterprises can support each other's operations, resulting in a win-win cooperation.

In the future, the internet of things will connect everything, creating a nature effect in which all stakeholders are connected with each other. Huge amount of data would flow across internet to every corner of the world. Data security has become a hot topic in terms of knowledge sharing and storage. Paying attention to digital developments would give enterprises an opportunity to prepare in advance. What could be a suitable way of coding and documenting data and information, particularly data preparation, would potentially become an area for knowledge management research. Searching for the right information for the right thing will no longer be a slogan, but a reality that is influencing the world. Rapid digital advancements empowered the development of knowledge management practices at each company, including recycling and waste management companies in Finland. To stay on top of such trend, attention need to be paid to RFID technology developments and QR code applications as they would have a significant impact on the future of recycling and waste management. Detecting such change would provide further opportunities to capture the blue ocean market and develop a unique product that matches the PSS context. Even though the mixture of product and service is already existing in current recycling industry, how to provide customized recycling services is still under development. Customization, as a big trend in the society, will eventually influence the business at EOL stage. It is a good idea to prepare in advance so that companies are not in trouble when the macro environment is changing.

For businesses at EOL stage, sustainability naturally has a great impact, because the whole business leans on circularity and sustainability issues. Noticing such influence made practitioners confident in what they are doing right now. Environmental awareness boosted in recycling industry in last century. Such progress will continue and bring this industry to be more modern and automated. The developments of climate sciences have provided this

industry with such an opportunity to thrive. Understanding this factor would provide directions on how companies at EOL stage can grow and develop.

Policy support is sufficient for recyclers in Finland, and people's degree of cooperation is high. Municipal waste collection points are well managed and designed. The waste collecting points are easily accessible to all residents, and waste collection service is well-designed to ensure a sustainable business. Policies influence business considerations in waste management companies. The government establishes standards for waste collection, sorting, and disposal. Although there is little room for extending the business, there is plenty space for improving the service quality. Companies can differentiate themselves from the competition by providing higher-quality services.

5.3 Limitations

In 2019, Finnish practitioners could not have predicted such huge change would occur in 2020 due to Covid-19. This thesis did not consider the effect of pandemic in knowledge management practices at EOL stage. However, changes must have happened, because it has happened in a large scale across all industries. Further discussions could be made to investigate the negative and positive effects of the social distance to the recycling and waste management industries. The positive thing is that digital tools are matured to be used as an office tool while people are at home. However, whether the quality of knowledge sharing, storing and reuse will be influenced by such situation is remain unknown.

As a broad topic, knowledge management is not only meant for information and data studies. This thesis took an approach of viewing knowledge management as a process composed with knowledge sharing, acquiring, storing, and reuse, which is not an uncommon practice in KM studies. Such approach allows a brief glimpse into the knowledge management practices in companies. But it does not provide a comprehensive picture with details because of the relatively scarce data. Knowledge management practices can be various from company to company, and a general knowledge management strategy benefits firms in resource saving and energy saving. However, a well-considered so called well-customized knowledge management system might result in better company culture and intellectual activities (Alavi & Leidner, 2001). The use of knowledge management tools is rare for most

of the companies involved in this study. The knowledge management tools mentioned in this thesis often refers to IT communication tools. The actual knowledge management applications are various and without a certain standard. However, it is still possible that knowledge management applications are used by companies at EOL stage in Finland, which could be for further investigated in the future.

5.4 Summary of the chapter

In summary, this thesis investigates knowledge sharing, storing, acquiring, and reuse practices at Finnish recycling and waste management companies by viewing them as stakeholders at EOL stage. The product lifecycle view under product-service systems context is taken into consideration for data analysis and interpretation due to the popularity of such topic and its potential contribution to a more sustainable and effective supply chain. Being a part of the global value chain, companies at any PLC stages face challenges and opportunities. The development of IoT and related infrastructures brings opportunities for companies at EOL stage to realize the goal of recycling more and better recycling. To grab this opportunity, companies must keep their eyes open for societal changes. Furthermore, the influence of third parties, government and equipment suppliers need to be added to the closed information loop of PLC stakeholders (Kiritsis, 2011; Xin, 2020).

