MASTER

Knowledge flow performance

Exploratory research into the efficiency and effectiveness of intra-organizational knowledge flows

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Knowledge flow performance: Exploratory research into the efficiency and effectiveness of intra-organizational knowledge flows

Master thesis report

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Abstract

Prior research has repeatedly stressed the strategic importance of knowledge as a key organizational resource. However, scholars have also demonstrated numerous barriers to the flow of knowledge, making the exploitation of an organization's knowledge stock not a straightforward affair. Therefore, the current study defined and operationalized the constructs of knowledge flow efficiency and effectiveness to identify the most productive ways to foster the intra-organizational flow of knowledge. Using both qualitative and quantitative research techniques, this study analyzed the efficiency and effectiveness of intra-organizational knowledge flows within the service department of a high-tech organization. Moreover, through a survey, this research compared the knowledge flow performance of various channels and investigated antecedents of both knowledge flow efficiency and effectiveness. The results indicate that the efficiency of knowledge flows is significantly influenced by the type of channel used to exchange knowledge, while such an effect was not found for knowledge flow effectiveness. Moreover, this study also identified antecedents of knowledge flow performance, such as characteristics of the recipient, characteristics of the relationship between source and recipient departments, and characteristics of the knowledge exchanged. In doing so, this study contributes to the fields of knowledge and innovation management by providing an understanding of how knowledge flows can be fostered productively to create a competitive advantage for organizations.

Keywords: Knowledge flow, Knowledge flow efficiency, Knowledge flow effectiveness, Knowledge sharing, Knowledge sourcing, Knowledge transfer, Knowledge flow channels

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Jonathan Verhaar

Contents

List of abbreviations

- KR: Knowledge repository
- D&E: Development and Engineering
- GSC: Global Support Center
- CS: Customer Support
- EUV: Extreme ultra-violet
- DUV: Deep ultra-violet
- CE: Competence Engineering
- CE'er: Competence engineer
- Non-CE'er: An individual from another department than Competence Engineering
- LKR: Local knowledge repository
- GKR: Global knowledge repository
- WC: Written communication
- VC: Virtual verbal communication
- PC: Physical verbal communication
- XLD: Extreme long down (of a machine)
- MTTR: Mean-time-to-repair
- Org: Organization
- MST: Media synchronicity theory

Chapter 1

Introduction

In today's modern economy, knowledge has become a strategic resource for companies to create a competitive advantage (Grant, 1996; Kogut and Zander, 1992). Especially in the high-tech sector, the investments in the creation of knowledge are enormous. For example, the likes of high-tech companies such as Amazon, Alphabet, Huawei, Microsoft, and Facebook all spent billions of dollars, equating to over 10% of their revenue, on research and development (Bajpai, 2021). While the investment in the creation of knowledge may increase the collective knowledge stock of those organizations, the key challenge for management lies within the process of leveraging that knowledge to create a difference (Drucker, 1993). Essential in the exploitation of knowledge within organizations are the flows of knowledge between units and departments (Darr et al., 1995; Epple et al., 1996).

The literature on knowledge management has highlighted that knowledge flows can generate significant benefits for organizations (Argote et al., 2000). However, contrary to the more conventional resources, such as land, money, or raw materials, the exchange of knowledge can be less straightforward. Research on knowledge management has repeatedly stressed the difficulty of transferring knowledge (Argote and Miron-Spektor, 2011; Szulanski, 1996, 2000; Zander and Kogut, 1995). Therefore, people have sought various ways to exchange knowledge, and over time developments have altered the ways through which knowledge is conveyed. For example, significant advancements in information technology over the last two decades, such as the rise of the internet and computers, have increased the possibilities to exchange knowledge with one another. Moreover, as the recent global COVID-19 pandemic has diminished the opportunities to exchange knowledge in a physical setting, organizations had to alter their ways how they exchanged knowledge. Thus, given recent developments, it is important to thoroughly evaluate how the flow of knowledge can be enabled to leverage knowledge as a key organizational asset.

Therefore, this graduation project aimed to analyze the efficiency and effectiveness of ways to leverage the flow of knowledge for the optimal exploitation of an organization's collective knowledge stock and identify antecedents of knowledge flow performance. This objective served the dual purpose of advancing the academic insights into the ways how knowledge flows through high-tech organizations as well as diagnosing and improving knowledge flows within ASML, the company at which the research was conducted. Hence, this master thesis report describes in detail the conducted exploratory research at ASML, consisting of both qualitative and quantitative methods, which was performed to accomplish the aforementioned objectives.

The outline of this master thesis report is as follows. Firstly, the analysis and diagnosis of the problem at hand are discussed and a problem definition is formulated. Secondly, the existent literature on the exchange of knowledge is discussed to provide a clear definition of an intra-organizational knowledge flow and develop the constructs of knowledge flow efficiency and effectiveness. Thirdly, a qualitative study is discussed to provide insight into the channels used to exchange knowledge, the types of knowledge which are exchanged, map what departments exchange knowledge with one another, and identify antecedents of the efficiency and effectiveness of knowledge flows. Fourthly, an exploratory empirical research approach is discussed in which knowledge flow efficiency and effectiveness were operationalized. Furthermore, through empirical research, antecedents of knowledge flow efficiency and effectiveness were quantitatively analyzed to understand if, when, and why these variables influence knowledge flow performance. Lastly, the findings of this master thesis report are extensively discussed and the limitations which surround this research are emphasized.

Chapter 2

Problem definition

This research was conducted at ASML, a high-tech company founded in 1984 as the result of a collaboration between Philips and ASM International, which aimed to develop lithography systems. Fast forward, a couple of decades later, ASML has become the innovation leader in the photo-lithography equipment industry. It has been able to obtain a dominant position in the semiconductor industry by following a first-mover strategy, providing its clients with the latest high-accuracy photo-lithography technology. Pivotal in ASML's strategy are reduced cycle times, high technological sophistication of their products, and extensive customer support, which require the optimal exploitation of all their available resources.

Knowledge has become a major resource for high-tech organizations to gain a competitive advantage (Grant, 1996). As innovation leader, ASML heavily invests in the creation of knowledge, which is reflected by their R&D expenditure, which in 2020 totaled 2.2 billion euros, equating to almost 14% of their revenue. By bridging the gap between knowledge creation and application, intra-organizational knowledge flows provide employees with access to knowledge. Therefore, effective knowledge flows are associated with positive effects on organizational performance. For instance, research has shown that cross-functional communication between units is positively associated with new product performance (Evanschitzky et al., 2012). Moreover, effective knowledge flows are also associated with innovation performance (Tsai, 2001), productivity, and organizational survival (Argote et al., 2000). Especially in times of globalization, distributed work and complex organizational structures, the flow of knowledge is essential to compete as an organization (Argote and Miron-Spektor, 2011). Thus, for organizations to excel in innovation and achieve a competitive advantage, their intra-organizational flows of knowledge are paramount.

Currently, ASML faces four challenges that require them to increase its focus on its intra-organizational knowledge flows. Firstly, ASML as an organization is growing at an enormous pace.

Over the last seven years, ASML doubled its number of employees from approximately 15.000 in 2015 to over 32.000 in 2022 with still over 1500 outstanding vacancies at the moment of writing (ASML, 2022). Consequently, knowledge needs to flow from experienced employees to new employees to bring them up to speed on ASML's technologies. Unfortunately, new employees often lack critical experience with the organization's processes of sourcing and transferring knowledge, which can inhibit the flow of knowledge (Teece, 1977; Valentine et al., 2019; Zander and Kogut, 1995). Secondly, as a consequence of such organizational growth, knowledge has become increasingly distributed over different units and departments, hindering access to and the flow of knowledge. Thirdly, with each product generation, the knowledge and technology to realize state-of-the-art lithography machines have become increasingly complex and difficult to codify. Unfortunately, such complexity and tacitness of knowledge are known to be barriers to the intra-organizational flow of knowledge (Szulanski, 1996; Teece, 1977; Zander and Kogut, 1995). Fourthly, the latest product generations are produced and serviced in lower volumes, which limits the accumulation of experience. Therefore, knowledge flows are especially important within ASML to facilitate the buildup of experience by learning from one another.

Consequently, actively engaging in knowledge management is critical for ASML to preserve and improve its position as innovation leader in the semiconductor industry. Therefore, having insight into how knowledge flows within the organization and being able to measure knowledge flow performance are paramount. Firstly, because the time of employees is an extremely scarce commodity within ASML. By identifying efficient and effective ways to enable the flow of knowledge, employees can more productively source and share knowledge within ASML. Secondly, quantifying the efficiency and effectiveness of knowledge flows can aid knowledge management in identifying knowledge flows in need of improvement. Furthermore, a quantitative approach to assessing the efficiency and effectiveness of knowledge flows enables knowledge management to evaluate the effects of their interventions and policies to demonstrate return on investment.

However, currently, ASML has only limited insight into its knowledge flows and best practices to enable the flow of knowledge, while also lacking a robust approach to measuring the efficiency and effectiveness of its intra-organizational knowledge flows, which is elaborated upon in Appendix A. Consequentially, with the discussed challenges ahead, ASML must analyze and enhance its knowledge flows if it wants to optimally leverage its knowledge resources to provide value to its customers through continuous innovation. Thus, it can be stated that:

ASML has limited insights into its intra-organizational knowledge flows and lacks a quantitative approach to measure the efficiency and effectiveness of knowledge flows, which both inhibit the opportunity to enhance ASML's innovation capabilities through the effective management of its knowledge flows.

Chapter 3

Theoretical background

3.1 Knowledge

Authors have varied in their notions of knowledge when investigating the movement of knowledge within or between organizations. For example, some authors referred to knowledge as best practices (Darr et al., 1995; Szulanski, 1996), know-how (Monteiro et al., 2008; Schulz, 2001, 2003), sets of routines (Szulanski, 2000; Yang et al., 2008), technological capabilities (Mowery et al., 1996) or experience (Argote and Ingram, 2000; Darr and Kurtzberg, 2000; Kane et al., 2005; van Wijk et al., 2008). Furthermore, some research focused on the flow of data or information instead of knowledge (Kyriakopoulos and de Ruyter, 2004; Martens and Sextroh, 2021) or analyzed the flow of both knowledge and either data or information (Appleyard, 1996; Gupta and Govindarajan, 1991). Although knowledge and information, as well as information and data, are sometimes used interchangeably, they all refer to distinct constructs.

Data consists of objective and simple facts such as raw numbers or figures, while information is processed data that provides meaning and context (Huber, 1991). Moreover, information can form a flow of messages, which acts as a medium for the formalization of knowledge (Nonaka, 1994). As opposed to information and data, knowledge has an important human component. Knowledge involves the understanding and interpretation of information, "anchored on the commitment and beliefs of its holder" (Nonaka, 1994, p.15). When individuals process information and infer beliefs, for example about cause-and-effect relations, information is transformed into knowledge. The other way around, information is formed when knowledge is expressed verbally or visually (Alavi and Leidner, 2001). The degree to which knowledge is expressible through codification is often referred to as the tacitness of knowledge. Tacit knowledge is per definition difficult to codify and is rooted in action, intuition, skills, and rules of thumb (Nonaka, 1994; Nonaka and von Krogh, 2008). On the other hand, explicit knowledge is more easily codifiable through language, for example via speech or writing. As such, tacit and explicit knowledge form two ends of a continuum (Nonaka and von Krogh, 2008).

Whether tacit or explicit, both types of knowledge provide individuals with the capacity to act, for example through intuition or written procedures respectively. As such, a dominant definition in knowledge management has referred to knowledge as "a justified belief that increases an entity's capacity for effective action" (Alavi and Leidner, 2001, p.109). This definition has a relatively broad notion of knowledge, which can include but is not limited to, know-how, routines, best practices, technological capabilities, and experience. However, central is the ability of knowledge to increase its holder's capabilities to act effectively. From that notion, the transfer of knowledge is predominantly seen as beneficial, as the more knowledge a unit has, the better a unit can perform its tasks. Consequentially, significant attention in knowledge management research has gone on to investigate how knowledge can be transferred from one unit to another.

3.2 Knowledge transfer and knowledge flow

A widely used definition of the transfer of knowledge (e.g., Björkman et al., 2004; Darr and Kurtzberg, 2000; Inkpen and Tsang, 2005; van Wijk et al., 2008) defines knowledge transfers as "the process through which one unit is affected by the experience of another" (Argote and Ingram, 2000, p.151). The knowledge transfer process consists of the contribution of knowledge, making one's knowledge available to others (Watson and Hewett, 2006) and the use of such knowledge, which includes the identification, acquisition, and application of knowledge. The definition of a knowledge transfer by Argote and Ingram (2000) is relatively broad as it can refer to the one-time exchange of knowledge between two individuals of two different groups or departments, but it can also refer to the regular or continuous exchange of knowledge between a multitude of people from two different departments. The latter is sometimes also referred to as the flow of knowledge (e.g., Sammarra and Biggiero, 2008; Schulz, 2001, 2003). In the knowledge management literature, research has used the terms knowledge flow and knowledge transfer sometimes interchangeably to refer to the exchanges of knowledge within organizations (e.g., Forman and van Zeebroeck, 2019; Ravichandran and Giura, 2019).

However, semantically speaking, a knowledge transfer refers to the act of conveying one's knowledge, while a knowledge flow refers to the regular or continuous movement of knowledge from one knowledge repository to another. Therefore, this study refers to a knowledge transfer as the one-off act of knowledge sharing by an individual to one or more recipients. In contrast, the flow of knowledge refers to the regular or continuous exchange of knowledge between multiple individuals of a source unit and multiple individuals from a recipient unit. Thus, while in a knowledge transfer there is only a single moment of accumulation of knowledge by the recipient, in a knowledge flow knowledge is exchanged on multiple occasions with a regular or continuous character, although the intervals between and intensity of those knowledge exchanges may vary. In this study, the use of knowledge flow rather than knowledge transfer aims "to capture the overall amount of know-how and information transmitted between sub-units in all kinds of ways, e.g., via telephone, e-mail, regular mail, policy revisions, training, meetings, job rotation, shared technologies, and reviews of prototypes" (Schulz, 2003, p.444).

In the knowledge management literature, the unit providing the knowledge is often identified as the source unit, while the receiver of knowledge is often referred to as the target unit of a knowledge flow (Gupta and Govindarajan, 2000; Mudambi and Navarra, 2004). Hence, the flow of knowledge is seen as a dyadic process because knowledge is transferred through a transmission channel from a source unit to a target unit (Gupta and Govindarajan, 2000; Mudambi and Navarra, 2004). The knowledge flows' transmission channel refers here to the way knowledge is transferred (Schulz, 2003). For instance, knowledge may be transferred through telephone calls, emails, chat programs, group meetings, electronic knowledge repositories, one on one conversations, or other means of communication.

Where some channels provide direct contact between the source and the target unit, like meetings, other channels do not provide such an opportunity for dialogue, such as electronic knowledge repositories (KRs) (Haas and Hansen, 2007). Furthermore, channels may differ in the number of people they provide simultaneously with access to knowledge (Gray and Meister, 2004). For example, in a group meeting, a presenter may share his or her knowledge with multiple individuals at the same time, while a single letter may only convey knowledge from one individual to another. The type of channel can also affect the degree to which knowledge shared by the source unit is understood by the target unit, through the number of transmitted cues. A face-to-face meeting may convey verbal, but also non-verbal cues, such as body language, which can aid the development of a shared understanding and thus the transfer of knowledge. The capacity of a channel to enable the shared understanding of knowledge between a source unit and a target unit is also referred to as the richness of a channel (Daft and Lengel, 1986).

Via these channels, knowledge may be exchanged in both directions between units. Hence, units can simultaneously be a source and a target of a knowledge flow. However, when knowledge flows bidirectionally, this study distinguishes two flows of knowledge, in which each unit is either the source or target unit. Therefore, the flow of knowledge is seen as a simplex process, rather than duplex. As a result, knowledge flows are seen "to be node-specific and dyadic" (Mudambi and Navarra, 2004, p.389). Thus, a knowledge flow is characterized by a single source and recipient department, which implies the directionality of the flow, and a transmission channel through which the knowledge is exchanged.

As the flow of knowledge can be either by design or by accident, several studies have also used knowledge flows to refer to knowledge 'spillovers' (e.g., Battke et al., 2016; Cantwell, 2009; Driffield et al., 2010), the unintended flow of knowledge to others than the intended recipient(s). For example, critical questions of a supplier on the functioning of a certain part may lead an engineer to reveal more than actually intended. Therefore, Martens and Sextroh (2021) argued that interactions can facilitate the flow of knowledge, even though there was no incentive or intention to transfer particular knowledge. Such 'spillovers' are thus often the side effect of knowledge flows (Conti et al., 2018). Both the intended flow of knowledge and these spillovers enable the diffusion of knowledge and the spread of knowledge in a population. However, this study focuses explicitly on the intended flow of knowledge and therefore does not cover 'spillovers'.

3.3 Barriers to the transfer of knowledge

Unfortunately, the transfer of knowledge, and thereby also the flow of knowledge, is not always straightforward as knowledge can be difficult to exchange (Argote and Miron-Spektor, 2011; Szulanski, 1996, 2000; Zander and Kogut, 1995). To understand the difficulty of the transferring process, research has extensively focused on the barriers to knowledge transfers. Such research has analyzed how characteristics of the source or recipient, their relationship, or characteristics of knowledge impeded the transfer of knowledge (Argote et al., 2003). For example, characteristics of knowledge that have been found to impede the transfer of knowledge are its tacitness (Zander and Kogut, 1995), its complexity (Galbraith, 1990; Teece, 1977), its casual ambiguity (Argote and Ingram, 2000) and its unproveness (Szulanski, 1996). Secondly, characteristics of the source and recipient can hamper the transfer of knowledge. For example, a source could lack the motivation to transfer knowledge or may not be conceived trustworthy by the recipient (Szulanski, 2000). The difficulties in the transfer of knowledge can also be attributed to the characteristics of the recipient. For example, a recipient may lack the absorptive capacity to assimilate the transferred knowledge (Szulanski, 2000) or lack the motivation to acquire knowledge (Gupta and Govindarajan, 2000). Furthermore, the access to knowledge by a recipient is influenced by his or her network centrality within an organization (Tsai, 2001; Valentine et al., 2019). Thirdly, the relationship between the source and recipient influences the difficulty of knowledge transfers. For instance, the hierarchy between source and recipient affects the type of knowledge transferred (Cross and Sproull, 2004) and the tie strength between the two predicts the difficulty of knowledge transfer (Hansen, 1999). Lastly, apart from the ability and motivation of units, Cabrera and Cabrera (2002) argued that units also just simply may lack the time or resources to transfer knowledge. Thus, although the transfer of knowledge can yield significant benefits for performance, they are difficult to realize (Argote, 1999).

All these barriers to the transfer of knowledge make it a costly process for both the source and the recipient of the transfer. Hence, the successful transfer of knowledge requires a significant investment of resources. On the one hand, the source must invest time and effort to convey his or her knowledge in a for the recipient understandable way (Reagans and McEvily, 2003). On the other hand, recipients incur costs as they have to dedicate effort and time to the identification, acquisition, and application of knowledge (Hansen et al., 2005). The time spent on providing, sourcing, or acquiring knowledge takes time away from other activities. Especially in situations with significant time pressure, such opportunity costs can be substantial (Haas and Hansen, 2005). Besides the direct costs of time and effort, Borgatti and Cross (2003) argued that the transfer of knowledge may also be costly for the knowledge seeker as it may signal a lack of knowledge. Furthermore, they argued that the knowledge seeker may incur costs as the source of the knowledge may have expectations of reciprocity and the knowledge seeker has the moral obligation to help the source out next time around. Thus, both the source and recipient of knowledge flows incur various costs when engaging in the transfer of knowledge.

3.4 The net effect of knowledge transfers

As the transfer of knowledge requires significant costs but can also yield benefits for units (Haas and Hansen, 2007) and organizations (e.g., Darr et al., 1995; Epple et al., 1996; Hargadon and Sutton, 1997), the extent of empirical research weighing the costs versus the benefits of knowledge flows is surprisingly scarce. Research on the costs of knowledge flows often analyzed the difficulty or ease with which knowledge was transferred without evaluating the benefits the transfers delivered for organizations (e.g., Jensen and Szulanski, 2004; Reagans and McEvily, 2003; Szulanski, 2000). In contrast, research on the performance implications of knowledge transfers has often neglected to explicitly measure the costs of knowledge transfers (e.g., Escribano et al., 2009; Subramaniam and Venkatraman, 2001; Tsai, 2001). However, considering both the costs and benefits of knowledge transfers simultaneously may create an understanding of why the impact of knowledge flows varies amongst different cases and contexts (Levine and Prietula, 2012).

Research that analyzed both the costs and benefits of knowledge flows has found that the benefits of knowledge transfers do not always outweigh their costs. For example, on an organizational level, Cassiman and Valentini (2016) showed that, although the investments in increasing knowledge in and outflows of the company yielded higher sales, the benefits were countered by increasing monetary costs made to enable these flows. Moreover, Levine and Prietula (2012) found that, when costs were included in their simulation model, the benefits of knowledge flows were contingent on several factors. They showed, for example, that knowledge transfers are less beneficial in situations where organizational support for learning is high rather than low and when the organizational environment is turbulent rather than stable.

On a team level, Haas and Hansen (2005) demonstrated that frequently sourcing and acquiring knowledge did not per se lead to an increase in performance for project teams in the consultancy industry. For example, they showed that when consultants were highly experienced themselves, frequently relying on internal knowledge sources could actually harm their performance. In their follow-up study, Haas and Hansen (2007) compared the knowledge inputs, the usage of electronic documents and advice, to task performance outcomes, such as work quality, time saved, and signaling competence to clients. Their findings indicated again that "it is unsafe to assume that more knowledge sharing is always better" (Haas and Hansen, 2007, p.1150). Therefore, they call on research to focus on how knowledge flows improve task performance considering their costs, instead of analyzing the antecedents of knowledge transfers.

Thus, although the costs of knowledge flows can outweigh the benefits of the receipt of such knowledge, empirical research on the ratio between the costs and benefits of knowledge flows is relatively scarce. Therefore, this study adopted a productivity perspective on knowledge flows by analyzing both the costs and benefits of knowledge flows (Haas and Hansen, 2007). However, where prior research predominantly evaluated when the costs of knowledge transfers outweighed the benefits, this study aimed to, given the costs of knowledge flows, identify what the most efficient and effective channels are to enable the flow of knowledge. While the choice of transmission channel influences the costs of enabling the flow of knowledge, such as the time investment needed by source and recipient, this topic has been left relatively untouched by prior studies. Furthermore, the choice of transmission channel may affect the degree of understanding of the knowledge by the recipient and thereby the effectiveness of knowledge flows. Therefore, through the identification of effective and efficient transmission channels, this study aimed to shed light on the most productive ways to enable the flow of knowledge. Measuring the efficiency and effectiveness of knowledge flows is similar to the work of Perez-Nordtvedt et al. (2008). However, their measure of efficiency only reflected the costs of transferring knowledge and they did not evaluate which knowledge flows channels are both efficient and effective. Therefore, this study aimed to contribute to the knowledge management literature by the identification of which knowledge flow channels are the most productive, the state of simultaneously being efficient and effective, across various contexts.

This research direction is especially relevant as the time of employees is a scarce commodity. Consequently, employees must not only know what the most productive channels are to source and acquire knowledge, but it is equally important to guide them to the most productive channels for them to make their knowledge available to others. Furthermore, by shedding light on the most efficient and effective knowledge flow, organizations gain more insight into how to deploy their valuable resources to enable the flow of knowledge. Moreover, measuring the efficiency and effectiveness of knowledge flows provides companies with the opportunity to evaluate whether their efforts to capture knowledge correspond to the ways through which knowledge is sourced, acquired, and applied.

Contrary to prior research in this area, which has predominantly focused on the consultancy industry (Haas and Hansen, 2005, 2007; Levine and Prietula, 2012), this study analyzed the costs and benefits of knowledge flows in the context of the semiconductor industry at a photo-lithography equipment manufacturer. Although the semiconductor industry is also very knowledge-intensive, it offers a different context to evaluate the balance between the costs and benefits of knowledge flows. In doing so, this study aimed to shed more light on the ratio between the costs and benefits of knowledge flows in a different context than the consultancy industry.

All in all, this study firstly set out to identify, map, and categorize how knowledge flows between units and especially what transmission channels are used. Therefore, this study analyzed qualitative data obtained through a priorly conducted diary study and a new case study. Secondly, this study set out to measure the efficiency and effectiveness of knowledge flows, characterized by their source unit, transmission channel, and recipient unit. Therefore, in the remainder of this section, knowledge flow efficiency and effectiveness are defined.

3.5 Knowledge flow efficiency

A knowledge flow is deemed to be efficient when the costs of individuals from the source unit to make their knowledge available and the costs incurred by the target unit to obtain and apply the knowledge are low, while the knowledge received by the target unit is used frequently. Here, the costs of a knowledge flow refer thus to the sum of the effort of making knowledge available by the source unit for the target unit and the effort required to obtain and apply this knowledge by the target unit. These efforts made by individuals carry costs, as they have to dedicate resources to knowledge contribution or utilization, which also could have been dedicated to other activities. Contrary to Haas and Hansen (2007) who only considered the costs incurred by the user of knowledge, this study also includes the costs of making knowledge available to others, as Reagans and McEvily (2003) argue that a significant part of the costs of a knowledge transfer is on the account of the source. Therefore, studies that only measured the costs of knowledge transfers incurred by its users, may have provided relatively conservative measurements of the costs of knowledge transfers. Thus, this research set out to also include all the costs of knowledge contribution, the act of making one's knowledge available to others (Watson and Hewett, 2006).

Research that has analyzed the efforts required to contribute and to use knowledge, predominantly investigated the difficulty (Szulanski, 1996, 2000) or ease (Reagans and McEvily, 2003; Tortoriello et al., 2012) of these processes. However, a task can also be relatively easy, but still require significant effort in the form of a large time investment. For example, reviewing a large amount of well-structured, understandable documents may require little cognitive effort, but can still involve a significant time investment. Moreover, time spent on contributing knowledge or obtaining and applying knowledge may be a less subjective measure than cognitive effort as individuals can use their agenda, email, and other software to anchor on, as these often contain timestamps of when an activity was performed and the duration of the activity. Lastly, management processes within organizations often revolve around the most efficient and effective use of available time. Therefore, this study followed Haas and Hansen (2005, 2007) by defining the costs incurred by contributing or utilizing knowledge as the time investment those activities required.

3.6 Knowledge flow effectiveness

Prior studies which analyzed knowledge flows or knowledge transfers often used the frequency of transfers as dependent variable (Gupta and Govindarajan, 2000; Schulz, 2001, 2003; Yang et al., 2008). However, as Haas and Hansen (2005) showed that the frequency of relying on others' knowledge does not necessarily translate to the improvement of task performance, the frequency of knowledge transfers would not necessarily be an appropriate measure of the effectiveness of knowledge flows. Besides knowledge transfer frequency, one could argue that the degree to which the knowledge is understood by the recipient is a measure of the effectiveness of knowledge flows. However, as the definition of knowledge entails that it should increase the recipient's capacity to act, the effectiveness of knowledge flows would be measured more logically by how the receipt of knowledge enabled its recipients to act. Therefore, research should focus on measuring if the receipt of knowledge enhances the performance of its recipients. For example, Haas and Hansen (2007) analyzed how the use of knowledge improved the recipient unit's performance, by measuring if the receipt of knowledge increased the work quality, saved time on a project, or helped them in signaling competence to clients. This study used a similar approach as here the effectiveness of knowledge flows refers to the degree to which recipients of knowledge perceived that the receipt of knowledge enabled them to increase their contribution to the performance of the organization, similar to the perceived receipt of useful knowledge (Levin and Cross, 2004).

Chapter 4

Research objectives and context

4.1 Research objectives

The primary aim of this research was to provide qualitative and quantitative insights into the intra-organizational knowledge flows within ASML. Therefore, the first objective was to identify how knowledge exactly flows through ASML, what transmission channels are used to enable the flow of knowledge and what factors affect the flow of knowledge. The second objective was to operationalize knowledge flow productivity by designing a measurement approach for ASML to quantify the efficiency and effectivity of knowledge flows. Thirdly, this research aimed to measure the efficiency and effectiveness of knowledge flows to gain insight into the most productive channels to exchange knowledge with one another. Lastly, this research focused on identifying antecedents of knowledge flow effectiveness and efficiency. In doing so, this research contributed to the extant literature on knowledge management, in particular by offering insight into the productivity of various channels to enable the flow of knowledge. To accomplish the aforementioned objectives, this research sought to answer the following research questions.

4.2 Research questions

Building on the problem definition, theoretical background, and the research objectives, the following research questions were determined. The main research question was:

How can ASML measure the performance of its intra-organizational knowledge flows and identify antecedents of knowledge flow performance to improve the current state of its knowledge flows and thereby its ability to innovate?

The research question was split up into multiple sub-questions according to the different objectives of the research. The first objective was to map and categorize how knowledge flows within ASML:

Research question 1: *How does knowledge flow within ASML to its field operations and from its field operations back to the headquarters?*

The second objective was to develop a measurement approach to assess knowledge flow productivity, which led to the following research question:

Research question 2: *How can knowledge flow efficiency and effectiveness be operationalized?*

The third objective was to measure the knowledge flow efficiency and effectiveness of the channels through which knowledge flows within ASML, to assess the productivity of these knowledge flows. As such, the third and fourth research questions were:

Research question 3: *How efficient are the channels used to enable the flow of knowledge within ASML?*

Research question 4: *How effective are the channels used to enable the flow of knowledge within ASML?*

The fourth objective was to identify antecedents of the effectiveness and efficiency of knowledge flows. Therefore, the last research question was:

Research question 5: What are antecedents of knowledge flow efficiency and effectiveness within ASML?

To answer these research questions, this study was divided into two stages. The first stage was comprised of the first research question and the second stage aimed to answer the remaining research questions. These two stages both employed a different methodology and are referred to as study I and study II.

4.3 Organizational context

The company of interest in this study was ASML, which operates worldwide with offices in Asia, Europe, and the United States. ASML is a matrix organization with three main departments, Development and Engineering (DE), Manufacturing (MAN), and a large service department Customer Support (CS). The main focus of DE is the design of new lithography machines and its main internal customers are MAN and CS. Once a machine is designed, MAN ensures the production and installation of the machines. Once the machines are at the customer site, the responsibility for keeping them up and running predominantly lies within the department of CS. The responsibility of CS is to assist ASML's customers to ensure the proper functioning of the lithography machines. Therefore, the CS department consists for a large part of a service organization in the field with engineers co-located at customer sites or in centralized hubs in the regions near their customers. Furthermore, CS also feeds customer requests about solutions to product issues and future products back in the organization to DE. Besides these three main departments, there is also a business line structure centered around three product types, the EUV, DUV, and Applications business line.

The main focus of this study was the flow of knowledge from ASML's headquarters to the CS field engineers and from the CS field engineers back to the headquarters. In the conversations with ASML's knowledge management experts, they indicated that these flows are vital for two reasons. Without access to technical and procedural knowledge, it becomes very difficult for field engineers to keep the products at client's sites up and running, while the ability to produce chips is the main value proposition of ASML. Furthermore, the flow of knowledge from the field back into the organization comprises valuable insights into the needs of field engineers and customers. These customer requirements provide the organization with valuable knowledge to solve issues and design the next generation of lithography machines. Furthermore, this study focused on the EUV business line as they produce the latest state-of-the-art lithography machines. These EUV machines are relatively new, thus the processes around them are often not yet fully crystallized and the technology in the products is relatively more complex than in prior product generations, such as ASML's DUV machines. Therefore, this environment within the business line EUV can benefit the most from a qualitative and quantitative analysis of their knowledge flows.

Field engineers receive knowledge via two main flows. Firstly, when a new product is installed at the customer or updates are provided, they receive knowledge mostly upfront on this product or update. Secondly, when urgent problems arise in the field, there is an escalation procedure to ensure that field engineers receive the necessary knowledge to get the machines back up and running. The second knowledge flow is more reactive, time-sensitive, and only occurs when a time-critical problem arises at a customer, which field engineers are not able to solve immediately. The more complex and persistent the problems, the higher the level of escalation and the longer the downtime. As such downtimes are very costly for both ASML and its customers, it is vital to reduce them. To prevent such escalations from causing significant downtime, the flow of knowledge to field engineers accompanying new products or updates is vital, because it can prevent such extremely long escalations from happening. Furthermore, field engineers can feed persistent issues or customer requests back into the organization, which serves as input for designing solutions to issues as well as new features, products, and procedures. Therefore, this study will focus on the non-escalation-related flow of knowledge to the field and the non-time-sensitive escalation-related flow of knowledge from the field back into the organization about customer issues and requests.

The department which occupies a central position in these knowledge flows is CS EUV Competence Engineering (CE). This group functions as the bridge between the field and the rest of the organization, as it ensures that the highly complex and technical knowledge from DE is converted into useful knowledge for the field, and knowledge from the field is translated to structural solutions or design inputs for DE. The group consists of approximately 120 engineers who are divided into eight teams and each team is specialized in a subgroup of components. In study I qualitative research was conducted at CE to map, identify and categorize the channels through which knowledge flows from the headquarters to the field and from the field back to the headquarters, while in study II the efficiency and effectiveness of the knowledge flows identified in study I were measured using a quantitative approach.

4.4 Empirical context

This study sought to answer the research questions through the combination of a qualitative and quantitative research approach. Firstly, the channels through which knowledge flows between the different departments were identified through observations of meetings, interviews, and the analysis of diary data. The analysis of diary data provided insight into the general channels through which knowledge is transferred within ASML. The observations were conducted during meetings of CE with stakeholders from outside the CE department. Acting as a fly on the wall, the observations of meetings were a relatively non-intrusive way to evaluate how knowledge flows. After the observations of meetings, multiple interviews were conducted to create more in-depth insight into how knowledge exactly flows between CE, the field, and the rest of the organization.

The second phase of this research aimed to measure knowledge flow efficiency and effectiveness by employing a survey, a frequently used method by research to analyze the flow of knowledge (e.g., Gupta and Govindarajan, 2000; Monteiro et al., 2008; Reiche et al., 2015; Yang et al., 2008). A quantitative subjective approach was used as this study aimed to measure the costs incurred to realize knowledge flows and the impact of knowledge flows on its recipients, which are difficult to measure with objective data. For example, measuring the impact of a knowledge flow on a unit's performance through objective data is challenging, as one has to control for a large number of variables (Argote, 1999). Furthermore, the costs incurred to make knowledge available are best determined by the contributors of a knowledge flow, while the impact of the knowledge is best assessed by its recipients.

Chapter 5

Study I

5.1 Introduction

The first stage of this research aimed to identify how knowledge flows to and from CE. More specifically, this study aimed to answer the following sub-questions to gain qualitative insights into the knowledge flows of CE:

- From which units does CE receive knowledge and to which units does CE supply knowledge?
- What types of knowledge are sought and shared by CE and its counterparts within ASML?
- What types of channels are used to source and share knowledge by CE and its counterparts within ASML?
- What antecedents influence the ease with which knowledge flows?

In study I a set of interviews was conducted with individuals of CE to identify how knowledge flows to and from CE and with which counterparts CE exchanged knowledge. Complementary to these interviews, priorly collected data from an ASML-wide diary study was analyzed for two reasons. Firstly, although interviews are an often used method to develop rich insights, interviews can suffer from retrospective biases when analyzing behavior of the past (Huber and Power, 1985). For example, the responses of interviewees can be distorted by misinterpreting frequency distributions of events (Tversky and Kahneman, 1971), a large emphasis on vivid memories (Nisbett and Ross, 1980) or be susceptible to an attributional bias (Kahneman et al., 1982). Therefore, the interview results about the ways how knowledge is sought and shared, the type of knowledge sought and shared, and the factors which ease the flow of knowledge can be distorted as a result of such retrospective biases. In contrast, retrospective biases are reduced in a diary study as the time interval between the occurrence of an event and the coding of the same event is severely decreased. Moreover, in the diary study, the behavior of individuals is studied over a longer period, providing a more robust image of their common ways of working.

Secondly, the interviews only provided insight into how individuals from CE sought and shared knowledge. However, it was equally important to gain insight into how other departments searched for knowledge made available by CE or shared knowledge with CE. It could be for instance that these ways are not fully synchronized, which may lead to efficiency and effectiveness losses in the flow of knowledge. As the diary study was conducted over the whole value chain of ASML, it also included the departments with whom CE should be in regular contact, such as field engineers, customer support departments, and engineering departments within DE. Thus, by converging the data from the interviews and diary study, robust insights were developed into the ways through which knowledge is sought and shared by CE as well as their counterpart throughout the organization, while at the same time reducing retrospective biases.

This diary study was conducted during a prior internship at ASML to analyze the micro-foundations of how employees source, acquire, transfer and retain knowledge within the organization. The exact procedure and results of the diary study are available upon request of the authors (Broeken and Verhaar, 2021). In addition to the exploratory interviews and diary data analysis, also meetings of CE with their counterparts were observed to understand and analyze how CE exchanges knowledge with them.

5.2 Methodology study I

5.2.1 Interviews

The objective of the interviews was to create an in-depth understanding of how knowledge flows from the headquarters to the field and back, and thus how knowledge flows to and from CE, as CE occupies a central position in these knowledge flows. Furthermore, the analysis of knowledge flows provided input for the operationalization of knowledge flow efficiency and effectiveness. The structure of CE is centered around multiple technical competencies, with each team focusing on one or two competencies. In total eight teams cover ten technical competencies, with six teams who cover each one technical competence and two teams who cover both two technical competencies. For each team, two team members were interviewed to get insights into each technical competence from two perspectives, resulting in a total of 16 interviews with individuals from CE. During the interviews, the interviewees were asked in semi-structured interviews how they sourced and shared knowledge. More specifically, the questions aimed to capture what channels individuals used to source and share knowledge, what type of knowledge they sourced and shared, with whom they exchanged knowledge, and what factors eased the exchange of knowledge. The questions of the semi-structured interviews are attached in Appendix C. Besides the interviews, meetings were observed to understand and analyze how CE exchanges knowledge with other departments. These meetings included regular meetings of CE teams with their counterparts across the organization. The meeting observations were performed to ensure that topics that were not frequently mentioned in the interviews but did seem to affect how knowledge is exchanged, were still included. In total 12 meetings of different CE teams of at least 60 minutes were observed in which individuals from CE and other departments were involved.

The sample of the interviewees was predominantly male, as only two of the interviewees were female. Furthermore, the interviewees were on average 43 years old (S.D. = 11, [27, 58]), worked on average already 10.7 years for ASML (S.D. = 9.0, [2.5, 33]) and had on average 3.8 years experience in their current function (S.D. = 2.4, [0.25, 8]). Although the interviews were not recorded, for reasons of confidentiality, extensive meeting notes were made during the interviews by the researcher who typed along with the answers of the interviewees. After each question, the meeting notes were summarized to the interviewees to validate their answers. To analyze these elaborate meeting notes, the data was analyzed in NVivo, version 12, release 1.5.1. The data of the interviews was iteratively coded per question on keywords in the meeting notes. Coding iterations were made to identify emerging categories and themes. The same program and procedure were used to code the diary data.

5.2.2 Diary study

The objective of the priorly conducted diary study was to increase the understanding of how employees sourced, acquired, transferred, and retained knowledge within the ASML. Therefore, 21 participants working in one of the three departments (8 from DE, 7 from MAN, and 6 from CS), filled in a daily questionnaire for ten consecutive working days, which asked them to describe in detail how they sourced, acquired, transferred, or retained knowledge that day. The sample was also predominantly male, as only three participants were female. Furthermore, the participants were on average 34.3 years old (S.D. = 7.8, [23, 52]). The experience of the participants varied extensively as some had already worked over a decade for the organization, while some just finished onboarding. Although the average experience of the participants was 7.6 years (S.D.=8.2, [0.6, 32]), the average tenure in their current function was only 2.7 years with a standard deviation of 1.5 years. Moreover, all participants had obtained at least a bachelor's or master's degree in engineering.

During the diary study, the participants received each day a questionnaire for ten consecutive working days. Furthermore, two interviews were conducted with each participant, at the halfway point and at the end of the ten days, to clarify the diary entries. The daily questionnaire asked participants to describe how they acquired, transferred, or retained knowledge, what barriers they encountered in doing so and how much time they spent on those particular activities. As such, the qualitative data set provided insights into the various knowledge flows within the organization. However, as the prior study focused predominantly on identifying the barriers to the acquisition, transfer, and retainment of knowledge, the channels through which knowledge flows were left relatively unexplored in the diary study. Therefore, this study aimed to identify the knowledge flow channels which were used within ASML by analyzing the diary study data. Simultaneously, the current diary data analysis also focused on what types of knowledge are often sought or shared.

5.3 Results study I

In this section, the results of both the interviews and the diary data analysis are discussed together per topic. A full summary of all the results from the interviews with individuals of CE and the results from the diary data analysis, as well as a side-by-side comparison of these results are shown in Appendix D in Table D.1.

5.3.1 Types of knowledge sought and shared

The first objective of study I was to identify the types of knowledge sought and shared by CE and its counterparts. Through iterative coding of the interview data and the diary data, two dominant types of knowledge appeared to be exchanged within the organization. The first type of knowledge was categorized as technical knowledge, which covered all knowledge related to the technical and engineering-related aspects of products, parts, (sub-)systems, modules, machines, and the physics behind them. The second type of knowledge that was identified was labeled organizational knowledge. This knowledge comprised all knowledge that was non-technical and related to organizational-specific processes, procedures, projects, ways of working, customers, departments, routines, the distribution of responsibilities, the organizational layout, etc.

These two types of knowledge have two key differences between them, namely their relatedness to engineering and physics, and their embeddedness in organizational contexts. The latter refers to the degree to which the ability of knowledge to render individuals with the capacity to take effective action, is dependent on the context in which it was developed. Contrary to technical knowledge, organizational knowledge is, as defined by Tsoukas and Vladimirou (2001), context-specific and built upon collective experiences within a certain environment. For instance, technical knowledge about the heat dissipation of certain materials may be applicable in the context of multiple organizations, while the knowledge about a certain way of working is predominantly useful in the organizational context in which it was developed. Thus, while technical knowledge about engineering, products, systems, and the physics behind those are, to varying degrees, often useful and applicable across a variety of different contexts, organizational knowledge is more rooted within the context of an organization and is less applicable outside the boundaries of this context.

Nevertheless, technical knowledge inherently also contains an organizational component, as the technical knowledge is created, maintained, transferred, and applied within an organizational-specific context. As a result, knowledge is rarely completely technical, and especially within high-tech organizations, organizational knowledge can also contain technical elements. Therefore, much like the definition of tacit and explicit knowledge by Nonaka (1994), technical and organizational knowledge were viewed as two ends of a continuum, instead of two distinct categories. However, for the sake of simplicity in the analysis, knowledge was either categorized as technical knowledge or organizational knowledge, depending on whether it was evaluated to be closer to one end of the continuum than the other end.

In the interviews with CE'ers, all interviewees indicated that they sourced and acquired technical knowledge to fulfill their job. Furthermore, in the same interviews, 14 out of the 16 interviewees also indicated that they shared such technical knowledge with other departments, as shown in Table 5.1. Moreover, in the diary study 38% of the 94 cases in which the type of knowledge that the participants sought could be identified, the sought knowledge was found to be technical. Furthermore, in 27% of the 74 cases in which the type of knowledge that the participant shared could be identified, the shared knowledge was technical.

In contrast, organizational knowledge was indicated to be sought in 15 out of the 16 interviews with individuals from CE, while the same number of CE'ers, 15 out of 16 that were interviewed, indicated to also frequently share organizational knowledge with others. Furthermore, in the diary study data the knowledge sought by participants was in 62% of the cases organizational, while when they shared knowledge, this part was even higher, namely 73%. Thus, although CE'ers indicated in the interviews to seek and share both technical and organizational knowledge, the results of the diary study indicate that organizational knowledge is sought and shared more frequently than technical knowledge within ASML.

5.3.2 Knowledge flow channels

The second objective was to identify through which ways knowledge was sought and shared by CE and its counterparts. In the interviews, the interviewees were asked what channels they used to

Table 5.1: The types of knowledge shared and received as indicated in the interviews with the individuals from CE

Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Types of knowledge sourced and acquired by CE																	
Technical	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Organizational	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	15
Types of knowledge shared by CE																	
Technical	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		14
Organizational	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	15

source and share knowledge. From the interviews, multiple channels were identified through which knowledge was exchanged by CE. Amongst these channels were a broad variety of various digital knowledge repositories. These digital knowledge repositories can be broadly divided into two categories. The first category is comprised of all the digital knowledge repositories which are accessible ASML-wide by multiple departments and thereby tailor knowledge to a large company-wide audience. These knowledge repositories are in this study defined as global knowledge repositories. An example of such a global knowledge repository is the ASML Issue Resolution database, in which machine issues are followed up by various departments within ASML. The second category of knowledge repositories is comprised of smaller knowledge repositories, which are only accessible to a small specific group of people, predominantly from one department, and thus the knowledge is tailored to a small audience. These smaller, more locally oriented and less formal knowledge repositories were in this study defined as local knowledge repositories. Examples of such local knowledge repositories are local Onedrives, Onenotes, or shared MS teams drives. Besides such knowledge repositories, individuals indicated that they often used face-to-face meetings, virtual meetings, company e-mail, or MS team chat to exchange knowledge with one another.

When searching for knowledge, the interviewees of CE indicated that they predominantly used global knowledge repositories (15/16), company e-mail (15/16), and meetings (14/16) as shown in Table 5.2. To a lesser extent, the interviewees also used the chat function of MS teams (6/16) and local knowledge repositories (5/16). For sharing knowledge, the same set of channels is used, only to different degrees. The most mentioned channels by interviewees to share knowledge were meetings (16/16) and email (13/16). To a lesser extent interviewees indicated also using global knowledge repositories(6/16), local knowledge repositories(6/16), and the chat function of MS teams(5/16) to share knowledge with other departments.

In the diary data, 121 instances were identified in which it was evident which channel was used to source and acquire knowledge. The most used way to source and acquire knowledge was through global knowledge repositories. In 37% of all cases, knowledge was retrieved by consulting

Table 5.2: The channels used by CE to source and acquire knowledge, identified in the interviews with individuals from CE

Interviewees	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Total**
Channels used to source and acquire knowledge																	
Global KRs	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		15
E-mail	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	15
Meetings	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		14
Online chat							✓	✓	✓		✓	✓		✓	✓		6
Local KRs		✓		✓		✓						✓		✓	✓		5
Channels used to share knowledge																	
Meetings	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Email	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	13
Global KRs	✓		✓								✓	✓		✓	✓		6
Local KRs				✓	✓	✓						✓		✓	✓		6
Chat			✓									✓	✓	✓	✓		5

global knowledge repositories, followed by company e-mail (21%) and local knowledge repositories (19%). Furthermore, the participants of the diary data study used to a lesser extent also meetings (12%) and MS team's chat (11%) to source and acquire knowledge. Thus, the channels identified in the interviews to be used by CE are similar to those used by other departments within ASML to source and acquire knowledge. Across the interviews and diary study analysis, global knowledge repositories seemed to be the most used channel to source and acquire knowledge, followed by company email and local knowledge repositories.

Furthermore, in the diary data analysis, a total of 120 instances were identified in which knowledge was shared by the participants. In 27% of all cases, the knowledge was shared via meetings. Moreover, knowledge was also often shared via local knowledge repositories (18%), company email (17%), and to a lesser extent via global knowledge repositories (13%) and MS team's chat (3%). Lastly, in a significant amount of cases (22%), the participants reported that they talked to or explained the knowledge to their colleagues, but it was not exactly clear what channel was used. When compared to the channels indicated in the interviews to share knowledge, a similar pattern can be observed, namely that knowledge is shared predominantly via channels in which direct communication between the source and target unit was possible.

5.3.3 Knowledge customers and knowledge providers

The third objective was to identify the departments that regularly provide knowledge to CE or to whom CE shares knowledge. In the interviews, the interviewees were asked who they regularly

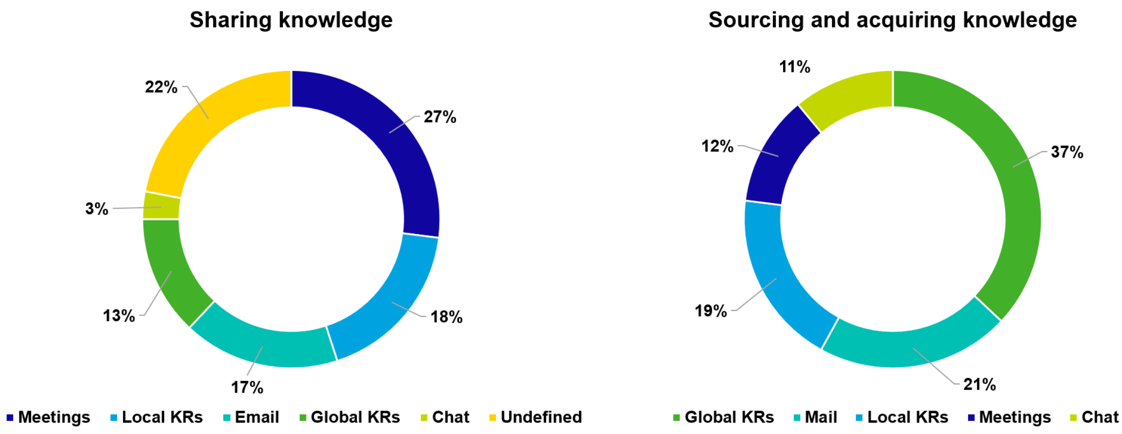

Figure 5.1: On the left the distribution of the types of channels used to share knowledge and on the right the distribution of the types of channels used to source and acquire knowledge, based on the diary data.

supplied with knowledge and from whom they regularly received knowledge. One of the major tasks of individuals of competence engineering is providing the engineers in the field with the knowledge they need. Therefore, unsurprisingly, the most frequently mentioned customer of knowledge from CE are second-line engineers (14/16). Furthermore, a large knowledge customer of CE's knowledge is the department of D&E (12/16). The interviewees indicated that the supply of knowledge from the field to D&E about machine configurations, local ways of working, and structural machine issues is a main responsibility of CE. Although to a lesser extent, the department of GSC is also a customer of the knowledge of CE (7/16). As GSC works on time-sensitive issues, the interviewees indicated that they predominantly shared structural solutions to issues, which aid GSC in its troubleshooting capacity.

The departments from whom CE receive knowledge are similar to the departments with whom they share knowledge. CE is the most dependent on the knowledge coming from D&E (16/16), closely followed by the knowledge coming from second-line engineers (14/16), which emphasizes the key role of CE in the exchange of knowledge between the field and DE. Furthermore, interviewees indicate also to receive knowledge from Manufacturing (4/16) and the Global support center (2/16), albeit with a lower frequency.