The **Figure 10** (see next page) presents an example PLC with closed information loop and consideration in knowledge sharing with third parties and government. Further studies can be done regarding to knowledge management practices in Covid-19 time and how digital tools are help/preventing it. Further investigation on knowledge management applications in Finnish recycling and waste management companies can be studied to get a solid conclusion on the knowledge management system in these companies.

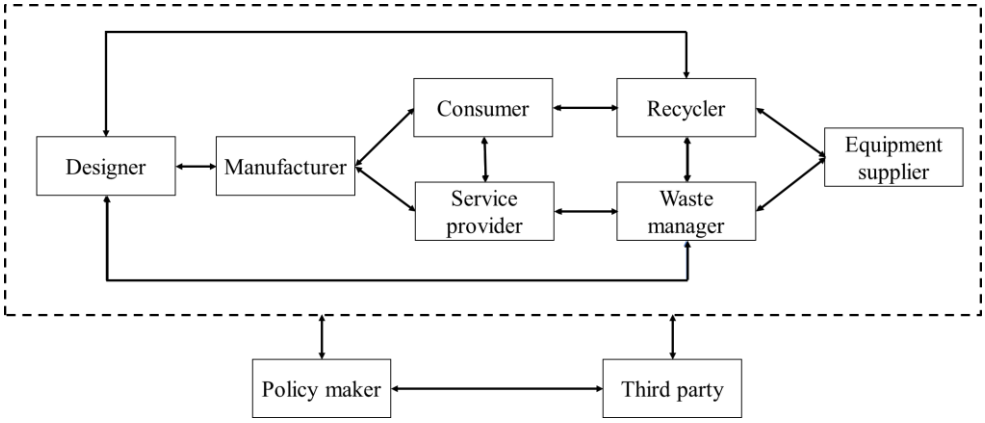

Figure 10 Scenario of a closed-loop PLC

6 SUMMARY

Knowledge management theories and practices have been studied extensively during the past decades. With the increasing popularity of cross-discipline studies in the 21st century, the combination of product lifecycle management (PLM) and knowledge management (KM) has been applied to various disciplines. From information technology to management theories, the call for a closed-loop PLM was heard across the board. Understanding the status-quo of knowledge management practices at each product lifecycle (PLC) stage becomes necessary for developing a closed-loop PLM. Previous studies on knowledge management practices at BOL and MOL stages shed light on the knowledge acquiring, sharing, and reuse. This thesis investigated knowledge management practices in Finnish recycling and waste management companies to enrich the KM studies at EOL stage.

Chapter 1 introduced the background on this topic and the research objective. Chapter 2 provided the theoretical background on knowledge management across PLC in the context of a product-service systems (PSS). Chapter 3 provided information related to research strategy and data collection methods. Chapter 4 presented the result of interviews carried out by author. Chapter 5 concluded the theoretical contributions and practical implications, with limitations of this study and possible future research directions.

This study presented a general picture of simple knowledge management practices at and between companies involved at EOL stage. Knowledge acquiring, sharing, storing, and reuse were explored through qualitative research method. Companies at EOL stage practices good knowledge management skills within their companies and between companies. However, there are constraints and circumstances that make the information loop between stakeholders at EOL stage and stakeholders at BOL and MOL stages incomplete. Suggestions were offered to remedy the issue in chapter 5. Adapting these recommendations could help to improve knowledge management across PLC.

In summary, the research question “What are the KM practices in EOL phase under PSS context?” was answered through studies on Finnish recycling and waste management companies. Four companies participated in this study. Although, the number was small, the result is reliable because the different sizes and types of companies provide an interesting view into this industry. The findings of this thesis can be used to future PLM studies

involving a product-based system or a product-service-based system. The service nature of the companies involved at EOL stage gave a holistic view on knowledge management practices in a product-service based firm. Practitioners would benefit from the results by applying them to their businesses to improve their KM performance.

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