5.3.4 Antecedents of knowledge flow performance

The fourth objective of the interviews was to analyze what factors influence the ease with which knowledge is exchanged. In the interviews, participants were asked if they encountered barriers to finding and sharing knowledge, as well as what would for them be the most useful and easy

Table 5.3: The departments with whom CE regularly exchanges knowledge, based on the interviews with individuals from CE

Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Departments with whom CE shares knowledge																	
2nd line	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		14
D&E	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				✓	✓	12
GSC	✓			✓		✓					✓	✓		✓	✓		7
Manufacturing									✓						✓		2
Others		✓					✓								✓		3
Departments from whom CE receives knowledge																	
D&E	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
2nd line	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		14
Manufacturing			✓						✓						✓	✓	4
GSC												✓		✓			2
Others			✓														1

ways to find and share knowledge. The most cited factor by the interviewees which influenced the ease with which knowledge was exchanged, was physical proximity (11/16). The interviewees emphasized the value of working at the same office location, in the same building, or even on the same floor as their colleagues with whom they exchanged knowledge regularly. According to the interviewees, this stimulated spontaneous interactions such as bumping into each other in the hallways or at the coffee machine, which spiked the spontaneous exchange of knowledge. Such spontaneous interactions were valued by the interviewees as through these conversations they spoke to people outside their team or process. Interviewees also indicated that being in the same room and talking to each other felt more personal and thereby eased the transfer of knowledge. Besides, asking a question to a colleague via email or chat was indicated to have a higher threshold than just walking over to each other's desk for example to ask a question.

The second most cited factor which influenced the ease with which knowledge is exchanged was the amount of working experience of an individual within ASML (10/16). Interviewees indicated various reasons why the accumulation of experience within ASML eased the processes of finding and sharing knowledge. For example, experienced employees more often had access to a larger set of tools to search for knowledge and knew better where to find knowledge within the organization. Furthermore, they were more accustomed to the organization's processes, projects, and specific ways of working, which enabled them to find knowledge quicker than their less experienced colleagues. Besides, experienced colleagues struggled less with the large number of abbreviations used in the organization, knew the customers better, and why certain decisions were made in the past. All in all, the interviews suggested that experience provided employees with a better ability to source and share knowledge.

Thirdly, the interviewees indicated that the tie strength with the departments with whom they communicate, influenced the ease with which knowledge was exchanged between them (9/16). For example, the interviewees indicated that when you already know each other, it eases communication as people are willing to share more with you and also are less hesitant about asking questions to one another. Furthermore, interviewees indicated that if you have a good working relationship with people from other departments, you have a better feeling of where knowledge is located in such a department. Thus, the tie strength between the source and the recipient department of a knowledge flow seemed to impact the ease with which knowledge was found, but also the ease with which knowledge was shared.

Fourthly, interviewees indicated that the size of one's network is of particular importance within ASML for one's ability to find and share knowledge (8/16). Obviously, a larger base of contacts to tap into when searching for knowledge influences the ease with which knowledge is found. One of the reasons that having a good network could be so important within ASML, is that the interviewees also indicate that knowledge in knowledge repositories is often outdated or too complex to understand from the documentation. Therefore, having a large network to rely on is especially relevant within ASML.

Fifthly, the interviewees indicated that the time pressure they perceived within ASML limited their ability to allocate and exchange knowledge (8/16). For example, interviewees indicate that people within ASML are too busy to keep files up to date, remove outdated knowledge or just simply have no time to participate in meetings as they are fully booked. Therefore, prioritizing your work is of great importance and when an activity, such as sharing your knowledge with others, does not reduce your backlog, interviewees indicated that it is often susceptible to delay or not performed at all. As a result of such time pressure, it is difficult to source and acquire knowledge.

Sixthly, interviewees indicated that, although to a lesser extent, the complexity of knowledge affects the ease with which knowledge is found and acquired (6/16). In the interviews, participants indicate that there are so many complex parts and dependencies that it is sometimes difficult to understand certain knowledge and validate this knowledge, which as a result can take up a lot of time. Thus, the results suggest that complex knowledge can increase the time needed to source and acquire knowledge.

Seventhly, concerning the communication between CE and second-line engineers, it is mentioned in the interviews that second-line engineers are somewhat hesitant to speak up (8/16). A part of the interviewees (4/16) reported that second-line engineers, especially in Asia, were sometimes afraid to speak up, afraid of asking a 'dumb' question, afraid to disagree with competence engineers or that they felt ashamed when they did not have an answer, which all could

Table 5.4: Antecedents of the ease with which knowledge is sought and shared, based on the interviews with individuals from CE

Interviewees	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**Total**
Antecedents of knowledge flow performance																	
Physical proximity	✓				✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	11
Work experience		✓	✓		✓	✓		✓	✓	✓	✓			✓	✓		10
Tie strength			✓	✓			✓		✓	✓		✓	✓		✓		9
Network size					✓	✓	✓	✓			✓	✓	✓	✓			8
Time pressure	✓				✓	✓	✓		✓	✓		✓	✓				8
Complexity of knowledge		✓		✓	✓				✓		✓				✓		6
Psychological safety									✓			✓	✓	✓			4
Corporate language proficiency									✓								1

point to a lack in perceived psychological safety by second line engineers. Moreover, as observed in CE meetings with those second-line engineers, the interaction was very low. To verify this, two extra interviews with second-line engineers were conducted in which these feelings were validated. Therefore, the results suggest that psychological safety impacts the ease with which knowledge is exchanged in the knowledge flows to and from CE.

Lastly, the proficiency of the English language, the official corporate language within ASML, seemed to affect the exchange of knowledge. Although only mentioned once in the interviews, from the observations of meetings the proficiency of English seemed to affect how knowledge was sought and shared. For example, questions were misinterpreted or had to be repeated multiple times to be understood. Furthermore, people who were not so proficient in English just participated less in conversations and asked fewer questions. During the meeting observations, people who were proficient in English seemed more confident to participate in discussions and voice their opinion. Therefore, the proficiency in English, the official corporate language at ASML, seemed to affect the ease with which knowledge was sought and shared.

5.4 Discussion study I

Study I had the objective to identify with whom CE exchanged knowledge, what types of knowledge were exchanged, through which channels knowledge is exchanged, what factors ease the exchange of knowledge, and what barriers there exist against the exchange of knowledge. From the series of interviews came forward that CE is predominantly in contact with three other groups, namely with second-line engineers in the field, engineers at D&E, and engineers at the global support center (GSC). This is expected as CE plays a central role in translating knowledge from D&E

to the field, where the second-line engineers are the first point of contact. The reason why CE does not communicate directly with first-line engineers is that the second-line engineers are also specialized in a certain competency, while first-line engineers are more generalists. Furthermore, CE also exchanged knowledge with GSC and MAN. Where GSC is responsible for the time-sensitive escalations and solving these as soon as possible, the department of CE is more focused on solving recurring issues by providing non-design-related solutions or triage problems such that D&E can provide design-related solutions. Therefore, obviously, these two have some interfaces where their responsibilities and specialisms overlap. Lastly, CE exchanges knowledge with MAN, who like CE, translate knowledge coming from D&E to engineers, although MAN does this for the engineers in the factories of ASML instead of for the field operations. Moreover, from the results of the interviews, the exchange of knowledge between the two seems relatively limited, a result of a different focus between the two departments.

The second objective was to identify what types of knowledge were exchanged by CE to enable the flow of knowledge from D&E to the field. Identifying the types of knowledge which are exchanged between CE and its counterparts is important as Sammarra and Biggiero (2008) showed that different types of knowledge are not always uniformly distributed and exchanged, demonstrating that the exchange of knowledge is knowledge specific. Therefore, the type of knowledge exchanged could explain variance observed in the efficiency and effectiveness of knowledge flows. From the analysis of the interviews and the diary study, it came forward that two main types of categories are exchanged, namely technical knowledge and organizational knowledge. Here, technical knowledge comprises all knowledge related to products and technologies (Maurer et al., 2011). For example, it covers skills and know-how for product design and development (Sammarra and Biggiero, 2008). The second category, organizational knowledge, is a combination of pragmatic knowledge (Alavi and Leidner, 2001) and managerial knowledge (Sammarra and Biggiero, 2008), which comprises amongst others know-how about projects, processes, management systems, best practices, procedures, and organizational resources. Moreover, organizational knowledge was defined to be to a higher degree embedded in the context of the organizational than technical knowledge.

The third objective of study I was the identification of the channels through which knowledge flows in and out of CE. From interviews and diary data came forward that knowledge was predominantly exchanged through local knowledge repositories, global knowledge repositories, written communication, and meetings, either virtual or in a physical setting. When seeking knowledge, the interviewees and diary study participants both most frequently cited using global knowledge repositories. However, also the use of email and meetings to source and acquire knowledge were frequently cited, albeit more often in the interviews than within the diary data.

For sharing knowledge predominantly channels that allow interaction, such as meetings and email were cited to be used, in both the interviews as well as in the diary study. Moreover, the use of global knowledge repositories to share knowledge seemed to play a smaller role. This is perhaps surprising as the most cited way to source knowledge was through consulting these global knowledge repositories. Nevertheless, it could well be the case that sharing knowledge through global knowledge repositories is an efficient way to do so, requiring only a limited amount of people to share their knowledge, while serving a lot of knowledge seekers.

Fourthly, study I identified several antecedents which were cited to influence the ease with which knowledge is sourced and shared. The majority of these antecedents have also already been found in prior studies to affect the frequency with which knowledge is exchanged, such as physical proximity (Levin and Cross, 2004), inter-departmental tie strength (Hansen, 1999), corporate language proficiency (Peltokorpi, 2015), psychological safety (Schulte et al., 2012; Siemsen et al., 2009), one's network position (Valentine et al., 2019), experience within the company (Valentine et al., 2019) and the complexity of the knowledge (Galbraith, 1990). In addition, the perceived time pressure within the organization was cited to affect how people shared knowledge as they felt they often did not have enough time to make their knowledge available to others. Such a high perceived time pressure is not surprising as ASML is growing tremendously and cannot fulfill all the demands of its customers, resulting in a high workload and high perceived time pressure.

5.5 Limitations study I

Like all studies, the findings of study I should be viewed in the context of several limitations. Firstly, the number of interviews was limited due to time and availability constraints of the individuals working at CE. Although pre-caution was taken by interviewing at least two members of each team, there could be deviations between the opinions voiced by the sample of the interviewees and the rest of the department. Secondly, the interviews were conducted in a period in which working from home restrictions were present for all employees of the organization. Therefore, the interviews were conducted in an online setting via teams with video instead of face to face in the office. This created a little more distance and was somewhat less personal, which could have impacted the degree to which the interviewees were willing to voice their opinions. Furthermore, as the interviewees worked from home, their answers are obviously less representative of situations in which these working from home restrictions are not present.

Thirdly, the interviews reflect only the views and perceptions on the flow of knowledge of the interviewees who all worked at CE and not their counterparts with whom they exchange knowledge. Therefore, antecedents which may apply to CE are perceived to have less of an impact on the exchange of knowledge as perceived by their counterparts. For one variable, the perceived psychological safety of second-line engineers, the counterparts of CE were also interviewed to confirm this. However, only two interviews were conducted due to the busy schedule and differences in time zones with these second-line engineers.

Fourthly, the identification of the set of antecedents only indicates that these variables seem to influence how knowledge is sourced and shared but do not shed light on their impact. For example, although a variable is frequently mentioned within the interviews, it could be that its effect size on how knowledge is sourced and shared is relatively limited and thus may be of less importance than a variable that is less frequently mentioned but perhaps has a larger effect size. Therefore, the influence of these antecedents on the efficiency and effectiveness of knowledge flows was analyzed in study II.

Fifthly, for the scope of this study the processes of sourcing and acquiring knowledge were analyzed combined as one process of obtaining knowledge. This approach was adopted as the primary objective here was to identify all channels used for both sourcing or acquiring knowledge. However, sourcing and acquiring knowledge are in fact two separate processes for which people could use different sets of channels or could use similar channels but to a different extent. Nevertheless, the results presented in this study do not shed light on any possible differences between these two processes.

5.6 Conclusion study I

The interviews and diary study analysis have leveraged qualitative insight into which parties facilitate the flow of knowledge to the field, what channels they use, what barriers they encounter, and what factors influence the ease with which knowledge is exchanged. The knowledge flow to the field is facilitated by the department of CE which functions (partially) as a hub between the second-line engineers in the field, D&E, and GSC. Furthermore, individuals within and outside CE predominantly indicated to use global knowledge repositories when seeking knowledge, while making use of richer channels such as email and meetings to fulfill their knowledge needs. When individuals shared knowledge, they predominantly preferred to make use of richer channels over leaner channels such as knowledge repositories. Moreover, a set of antecedents were identified that influence the ease with which knowledge is exchanged. This set of variables consisted of characteristics of the source or recipient, characteristics of the relationship between the two, or the type of knowledge that was exchanged. In study II a quantitative approach is taken to analyze the efficiency and effectiveness of these knowledge flows and to assess the relationships between the identified antecedents and knowledge flow performance.

Chapter 6

Study II

6.1 Introduction study II

The first objective in study II was to measure the efficiency and effectiveness of knowledge flows between the units and through the channels identified in study I. Secondly, the influence of the antecedents identified in study I on the efficiency and effectiveness of knowledge flows was analyzed. Central in this research were the knowledge flows to and from the field enabled by the department of CE. Therefore, the knowledge flows included in study II are those in which either the source unit or the recipient unit is CE. The departments identified in study I to exchange knowledge with CE are the second-line engineers, the global support engineers, and engineers at D&E.

Besides the source and recipient department, a knowledge flow was also defined to be characterized by the channels used to exchange the knowledge. In study I five channels were identified to be predominantly used for the exchange of knowledge with one another, namely (i) local knowledge repositories (LKR), (ii) global knowledge repositories (GKR), (iii) written communication (WC), (iv) virtual verbal communication (VC) and (v) physical verbal communication (PC). Therefore, study II analyzed the efficiency and effectiveness of the knowledge flows in which either the source or recipient department was CE and which was enabled by one of the five channels identified in study I. Thus, study II aimed to identify what channels are most efficient and effective between source and recipient couples, but also, identify if there are differences between the efficiency and effectiveness of these five types of channels, independently of who the source or recipient unit was.

Secondly, study II aimed to quantitatively identify antecedents of knowledge flow efficiency and effectiveness. These antecedents may help to explain why certain flows are more efficient or effective than others in general or between certain source-recipient unit combinations. By

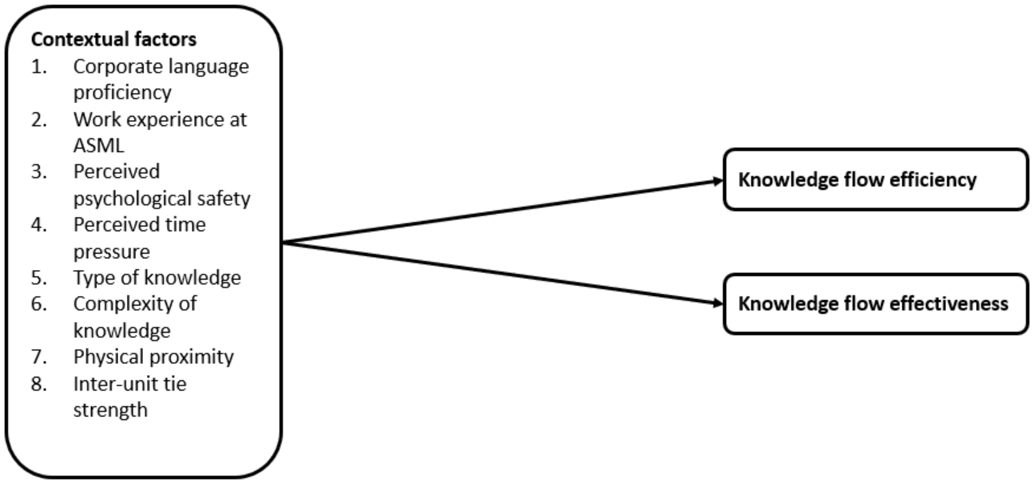

Figure 6.1: Empirical model of the effect of antecedents on the effectiveness and efficiency of knowledge flows. These antecedents are in the survey reported by the recipient

highlighting how these antecedents influence the effectiveness and efficiency of knowledge flows, organizations may better understand how to leverage the characteristics of these channels to achieve efficient and effective intra-organizational knowledge flows.

6.2 Study II: Methodology

To analyze the efficiency and effectiveness of the identified knowledge flows, study II employed an exploratory research approach through a survey sent out to the people of CE and their counterparts in the field, at DE and GSC.

6.2.1 Participants

The focal unit of interest was the CE department. Therefore, the knowledge flows of interest identified in study I, are the knowledge exchanges between CE and their counterparts in the field and the rest of the organization. Thus, the inclusion criteria for participants of the survey was that individuals either had to work at CE or had to be in regular contact with CE. From study I it came forward that CE was in contact with multiple other departments, namely second-line engineers in the field, engineers at GSC, and engineers at D&E. The department of CE consisted of 116 individuals who were divided into eight teams who were all invited to participate in the survey. To identify their counterparts in the field, GSC and D&E, these teams of CE were asked to provide a list of the people in those departments with whom they exchanged knowledge at least once per month. Besides the people these teams listed themselves, participants were also drawn from meeting invitation lists. On a biweekly basis, each team of CE hosted a competence meeting to discuss the latest updates and issues with their counterparts. For these meetings, all their counterparts within the field, GSC and D&E with the same competence are invited. The combination of the lists provided by the teams themselves and the meeting invitations provided a complete overview of the counterparts of CE across the organization. In total 468 individuals who did not work at CE, but who regularly exchanged knowledge with the department of CE were identified. Of this group, a total of 275 worked as second-line engineers in the field, 132 worked at D&E, and 65 worked at GSC.

As a knowledge flow in this study refers to the collective set of knowledge transfers between two departments, this study did not need to identify exactly which individuals exchanged knowledge with one another. Whereas research on knowledge transfers often focused on dyadic knowledge transfers in which they surveyed both the source and recipient of a knowledge transfer, here participants only have to be a contributor or user of the dyadic knowledge flow between their respective departments.

6.2.2 Procedure

The survey was constructed in MS Forms as other survey software was not available within the company's digital environment. The survey supplied to the participants from CE differed from the survey supplied to the non-CE participants. The latter received a survey in which the questions only related to whether they had provided knowledge to CE and received knowledge from CE, while the survey for the CE participants asked the same questions but then related to the exchange of knowledge with all the non-CE departments separately.

The first question of the survey for the non-CE participants was whether they at least once per month received knowledge from or shared knowledge with individuals from CE. If the answer to this question was negative, the survey thanked the participants for their participation and the survey closed. The second question to the non-CE participants was whether they worked as a second-line engineer, an engineer at GSC, an engineer at D&E, or somewhere else. If they indicated to work in another department, they got routed out of the survey. Only when the participants answered that they at least once per month receive knowledge from or share knowledge with individuals of CE and worked as a second-line engineer, at GSC or D&E, they were routed to the main part of the survey. This mechanism ensured that only the people from the departments identified in study I, who regularly exchanged knowledge with CE were included. Similarly, when non-CE participants indicated that they only received knowledge from CE, the survey was routed such that only the questions about the receipt of knowledge from CE were asked, while the questions about the provision of knowledge to CE were left out.

Where non-CE participants were only questioned on the flow of knowledge between them and CE, participants of CE were asked the same questions but then related to the provision to and receipt of knowledge from all the non-CE departments which were identified in study I to have contact with CE. So where the non-CE participants answered the questions about the flow of knowledge from them to CE and the other way around, participants of CE had to answer these questions about the multiple knowledge flows between them and the various non-CE departments. However, again the survey was routed such that if individuals from CE did not exchange knowledge with another, the questions related to those knowledge flows were left out to prevent inaccurate answers or missing values as well as to prevent survey fatigue.

The survey was initially supplied to the participants via an email sent out by the department manager of CE, after which the participants had a 21-day window to fill in the survey. During this period, multiple reminders were sent out to the participants if they, up until then, had not yet filled in the survey. The first round of reminders was sent out by all group leads of the eight teams at CE. Thereafter, the second and third rounds of reminders were sent out personally via MS team chat by the researcher. Besides these reminders, the researcher also presented the survey within the department meeting of CE such that individuals of CE also clearly understood the purpose and context of the survey. The same approach was used to explain the survey to non-CE participants as the survey was also presented in the biweekly competence calls of all CE teams with their counterparts from the field, GSC and D&E.

After the deadline, a total of 56 responses were recorded from individuals working at CE, while a total of 207 responses were recorded from non-CE individuals, resulting in a response rate of respectively 48.3% and 44.2%. Of those 207 responses to the non-CE survey, 13% of the respondents indicated not to work as second-line engineer, at GSC or D&E. Therefore, these answers were excluded. Furthermore, not all respondents indicated to at least once per month share or receive knowledge from CE. From the responses of second-line engineers, people at GSC, or people at D&E, respectively 72.9%, 77.2% and 84.0% indicated to at least share or receive once per month knowledge from individuals at CE. Therefore, the final data set of non-CE responses consisted of 136 useful responses of which 70 came from second-line engineers. 44 came from people working at D&E and 22 came from people working at GSC. In the survey for CE, all participants indicated to at least once per month source or share knowledge with at least one other department, so there no responses had to be removed.

6.2.3 Measures

Knowledge flow efficiency

A knowledge flow was deemed to be efficient when the transferred knowledge was often used by its recipients, while the effort needed to make the knowledge available by the source unit and the effort to source and acquire the knowledge by the recipients were low. Therefore, to determine the efficiency of a knowledge flow, the costs of knowledge contribution, the costs of knowledge utilization, and the frequency of knowledge utilization were measured. As priorly defined the costs of knowledge contribution or utilization were measured as the time these activities required, following Haas and Hansen (2005, 2007).

Time investment knowledge contribution. To measure per channel the time investment of individuals from the source unit to make their knowledge available to the target unit, the question was asked "How much time on average per week do you spend on sharing your knowledge to [recipient department] via [channel] in hours?". The period of a week was chosen to reduce retrospective biases and to make it easy to anchor on their weekly agendas and activities. The respondents of CE had to indicate the time investment in knowledge contribution to each non-CE department and for each channel, while the non-CE respondents only had to indicate per channel how much time they spent on contributing their knowledge to CE. The set of channels consisted for all questions of all five channels identified in study I.

Time investment sourcing and acquiring knowledge. To measure per channel the time investment of individuals from the target unit to source and acquire knowledge made available by the source unit, the question was asked "How much time in hours do you spend on average per week on sourcing and acquiring knowledge made available by [source department] via [channel]?". Again, the respondents of CE had to indicate the time investment in sourcing and acquiring knowledge made available by each non-CE department and for each channel, while non-CE respondents only had to indicate this concerning the knowledge made available by CE via each channel.

Frequency of knowledge utilization To measure the frequency with which knowledge, made available by a source department, was utilized by the target unit, individuals of the target unit were asked to indicate on a 7-point Likert scale with the options (1) never, (2) very rarely, (3) rarely, (4) occasionally, (5) frequently, (6) very frequently, and (7) always, for each channel how frequently they used and applied the knowledge received from a source unit via that specific channel. The CE participants were asked to indicate the frequency of knowledge utilization of knowledge received from the multiple non-CE departments, whereas non-CE participants only had to indicate this for the receipt of knowledge from CE.

Knowledge flow effectiveness

Knowledge flow effectiveness was defined as the degree to which the receipt of knowledge contributed to the performance of the individuals from the target unit. This definition is very similar to the perceived receipt of useful knowledge of Levin and Cross (2004). Therefore, the effectiveness of a knowledge flow is measured by the perceived receipt of useful knowledge. However, as Levin and Cross (2004) conducted their research within three companies in the pharmaceutical, banking, and energy industry, their items measuring the perceived receipt of useful knowledge were rather general and tailored to projects. Therefore, based on their items, this research developed new items to fit the specific context of the departments of ASML in which this research was conducted. The departments within ASML to which the survey was supplied had four common goals, namely improving the machine availability of customers, reducing the occurrence of extreme long downs (XLDs) of customer's machines, decreasing the labor hours per machine, and improving the meantime to repair (MTTR, the average time it takes to repair a machine). How the items of the perceived receipt of useful knowledge of Levin and Cross (2004) map onto the newly developed items can be observed in Appendix F. To measure how useful the receipt of knowledge from a target unit via a specific channel was, each respondent had to indicate on a 7-Likert scale ranging from (1) contributed very negatively, to (7) contributed very positively, the degree to which the receipt of knowledge contributed to improving machine availability, reducing the occurrences of XLDs, reducing the labor hours per machine and improving the mean-time-to-repair.

Antecedents

In the set of interviews conducted in study I, several antecedents of knowledge flow performance were identified, which seemed to influence the effectiveness and efficiency of knowledge flows. These antecedents were categorized as characteristics of the exchanged knowledge, characteristics of the source or recipient department, and characteristics of the relationship between the two.

Perceived psychological safety. The perceived psychological safety was only included in the survey for non-CE'ers, as from the interviews it came forward that a lack of psychological safety was predominantly of influence for non-CE'ers. The perceived psychological safety was measured by the five items of van Ginkel and van Knippenberg (2008), which were based on Edmondson (1999). The items were again slightly adjusted to fit the context. Therefore, in each statement, "other group members" was replaced by "people of CS Competence Engineering". For all five items, respondents had to indicate on a 7-point Likert scale ranging from (1) strongly disagree to (7) strongly agree, the extent to which they agreed with each statement.

Physical proximity. Research analyzing physical proximity or geographical distance has predominantly operationalized it by asking each respondent's ZIP code to calculate the exact distance in kilometers or miles between individuals, teams, or departments. However, this measure was privacy-sensitive as a lot of people worked from home instead of in the office. To still capture the physical proximity, while keeping in mind the privacy of respondents, the physical proximity scale of Levin and Cross (2004) was used. This scale was slightly adapted such that it could also be identified if people who exchanged knowledge worked on a different continent, as travel restrictions especially hindered the travel across continents more than within a continent. Thus, people had to indicate if the people from another department with whom they communicated were predominantly located on: (1) the same floor in the same building, (2) in the same building but on a different floor, (3) in a different building on the same office location, (4) on a different office location in the same country, (5) on a different office location in another country, but on the same continent or (6) at a different office location on another continent.

Inter-unit tie strength. The items measuring inter-departmental tie strength were based on the items of inter-unit tie weakness from Hansen (1999). The two items used by Hansen (1999) were adjusted such that respondents had to indicate on a 7-point Likert scale the extent to which they agreed, ranging from (1) strongly disagree to (7) strongly agree, with two statements related to the frequency of contact and the closeness of their working relationship with individuals from other departments.

Corporate language proficiency. The items measuring corporate language proficiency were based on the three items of corporate language proficiency of Peltokorpi (2015). These three items were slightly adjusted to fit the context within ASML. For this purpose, the corporate language was made explicit by asking the proficiency in English. Furthermore, in study I it was observed that the proficiency in English varied within groups and departments. Therefore, respondents were asked to rate their own proficiency in English instead of the proficiency in English of other individuals or departments. This adjustment is more vulnerable to a possible social desirability bias, however, as the proficiency in English varied within groups, measuring the average proficiency in English of groups or departments would not account for the variety in the proficiency in English across individuals. Therefore, respondents were asked to indicate the extent to which they agreed on a 7-point Likert scale ranging from (1) strongly disagree to (7) strongly agree with the following statements: (1) I am proficient in speaking in English, (2) I am proficient in writing in English, and (3) I am proficient in understanding English.

Perceived time pressure. The items measuring the perceived time pressure of respondents were based on the first three items of the perceived time pressure of Madjar and Oldham (2006) and both two items of experienced creative time pressure of Baer and Oldham (2006). These items were slightly adjusted to fit the scope of this research. For example, in the item of Madjar and

Oldham (2006), "tasks" were adjusted to 'knowledge sharing'. The items in the survey for non-CE'ers were related to sharing knowledge with CE'ers, while the items in the survey for CE'ers related to sharing knowledge with non-CE'ers. For all five items, respondents had to indicate on a 7-point Likert scale ranging from (1) strongly disagree to (7) strongly agree, the extent to which they agreed with each statement.

Level of experience of respondents within ASML. The level of experience of respondents within ASML was measured by asking respondents "How long have you already worked for ASML?" and "How long have you already worked for ASML in your current function?".

Complexity of knowledge. The complexity of knowledge exchanged in each knowledge flow was measured by a self-developed single item, which asked participants, for each channel, to indicate the extent to which they agreed, on a 7-point Likert scale, ranging from (1) strongly disagree to (7) strongly agree, with the statement that the knowledge sought or shared via that channel was complex. It was chosen to measure the complexity of knowledge with a single item to keep the survey short, as respondents had to indicate the complexity of knowledge sought and shared for each channel and in case of CE also for the contact with multiple other departments.

Type of knowledge. From the set of interviews, two dominant types of knowledge emerged, namely technical knowledge and organizational knowledge, which could be seen as two ends of a continuum. Therefore, respondents had to indicate for each channel whether the knowledge they sourced or shared was predominantly technical or organizational knowledge on a self-developed scale starting with 1) 100% technical knowledge – 0% organizational knowledge to 6) 0% technical knowledge – 100% organizational knowledge. The options in between those ends were divided by increasing the proportion of organizational knowledge by 20% while decreasing the proportion of technical knowledge by 20%. Again, this single-item measurement was developed for this study to limit the time investment needed for participants to complete the survey. For the sake of simplicity and interpretation, this antecedent is hereafter referred to as the degree of organizational knowledge. A full overview of all questions and the exact formulation of each question is attached in Appendix E.

6.2.4 Data analysis

Data preparation

Once the data collection was completed, the data were extracted from the MS forms environment into two Excel files, one of the CE survey and one of the non-CE survey, to be processed within the software R, version 4.1.2. Before loading the data into R, the data was first prepared and cleaned from invalid values. Firstly, the responses to open questions, such as age, experience within ASML, experience within their current function, and the time the participants spent on sourcing and sharing knowledge were checked to ensure these contained purely numerical values. All non-numerical symbols were removed, such as '25years', which was converted to only the numerical value '25'. In some cases, respondents provided ranges to questions, for example about how much time they spent on making their knowledge available via a certain channel to another unit. In these cases, the mid-value of the provided range was taken. For instance, if a respondent answered that he or she spent 1 to 2 hours on average per week sharing knowledge with another department, the mid-value, so 1.5 hours was used. Occasionally respondents also provided a range with only a lower limit, so for example '> 2 hours'. In these rare cases, the value of the lower limit was used as a conservative measure for their time effort.

Secondly, the non-CE and CE data sets were combined into two new data sets, one with all the answers related to the sharing of knowledge, while in the other all answers related to sourcing and acquiring knowledge. For example, if a non-CE respondent indicated to receive knowledge from CE as well as share knowledge with CE, the answers related to sharing knowledge with CE were moved to the sharing data set, while the other answers were moved to the sourcing data set. The variables included in both the sourcing data set and the sharing data set can be observed in Table 6.3 and Table 6.2 respectively. The same was done for the answers provided by the participants from CE. However, where non-CE participants were only questioned if they exchanged knowledge with one other unit, namely CE, the respondents from CE were asked if they exchanged knowledge with multiple other units, namely with second-line engineers, with individuals from GSC, and with individuals from D&E. If respondents of the CE survey answered that they, for example, shared knowledge with second-line engineers, people from GSC, and people from D&E, their answers were converted into three separate entries in the sharing data set, as shown in Figure 6.2. Similarly, if a respondent of CE indicated to source and acquire knowledge made available by second-line, by people from DE, and by people from GSC, this resulted also in three separate entries in the sourcing data set.

Thirdly, the sharing data set consisted of 39 entries of CE'ers sharing knowledge to 2nd line engineers, 41 entries of CE'ers sharing knowledge to DE, 32 entries of CE'ers sharing knowledge to GSC, and 107 entries of non-CE'ers sharing knowledge to CE. The final data sets on sharing knowledge contained thus 219 entries about how people shared knowledge with another department. The sourcing data set contained 33 entries about how CE'ers sought knowledge made available by 2nd line engineers, 41 entries about how CE'ers sought knowledge made available by DE, 28 entries about how CE'ers sought knowledge made available by GSC, and 110 entries about how non-CE'ers sought knowledge made available by CE. Therefore, the sourcing data set contained 212 entries about how people sourced and acquired knowledge from another department.

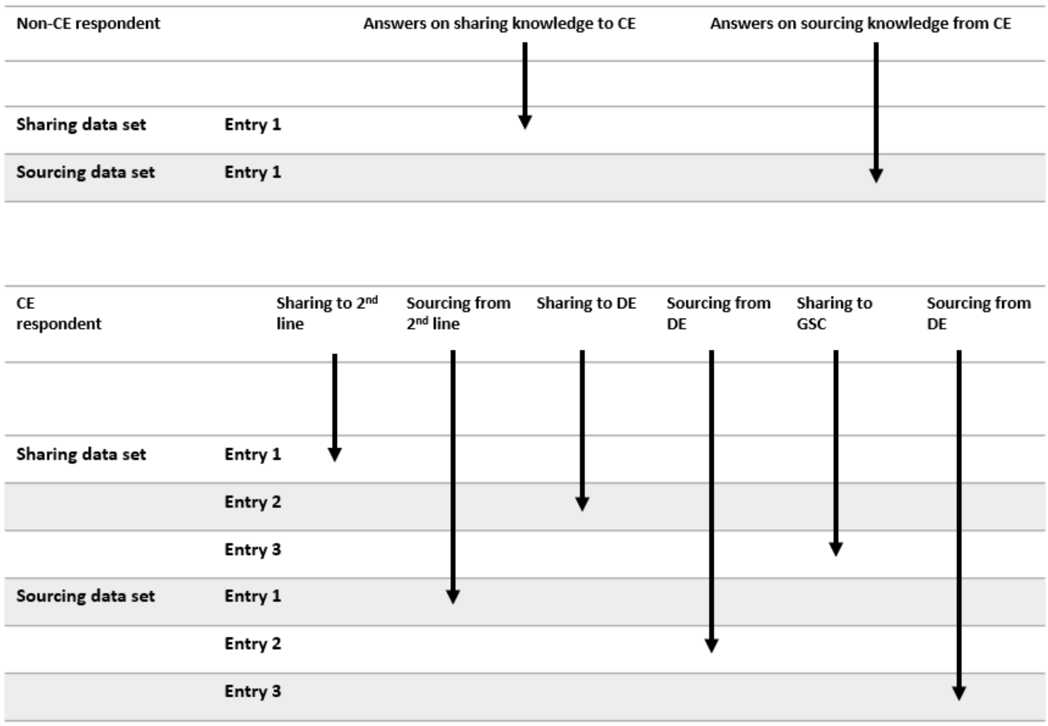

Figure 6.2: Construction of the two data sets, one with all the answers related to sharing knowledge, the other with all the answers related to sourcing and acquiring knowledge

Thus, the data in both the sharing data set and the sourcing dataset are partially nested as they contain multiple entries made by the same individuals of CE. In Table 6.1 the absolute numbers can be observed of the number of entries per source-recipient couple who exchanged knowledge.

Reliability and missing values

To determine the reliability of the multi-item constructs, their Cronbach alpha's were calculated. These are reported in Table G.1 for each data set respectively. The initial Cronbach alpha of psychological safety measured over all six items was very poor (0.44). However, R issued a warning that the two reverse coded items should be reversed coded, while this was already performed. Therefore, it seemed as if both reverse-coded items of psychological safety were perhaps misread by the participants. As such, these items were dropped to increase the Cronbach alpha from 0.44 to 0.78 and 0.79 for the data set sharing and the data set sourcing respectively. All other variables reported Cronbach alpha's of above 0.8, which can be considered good, while the values for psychological safety, which were slightly below 0.8, are still deemed to be reasonable. Therefore, the items of multi-item scales were averaged to compute the average value for each construct.

Besides the reliability of multi-scale items, the data sets were also investigated on missing

Table 6.1: The number of responses per knowledge flow, with in the first column the number of people who shared their knowledge to the recipient department and in the second column the number of people who sourced and acquired knowledge from the source department

Knowledge flow	N sharing	N sourcing
CE to 2nd line	39	63
CE to DE	41	26
CE to GSC	32	21
2nd line to CE	51	33
DE to CE	36	41
GSC to CE	20	28
Total	219	212

values. Unfortunately, in both data sets, there were missing values across almost all variables. The main reason for these missing values is that none of the questions were mandatory and therefore if a respondent forgot to answer a question, he or she was not reminded to do so and could just continue with the rest of the survey. This was an important condition requested by the privacy committee within ASML to gain approval to send out the survey within ASML. For each variable, the number of missing values was relatively small and varied approximately between the five and ten percent. The missing data were analyzed to identify if the missing values were completely random or contained structured and hand dependencies

Besides random noise of missing data throughout the data set, there also seemed to be two types of structure in the missing values. Firstly, a couple of respondents did not fill in their age, experience within ASML, and their experience in their current function. Although in the survey and presentations it was stressed explicitly that the survey was completely anonymous and that the data was only viewed by the external researcher, these respondents may have doubted the anonymity of the survey when asked for such personal information.

Secondly, there seemed to be more missing values to the questions related to physical verbal communication than for the other channels. As the survey was conducted during a period in which (at least partially) working from home restrictions were still enforced, it could be that respondents left a question unanswered when they had not sought or shared knowledge via that channel, although the majority of the respondents answered with '0' when they had not sought or shared knowledge via a certain channel. Thus, it cannot be said with certainty that people who left a particular question open about the time investment of sourcing and sharing knowledge via a particular channel did not source or share knowledge at all via that channel.

A downside of treating these missing values not as a zero value for the time investment of sharing knowledge via a certain channel is that it may lead to a higher average time investment of sharing knowledge via a certain channel. The average time investment of sharing knowledge is used to determine the efficiency of a knowledge flow, thus thereby the knowledge flows with more missing values for the time investment in sharing knowledge via a specific channel could lead to a somewhat more optimistic value for the knowledge flow efficiency. Nevertheless, as for almost all variables, the number of missing values was below 10% and there was no major structure present in the missingness of values, these missing values were ignored (Hair et al., 2014). Therefore, in the data analysis, pairwise deletion was used instead of list-wise deletion to optimally use the available data. If list-wise deletion was used, a significant part of the data was left unused as the missing values were relatively evenly spread out over all entries, such that a significant proportion of the entries contained at least one missing value for a random variable.

Knowledge flow effectiveness

The effectiveness of knowledge flows was measured in the survey through the perceived receipt of useful knowledge. Respondents had to answer in the survey how the receipt of knowledge from a specific source unit via a specific channel contributed to reducing MTTR, the occurrence of XLDs, labor hours needed per machine, and improving machine availability. Therefore, the effectiveness of a knowledge flow as perceived by recipient j is determined by averaging the four items of the perceived receipt of useful knowledge. The average effectiveness of a knowledge flow between source-recipient department couple k via channel c is calculated by averaging:

$$KFE_{c,k} = \frac{\sum_{k=1}^{m_{c,k}} KFE_{c,j,k}}{m_{c,k}} \tag{6.1}$$

where $KFE_{c,k}$ is the effectiveness of a knowledge flow characterized by source-recipient department couple k and the used transmission channel c, $KFE_{c,j,k}$ is the perceived knowledge flow effectiveness by individual j, as part of the flow of knowledge between source-target department couple k via channel c and $m_{c,k}$ is the total number of individuals in the recipient unit who received knowledge from the source unit of that specific knowledge flow via channel c.

Knowledge flow efficiency

A knowledge flow is deemed to be efficient when the time investment of the source department to make their knowledge available and the time investment of the recipient department to identify, acquire and apply this knowledge are low, while the knowledge received by the recipient department is used frequently. Therefore, a way to determine the efficiency of a knowledge flow is to analyze how much time it costs individuals from the recipient department per week to identify, acquire and apply this knowledge and how often per week they use this knowledge, given the average time investment per week by individuals from the source department to make their knowledge available to the recipient department. The efficiency of a knowledge flow as perceived by a recipient j is then obtained by dividing the frequency of knowledge utilization by recipient j of the knowledge received from a source department by the sum of the average time investment of knowledge contribution of individuals from the source unit and the time it costs recipient j to source, acquire and apply this knowledge. Thus, the efficiency of a knowledge flow between a source-recipient department couple k and via channel c, as perceived by recipient j from the recipient unit, can be calculated as follows:

$$KF\eta_{c,j,k} = \frac{FU_{c,j,k}}{\frac{\sum_{i=1}^{n_{c,k}} TC_{c,i,k}}{n_{c,k}} + TU_{c,j,k}} \tag{6.2}$$

where $KF\eta_{c,j,k}$ is the efficiency of a knowledge flow between a source-recipient department couple k and via channel c, as perceived by recipient j, $FU_{c,j,k}$ is the frequency of knowledge utilization by recipient j of the knowledge received from that specific source department, $TC_{c,i,k}$ is the average time spent per week on knowledge contribution by individual i of the source department to the recipient department via channel c, $n_{c,k}$ is the total number of knowledge contributors from the source department and $TU_{c,j,k}$ is the average time spent per week by recipient j to source and acquire knowledge made available by the source department via channel c. The efficiency of the complete flow of knowledge between a source-recipient department couple k and via channel c is then determined by the average of all these individually perceived efficiencies, resulting in:

$$KF\eta_{c,k} = \frac{\sum_{j=1}^{m_{c,k}} KF\eta_{c,j,k}}{m_{c,k}} \tag{6.3}$$

where $KF\eta_{c,k}$ is the average efficiency of the knowledge flow between source-recipient department couple k via channel c and $m_{c,k}$ is the total number of recipients of the flow of knowledge between source-recipient department couple k via channel c.

6.3 Results study II

The descriptive statistics of the variables included in the sharing data set and in the sourcing data set are reported in Table 6.2 and Table 6.3 respectively, while their respective correlation matrices are shown in Table 6.4 and Table 6.5. Note that the sample size n of psychological safety is considerably smaller than the other constructs, as psychological safety was only measured for non-CE participants. Furthermore, the n of knowledge flow efficiency via physical verbal communication is also considerably smaller than the n of the knowledge flow efficiencies via other channels. This is caused by a significant number of participants who answered that they did not spent time on seeking and acquiring knowledge via physical verbal communication and therefore an efficiency score could not be determined. As working from home restrictions were still enforced by ASML during the period the survey was taken and the infection rate was on the rise, people probably limited the number of physical meetings compared to pre-COVID.

The participants of the survey were on average 38.6 (S.D. = 10.5) and 38.2 (S.D. = 10.5) years old, while they had on average already worked for 8.7 (S.D. = 6.8) and 8.5 (S.D. = 6.8) years for ASML. Furthermore, the average tenure of the participants in their current function was 3.3 (S.D. = 3.5 and S.D.= 3.5) years. Lastly, the sample was relatively highly educated as the majority of the participants had obtained at least a Bachelor's degree. The average proficiency in English of the sample was also high with average values of 6.0 (S.D. = 1.5 and S.D. = 1.4). Furthermore, contrary to the findings in study I, the averaged perceived time pressure was not high with a score of 3.97 on a 7-point Likert scale.

The first objective of the data analysis was to determine the efficiencies and effectiveness of the different knowledge flow channels, which are reported in the descriptive statistics of Table 6.3. From Table 6.3 there seem to be small differences between the effectiveness and efficiency of the different types of channels used to exchange knowledge. To test whether there exist significant differences in efficiency and effectiveness based on channel type, an analysis of variance was performed.

6.3.1 Knowledge flow efficiency per channel

Firstly, knowledge flow efficiency was analyzed to determine if, for knowledge flows, the efficiency was affected by the type of channel used by the source and recipient unit for the exchange of knowledge. Thus, the unit of analysis was the efficiency of knowledge flows between source-recipient couples for different types of channels. Therefore, the sourcing data set was divided into six separate datasets, based on source-recipient department couples. As most recipients indicated in the survey to make use of multiple channels to source and acquire knowledge, subjects were measured multiple times on the same outcome variable (the efficiency or effectiveness of a knowledge flow) under different conditions, namely for the use of different channels. Moreover, Table 6.3 also shows moderate to high correlations between the times spent sourcing knowledge via the different channels. Therefore, repeated-measures ANOVA was used as recipients showed up in multiple groups. For repeated measures ANOVA, several assumptions have to be met. Firstly, the data must be independent (Stevens, 2013). The independence assumption is met as the respondents form a random and representative part of the population and are not related

Table 6.2: Descriptive statistics of the variables in the sharing data set

Statistic	N	Mean	St. Dev.	Min	Max
Age source	218	38.56	10.45	24.0	66.0
Experience at ASML source	218	8.69	6.79	0.0	35.0
Experience in current function source	218	3.33	3.54	0.0	28.0
Educational level source	217	3.59	0.72	1.0	5.0
Time sharing via LKR	213	1.65	2.44	0.0	20.0
Time sharing via GKR	212	1.76	2.69	0.0	20.0
Time sharing via WC	213	2.70	3.01	0.0	20.0
Time sharing via VC	212	2.16	2.57	0.0	20.0
Time sharing via PC	203	1.11	2.33	0.0	16.0
Degree of organizational knowledge shared via LKR	200	2.44	1.06	1.0	6.0
Degree of organizational knowledge shared via GKR	201	2.44	1.17	1.0	6.0
Degree of organizational knowledge shared via WC	208	2.46	1.05	1.0	6.0
Degree of organizational knowledge shared via VC	206	2.59	1.05	1.0	6.0
Degree of organizational knowledge shared via PC	192	2.62	1.11	1.0	6.0
Complexity of knowledge shared via LKR	203	4.66	1.44	1.0	7.0
Complexity of knowledge shared via GKR	204	4.60	1.51	1.0	7.0
Complexity of knowledge shared via WC	210	4.50	1.60	1.0	7.0
Complexity of knowledge shared via VC	208	4.51	1.62	1.0	7.0
Complexity of knowledge shared via PC	195	4.34	1.64	1.0	7.0
Physical proximity to recipient	201	3.31	2.03	1.0	6.0
Corporate language proficiency source	219	6.03	1.45	1.0	7.0
Inter-department tie strength to recipient	200	5.70	1.16	1.50	7.0
Perceived time pressure on sharing	217	3.97	1.29	1.0	6.60
Perceived psychological safety	88	5.44	0.96	2.50	7.0

Table 6.3: Descriptive statistics of the variables in the sourcing data set

Statistic	N	Mean	St. Dev.	Min	Max
Age recipient	211	38.23	10.71	23.0	66.0
Experience at ASML recipient	211	8.52	6.84	0.0	35.0
Experience in current function recipient	211	3.31	3.62	0.0	28.0
Educational level recipient	210	3.63	0.74	1.0	5.0
Time sourcing via LKR	204	2.01	2.86	0.0	20.0
Time sourcing via GKR	206	2.24	2.99	0.0	20.0
Time sourcing via WC	205	2.33	2.85	0.0	20.0
Time sourcing via VC	205	2.16	2.73	0.0	20.0
Time sourcing via PC	199	1.28	2.13	0.0	16.0
Frequency of knowledge use, acquired via LKR	199	4.24	1.53	1.0	7.0
Frequency of knowledge use, acquired via GKR	201	4.53	1.31	1.0	7.0
Frequency of knowledge use, acquired via WC	202	4.90	1.15	1.0	7.0
Frequency of knowledge use, acquired via VC	202	4.75	1.17	2.0	7.0
Frequency of knowledge use, acquired via PC	193	3.49	1.72	1.0	7.0
Degree of organizational knowledge sourced via LKR	195	2.48	1.03	1.0	6.0
Degree of organizational knowledge sourced via GKR	200	2.50	1.06	1.0	6.0
Degree of organizational knowledge sourced via WC	203	2.49	1.01	1.0	6.0
Degree of organizational knowledge sourced via VC	200	2.50	1.03	1.0	6.0
Degree of organizational knowledge sourced via PC	188	2.67	1.11	1.0	6.0
Complexity of knowledge sourced via LKR	195	4.48	1.42	1.0	7.0
Complexity of knowledge sourced via GKR	199	4.55	1.47	1.0	7.0
Complexity of knowledge sourced via WC	199	4.55	1.50	1.0	7.0
Complexity of knowledge sourced via VC	198	4.58	1.57	1.0	7.0
Complexity of knowledge sourced via PC	187	4.36	1.47	1.0	7.0
Physical proximity to source	208	3.21	2.01	1.0	6.0
Corporate language proficiency recipient	212	6.01	1.41	1.0	7.0
Inter-department tie strength to source	206	5.62	1.23	1.50	7.0
Perceived psychological safety	105	5.43	0.94	2.50	7.0
Effectiveness KFs via LKR	198	5.05	1.02	1.25	7.0
Effectiveness KFs via GKR	200	5.16	1.01	1.0	7.0
Effectiveness KFs via WC	201	5.16	0.92	1.0	7.0
Effectiveness KFs via VC	201	5.12	0.97	1.25	7.0
Effectiveness KFs via PC	192	4.85	1.02	1.00	7.0
Efficiency KFs via LKR	163	1.52	0.75	0.34	4.12
Efficiency KFs via GKR	175	1.42	0.66	0.14	4.07
Efficiency KFs via WC	189	1.14	0.46	0.26	3.02
Efficiency KFs via VC	186	1.29	0.50	0.27	2.97
Efficiency KFs via PC	102	2.00	1.32	0.30	8.49

Table 6.4: Correlation matrix sourcing data set (1/2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Age recipient	1.00																
2. Experience at ASML	0.78***	1.00															
3. Experience current function	0.42***	0.49***	1.00														
4. Educational level	0.03	-0.17*	-0.05	1.00													
5. Time sourced via LKR	0.05	0.05	0.08	-0.12	1.00												
6. Time sourced via GKR	0.09	0.06	-0.02	0.01	0.67***	1.00											
7. Time sourced via WC	-0.11	-0.15*	-0.04	-0.15*	0.76***	0.60***	1.00										
8. Time sourced via VC	-0.14*	-0.18**	-0.04	-0.11	0.63***	0.52***	0.81***	1.00									
9. Time sourced via PC	-0.09	-0.15*	0.01	-0.16*	0.56***	0.46***	0.58***	0.61***	1.00								
10. Degree of org. knowledge sourced via LKR	-0.09	-0.08	-0.01	-0.06	0.15*	0.10	0.15*	0.15*	0.15*	1.00							
11. Degree of org. knowledge sourced via GKR	-0.14*	-0.16*	-0.04	-0.11	0.05	0.02	0.07	0.07	0.10	0.75***	1.00						
12. Degree of org. knowledge sourced via WC	-0.06	-0.09	-0.10	-0.04	0.06	0.16*	0.02	-0.03	0.11	0.58***	0.60***	1.00					
13. Degree of org. knowledge sourced via VC	-0.06	-0.10	-0.06	-0.07	0.12	0.08	0.03	-0.02	0.09	0.51***	0.49***	0.75***	1.00				
14. Degree of org. knowledge sourced via PC	-0.07	-0.05	-0.04	-0.00	0.12	0.17*	0.09	0.14	0.01	0.45***	0.45***	0.64***	0.70***	1.00			
15. Complexity of knowledge sourced via LKR	-0.04	-0.01	-0.04	-0.03	0.01	-0.01	0.05	0.05	-0.01	-0.09	-0.13	-0.02	-0.06	0.01	1.00		
16. Complexity of knowledge sourced via GKR	0.08	0.04	-0.03	-0.09	0.09	0.02	0.04	0.03	0.02	-0.08	-0.13	-0.00	-0.00	-0.01	0.72***	1.00	
17. Complexity of knowledge sourced via WC	-0.03	-0.05	-0.09	-0.12	0.04	0.01	0.04	0.01	0.03	0.07	0.05	0.01	0.07	0.00	0.60***	0.69***	1.00
18. Complexity of knowledge sourced via VC	-0.00	-0.01	-0.07	-0.10	0.06	0.01	0.06	0.02	0.03	0.06	0.05	0.03	0.04	-0.02	0.52***	0.62***	0.88***
19. Complexity of knowledge sourced via PC	0.01	-0.04	-0.05	-0.07	-0.03	-0.06	0.08	0.03	0.11	0.06	0.07	-0.04	-0.03	-0.09	0.42***	0.42***	0.62***
20. Physical proximity	-0.03	-0.08	-0.14*	0.03	0.02	-0.01	0.02	0.03	0.19**	-0.17*	-0.18*	-0.11	-0.06	-0.21**	0.08	0.05	0.02
21. Corporate language proficiency	-0.11	-0.15*	0.05	-0.14*	-0.15*	-0.33***	0.02	0.05	-0.01	0.04	0.01	-0.04	-0.00	-0.04	0.28***	0.27***	0.23**
22. Inter-departmental tie strength	0.05	0.03	-0.01	-0.00	-0.07	-0.08	0.03	0.11	0.02	-0.12	-0.13	-0.13	-0.08	-0.10	0.20**	0.14	0.10
23. Psychological safety	0.08	0.02	-0.05	0.10	-0.20*	-0.17	-0.13	-0.26**	-0.23*	-0.04	-0.04	0.09	0.12	0.17	0.19	0.13	0.19
24. Effectiveness LKR	0.03	-0.04	-0.11	0.05	0.08	-0.04	-0.01	0.03	-0.09	-0.17*	-0.07	0.08	0.04	0.12	0.40***	0.29***	0.16*
25. Effectiveness GKR	0.11	0.07	0.01	0.07	0.07	0.01	0.00	0.04	-0.15*	-0.12	-0.07	0.09	0.05	0.15*	0.29***	0.32***	0.15*
26. Effectiveness via WC	0.05	-0.00	-0.07	0.04	-0.01	-0.06	-0.05	-0.06	-0.16*	-0.14	-0.08	0.02	0.01	0.10	0.34***	0.37***	0.30***
27. Effectiveness VC	0.04	-0.03	-0.04	0.05	-0.10	-0.10	-0.04	-0.03	-0.17*	-0.11	-0.08	-0.03	-0.04	0.08	0.37***	0.30***	0.20 **
28. Effectiveness PC	0.01	-0.05	-0.07	-0.01	-0.08	-0.13	-0.03	-0.01	-0.03	-0.10	-0.07	-0.03	-0.01	0.05	0.34***	0.24**	0.11
29. Efficiency LKR	0.08	0.01	-0.00	0.15	-0.54***	-0.42***	-0.41***	-0.40***	-0.39***	-0.22**	-0.15	-0.14	-0.20*	-0.26**	0.10	0.00	-0.01
30. Efficiency GKR	0.12	0.08	0.12	0.16*	-0.41***	-0.61***	-0.43***	-0.41***	-0.41***	-0.18*	-0.18*	-0.14	-0.12	-0.15	0.14	0.09	0.08
31. Efficiency WC	0.16*	0.17*	0.08	0.17*	-0.45***	-0.42***	-0.56***	-0.44***	-0.40***	-0.25***	-0.26***	-0.20**	-0.16*	-0.17*	0.07	0.09	0.06
32. Efficiency VC	0.14	0.15*	0.05	0.13	-0.47***	-0.44***	-0.51***	-0.61***	-0.45***	-0.26***	-0.23**	-0.20**	-0.19*	-0.23**	0.09	0.09	0.03
33. Efficiency PC	-0.01	0.04	0.00	0.10	-0.35***	-0.35***	-0.38***	-0.41***	-0.54***	-0.18	-0.18	-0.20*	-0.27**	-0.30**	0.13	0.12	0.12

Table 6.5: Correlation matrix sourcing data set (2/2)

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
18. Complexity knowledge sourced via VC	1.00															
19. Complexity knowledge sourced via PV	0.73***	1.00														
20. Physical proximity	0.03	0.10	1.00													
21. Corporate language proficiency	0.17*	0.21**	0.02	1.00												
22. Inter-departmental tie strength	0.05	0.11	0.06	0.07	1.00											
23. Psychological safety	0.18	0.21*	-0.05	0.24*	0.32**	1.00										
24. Effectiveness LKR	0.19*	0.22**	0.08	0.12	0.28***	0.40***	1.00									
25. Effectiveness GKR	0.16*	0.22**	0.10	0.05	0.28***	0.27*	0.75***	1.00								
26. Effectiveness WC	0.30***	0.21**	0.09	0.12	0.30***	0.44***	0.69***	0.71***	1.00							
27. Effectiveness VC	0.19**	0.20*	0.10	0.21**	0.35***	0.26*	0.66***	0.68***	0.81***	1.00						
28. Effectiveness PC	0.09	0.25**	0.15	0.18*	0.30***	0.20*	0.61***	0.56***	0.56***	0.73***	1.00					
29. Efficiency LKR	0.02	0.04	0.11	0.12	0.24**	0.16	0.19*	0.15	0.20*	0.22**	0.21*	1.00				
30. Efficiency GKR	0.12	0.14	-0.02	0.22**	0.20**	0.12	0.21**	0.19*	0.20*	0.22**	0.18*	0.62***	1.00			
31. Efficiency WC	0.09	0.08	0.11	0.11	0.27***	0.17	0.15	0.23**	0.24**	0.24**	0.17*	0.59***	0.75***	1.00		
32. Efficiency VC	0.07	0.06	0.09	0.11	0.24***	0.18	0.13	0.22**	0.23**	0.29***	0.26***	0.60***	0.68***	0.80 ***	1.00	
33. Efficiency PC	0.11	0.03	0.08	0.12	0.18	0.18	0.11	0.18	0.16	0.22*	0.19	0.62***	0.58***	0.62 ***	0.66***	1.00

Table 6.6: Correlation matrix sharing data set

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Age source	1.00																							
2. Experience at ASML	0.76***	1.00																						
3. Experience in current function	0.42***	0.50***	1.00																					
4. Educational level	-0.01	-0.19**	-0.08	1.00																				
5. Time sharing knowledge via LKR	0.10	0.06	0.03	-0.13	1.00																			
6. Time sharing knowledge via GKR	0.12	0.02	0.02	-0.08	0.58***	1.00																		
7. Time sharing knowledge via WC	-0.16*	-0.22**	-0.08	-0.10	0.50***	0.60***	1.00																	
8. Time sharing knowledge via VC	-0.10	-0.19**	0.01	0.01	0.33***	0.54***	0.63***	1.00																
9. Time sharing knowledge via PC	-0.07	-0.08	-0.09	0.00	0.39***	0.10	0.29***	0.49***	1.00															
10. Degree of org. knowledge shared via LKR	-0.00	0.03	0.05	-0.10	0.02	-0.01	-0.04	0.05	0.04	1.00														
11. Type of knowledge shared via GKR	-0.08	-0.09	-0.11	-0.14*	0.19**	-0.07	0.06	-0.01	0.11	0.70***	1.00													
12. Degree of org. knowledge shared via WC	-0.09	-0.09	-0.05	-0.11	0.10	-0.06	-0.04	-0.01	0.03	0.59***	0.63***	1.00												
13. Degree of org. knowledge shared via VC	-0.08	-0.08	-0.06	-0.14*	0.11	-0.02	0.07	0.09	0.06	0.42***	0.52***	0.72***	1.00											
14. Degree of org. knowledge shared via PC	-0.10	-0.09	-0.01	-0.08	0.02	0.06	-0.02	0.04	-0.08	0.44***	0.46***	0.58***	0.66***	1.00										
15. Complexity of knowledge shared via LKR	-0.14	-0.05	-0.02	-0.14	0.07	-0.03	-0.08	-0.04	-0.07	0.02	-0.04	0.09	0.04	0.12	1.00									
16. Complexity of knowledge shared via GKR	-0.07	0.01	0.01	-0.18**	0.04	-0.07	-0.04	-0.06	-0.08	0.04	0.01	0.12	0.11	0.12	0.67***	1.00								
17. Complexity of knowledge shared via WC	-0.13	-0.08	-0.03	-0.21**	0.01	-0.07	-0.00	0.03	-0.03	0.13	0.11	0.21**	0.11	0.10	0.50***	0.54***	1.00							
18. Complexity of knowledge shared via VC	-0.13	-0.04	-0.03	-0.23**	-0.01	-0.05	0.00	0.02	-0.06	0.17*	0.10	0.17*	0.05	0.04	0.40***	0.43***	0.83***	1.00						
19. Complexity of knowledge shared via PC	-0.09	-0.05	-0.05	-0.11	0.01	-0.13	-0.01	0.03	0.01	0.16*	0.10	0.16*	0.11	0.04	0.34***	0.29***	0.58***	0.71***	1.00					
20. Physical proximity	-0.05	-0.11	-0.16*	0.11	-0.05	-0.00	-0.10	-0.00	0.18*	-0.13	-0.09	-0.08	-0.13	-0.07	-0.03	-0.08	-0.03	-0.07	-0.04	1.00				
21. Corporate language proficiency	-0.09	-0.17*	0.01	-0.10	-0.14*	-0.12	-0.03	0.06	-0.04	0.03	-0.02	0.11	0.07	-0.10	0.11	0.17*	0.23***	0.14*	0.03	-0.02	1.00			
22. Inter-departmental tie strength	0.08	0.07	-0.00	0.06	-0.02	0.01	0.07	0.09	0.08	-0.20**	-0.18*	-0.20**	-0.11	-0.11	0.09	0.03	0.08	-0.02	-0.05	-0.00	-0.01	1.00		
23. Time pressure on sharing knowledge	0.13	0.06	0.01	0.04	0.14*	0.07	0.16*	0.14*	0.13	0.07	0.03	0.04	0.06	0.08	-0.02	-0.10	0.01	-0.04	-0.01	0.02	-0.08	0.05	1.00	
24. Psychological safety	0.08	-0.01	-0.07	0.16	-0.06	-0.17	-0.06	-0.16	-0.05	0.07	0.21	0.22*	0.20	0.01	-0.10	0.06	-0.11	-0.16	-0.10	-0.09	0.24*	0.33**	-0.04	1.00

to one another. From the design of the survey there are no reasons to doubt this assumption, although due to the anonymity of the survey, the reasons why individuals did not take part in the survey are unknown.

Secondly, the normality assumption describes that the dependent variable should be normally distributed for each group (Stevens, 2013). According to the central limit theorem "for a large number of independent identically distributed random variables $X_1, ..., X_n$, with finite variance, the average $\overline{X_n}$ approximately has a normal distribution" (Dekking, 2005, p.195). Moreover, as a rule of thumb, the central limit theorem already holds for sample sizes between 30 and 50 (Ross, 2017). However, as reported in Table 6.7, the sample size n is for some channels and source-recipient departments below 30. Furthermore, it can be observed that n is smaller for the efficiency of physical verbal communication when compared to other channels. This lower n is caused by the fact that for physical verbal communication, participants more frequently than for other channels indicated that they spent zero hours on sourcing knowledge via that channel. Unfortunately, these smaller sample sizes limited the statistical power of the analysis of variance and increased the probability of a type II error, in which the null hypothesis is failed to be rejected, while it should have.

Table 6.7: Sample sizes per knowledge flow for knowledge flow efficiency

Source-recipient units	n total	n LKR	n GKR	n WC	n VC	n PC
CE - 2nd line	63	51	55	56	53	31
2nd line - CE	33	26	30	32	29	13
CE - DE	26	17	15	22	24	8
DE - CE	41	34	36	36	39	27
CE - GSC	21	15	20	19	17	6
GSC - CE	28	20	19	24	24	17

As the rule of thumb of the Central limit theorem did not apply to the sample sizes of all knowledge flows, Shapiro-Wilk tests were performed to test for normality of the knowledge flow efficiencies. The results of the Shapiro-Wilk tests are shown in Table G.2. The results shown in Appendix G in Table G.2 indicate that the assumption of normality is violated for several knowledge flow efficiencies, thus a non-parametric version of repeated measures ANOVA was more suitable to analyze whether any differences in efficiency or effectiveness are present in these knowledge flows based on the type of channel used to exchange knowledge.

The non-parametric alternative to the parametric repeated measures ANOVA is the Friedman's test (Friedman, 1937). Unfortunately, due to missing data, the block design is unbalanced and incomplete, while the Friedman's test requires a balanced complete block design. Thus, the Friedman's test can only be used by applying list-wise deletion. However, using list-wise deletion when analyzing the difference in efficiency based on channel type would reduce the sample size n from 212 observations to only 84 observations. Therefore, the Skillings Mack test was used, an alternative to the Friedman's test, which can cope with unbalanced and incomplete block designs due to arbitrary missing data (Skillings and Mack, 1981). The Skillings Mack test requires that for each block there are at least two or more values. Therefore, all participants of whom only for one channel the efficiency could be determined were removed, which slightly decreased the combined total n of all knowledge flows from respectively of 212 observations to 197 observations.

The results of the Skillings Mack test for each source-recipient couple are shown in Table 6.8. As reported, the Skillings Mack test statistic is for all source-recipient department couples significant, except for the exchange of knowledge between CE and GSC. Therefore, there is strong evidence to reject the null hypothesis for most source-recipient department couples that the efficiency of a knowledge flow does not depend on the type of channel used. In other words, the data shows that for almost all knowledge flows, the efficiency of the knowledge flow is dependent on the type of channel used for the exchange of knowledge.

Table 6.8: Results of the Skillings-Mack test

Source-recipient couple	n	Test-statistic	df	P-value
Efficiency				
CE - 2nd line	57	87.81	4	2.2e-16***
2nd line - CE	33	27.67	4	1.46e-5***
CE - DE	23	29.38	4	6.53e-6***
DE - CE	39	57.37	4	1.03e-11***
CE - GSC	20	2.73	4	0.60
GSC - CE	25	41.81	4	1.83e-8***

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

As knowledge flow efficiency significantly differed based on the type of channel used, a pairwise comparison was performed to determine if certain channels are more efficient than others. For such a pairwise dependent samples t-test several assumptions must hold, like the assumption of independence, normality, and homoscedasticity (Sheskin, 2011). Firstly, the assumption of independence requires that the sample represents a random part of the population, which is assumed to be the case in the survey. The assumption of normality of the difference in knowledge flow efficiency between channel pairs was tested by applying the Shapiro-Wilk test. However, from the results came forward that the assumption of normality was violated for several channel pairs. Therefore, a non-parametric alternative had to be used for the pairwise comparisons. Although for some pairs of channels the difference in knowledge flow efficiency did not violate the normality assumption, it was decided to employ a non-parametric for all the channel pairs. The reason for this is the interpretability of the results, as otherwise some pairs would be tested for a difference in means via the dependent samples t-test, while other channels would have been evaluated for a difference in medians. A consequence of this decision is that for the pairs of channels that met the normality assumption, statistical power is reduced when using a non-parametric test when compared to a parametric test. Therefore, the results of these tests are slightly more conservative, which could increase the probability of a type II error. To conclude, a non-parametric dependent samples test was used for all pairs of channels. Such a dependent samples test that does not require the assumption of normality is the Wilcoxon matched-pairs signed-rank test (Sheskin, 2011).

The Wilcoxon signed-rank test still requires two assumptions to hold. Firstly, the values of the dependent variable must have been measured on an interval or ratio scale, which is the case. Secondly, the distribution of the differences between the efficiencies must be symmetrical around the median of the distribution of the differences (Sheskin, 2011). To evaluate this assumption the differences between the efficiencies of channels were calculated for all source-recipient unit couples. Thereafter, the histogram plots were visually inspected to assess the degree of symmetry of the distribution of differences around the median. For the sake of brevity, the histograms are left out, as with 5 channels, there are 10 pairs of channels to compare for each source-recipient couple, which required 50 histograms. If the difference in efficiency of a pair of knowledge flow channels was not symmetrically distributed around the median, an alternative type of test was used instead of the Wilcoxon signed-rank test. The alternative test used was the binomial sign test for dependent samples, which, unlike the Wilcoxon signed-rank test, does not require the assumption of symmetry Sheskin (2011). Although providing less statistical power, the binomial sign test for dependent samples only requires that the values which are compared can be rank-ordered (Sheskin, 2011). Thus, when symmetry was present, the Wilcoxon signed-rank test was used, while when symmetry was absent, the Binomial sign test was used.

All tests were performed as one-sided to evaluate which of the two channels was more or less efficient than the other. The null hypotheses of these tests were that the medians of the knowledge flow efficiency of the channels were equal. The alternative hypotheses, H_1, of which channel the efficiency was greater or smaller than the other were based on the average channel efficiencies reported in Table 6.3. Furthermore, the type of test used can be deducted from the test statistic where the V represents the test statistic of the Wilcoxon signed-rank test, while the S is the test statistic of the Binomial sign test. Lastly, the Bonferroni correction was used to cope with the problem of multiplicity and thus to reduce the probability of a Type I error (Sheskin, 2011). The full results of the pairwise comparisons of the efficiencies of different channel pairs for each source-recipient couple are shown in Table 6.9, Table 6.10 and Table 6.11. In these tables, H_1 describes the alternative hypothesis of the pairwise comparisons, which can either be less or greater, which means that the efficiency of the left-hand channel is less or greater than the efficiency of the right-hand channel. A summary of all pairwise comparisons for all source-recipient couples is provided in Table 6.12.

Table 6.9: The results of the pairwise comparisons with Bonferroni correction of the efficiency of knowledge flows via different channels for the exchange of knowledge between CE and 2nd line, where H1 is the alternative hypothesis of the one-sided pairwise comparisons

	CE - 2nd line			**2nd line - CE**		
	Test-statistic	P-value	H1	Test=statistic	P-value	H1
LKR - GKR	V = 904	6.06e-03***	Greater	V = 33	1.55e-03**	Less
LKR - WC	V = 1142	7.12e-07***	Greater	S = 13	1.00	Greater
LKR - VC	V = 848	9.77e-04***	Greater	S = 7	0.47	Less
LKR - PC	V = 31	2.89e-04***	Less	S = 2	0.19	Less
GKR - WC	V = 1335	1.72e-06***	Greater	V = 385	1.52e-03**	Greater
GKR - VC	V = 871	0.26	Greater	V = 252	0.26	Greater
GKR - PC	S = 6	4.39e-03**	Less	V = 55	1.00	Greater
WC - VC	V = 95	5.18e-07***	Less	V = 78	1.13e-02*	Less
WC - PC	S = 2	2.31e-06***	Less	S = 3	0.46	Less
VC - PC	S = 3	4.22e-05***	Less	V = 22	1.00	Less

Note: *p<0.05; **p<0.01; ***p<0.001

The data in Table 6.12 present four interesting findings. Firstly, it can be observed that the median efficiency of physical verbal communication was for no source-recipient context significantly smaller than the median efficiency of any other channel. On the contrary, the median efficiency of physical verbal communication was in all comparisons with the other channels for at least two out of six contexts significantly higher. Therefore, the data suggests that of all channels, physical verbal communication is the most efficient channel to exchange knowledge between two departments.

Secondly, the median efficiency of written communication was in no comparison significantly higher than any other channel. Moreover, the median efficiency of written communication was in all comparisons with the other channels for at least three out of six contexts significantly

Table 6.10: The results of the pairwise comparisons with Bonferroni correction of the efficiency of knowledge flows via different channels for the exchange of knowledge between CE and DE, where H1 is the alternative hypothesis of the one-sided pairwise comparisons

	CE - DE			DE - CE		
	Test-statistic	P-value	H1	Test=statistic	P-value	H1
LKR - GKR	V = 88	1.60e-02*	Greater	V = 348	0.26	Greater
LKR - WC	S = 14	2.10e-02*	Greater	S = 28	9.65e-05***	Greater
LKR - VC	S = 14	6.40e-02	Greater	V = 503	2.28e-03**	Greater
LKR - PC	S = 3	1.00	Less	V = 121	0.87	Less
GKR - WC	S = 10	0.46	Greater	V = 474	4.47e-04***	Greater
GKR - VC	S = 9	1.00	Greater	V = 498	1.40e-02*	Greater
GKR - PC	S = 0	0.31	Less	V = 64	6.30e-2	Greater
WC - VC	S = 5	0.13	Less	V = 170	5.30e-02	Less
WC - PC	S = 0	3.90e-02*	Less	V = 20	4.13e-04***	Less
VC - PC	S = 1	0.35	Less	V = 46	3.09e-3**	Less
Note:						*p<0.05; **p<0.01; ***p<0.001

Table 6.11: The results of the pairwise comparisons with Bonferroni correction of the efficiency of knowledge flows via different channels from GSC to CE, where H1 is the alternative hypothesis of the one-sided pairwise comparisons

	GSC- CE		
	Test-statistic	P-value	H1
LKR - GKR	S = 14	6.40e-02	Greater
LKR - WC	S = 16	2.10e-02*	Greater
LKR - VC	S = 13	1.00	Greater
LKR - PC	S = 2	3.70e-2*	Less
GKR - WC	S = 13	0.25	Greater
GKR - VC	S = 12	1.00	Greater
GKR - PC	S = 0	3.05e-4***	Less
WC - VC	S = 4	1.30e-02*	Less
WC - PC	S = 0	3.05e-04***	Less
VC - PC	S = 1	2.59e-03**	Less
Note:			*p<0.05; **p<0.01; ***p<0.001

Table 6.12: Summary of all the pairwise comparisons to analyze the difference in efficiency based on the type of channel

	CE - 2nd line	**2nd line - CE**	**CE - DE**	**DE - CE**	**CE - GSC**	**GSC - CE**
LKR - GKR	Greater	Less	Greater	n.s.d.	n.s.d.	n.s.d.
LKR - WC	Greater	n.s.d.	Greater	Greater	n.s.d.	Greater
LKR - VC	Greater	n.s.d.	n.s.d	Greater	n.s.d.	n.s.d.
LKR - PC	Less	n.s.d.	n.s.d.	n.s.d.	n.s.d.	Less
GKR - WC	Greater	Greater	n.s.d.	Greater	n.s.d.	n.s.d.
GKR - VC	n.s.d.	n.s.d.	n.s.d.	Greater	n.s.d.	n.s.d.
GKR - PC	Less	n.s.d.	n.s.d.	Less	n.s.d.	Less
WC - VC	Less	Less	n.s.d.	n.s.d.	n.s.d.	Less
WC - PC	Less	n.s.d.	Less	Less	n.s.d.	Less
VC - PC	Less	n.s.d.	n.s.d.	Less	n.s.d.	Less

Note: n.s.d.: no significant difference

lower. Therefore, the data strongly suggests that written communication is of all channels the least efficient channel to exchange knowledge between departments.

Thirdly, the results indicate that the second most efficient way to exchange knowledge is to make use of knowledge repositories, indifferent of the type. Although the medians of the efficiency of both local and global knowledge repositories are in at least two contexts smaller than physical verbal communication, they are also in at least two contexts significantly higher than virtual verbal communication and written communication. Moreover in no context was the median efficiency of local and global knowledge repositories significantly lower when compared to virtual verbal communication and written communication. When comparing the median efficiencies of local and global knowledge repositories with one another, no clear order can be established based on the data about which channel looks more efficient than the other. While the median efficiency of local knowledge repositories was significantly higher for two contexts, the median efficiency of global knowledge repositories was significantly higher for the exchange of knowledge between second-line engineers and competence engineers. Therefore, results indicate that while the use of knowledge repositories is relatively efficient compared to the other channels, the difference in efficiency between local or global knowledge repositories seems to depend on the context in which they are applied.

Fourthly, the available data suggest that while virtual verbal communication is less efficient than physical verbal communication and the use of knowledge repositories, it is more efficient than written communication. When compared to physical verbal communication and knowledge repositories, the median efficiency of virtual verbal communication was in no context significantly higher, while for the comparisons with each other channel, it proved for two contexts to be significantly smaller, except for the pairwise comparisons with global knowledge repositories.

Thus, according to the data on knowledge flow efficiency, physical verbal communication is the most efficient channel to exchange knowledge, followed by knowledge repositories, virtual verbal communication, and written communication. Furthermore, the difference in efficiency between local and global knowledge repositories seems to depend on the context in which the channels were used.

6.3.2 Knowledge flow effectiveness per channel

To identify if the effectiveness of knowledge flows depended on the type of channel, the same approach was used as for knowledge flow efficiency. Thus, the unit of analysis was the effectiveness of knowledge flows between source-recipient couples for different types of channels. The Skillings Mack test was performed as normality was violated (see Table G.3 in Appendix G) and the block design was again unbalanced as well as incomplete (see Table 6.13). Nevertheless, as the same data set was used, the assumption of independence still holds. The results of the Skillings Mack test are shown in Table 6.14. Contrary to the efficiency, the effectiveness of knowledge flows seemed to depend less on the type of channel used, as only for two source-recipient couples the Skillings Mack test proved significant, as shown in Table 6.14. Therefore, only for those two source-recipient couples, there was strong evidence to reject the null hypothesis that there was no difference in knowledge flow effectiveness based on the type of channel. Pairwise comparisons of knowledge flow effectiveness were made for all pairs of channels of those source-recipient couples for which the Skillings Mack test was significant.

Table 6.13: Sample sizes per knowledge flow for knowledge flow effectiveness

Source-recipient units	n total	n LKR	n GKR	n WC	n VC	n PC
CE - 2nd line	63	58	57	56	56	56
2nd line - CE	33	32	33	33	32	30
CE - DE	26	19	19	19	20	17
DE - CE	41	39	40	38	38	38
CE - GSC	21	18	19	19	17	17
GSC - CE	28	25	25	25	25	25

To test which channels differ in knowledge flow effectiveness, first, the normality assumption was evaluated to select the appropriate comparison test. However, from the Shapiro-Wilk tests came forward that the assumption of normality was violated for several channel pairs. Therefore,

Table 6.14: Skillings-Mack test to analyze the difference in knowledge flow effectiveness depending on channel type

Source-recipient couple	n	Test-statistic	df	P-value
CE - 2nd line	57	15.56	4	3.68e-3***
2nd line - CE	33	3.66	4	0.45
CE - DE	20	3.52	4	0.47
DE - CE	40	2.15	4	0.71
CE - GSC	19	11.37	4	0.02*
GSC - CE	25	2.10	4	0.71
Note:		*p<0.05; **p<0.01; ***p<0.001		

a non-parametric alternative had to be used for the pairwise comparisons. Although of some pairs of channels the difference in knowledge flow efficiency did not violate the normality assumption, it was again decided to employ a non-parametric for all the channel pairs for the priorly mentioned reason of interpretability. Therefore, the results of these tests are slightly more conservative, which could increase the probability of a type II error.

As the assumption of normality was violated, a non-parametric alternative comparison test was used, the Wilcoxon matched-pairs signed-rank test. The Wilcoxon signed-rank test assumes that the difference in effectiveness between two samples must be symmetrically distributed around the median (Sheskin, 2011). Therefore, the histograms were plotted of the difference in effectiveness between all pairs of channels. Visual inspection of these histograms led to the conclusion that not for all tests the assumption of a symmetrical distribution of the difference held. For those pairs for which this assumption was violated, the Binomial sign rank test was used. The type of test used is shown in Table 6.15, where the test statistic V indicates that the Wilcoxon signed-rank test is used, while the S statistic indicates the use of the Binomial sign rank test.

Moreover, the Bonferroni correction was again applied to prevent the problem of multiplicity. Lastly, most tests were conducted as two-sided as the overall means of the effectiveness per channel reported in Table 6.3 were very closely matched, except for the effectiveness of physical verbal communication, which seemed lower than the other channels. Therefore, all pairwise comparisons with physical verbal communication were tested as one-sided. The alternative hypothesis used was that the true difference in the median is greater than zero, or in other words, that the medians of the effectiveness of the other channels are larger than the median of the effectiveness of physical verbal communication. The results of these pairwise comparisons are shown in Table 6.15. A summary of all the differences between the effectiveness of all channels for all source-recipient couples is shown in Table 6.16.

Table 6.15: The results of the pairwise comparisons with Bonferroni correction of the effectiveness of knowledge flows via different channels from CE to 2nd line engineers and from CE to GSC, where H1 is the alternative hypothesis of the one-sided pairwise comparisons

	CE - 2nd line			**CE - GSC**		
	Test statistic	P-value	H1	Test-statistic	P-value	H1
LKR - GKR	V = 282	1.00	unequal	S = 4	1.00	unequal
LKR - WC	S = 21	1.00	unequal	V = 43	1.00	unequal
LKR - VC	S = 26	0.20	unequal	S = 7	1.00	unequal
LKR - PC	S = 29	1.93e-4 *	Greater	S = 11	0.11	Greater
GKR - WC	V = 311.5	1.00	unequal	S = 8	1.00	unequal
GKR - VC	V = 510	0.17	unequal	S = 11	0.06	unequal
GKR - PC	S = 26	0.17	Greater	S = 12	0.06	Greater
WC - VC	S = 23	1.00	unequal	V = 75	1.00	unequal
WC - PC	S = 31	0.01*	Greater	V = 68.5	0.58	Greater
VC - PC	S = 20	0.49	Greater	S = 7	1.00	Greater

Note: *p<0.05; **p<0.01; ***p<0.001

The results in Table 6.16 strongly indicate that knowledge flow effectiveness does not seem to depend on the type of channel used to exchange knowledge. For almost all pairwise comparisons, no significant differences were found in knowledge flow effectiveness based on the type of channel used. Only in two pairwise comparisons the data show a significant difference in effectiveness, all for the knowledge shared by competence engineers to second-line engineers. For the knowledge flow of competence engineers to second-line engineers, the data indicate that local knowledge repositories and written communication are more effective than the use of physical verbal communication.

Although the Skillings Mack test was significant for the source-recipient couple CE - GSC, the pairwise comparisons did not show significant differences in knowledge flow effectiveness between pairs of channels. The reasons for this could be that for the comparison of the effectiveness of global knowledge repositories with virtual verbal communication, no a priori assumption was made on which of the two channels was more or less effective than the other. As can be observed the p-value is equal to 0.06, thus as the test was conducted as one-sided with the alternative hypothesis that the effectiveness of global knowledge repositories was greater than the effectiveness of virtual verbal communication then the test statistic would have been significant.

Table 6.16: Summary of all the pairwise comparisons and Skilling-Mack tests to analyze the difference in effectiveness based on the type of channel. Note that only pairwise comparisons were performed for CE - 2nd line, as the Skillings-Mack test indicated that there were no significant differences for the other source-recipient couples

	CE - 2nd line	**2nd line - CE**	**CE - DE**	**DE - CE**	**CE - GSC**	**GSC - CE**
LKR - GKR	n.s.d	n.s.d.	n.s.d	n.s.d.	n.s.d.	n.s.d.
LKR - WC	n.s.d	n.s.d.	n.s.d	n.s.d	n.s.d.	n.s.d
LKR - VC	n.s.d	n.s.d.	n.s.d	n.s.d	n.s.d.	n.s.d.
LKR - PC	Greater	n.s.d.	n.s.d.	n.s.d.	n.s.d.	n.s.d
GKR - WC	n.s.d	n.s.d	n.s.d.	n.s.d	n.s.d.	n.s.d.
GKR - VC	n.s.d.	n.s.d.	n.s.d.	n.s.d	n.s.d.	n.s.d.
GKR - PC	Greater	n.s.d.	n.s.d.	n.s.d	n.s.d.	n.s.d
WC - VC	n.s.d	n.s.d	n.s.d.	n.s.d.	n.s.d.	n.s.d
WC - PC	Greater	n.s.d.	n.s.d	n.s.d	n.s.d.	n.s.d
VC - PC	n.s.d	n.s.d.	n.s.d.	n.s.d	n.s.d.	n.s.d

Note: n.s.d.: no significant difference

Thus, contrary to knowledge flow efficiency, the data strongly indicates that the effectiveness of a knowledge flow does not depend on the type of channel used. Combined with the results on knowledge flow efficiency, the data suggests that the knowledge received via different channels equally contributes to organizational performance, however, as some channels are more efficient than others, it may take more time to get the knowledge across. Moreover, the data suggest that sharing knowledge in a written format through local knowledge repositories or written communication is on average significantly more effective than the use of physical verbal communication. However, these differences are only found for one specific context of the six contexts which were evaluated, namely only for the knowledge shared by competence engineers to second-line engineers.

6.3.3 Regression analysis

In study I, several possible antecedents of knowledge flow efficiency and knowledge flow effectiveness were identified. Through multiple linear regression analysis, these antecedents were quantitatively analyzed for both knowledge flow efficiency and effectiveness. Thus, in these analyses, the antecedents were regressed onto knowledge flow efficiency and effectiveness. However, as knowledge flow efficiency and effectiveness are determined per channel, each of them was split up into five separate dependent variables, namely the knowledge flow efficiency or effectiveness via i) local knowledge repositories, ii) global knowledge repositories, iii) written communication, iv) virtual verbal communication and v) physical verbal communication. For each of these channels, regression analysis was performed to identify what antecedents are of the knowledge flow efficiency and effectiveness via that channel. Here, the unit of analysis was the perceived knowledge flow efficiency and effectiveness by the individual recipients of the knowledge flows, thus on an individual level. In the regression analysis, the unit of analysis was on an individual level to be able to regress the antecedents identified in study I on knowledge flow efficiency and effectiveness. The antecedents included in the regression analysis are: i) the physical proximity of the recipient to the source department, ii) the inter-department tie strength between the source and recipient department as perceived by the recipient, iii) the degree of organizational knowledge sourced and acquired via a channel as perceived by the recipient, iv) the complexity of the knowledge sourced and acquired via a channel as perceived by the recipient, v) the self-reported proficiency in English of the recipient, and vi) the perceived psychological safety of the recipient[1]

Multiple linear regression is based on four assumptions that must be evaluated, namely 1) Independence of the error terms, 2) Linearity, 3) Normality of residuals, and 4) Homoscedasticity (Hair et al., 2014). The first assumption required for multiple linear regression is the assumption of the independence of the error terms. Dependence between the error terms can be caused by relationships between variables based on a factor that was not included in the model. Now, remember that for the creation of the sourcing data set, the answers related to how a recipient j from CE sourced and acquired knowledge from second-line engineers, D&E, or GSC were taken as separate entries. However, how recipient j from CE sources and acquires knowledge from for example D&E, could well be related to how the same recipient sources and acquires knowledge from for example GSC. Therefore, the data is nested and at least conceptually not independent, which could violate the assumption of independence of error terms.

One way to evaluate if the error terms were dependent based on the fact that the answers of multiple entries are reported by the same participant is to check if there are significant auto-correlations for certain lags present between the error terms due to the entries made by the same recipient. However, evaluating the presence of auto-correlations between the error terms of entries of the same recipient is difficult, as all entries are randomly distributed throughout the sourcing data set. Therefore, the intervals between entries made by the same recipient vary, thus probably resulting in the absence of auto-correlations for any lag. Therefore, a new dataset was created in which only the entries were included of CE'ers who sourced and acquired knowledge from more

[1]The perceived psychological safety was only asked in the survey for the non-CE participants. Therefore, including it in the regression analysis would halve the sample size n. Furthermore, the effect of psychological safety on knowledge flow efficiency and effectiveness seemed to be mediated by the inter-department tie strength. Therefore, the effect of the psychological safety on knowledge flow efficiency and effectiveness is investigated in the post hoc analysis

than one department. Furthermore, these entries were ordered such that the entries reported by the same recipient, but related to the receipt of knowledge from different departments, were listed below one another. Furthermore, they were ordered such that the first entry of a recipient always related to the receipt of knowledge from second-line engineers, the second entry to the receipt of knowledge related to DE'ers, and the third entry to the receipt of knowledge from GSC'ers. Thus, when dependence is present between the error terms, the error terms of a linear regression model based on this dataset would have significant auto-correlations for lag one or two (Hair et al., 2014).

A statistical test that can be used for the detection of autocorrelations is the Durbin-Watson test (Durbin and Watson, 1971). The Durbin-Watson evaluates the significance of the autocorrelations of the errors of a regression model for a lag of 1. However, as CE'ers frequently reported that they sourced and acquired knowledge from more than two departments, higher-order autoregressive models are needed. Therefore, the Breusch-Godfrey test was used, to evaluate whether there were any significant autocorrelations present, as the Breusch-Godfrey test can cope with higher-order autocorrelations (Godfrey, 1978). The Breusch-Godfrey test was evaluated for a maximum lag of 2 as the individuals from CE could only report on the acquisition of knowledge from a maximum of three different sources.

The results of the Breusch-Godfry test, as shown in Table H.1, indicate that for three models the assumption of independent error terms was violated. Thus, besides the fact that the different entries are conceptually not independent, there is also evidence to believe the error terms are correlated. Therefore, normal multiple linear regression is not applicable for this analysis. Fortunately, hierarchical linear models do not require this assumption and therefore they can handle such nested data of repeated measures (Garson, 2013). Moreover, controlling for a higher-level variable, such as the recipient's department, in a regression analysis also requires a multi-level model (Garson, 2013). Therefore, hierarchical linear models were used to cope with the nested data and different level variables. Thus, a linear mixed model was used in which the recipient's ID and the recipient departments were modeled as random effects, while fixed effects were used to model the antecedents of knowledge flow efficiency and effectiveness as well as the other control variables on an individual level. Employing such a linear mixed model provides another advantage of general linear models as the use of maximum likelihood in linear mixed models can cope better with unbalanced data than general linear models (Garson, 2013).

Although hierarchical linear models were used, the remaining assumptions of linear regression should still hold. The second assumption, the linearity assumption, describes that the independent and dependent variables should be linear related. To evaluate this assumption of linearity, the dependent variables were plotted against the independent variables to visually inspect if there was any indication of a non-linear relationship between the two. Furthermore, the residual plots of the models were analyzed to visually evaluate whether any structure was present that could point to a violation of the assumption of linearity. From both the plots of the dependent versus the independent variables, as well as the residuals plot, there were no signs that non-linearity was present for any model.

The third assumption that should be met for multiple linear regression is the assumption of homoskedasticity, or in other words, the constant variance of the error term. If homoskedasticity is violated, the calculations of the standard errors, confidence intervals, and p-values are incorrect. The presence of homoskedasticity can be evaluated by inspection of the plots of the residuals. These plots should not show any structure, the values should be centered around a mean of zero and the variance must be constant (Hair et al., 2014). From the residual plots shown in Appendix H, there seems to be no structure or other indications which could point to a violation of the assumption of homoscedasticity. Nevertheless, two types of structure are present in some of the residual plots, which are worth discussing. Firstly, in Figure H.1, Figure H.2 and Figure H.5, there seems to be some slope in the residual plot, which could point to a violation of the fourth assumption, the assumption of normality, which is discussed in the consecutive paragraph. Secondly, in residual plots of the final models for knowledge flow effectiveness, especially in Figure H.7, Figure H.8 and Figure H.10, the residuals form to some degree parallel lines. The occurrences of these parallel patterns in the residual plots are caused by the fact that the knowledge flow effectiveness is measured on a Likert-scale (Nelder, 1990; Searle, 1988). As a result of these parallel structures, it can be difficult to interpret the residual plots. Nevertheless, as the knowledge flow effectiveness is the average of four Likert-scale items, the degree of these parallel structures is relatively limited and thus the residual plots still provided a good assessment of the presence of homoscedasticity.

The fourth assumption is the assumption of normally distributed error terms. As indicated in the previous paragraph, in the residual plots there seemed to be some slope present, which could point to a violation of normality. However, fortunately, as the sample size was well above the rule of thumb for the central limit theorem to hold, it can be assumed that the residuals follow a normal distribution. Besides these four assumptions, it is important to evaluate other conditions, namely the problem of multicollinearity, possible outliers, and sample sizes. Firstly, when multicollinearity is present, the reliability of a model can be reduced (Sheskin, 2011). The presence of multicollinearity was evaluated by calculating the variance inflation factor (VIF) scores, which are reported in Appendix H in Table H.2. All VIF scores were below 5, a strong indication that multicollinearity is not present (Sheskin, 2011). Secondly, the presence of outliers was checked by plotting the independent and dependent variables. Although there were some extreme points identified, upon further inspection these points were caused by high values reported by individuals for the time they sought and acquired knowledge, which were still realistic. Therefore, no points were classified as outliers in the data. Lastly, as with most statistical tests, the statistical power is affected by the sample size and for linear mixed models also by the similarity of group sizes, which can affect the probability of a type I error (Garson, 2013). Unfortunately, the group sizes of the different recipient departments varied widely, which could inflate the probability of type I errors. Therefore, the results of this exploratory research can be considered to be relatively conservative.

Stepwise regression analysis was used to identify which of the regressors were antecedents of knowledge flow efficiency and knowledge flow effectiveness. Unfortunately, both forward and backward stepwise regression have disadvantages, such as that only a limited set out of all possible combinations of regressors is analyzed and that a regressor may be excluded, while when it is added jointly with another regressor it could prove significant (Ryan, 2009). For the exploratory nature of this research backward regression was used to identify all significant antecedents of knowledge flow efficiency and effectiveness. Moreover, backward regression was preferred over forward regression as forward regression can yield final models with insignificant variables due to suppressor effects, the phenomena in which a regressor becomes insignificant after a new regressor was added.

Starting with the full model in which all the regressors were included, in each step the least significant regressor was removed until a model was obtained with only significant regressors, apart from the control variables. The significance of the regressors was used as a criterion for model selection instead of model fit parameters such as the Akaike or Bayesian-Schwartz information criteria and log-likelihood, as the objective of this study was to identify significant antecedents of knowledge flow efficiency and effectiveness instead of identifying the best fitting model to explain knowledge flow efficiency and effectiveness. Although methods for calculating significance levels for linear mixed models are disputed as the method to determine the degrees of freedom in the denominator is unclear, the Kenward-Roger approximation produces acceptable p-values (Luke, 2017). Therefore, the Kenward-Roger approximation was used to determine the significance levels of the fixed effects in the linear mixed models.

6.3.4 Antecedents of knowledge flow efficiency

First, a full model was created in which all regressors were included. These initial models are shown in Appendix H in Table H.3 and Table H.4 for knowledge flow efficiency and effectiveness respectively. Thereafter backward stepwise regression was applied, resulting in the final models where only the significant regressors remained. The results of these final models are shown in Table 6.17 and Table 6.18 for knowledge flow efficiency and effectiveness respectively. For the fixed effects, the β-coefficients are reported as well as their corresponding p-values. For the random effects, the intraclass correlations were calculated to determine how much of the variance was explained by the grouping levels. Furthermore, confidence intervals were determined for the ICCS following the approach of (McGraw and Wong, 1996). Only the ICCs of the effect of the recipient department were determined, as the variance explained by individual-level was not of interest. Lastly, the marginal and conditional R^2 of the models were determined using the approach of Nakagawa et al. (2013).

Firstly, the results in Table 6.17 show that the reduced final models provide a (marginally) worse fit to the data when comparing the AICs, BICs and R^2 to the full models with all regressors included as reported in Appendix H in Table H.3. However, this is not surprising as the objective of the backward stepwise regression was not to optimize model fit but to identify significant antecedents of knowledge flow efficiency. Moreover, it can be observed that the marginal R^2 of the final models are relatively low (6.6%-15.0%), indicating that the fixed effects only explain a small proportion of the variance observed in knowledge flow efficiency. In contrast, the conditional R^2 of the final models were significantly higher, indicating that the fixed and random effects combined explained a higher proportion of the variance observed in knowledge flow efficiency. However, of the random effects, the most variance is explained by the individual level, as the random effects of the recipient departments showed only for three out of five channels weak to moderately significant ICCs. For global knowledge repositories (ICC = 0.141), written communication (ICC = 0.330), and virtual verbal communication (ICC = 0.191), the 95% confidence intervals did not include zero, while the ICCs for local knowledge repositories and physical verbal communication were not significantly different from zero. Thus, the results indicate that for global knowledge repositories, written communication, and virtual verbal communication, the knowledge flow efficiency varies marginally according to the recipient's department.

Secondly, the personal characteristics of the recipient also seem to be significantly related to knowledge flow efficiency. A clear effect can be observed from the educational level obtained by the recipient. The higher the level of education followed by the recipient, the higher the knowledge flow efficiency through global knowledge repositories ($\beta = 0.190, p\text{-}value = 0.012$), written communication ($\beta = 0.130, p\text{-}value = 0.006$) and virtual verbal communication ($\beta = 0.129, p\text{-}value = 0.017$). Moreover, the experience of the recipient at ASML had only a relatively small positive effect on the knowledge flow efficiency via written communication ($\beta = 0.021, p\text{-}value = 0.007$) and physical verbal communication ($\beta = 0.066, p\text{-}value = 0.033$), contrary to the findings from study I. Furthermore, the experience in the current function of the recipient was not significantly related to knowledge flow efficiency. Furthermore, the data suggest that the older the recipient, the more efficient the processes of sourcing and acquiring knowledge via local knowledge repositories, although, again the effect size is relatively small ($\beta = 0.019, p\text{-}value = 0.046$). Lastly, the corporate language proficiency of the recipient had a positive effect on the knowledge flow efficiency via global knowledge repositories ($\beta = 0.113; p\text{-}value = 0.002$), but there was no effect

Table 6.17: Regression results for the antecedents of knowledge flow efficiency

	Dependent variable:				
	Efficiency LKR	Efficiency GKR	Efficiency WC	Efficiency VC	Efficiency PC
	(1)	(2)	(3)	(4)	(5)
Constant	0.560	0.005	0.176	0.349	0.879
	(0.140)	(0.992)	(0.526)	(0.242)	(0.803)
Age recipient	0.019*	−0.003	−0.003	−0.002	0.004
	(0.046)	(0.676)	(0.533)	(0.729)	(0.019)
Experience ASML	−0.005	0.013	0.021**	0.015	0.066*
	(0.750)	(0.319)	(0.007)	(0.105)	(0.033)
Experience function	−0.016	0.009	−0.007	0.001	−0.018
	(0.385)	(0.570)	(0.479)	(0.927)	(0.033)
Educational level	0.088	0.190*	0.130**	0.129*	0.244
	(0.294)	(0.012)	(0.006)	(0.017)	(0.169)
Inter-departmental tie strength			0.083***	0.071**	
			(<0.001)	(0.010)	
Corporate language proficiency		0.113**			
		(0.002)			
Degree of organizational knowledge					-0.201.*
					0.043
Intra-class correlation ICC (95% CI [LL:UL])					
Recipient department	0.00 [-0.019:0.189]	0.141 [0.015:0.628]	0.330 [0.085:0.834]	0.191 [0.038:0.728]	0.069 [-0.014:0.522]
Observations	162	173	183	180	99
Marginal R^2	0.066	0.088	0.108	0.082	0.150
Conditional R^2	0.459	0.518	0.580	0.454	0.462
Log Likelihood	−166.843	−157.498	−81.150	−108.543	−146.848
Akaike Inf. Crit.	349.687	332.997	180.299	235.085	311.696
Bayesian Inf. Crit.	374.387	361.376	209.184	263.822	335.052

Note: *p<0.05; **p<0.01; ***p<0.001

of the proficiency in English on the knowledge flow efficiency via the other channels.

Thirdly, the results suggest that the type of knowledge only influenced the knowledge flow efficiency via physical verbal communication ($\beta = -0.201; p\text{-}value = 0.043$). More specifically, the higher the degree of organizational knowledge, or the lower the degree of technical knowledge, exchanged via that channel, the lower the knowledge flow efficiency. Thus, the results suggest that physical verbal communication is less efficient to exchange organizational knowledge and more suitable for the efficient exchange of technical knowledge. Furthermore, surprisingly, the complexity of knowledge did not significantly affect the knowledge flow efficiency for any type of channel, as can be observed in Appendix H in Table H.3, contrary to the expectations from study I.

Fourthly, the inter-departmental tie strength affected the knowledge flow efficiency via electronically mediated communication, namely via written communication ($\beta = 0.083; p\text{-}value < 0.001$) and virtual verbal communication ($\beta = 0.071; p\text{-}value = 0.010$) but not for physical verbal communication nor the use of knowledge repositories. Moreover, the estimated regression coefficients for inter-departmental tie strength are relatively small and thus only explain a limited amount of variance observed in the efficiency of knowledge flows. Nevertheless, the results suggest that a close working relationship is an antecedent of knowledge flow efficiency for electronically mediated communication. Contrary to the inter-departmental tie strength, the physical proximity of the recipient to the source did not impact the knowledge flow efficiency for all channels, as can be observed in Appendix H in Table H.3.

6.3.5 Antecedents of knowledge flow effectiveness

The same procedure was used to analyze the influence of the antecedents identified in study I on the effectiveness of knowledge flows. The results of the regression analysis on the effectiveness of knowledge flows are shown in Table 6.18.

Firstly, the results show that, although it was not an objective of the stepwise regression, the final reduced models provide a better fit to the data than the initial models in which all the regressors were included. For each model, the reported AIC and BIC are lower for the reduced models than for the initial models. Moreover, the variance in knowledge flow effectiveness explained by the fixed effects in the final models ranged for the different channels between a minimum of 12.6% for physical verbal communication to a maximum of 26.8% for local knowledge repositories. In addition, the conditional R^2, explaining the variance of both the fixed and random effects, ranged between a minimum of 0.292 for virtual verbal communication and a maximum of 0.692 for written communication. Nevertheless, the random effects reporting the variance in knowledge flow effectiveness explained by the recipient's department did not significantly differ from zero as

Table 6.18: Regression results of the antecedents of knowledge flow effectiveness

	Dependent variable:				
	Effectiveness LKR	Effectiveness GKR	Effectiveness WC	Effectiveness VC	Effectiveness PC
	(1)	(2)	(3)	(4)	(5)
Constant	2.921^{***}	2.263^{***}	2.781^{***}	2.377^{***}	2.242^{**}
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(0.004)
Age recipient	0.017	0.002	0.008	0.010	0.009
	(0.096)	(0.887)	(0.432)	(0.317)	(0.624)
Experience ASML	−0.015	0.013	0.003	−0.006	0.003
	(0.366)	(0.446)	(0.863)	(0.702)	(0.956)
Experience function	-0.046^{*}	−0.015	−0.022	−0.022	−0.038
	(0.026)	(0.481)	(0.269)	(0.272)	(0.183)
Educational level	0.024	0.165	0.099	0.081	0.015
	(0.811)	(0.106)	(0.330)	(0.392)	(0.847)
Inter-departmental tie strength	0.208^{***}	0.236^{***}	0.178^{***}	0.249^{***}	0.220^{***}
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Corporate language proficiency				0.128^{**}	
				(0.008)	
Degree of organizational knowledge	-0.200^{**}				
	(0.003)				
Complexity of knowledge	0.219^{***}	0.182^{***}	0.165^{***}		0.173^{**}
	(<0.001)	(<0.001)	(<0.001)		(0.002)
Intra-class correlation ICC (95% CI [LL:UL])					
Recipient department	0.056 [-0.014:0.220]	0.083 [-0.008:0.345]	-0.00 [-0.019: 0.00]	0.00 [-0.015:0.164]	0.00 [-0.017:0.152]
Observations	186	192	192	197	179
Marginal R^2	0.268	0.185	0.168	0.163	0.126
Conditional R^2	0.364	0.408	0.629	0.292	0.485
Log Likelihood	−237.829	−248.329	−221.760	−247.841	−268.820
Akaike Inf. Crit.	497.659	516.659	463.520	515.683	559.639
Bayesian Inf. Crit.	533.142	549.233	496.095	548.515	594.700

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

indicated by the 95% confidence intervals of the ICCs. Therefore, the explained variance by the random effects is predominantly a result of controlling on the individual level for the nested data. Nevertheless, the models seem to provide an adequate fit to the data as the fixed effects account for a significant proportion of the variance observed in knowledge flow effectiveness.

Secondly, the final models show that the personal characteristics of the recipient are of little influence on the knowledge flow effectiveness. The education of the recipient and the recipient's experience at ASML did not significantly affect the knowledge flow effectiveness for all channels, while the experience of the recipients in their current function only affected the knowledge flow effectiveness via local knowledge repositories. The higher the experience of the recipient in its current function, the less effective it was for the recipient to source and acquire knowledge via local knowledge repositories ($\beta = -0.046, p\text{-}value = 0.026$), although the effect was relatively small. Furthermore, the corporate language proficiency of the recipient affected the knowledge flow effectiveness via virtual verbal communication. The higher the proficiency in English of the recipient, the more effective it was for the recipient to source and acquire knowledge via virtual verbal communication ($\beta = 0.128, p\text{-}value = 0.008$). Thus, although there are some small influences of personal characteristics on the knowledge flow effectiveness via certain channels, the influence of personal characteristics on knowledge flow effectiveness is limited based on the antecedents included in this study.

Thirdly, the results suggest that characteristics of the knowledge exchanged influence the knowledge flow effectiveness. For example, the perceived complexity of knowledge by the recipient was positively associated with the knowledge flow effectiveness via local knowledge repositories ($\beta = 0.219, p\text{-}value = (< 0.001)$, global knowledge repositories ($\beta = 0.182, p\text{-}value < 0.001$), written communication ($\beta = 0.165, p\text{-}value < 0.001$) and via physical verbal communication ($\beta = 0.173, p\text{-}value = 0.002$). Thus, except for virtual verbal communication, sourcing, and acquiring, knowledge was more effective when the obtained knowledge was complex rather than simple. Besides the complexity of knowledge, the type of knowledge affected the knowledge flow effectiveness via local knowledge repositories. The higher the degree of organizational knowledge or the lower the degree of technical knowledge exchanged via local knowledge repositories, the less effective the flow of knowledge via local knowledge repositories ($\beta = -0.200, p\text{-}value = 0.003$).

Lastly, the inter-departmental tie strength between the source department and the recipient department, as perceived by the recipient, affected the knowledge flow effectiveness of all channels. The higher the inter-departmental tie strength between the source and recipient unit, the higher the knowledge flow effectiveness via local knowledge repositories ($\beta = 0.208, p\text{-}value < 0.001$), global knowledge repositories ($\beta = 0.236, p\text{-}value < 0.001$), written communication ($\beta = 0.178, p\text{-}value < 0.001$), virtual verbal communication ($\beta = 0.249, p\text{-}value < 0.001$) and physical verbal communication ($\beta = 0.22, p\text{-}value < 0.001$). Thus, a close working relationship and frequent communication between the source and recipient unit positively impacts the knowledge flow effectiveness via personal channels (written communication, virtual and physical verbal communication) as well as impersonal channels such as local and global knowledge repositories. Besides the inter-departmental tie strength, the effect of physical proximity on knowledge flow effectiveness was also analyzed. However, contrary to expectations from study I the regression analysis showed no significant effect of physical proximity on the knowledge flow effectiveness for all channels as shown in Appendix H in Table H.4.

Thus, the results indicate that, besides local effects for individual channels, there were two main effects of variables on the knowledge flow effectiveness for multiple channels. Firstly, the perceived complexity of knowledge sourced and acquired via knowledge repositories, written communication, and physical verbal communication positively impacted the knowledge flow effectiveness of those channels. Secondly, the inter-departmental tie strength between the source and recipient unit positively impacted the knowledge flow effectiveness for all channels. Together, these variables explained a significant proportion of the variance observed in the knowledge flow effectiveness of all five channels used to exchange knowledge.

6.4 Post-hoc analysis

Up until now the effect of psychological safety on knowledge flow efficiency and effectiveness was not yet investigated, because it would have reduced the sample size by half as psychological safety was only measured for non-CE participants. This decision was made to shorten the survey for CE participants as their survey was relatively long because they had to answer all questions about the exchange of knowledge with three departments. Furthermore, from study I, the effect of psychological safety on the exchange of knowledge seemed to be especially relevant for second-line engineers, thus non-CE participants. From the correlation matrix in Table 6.3, it can be observed that there are moderate correlations ($0.20 < \rho =< 0.44$) between psychological safety and knowledge flow effectiveness for all channels. For knowledge flow efficiency, there were no moderate or strong correlations between psychological safety and knowledge flow efficiency for any channel. Moreover, from Table 6.3 psychological safety seemed also to interact with inter-departmental tie strength ($\rho = 0.32$). Therefore it was determined to analyze the effects of psychological safety on knowledge flow effectiveness and any possible interaction effects with inter-departmental tie strength in a post hoc analysis. As with all posthoc analyses, caution must be taken with interpreting any results, as the analysis was not a direct objective of the study. For instance, important variables could be omitted which are highly correlated with the independent or dependent variables, which might explain significant proportions of the variance observed in the dependent variable.

6.4.1 Effect of psychological safety on knowledge flow effectiveness

In this section, the effect of psychological safety on knowledge flow effectiveness is analyzed for all channels, and the interaction between psychological safety and inter-departmental tie strength. Prior research has already shown that psychological safety has a positive effect on knowledge sharing (Siemsen et al., 2009). Based on their results, Siemsen et al. (2009) reframed the conclusions of Hansen (1999) to conclude that instead of the tie strength, reflected as the frequency of communication, it is the psychological safety that is caused by such ties that influences the exchange of knowledge. To further analyze the interactions between tie strength, reflected as the frequency of communication, and psychological safety, Lee et al. (2011) proposed two competing hypotheses. The first hypothesis was that information sharing quality, which they defined as communication via formal procedures, processes, routines, and systems increased psychological safety. In contrast, the competing hypothesis stated that psychological safety increased information sharing quality. As support for both of the hypotheses was found, Lee et al. (2011) concluded that the psychological safety and information sharing quality are mutually reinforcing.

Research by Schulte et al. (2012) provided a more in-depth insight into the mutually reinforcing effects between psychological safety and inter-departmental tie strength as they distinguished between types of ties and perceptions of the source and the recipient. Consistent with the conclusion of Lee et al. (2011), they found that individuals high in psychological safety more frequently send advice ties, "a means for individuals to leverage their teammates' experiences and expertise, enhancing individual and team performance" (Schulte et al., 2012, p.566). In addition, individuals who are asked frequently for advice increase their perceptions of psychological safety, leading to a mutually reinforcing effect in dyads. However, they also anticipated finding the effect of retrospective sense-making, which entailed that individuals who frequently send out advice ties developed more positive perceptions of psychological safety than their colleagues who send out fewer advice ties. Nevertheless, as they did not find such an effect, their data suggest that it is rather the presence of psychological safety that fosters inter-departmental tie strength and the exchange of knowledge than vice versa.

In this research, the focus lies on the influence of the psychological safety of the recipient, thus the advice seeker, on the effectiveness of knowledge flows. Therefore, it is expected that, according to the results of Schulte et al. (2012), high psychological safety of the knowledge seeker leads to sending out more advice ties and thus a more effective flow of knowledge. Thus, it was hypothesized that psychological safety positively impacts knowledge flow effectiveness, while this effect is mediated by inter-departmental tie strength.

To analyze these effects, normal multiple regression using ordinary least squares was used for two reasons. As the psychological safety was only reported by non-CE participants, there are no pseudo-replication effects caused by the fact that the entries of how a CE'er exchanged knowledge with second-line engineers, DE, or GSC were taken as separate entries. Therefore, the data is not nested and there is no need to control on a participant level. Moreover, in the hierarchical linear models presented in the previous section, the recipient's department did not significantly explain any of the variance observed in the knowledge flow effectiveness via any channel. Therefore, a normal multiple linear regression model was used in the posthoc analysis.

Again, the assumptions of independent error terms, linearity, normality, and homoscedasticity were evaluated. Only the assumption of homoscedasticity seemed to be violated, following a visual inspection of the residual plots. To evaluate if there was a significant deviation of homoscedasticity, Breusch-Pagan tests were performed. The null hypothesis of this test is that homoskedasticity is present, while when heteroskedasticity is present the null hypothesis is rejected (Breusch and Pagan, 1979). The Breusch-pagan statistics can be observed in Appendix H in Table H.5 and Table H.7 for both the models related to the effect of psychological safety on inter-departmental tie strength, as well as the effect of the former to on knowledge flow effectiveness. The Breusch-Pagan tests indicated that for some models the assumption of homoskedasticity was violated. As heteroskedasticity can lead to invalid standard errors and as a result incorrect p-values, the standard errors were corrected by using the heteroscedasticity corrected covariance matrices using the "HC3" method as the sample size was below 250 (Long and Ervin, 2000).

To test this hypothesis, first the relationship between the independent variable and the mediator was analyzed, thus whether the psychological safety as perceived by the recipient affected the inter-departmental tie strength. The results in Table 6.19 clearly show indeed a strong positive effect of psychological safety on inter-departmental tie strength ($0.40 < \beta < 0.46$). The analysis was performed for all channels to be able to control for the type and complexity of knowledge exchanged. Thus, the results suggest indeed that the higher the perceived psychological safety, the higher the inter-departmental tie strength, as perceived by the recipient. Secondly, the effects of the mediator on the dependent variable were analyzed. Table 6.20 shows that inter-departmental tie strength has a positive effect on knowledge flow effectiveness for all channels ($0.22 < \beta < 0.42$), except for local knowledge repositories. Furthermore, it can be observed that psychological safety has no significant effect on knowledge flow effectiveness for global knowledge repositories, and virtual and physical verbal communication when inter-departmental tie strength is added to the model. The absence of these effects contradicts the alternative interpretation that psychological safety mediates the effect between inter-departmental tie strength and knowledge

Table 6.19: Regression analysis of the effect of psychological safety on inter-unit tie strength

	Dependent variable:				
	Inter-department tie strength				
	(LKR)	(GKR)	(WC)	(VC)	(PC)
Constant	2.915** (0.004)	2.496* (0.019)	2.684* (0.011)	3.221** (0.002)	3.621** (0.004)
Recipient DE	0.623* (0.032)	0.582* (0.045)	0.604* (0.04)	0.598* (0.04)	0.628* (0.046)
Recipient GSC	0.138 (0.64)	0.097 (0.74)	0.061 (0.83)	0.029 (0.92)	0.153 (0.62)
Age recipient	0.001 (0.96)	0.006 (0.73)	0.005 (0.78)	0.012 (0.50)	0.008 (0.68)
Experience ASML	−0.011 (0.63)	−0.015 (0.53)	−0.018 (0.47)	−0.024 (0.33)	−0.021 (0.43)
Experience function	0.020 (0.45)	0.014 (0.61)	0.018 (0.53)	0.007 (0.79)	0.010 (0.74)
Educational level	0.006 (0.97)	0.050 (0.77)	0.103 (0.55)	−0.007 (0.97)	−0.013 (0.94)
Physical proximity	0.016 (0.78)	0.016 (0.78)	0.010 (0.86)	0.003 (0.96)	−0.013 (0.84)
Corporate language proficiency	−0.097 (0.19)	−0.083 (0.27)	−0.064 (0.42)	−0.084 (0.26)	−0.083 (0.28)
Complexity of knowledge	0.187* (0.023)	0.114 (0.14)	0.157 (0.05)	0.021 (0.78)	0.012 (0.89)
Degree of organizational knowledge	−0.022 (0.84)	0.087 (0.41)	-0.096 (0.46)	-0.063 (0.58)	-0.108 (0.41)
Psychological safety	0.405*** (<0.001)	0.420*** (<0.001)	0.398*** (<0.001)	0.461*** (<0.001)	0.448*** (<0.001)
Observations	90	91	90	89	86
R^2	0.267	0.234	0.247	0.239	0.218
Adjusted R^2	0.164	0.128	0.141	0.130	0.101

Note: *p<0.05; **p<0.01; ***p<0.001

flow effectiveness, as there would be no relationship between the mediator and the dependent variable. Therefore, it supports the viewpoint that inter-departmental tie strength mediates the relationship between psychological safety and knowledge flow effectiveness. Lastly, the total mediation relationship was tested by estimating the indirect and direct effects of psychological safety on knowledge flow effectiveness by performing a quasi-Bayesian Monte Carlo approximation, a parametric method for analyzing such effects (Imai et al., 2010). Furthermore, the quasi-Bayesian Monte Carlo provides similar performance to other methods, while it is less restricted in its use and requires less computational power (Preacher and Selig, 2012).

The results in Table 6.21 show indeed that for all channels, except local knowledge repositories, there is a significant mediation effect. Thus, the results suggest indeed that inter-departmental tie strength indeed mediates the relationship between psychological safety and knowledge flow effectiveness. Furthermore, Table 6.21 shows that for global knowledge repositories, virtual verbal communication and physical verbal communication there is no direct effect of psychological safety. Thus, for those channels inter-departmental tie strength fully mediates the relationship between psychological safety and knowledge flow effectiveness. Lastly, the results indicate that the mediated effect is somewhat smaller for the exchange of knowledge via written communication ($E = 0.09$, $CI_{95\%} = [0.001 : 0.21], p\text{-}value = 0.046$), than for global knowledge

Table 6.20: Regression results of the effects of psychological safety and inter-departmental tie strength on knowledge flow effectiveness

	Dependent variable:									
	Effectiveness LKR		Effectiveness GKR		Effectiveness WC		Effectiveness VC		Effectiveness PC	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Constant	3.317*** (<0.001)	3.121** (0.001)	3.207* (0.019)	2.706* (0.028)	1.197 (0.19)	0.786 (0.37)	1.457 (0.14)	0.603 (0.52)	1.292 (0.35)	0.170 (0.90)
Recipient DE	−0.383 (0.16)	−0.543* (0.048)	−0.629 (0.13)	−0.868* (0.030)	−0.127 (0.62)	−0.307 (0.20)	−0.075 (0.79)	−0.348 (0.19)	−0.286 (0.43)	−0.600 (0.085)
Recipient GSC	−0.269 (0.35)	−0.353 (0.20)	0.015 (0.96)	−0.058 (0.82)	−0.190 (0.44)	−0.224 (0.33)	−0.211 (0.47)	−0.232 (0.37)	−0.369 (0.31)	−0.412 (0.22)
Age	−0.011 (0.54)	−0.014 (0.41)	−0.021 (0.24)	−0.026 (0.62)	0.009 (0.55)	0.004 (0.75)	0.018 (0.30)	0.010 (0.51)	0.022 (0.34)	0.014 (0.52)
Experience ASML	0.011 (0.65)	0.010 (0.65)	0.036 (0.12)	0.038 (0.069)	0.018 (0.39)	0.020 (0.31)	0.009 (0.72)	0.014 (0.51)	0.015 (0.62)	0.023 (0.43)
Experience function	−0.028 (0.28)	−0.031 (0.21)	0.005 (0.88)	0.001 (0.95)	−0.019 (0.42)	−0.023 (0.31)	−0.009 (0.74)	−0.013 (0.59)	−0.049 (0.15)	−0.053 (0.092)
Educational level	−0.079 (0.62)	−0.053 (0.73)	0.092 (0.60)	0.085 (0.61)	0.123 (0.41)	0.110 (0.43)	0.085 (0.61)	0.091 (0.54)	0.102 (0.63)	0.101 (0.62)
Physical proximity	0.068 (0.20)	0.053 (0.30)	0.112* (0.045)	0.088 (0.068)	0.065 (0.18)	0.046 (0.30)	0.102 (0.071)	0.084 (0.10)	0.131 (0.079)	0.119 (0.090)
Corporate language proficiency	0.035 (0.63)	0.050 (0.47)	0.019 (0.85)	0.041 (0.63)	0.025 (0.72)	0.027 (0.67)	0.054 (0.47)	0.081 (0.23)	0.067 (0.45)	0.096 (0.25)
Complexity of knowledge	0.240** (0.002)	0.152* (0.050)	0.174 (0.11)	0.094 (0.32)	0.168* (0.016)	0.107 (0.10)	0.163* (0.029)	0.114 (0.10)	0.230* (0.026)	0.184 (0.063)
Degree of organizational knowledge	−0.271* (0.012)	−0.305** (0.004)	-0.107 (0.50)	-0.176 (0.28)	0.117 (0.30)	0.126 (0.23)	0.114 (0.31)	0.093 (0.36)	0.084 (0.57)	0.073 (0.60)
Psychological safety	0.347** (0.002)	0.336** (0.004)	0.235 (0.13)	0.146 (0.32)	0.324** (0.002)	0.286** (0.005)	0.174 (0.12)	0.065 (0.56)	0.100 (0.48)	-0.039 (0.79)
Inter-department tie strength		0.143 (0.17)		0.325** (0.007)		0.217* (0.019)		0.351*** (<0.001)		0.416** (0.001)
Observations	91	90	92	91	90	90	90	89	87	86
R^2	0.376	0.412	0.244	0.350	0.295	0.370	0.208	0.306	0.186	0.280
Adjusted R^2	0.289	0.321	0.140	0.250	0.196	0.272	0.097	0.196	0.067	0.162
AIC	252.60	242.70	263.07	242.50	234.71	219.95	256.88	235.61	281.93	267.44

Note: *p<0.05; **p<0.01; ***p<0.001

Table 6.21: Analysis of mediation effect of inter-unit tie strength between psychological safety and knowledge flow effectiveness

Statistic	Estimate	95% CI lower	95% CI upper	P-value
Effectiveness LKR				
Average corrected mediation effect	0.0577	-0.0699	0.21	0.375
Average direct effect	0.3380	-0.0489	0.73	0.081
Total effect	0.3957	0.0697	0.72	0.019*
Proportion mediated	0.1301	-0.1957	1.16	0.393
Effectiveness GKR				
Average corrected mediation effect	0.1356	0.0249	0.29	0.0092**
Average direct effect	0.1451	-0.1466	0.44	0.3246
Total effect	0.2807	0.0120	0.54	0.0416*
Proportion mediated	0.4667	-0.007	2.71	0.0504
Effectiveness WC				
Average corrected mediation effect	0.08612	0.0012	0.21	0.0460*
Average direct effect	0.2861	0.0184	0.55	0.0354*
Total effect	0.3723	0.1217	0.61	0.0038**
Proportion mediated	0.2197	0.0005	0.85	0.0498*
Effectiveness VC				
Average corrected mediation effect	0.1631	0.0423	0.33	0.0038**
Average direct effect	0.0638	-0.2151	0.34	0.6512
Total effect	0.2268	-0.0394	0.49	0.0958
Proportion mediated	0.6593	-3.0989	4.66	0.0996
Effectiveness PC				
Average corrected mediation effect	0.1873	0.0409	0.39	0.0052**
Average direct effect	-0.0375	-0.4364	0.35	0.8540
Total effect	0.1498	-0.2172	0.50	0.4018
Proportion mediated	0.7026	-10.2348	11.34	0.4046

repositories ($E = 0.14$, $CI_{95\%} = [0.02 : 0.29], p\text{-}value = 0.01$), virtual verbal communication ($E = 0.16$, $CI_{95\%} = [0.04 : 0.33], p\text{-}value = 0.004$) and physical verbal communication ($E = 0.19$, $CI_{95\%} = [0.04 : 0.39], p\text{-}value = 0.005$), which is consistent with the partial mediation for written communication.

As expected, the positive effect of psychological safety of the recipient on knowledge flow effectiveness is mediated by inter-departmental tie strength. Thus, the data suggests that in order to frequently communicate and exchange knowledge, the recipient or advice seeker must feel psychologically safe to source and acquire knowledge. Although the results strongly indicate the presence of the hypothesized mediation, caution must be taken when interpreting these results of the post hoc analysis as it was not the primary objective of this study to analyze this relationship. Nevertheless, the results of the mediation analysis provide an interesting research direction in which further research can explore in more detail the interaction effects of psychological safety and inter-departmental tie strength on the effectiveness of knowledge flows.

6.5 Discussion study II

6.5.1 Knowledge flow efficiency

Although an organization's stock of knowledge and its combinative capabilities are key resources to create a competitive advantage (Kogut and Zander, 1992), research has paid little empirical attention to how such a stock of knowledge could be most efficiently and effectively exchanged within the organization. Therefore, this study analyzed how to efficiently and effectively enable the flow of knowledge such that the organization's knowledge stock can be exploited. The results yielded several interesting findings.

Firstly, the results showed strong evidence that the knowledge flow efficiency is dependent on the type of channel used. However, the results indicate that the richness of a channel does not always predict the efficiency of a channel as both lean (e.g., knowledge repositories), and rich (physical verbal communication) proved to be very efficient. Rather, the results are better explained by the theory of media synchronicity (MST) (Dennis et al., 2008), who distinguished two processes in the flow of knowledge, i) conveyance and ii) convergence. Here, conveyance is the process of transferring knowledge and convergence is the assimilation of knowledge and the creation of a shared understanding of the knowledge. Moreover, MST argues that the performance of communication is dependent on whether the goal is conveyance or convergence.

Coming back to the results of the current study, MST could explain the high efficiency of both physical verbal communication and knowledge repositories. For the higher performance of the process of convergence, a channel should enable high synchronicity Dennis et al. (2008), which is enabled by physical verbal communication. On the contrary, for the higher performance of the process of conveyance, channels should be lower in synchronicity (Dennis et al., 2008), such as provided by knowledge repositories. Therefore, it seems that channels which are especially low or high in synchronicity are very efficient. Unfortunately, MST presents a paradox between these two processes, as low synchronicity is required for the conveyance of knowledge, while high synchronicity is needed for convergence (Robert and Dennis, 2005). Thus, although the results indicated that in general physical verbal communication is more efficient than the use of knowledge repositories, the difference in efficiency between the two probability depends on the process for which they are used.

Secondly, the MST may also help explain the difference in efficiencies between the channels which allow feedback and interaction between the source and recipient, which may be especially important for the process of convergence. The results of the current study showed that physical verbal communication was found to be more efficient than virtual verbal communication and written communication, as well as the fact that virtual verbal communication was found to be more efficient than written communication. Although closely matched by Dennis et al. (2008), physical verbal communication has a higher ability to support synchronicity than virtual verbal communication, as physical verbal communication especially allows the conveyance of cues such as body language, facial expressions, and intonation (Daft and Wiginton, 1979). Moreover, both physical and virtual verbal communication allow higher synchronicity than written communication (Dennis et al., 2008). Therefore, differences found in efficiency for these types of channels support the notion of MST that in situations where feedback and interaction are required for the convergence of knowledge, channels that support higher synchronicity, provide a higher level of communication performance. Therefore, the results of study II provide initial empirical evidence for the theory of media synchronicity, especially for the process of convergence. Besides, the difference in efficiency between physical verbal communication and virtual communication may also be explained by the fact that virtual verbal communication has been found to lead to meeting fatigue (Waizenegger et al., 2020) as well as being of lower quality (Shaun et al., 2022).

Thirdly, the results indicate that the difference in knowledge flow efficiency between local versus global knowledge repositories was ambiguous. For the flow of knowledge from CE to second-line engineers, the use of local knowledge repositories was more efficient, while vice versa, the use of global knowledge repositories was found to be more efficient. These differences could be explained by the knowledge needs of second-line engineers and competence engineers. For example, the knowledge needs of second-line engineers may vary greatly depending per site as a result of the type of machines and machine configurations. On the contrary, competence engineers require relatively the same information from all these different sites of second-line engineers, such as the problems experienced, the symptoms of the problems, probable causes of problems, and the actions already taken to contain such problems. Therefore, analyzing whether the differences in efficiency between these types of knowledge repositories could be explained by the variance in knowledge needs of the people within the recipient unit, could prove a fruitful avenue for future research.

6.5.2 Antecedents of knowledge flow efficiency

Besides the type of channel, this study has also identified multiple antecedents of flow efficiency. The results of the current study indicated that characteristics of the recipient, characteristics of the relationship between the source and the recipient, and the type of knowledge influenced the knowledge flow efficiency to a different extent.

Firstly, although included as control variables, the age of a recipient had a marginally positive effect on knowledge flow efficiency via local knowledge repositories, while the educational level of a recipient positively impacted the knowledge flow efficiency for global knowledge repositories, written communication, and virtual verbal communication. The latter result should not be not surprising as especially higher-level education such as a Master's degree or PhD place a great emphasis on skills to acquire and assimilate knowledge, especially through reading. Furthermore, while Gray and Meister (2004) showed that tenure in a job decreases the amount of knowledge sourcing, this study found no effect of job tenure on knowledge flow efficiency for any channel. Combined, these results could indicate that although individuals with a higher job tenure spend less time sourcing knowledge, it is not because they are better at it and do this more efficiently. Instead, individuals with a higher job tenure probably have a lesser need to source knowledge as their stock of knowledge accumulated over the years can fulfill their knowledge needs better than compared to their less experienced colleagues.

Furthermore, this study also found small positive effects of the recipient's organizational tenure on the knowledge flow efficiency via written communication and physical verbal communication. This image is congruent with study I, which highlighted the importance of a large network for one's knowledge position within ASML. A higher organizational tenure of a recipient could provide a larger network and therefore recipients know faster who to go to. Hence, a high organizational tenure, enabling the development of a large network, could explain these positive effects which were specifically found for emails, chat communication, and face-to-face conversations. Lastly, contrary to expectations, the corporate language proficiency of the recipient did not affect the efficiency of knowledge flows, except for global knowledge repositories. As Peltokorpi (2015) did find a significant effect of corporate language proficiency on the amount of knowledge shared, it could well be that the effect of corporate language proficiency has more of an impact on the supply side, thus the ability to share and explain knowledge, than the demand side, possibly an interesting avenue for further research.

Secondly, the knowledge flow efficiency of channels was influenced by characteristics of the relationship between the source and recipient. For instance, this study showed that for written communication and virtual verbal communication, the inter-departmental tie strength had a positive influence on the knowledge flow efficiency. This finding provides further support to the conclusions of Hansen (1999) that strong inter-departmental ties ease the flow of knowledge. The fact that such an effect was only found for email, chat, and virtual meetings can be explained by the findings of Carlson and Zmud (1999), who found that for personal electronically mediated communication, experience with a communication partner enhanced the richness perceptions of the channel. Thus, in other words, frequent communication and having a good working relationship with your communication partners especially increase the ability to create a shared understanding when using personal electronically mediated communication and thereby enhance knowledge flow efficiency. On the contrary, no effect was found for physical proximity on knowledge flow efficiency. Moreover, although participants indicated in study I that physical proximity eased the exchange of knowledge, it is likely that the affordance to make more use of physical verbal communication accounted for this finding as research by Ganesan et al. (2005) also showed that physical proximity increased such face to face meetings. Thus, as co-location increases the use of physical verbal communication, which is a very efficient channel, it does not affect the efficiency with which knowledge is exchanged when knowledge repositories, written communication, and virtual verbal communication are used.

Thirdly, the type of knowledge strongly affected the efficiency of knowledge flows for physical verbal communication. This channel was found to be less efficient for the exchange of organizational knowledge than technical knowledge. A possible reason for this could be that such organizational knowledge requires channels that allow for rehearsability and reprocessability, such that the knowledge is clear, can be consulted numerous times, and is available for a large audience. Unfortunately, physical verbal communication offers only limited rehearsability and no reprocessability (Dennis et al., 2008). Therefore, when sharing processes, procedures, organizational updates or ways of working it seems wise to refrain from using physical verbal communication. Furthermore, contrary to expectations, the complexity of knowledge did not affect knowledge flow efficiency. A possible reason for this could be that people upfront already anticipate and choose a suitable channel depending on the complexity of knowledge, which could be a direction for future research.

6.5.3 Knowledge flow effectiveness

Contrary to the efficiency of knowledge flows, the results indicated that knowledge flow effectiveness did not depend on the type of channel used. Therefore, the results of this study suggest that regardless of the type of channel, the knowledge exchanged via different channels has the same capacity to enhance the recipient's capacity to act effectively. However, given the differences in knowledge flow efficiency, some channels are more efficient in enabling the flow of knowledge than others.

This finding contradicts the findings of Haas and Hansen (2007) who found that knowledge exchanged via electronic documents and direct contact between the source and recipient differed in the extent to which they enabled a recipient to take effective action. However, these differences may be caused due to how the effectiveness was measured. In this study, knowledge flow effectiveness was determined by the average of multiple items, based on the receipt of useful knowledge developed by Levin and Cross (2004), which measured among others how the receipt of knowledge contributed to the quality of work, costs reductions, and time savings. On the contrary, Haas and Hansen (2007) measured the effects on time savings and work quality in separate measures and showed that while the use of electronic documents increased time savings, it did not have any effect on work quality, and vice versa for the receipt of personal advice. As a result of averaging those items in this study, it may have contributed to not finding significant differences in knowledge flow effectiveness based on the type of channel. In addition, as the survey in this study was quite long and the measure of knowledge flow effectiveness quite repetitive, survey fatigue may have attenuated the differences in knowledge flow effectiveness based on the type of channel used. To resolve these conflicting findings, future research could combine the channel classification of the current study with measuring the different aspects of knowledge flow effectiveness separately.

6.5.4 Antecedents of knowledge flow effectiveness

This study also contributed to the further understanding of the contingencies of knowledge flow effectiveness by analyzing antecedents of knowledge flow effectiveness. More specifically, this study showed that the characteristics of the relationship between the source and recipient and the characteristics of the knowledge exchanged predominantly influenced the knowledge flow effectiveness. Moreover, the results of this study suggest that characteristics of the recipient have less of an influence on knowledge flow effectiveness and only exert local effects on the knowledge flow effectiveness for certain channels. For instance, the flow of knowledge through local knowledge repositories was marginally less effective when the job tenure of the recipient was high, however, such an effect was not found for the other channels. Moreover, the higher the corporate language proficiency of the recipient the higher the knowledge flow effectiveness via virtual verbal communication, but not for other channels. A reason for the effect on the exchange of knowledge via virtual verbal communication could be that the effect of corporate language proficiency on the exchange of knowledge is mediated by channel richness (Peltokorpi, 2015). However, one would then also expect to find an effect for physical verbal communications, while in this study such an effect was absent. Further research could investigate whether the absence of this effect could be caused by the higher ability of physical verbal communication to convey more cues, such as facial expressions, body language, and intonation, which could attenuate the impact of low proficiency in English.

Secondly, this study found that characteristics of the relationships between the source and the recipient proved to be antecedents of knowledge flow effectiveness. More specifically, the higher the psychological safety of the recipient, the higher the knowledge flow effectiveness for all channels, except for local knowledge repositories. Therefore, psychological safety is not only important on the supply side of a knowledge flow (Siemsen et al., 2009), but also on the demand side. Moreover, this effect of psychological safety is (partially) mediated by inter-departmental tie strength. Therefore, this study provides extra support for the importance of strong ties to enable the effective flow of knowledge (Hansen, 1999). Moreover, although Schulte et al. (2012) warn researchers that uni-directional models of inter-departmental tie strength and psychological safety are likely to misrepresent their interaction, the findings in this study are in line with their results for the interplay between inter-departmental tie strength and psychological safety for recipients. They found that while the psychological safety of the recipient positively influenced the development of advice ties, vice versa, advice ties did not have a positive influence on the psychological safety of a recipient. Similarly, this study did not find evidence that psychological safety mediates the relationship between inter-departmental tie strength and knowledge flow effectiveness.

Lastly, knowledge flow effectiveness is influenced by the characteristics of the knowledge exchanged. In this study, the effect of the type and complexity of knowledge were analyzed on the effectiveness of knowledge flows. The results showed a clear effect of the complexity of knowledge; the higher the complexity of knowledge exchanged via knowledge repositories, written communication, and physical verbal communication, the higher the knowledge flow effectiveness for those channels. Therefore, the results indicate that there is a strong need for complex knowledge to be effective in one's job within ASML. Contrary to the complexity of knowledge, the type of knowledge only affected the knowledge flow effectiveness via local knowledge repositories. Based on the results, it is not advisable to share high degrees of organizational knowledge via local knowledge repositories, perhaps because such knowledge about organizational processes, procedures, and ways of working are intended for an organization-wide audience, which is not compatible with the outreach of such local knowledge repositories.

6.6 Limitations study II

As with all research, this study should be interpreted within the context of several limitations. First of all, study II was performed within the context of the service department of one high-tech company in the semiconductor industry, thus the findings of this study may not necessarily generalize across other contexts. Moreover, this study was conducted during the global COVID-19 pandemic and the survey was sent out during a period when employees just started to come back to the office for a couple of days a week after long periods of enforced working from home. Therefore, the insights into the efficiency and effectiveness of knowledge flows may differ from the pre-pandemic period or when regulations are alleviated again to allow employees to return to the office instead of working from home.

Secondly, this study originally set out to perform a comparative performance analysis by evaluating the most efficient and effective knowledge flows versus the rest, similar to the work of Markham and Lee (2013) on antecedents of new product performance. As such, it would have been possible to identify both characteristics of source units as well as of recipient units which affect knowledge flow efficiency and effectiveness. Unfortunately, the knowledge flows included in this study were on average relatively similar and therefore the best versus the rest analysis did not lead to the identification of any significant differences between the two. As an alternative, an analysis of variance was performed in combination with regression analysis on knowledge flow efficiency and effectiveness. However, as a result of the changed data analysis, the antecedents measured for the source unit could not be included in the regression analysis. Nevertheless, these variables were measured in the survey, which made the survey quite long. Furthermore, as knowledge flow effectiveness was measured for multiple source-recipient combinations and multiple channels, these questions were relatively repetitive in the survey. The combination of the length of the survey with the repetitive nature of the survey could have led to survey fatigue, which in turn could have influenced the absence of large differences in knowledge flow effectiveness between channels.

Thirdly, there are limitations that restricted the accuracy of the statistical analysis of this study. For instance, the sample sizes per knowledge flow varied significantly and overall were relatively small. Unfortunately, in general, smaller sample sizes provide relatively less statistical power (Hair et al., 2014). Moreover, as a result of small sample sizes, normality could not be assumed and non-parametric tests were used, which have less statistical power (Ross, 2017). Consequently, the small sample sizes and the use of non-parametric statistical methods increased the probability of type two errors. This could have led to relatively conservative findings, for instance when comparing the knowledge flow efficiency and effectiveness of different channels. Nevertheless, these shortcomings can be simply addressed by reproducing the study with a larger sample size for each knowledge flow.

Fourthly, the measurement scales used in the survey are susceptible to measurement errors, which could have reduced the reliability and validity of the measured constructs. For example, to reduce the length of the survey, the type and the complexity of knowledge were measured as single-item scales. However, the use of single-item scales can introduce measurement errors and thereby have implications for the reliability and validity of the measured constructs. Lastly, corporate language proficiency was measured with a self-reported scale in which the participants rated their own proficiency, which could introduce a potential bias. When addressing the same research topic, future research could reduce such a self-report bias by asking individuals to rate their colleague's proficiency in English, instead of their own, as performed by Peltokorpi (2015).

6.7 Conclusion study II

Study II has analyzed the knowledge flow efficiency and effectiveness across various contexts. In doing so, this study has shown that knowledge flow efficiency depends on the type of channels used to exchange knowledge. Furthermore, the antecedents of knowledge flow performance identified in study I, such as the educational level of the recipient and the inter-departmental tie strength with the source positively affect the efficiency of knowledge flow. Lastly, knowledge flow efficiency also varied for the combination of the source unit's department and the type of channel used. In contrast, study II also showed that the knowledge flow effectiveness did not seem to depend on the type of channel used. Instead, knowledge flow effectiveness was predominantly affected by psychological safety, interdepartmental tie strength and the complexity of knowledge. Thereby, this study provided insight into the differences in knowledge flow efficiency and effectiveness across various channels, while it also identified several antecedents of knowledge flow performance.

Chapter 7

Discussion

7.1 Theoretical contributions

Knowledge has developed into a key strategic resource for high-tech organizations to create a competitive advantage (Grant, 1996). In the exploitation of such a collective knowledge stock, knowledge flows play an important role to get knowledge to where it is needed, especially in times of globalization, complex organizational structures, and distributed work (Argote and Miron-Spektor, 2011). Moreover, developments in information technology have provided the use of new ways to exchange knowledge, while the COVID-19 pandemic also forcefully changed the ways people worked and exchanged knowledge (Waizenegger et al., 2020). Therefore, this study analyzed the efficiency and effectiveness of knowledge flows and in doing so contributes to the knowledge management literature in several ways.

Firstly, this study contributes to the knowledge management literature by the development and operationalization of the constructs of knowledge flow efficiency and effectiveness to adopt a productivity perspective on the knowledge flow process. As Haas and Hansen (2005, 2007) have shown that more knowledge sharing is not always better, this study answered their call to move beyond measuring the frequency and quantity of knowledge sharing, by analyzing how the costs of different knowledge flow processes relate to their benefits. However, instead of evaluating when the costs of knowledge flows outweigh the benefits, this study analyzed what, given the costs, the most efficient and effective knowledge flows are. Moreover, where Haas and Hansen (2007) only investigated the use of personal advice and electronic documents, this study used a more fine-grained approach to evaluate the costs versus the benefits of a variety of different channels. To do so, the current study developed two new constructs, knowledge flow efficiency and effectiveness. Knowledge flow efficiency was defined and operationalized as the ratio between the frequency with which acquired knowledge was used and the sum of the time investment it cost the source unit to make the knowledge available and the time investment of the source to seek and acquire the knowledge. Furthermore, knowledge flow effectiveness was defined as the degree to which the receipt of knowledge enabled the recipient to contribute to organizational performance. This definition was developed as knowledge is often defined as a resource that increases its holder's capacity to take act effectively (Alavi and Leidner, 2001). Therefore, the definition of knowledge flow effectiveness is similar to the definition of the perceived receipt of useful knowledge of Levin and Cross (2004), but moves beyond the implications on individual or team performance and instead focuses on the recipient unit's performance as the flow of knowledge was defined to take place between two units instead of individuals.

Secondly, although the flow of knowledge can aid companies in the development of new products, the knowledge management literature has shown that the exchange of knowledge is not a straightforward process (Argote, 1999; Szulanski, 1996, 2000). Therefore, this study contributes to the knowledge management literature by identifying differences in knowledge flow performance based on the type of channel used. Where knowledge flow efficiency was found to be strongly dependent on the type of channel used, the evidence presented in this study does not indicate such a dependency on channel type for knowledge flow effectiveness. As both high and low synchronicity media are found to be very efficient, the results provide cautious empirical support for the media synchronicity theory of Dennis et al. (2008), who theorized that both low and high synchronicity media may yield significant knowledge flow performance, depending on whether they are used for conveyance or convergence respectively. Moreover, further empirical support is provided for MST by the fact that physical verbal communication was more efficient than virtual verbal communication and written communication, while virtual verbal communication was also more efficient than written communication. Dennis et al. (2008) theorized that, for creating a shared understanding, higher synchronicity media achieve better performance, and that media which can convey more cues are more capable of providing such high synchronicity. Indeed, the results of this study show that, of the channels capable of supporting interaction between the source and recipient, the channels which can convey the more cues achieve higher knowledge flow efficiency.

Interestingly, the most efficient channels as found in study II are not necessarily also the most used channels. On the contrary, in study I, in one fifth of all cases when knowledge was shared, written communication was used, while written communication was found to be the least efficient channel of the analyzed set of ways to convey knowledge. In addition, when knowledge was sourced, written communication such as company email and chat function was even used one third of all cases via written communication. Moreover, while face-to-face meetings have been found in the current study to be a relatively efficient channel to exchange knowledge, they were not often used to source and acquire knowledge as only in one out of nine cases this was done via physical verbal communication. A possible explanation for these findings could be that this study was conducted in the aftermath of COVID lock downs and when individuals worked still partly from home and therefore had to rely more on electronically mediated communication. Therefore, further research could identify if, in the absence of COVID regulations, individuals prefer the use of physical verbal communication over the less efficient use of written communication.

Thirdly, this study contributes to the extent literature on knowledge flows by identifying antecedents of knowledge flow performance. In order to do so, this study included a broad set of potential antecedents of knowledge flow performance, which have priorly been found to influence the ease with which knowledge is exchanged, such as psychological safety (Siemsen et al., 2009), inter-departmental tie strength (Hansen, 1999), the complexity of knowledge (Galbraith, 1990), physical separation (Levin and Cross, 2004), corporate language proficiency (Peltokorpi, 2015). The evidence presented in this study suggests that knowledge flow efficiency is influenced to a higher degree by personal characteristics of the source and recipient, such as their experience within the organization and level of education, than knowledge flow effectiveness. On the contrary, knowledge flow effectiveness is influenced to a higher degree by characteristics of the knowledge exchanged, such as its type and its complexity, than knowledge flow efficiency.

Moreover, characteristics of the relationship between the source unit and the recipient department affected the efficiency and effectiveness of knowledge flows. For instance, the inter-departmental tie strength positively influenced both knowledge flow efficiency and effectiveness, providing further support for the role of strong ties in the exchange of knowledge (Hansen, 1999; Levin and Cross, 2004). Although, for knowledge flow efficiency, this effect of inter-departmental tie strength was only limited to electronically mediated communication. Moreover, psychological safety was found to have a positive effect, mediated by inter-departmental tie strength on knowledge flow effectiveness, demonstrating the importance of psychological safety not only for the supply side (Siemsen et al., 2009), but also for the demand side of the knowledge flow. Furthermore, although in study I physical proximity was found to ease the exchange of knowledge, no effects where found of physical proximity on knowledge flow efficiency nor effectiveness. As a result, it seems more likely that physical proximity increases of the number of face to face meetings, as found by Ganesan et al. (2005), which is a very efficient channel, and thereby positively affects the ease with which knowledge is exchanged.

Fourthly, the findings of this study also shed light on how to leverage efficient and effective knowledge flows via electronically mediated communication. These findings are especially important for virtual teams or hybrid working arrangements in which people have to either fully or partially rely on such electronically mediated communication. For instance, similar to the findings of Peltokorpi (2015), this study found a positive effect of corporate language proficiency on the effectiveness of knowledge flows via virtual verbal communication. No effect of corporate language proficiency was found for the use of knowledge repositories and written communication, which can be explained by the fact that channel richness mediates the effects of corporate language proficiency on the transfer of knowledge (Peltokorpi, 2015). Thus, this study shows that especially when the rehearsability of a medium is low for electronically mediated communication, such as in virtual meetings, high proficiency in the corporate language is important for the effective flow of knowledge. Furthermore, this study also found that inter-departmental tie strength was especially important for the efficient flow of knowledge via written communication and virtual verbal communication. This finding echoes prior research of the importance of communication frequency for virtual teams (Shockley et al., 2021) as (DeSanctis and Monge, 1999) argue that it can foster the development of social contexts and norms which can aid in forming mutual understanding through electronically mediated communication. Thus, for virtual or hybrid work arrangements, personal communication is most efficient via virtual verbal communication, however, the efficiency of such virtual meetings hinges on the corporate language proficiency of the participants and strong inter-departmental ties to foster efficient communication via both email, chat and virtual meetings.

7.2 Practical implications

Besides theoretical contributions, this study provides also several practical implications for organizations and managers. Firstly, this study showed that channels significantly vary in their capacity to efficiently enable the flow of knowledge. For instance, face-to-face meetings and the use of knowledge repositories were found to be more efficient than the use of virtual meetings, email, and chat. Especially in the aftermath of the COVID-19 pandemic, organizations could therefore opt to focus on returning to face-to-face meetings and reducing the number of virtual meetings to increase the efficiency of their knowledge flows. For example, managers could stimulate the use of physical verbal communication through co-location, motivating individuals to work in the office, or in case of hybrid work arrangements plan meetings (predominantly) on office days. Moreover, as both local and global knowledge repositories were found to be very efficient for the exchange of knowledge, it could prove beneficial for organizations to invest in their digital infrastructure to provide employees with fast and effective search engines and simple-to-use knowledge repositories, to enhance the efficiency of their knowledge flows.

Secondly, both psychological safety and strong inter-departmental ties were found to enhance knowledge flow effectiveness. Therefore, managers must pay attention to creating an open and inclusive environment where all employees feel free and safe to express themselves.

Moreover, strong inter-departmental ties could, for example, be fostered by cross-training between departments, creating inter-departmental teams to work on shared problems, supporting and incentivizing frequent inter-departmental communication, or via visiting one another during work trips to develop more close and personal relationships. Furthermore, as social interaction to create psychological safety and strong ties is limited in a virtual environment (Waizenegger et al., 2020), managers should pay extra attention to fostering psychological safety and strong ties for virtual teams and when people rely on electronically mediated communication to cross large geographical distances. For example, managers could contribute to the development of psychological safety by creating clear social norms and guidelines, moderating discussions in virtual meetings, supporting participation in virtual meetings, showing vulnerability themselves, and checking in with team members who were quieter during meetings. Moreover, managers or moderators of virtual meetings should make use of the many options provided by modern information technology, such as hand-raising, breakout rooms, and tools to solicit anonymous feedback, such as polls, as these could aid to create a psychologically safe environment (Edmondson and Daley, 2020).

Thirdly, this study found that the personal characteristics of the recipient affect the efficiency and, to a lesser degree, the effectiveness of knowledge flows. For example, the higher the corporate language proficiency of the recipient, the more effective the flow of knowledge via virtual verbal communication. Therefore, in environments where virtual verbal communication is frequently used, HR should assess the corporate language proficiency of individuals, provide language courses and motivate employees to enhance their language skills. In addition, during the recruitment processes for vacancies that require frequent participation in virtual verbal meetings, hiring managers could place extra emphasis on the applicants' corporate language proficiency. Besides corporate language proficiency, the experience within ASML of the recipient positively influenced knowledge flow efficiency via written communication and physical verbal communication, perhaps as they know better who to go to for knowledge than their less experienced colleagues. Therefore, during onboarding, it could prove beneficial to connect each new hire with an experienced colleague, such that the experienced colleague can actively introduce the new hire to his or her network.

Fourthly, although face-to-face meetings and knowledge repositories are on average very efficient to exchange knowledge between departments, organizations and managers must pay attention to the types of knowledge exchanged via channels as some types of knowledge are better suited to the use of certain channels than others. For example, this study showed that exchanging high degrees of organizational knowledge via local knowledge repositories and face-to-face meetings was associated with lower levels of knowledge flow effectiveness and efficiency respectively. Therefore organizations must be careful in using such local knowledge repositories with a small reach to effectively communicate knowledge about organizational processes, procedures, and ways of working. Moreover, also the use of face-to-face meetings seems less suited to efficiently communicating such organizational knowledge and more suited to the exchange of technical knowledge. Lastly, in this study, complex knowledge positively influenced the knowledge flow effectiveness via all channels, except for virtual verbal communication. Therefore, instead of overly simplifying knowledge, which could deteriorate knowledge flow effectiveness, managers should support and fuel in-depth discussions and documentation of complex knowledge.

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Appendix A

Organizational background and problem analysis

A.1 Problem analysis

The problem definition, as proposed in the prior section, essentially describes two problems, the lack of insight into how knowledge flows within ASML and the absence of a quantitative approach to assess the efficiency and effectiveness of these knowledge flows, which limit the opportunities for ASML to improve them and increase its innovation capabilities. These two problems are discussed in a similar order in the consecutive paragraphs. Analysis of the problem statement is performed by reviewing prior internal research of ASML on knowledge flows, interviews with knowledge management experts within ASML, and reviewing intranet documents on knowledge management. The series of interviews, five in total, were conducted with employees of ASML who worked on various knowledge management projects within the organization. The interviewee's exact functions and the duration of these conversations are shown in Appendix B. In these conversations, the knowledge management experts were asked to describe the most important knowledge flows within ASML, the insight into these knowledge flows related to quality, efficiency, and effectiveness, and the state of knowledge management within ASML. For reasons of confidentiality, the names of the interviewees are not shown, however, meeting notes can be requested through the author.

A.1.1 Insight into intra-organizational knowledge flows

ASML's employees spent a significant proportion of their time, approximately 18%, sourcing and acquiring knowledge, indicating that people and knowledge within ASML are difficult to find[1]. To better understand the micro-foundations of how knowledge is sourced and shared between individuals, a diary study was employed in a prior internship in which the participants described their experiences with acquiring, retaining, and transferring knowledge on a day-to-day basis. This ten-day diary study with participants from all departments within ASML showed that there exist numerous barriers to the acquisition, retention, and transfer of knowledge within the organization hindering the flow of knowledge (see internship report Broeken and Verhaar, 2021). For example, people often do not even know where to search for knowledge, who to contact, for who their knowledge might be valuable, or if certain knowledge even exists. These barriers suggest that there is a limited overview of knowledge flows in the organization and in some cases if knowledge flows are present at all. Furthermore, obscuring the overview of knowledge flows within the organization is the indication that knowledge flows are often unstructured. In the diary study, participants also heckled the lack of standardization, the plethora of tools, and different ways of working, which resulted in the absence of structure in the flow of knowledge.

Consequentially, the ability of employees to do their work is hampered by these barriers for two reasons. Firstly, they have to spend excessive amounts of time to acquire, retain or transfer knowledge, which they could have spent on the core activities of their job, such as creating and developing new products, procedures, and services. Secondly, as a result of those barriers, in some cases knowledge may not even reach the employees for whom it might be useful, leading to 'reinvention of the wheel', limited learning, and reintroduction of priorly solved problems. As a result, ASML's employees are limited in their ability to optimally contribute to the innovation of new products and the optimization of ASML's operations.

In the conversations with internal knowledge management experts, they confirmed that (cross-sectoral) knowledge flows are indeed unstructured, obscuring the insight into the flow of knowledge. Therefore, it is often unclear how knowledge exactly flows within the organization. For example, research on the flow of knowledge from the headquarters to peripheral locations and customer sites showed that such flows are unstructured and resulted in non-uniform distribution of knowledge[2]. Moreover, the same research indicated that knowledge sometimes did not even reach the engineers in the field or reached them via unidentified pathways, which limited the ability to track and validate knowledge. The other way around, knowledge management experts indicated that the knowledge of customer requirements also did not properly flow back from the field into the

[1] From internal document 1, see Appendix A
[2] From internal document 2, see Appendix A

organization, while customer input is a predictor of new product performance (Evanschitzky et al., 2012). A similar situation was found to be the case with the flow of knowledge from experienced employees close to retirement to new hires. Internal research showed that it is often unclear how, where and if this knowledge flows, leading to a loss of knowledge[3]. Thus, these knowledge flows are often black boxes, which makes it difficult to improve them. Therefore, it can be concluded that:

ASML has limited insight into its knowledge flows blocking the opportunity to improve them, which limits ASML innovation capabilities.

A.1.2 Evaluating knowledge flow performance

In the interviews, ASML's knowledge management experts also indicated that knowledge management within ASML can have a reputation of being "fuzzy and abstract" for employees and management. As a result of this "fuzzy and abstract" reputation, upper management may question the dedication of resources towards knowledge management in absence of quantitative metrics to evaluate the impact of knowledge management. For example, in a case study on the implementation of knowledge management at Infosys, researchers found that "in the absence of such metric, Infosys' board of Directors started questioning [the] company's financial investment in the KM program" (Mehta et al., 2007, p.456). Hence, when one wants to improve knowledge flows, it could prove pivotal to have a quantitative approach available to demonstrate the impact of knowledge management interventions and policies, especially as resources within organizations are often limited.

Therefore, internal knowledge management experts emphasized the importance of measuring how knowledge flows contribute to the performance of individuals at the receiving end of the flow. As such, a measurement approach to quantify the state of knowledge flows can aid in shifting the reputation of knowledge management away from "fuzzy and abstract". Hence, ASML's Learning and KM roadmap 2025 stresses explicitly the need to quantify the state of knowledge management and drive interventions [4].

Moreover, such an approach to quantitatively assess the most efficient and effective ways to enable the flow of knowledge might also build support for knowledge management among employees within ASML. The time of employees at ASML is a very scarce commodity and has already proven to be a significant barrier to the engagement of employees in knowledge management activities (Broeken and Verhaar, 2021). Therefore, knowledge management, through the quantitative identification of best practices, could guide individuals to the most efficient and effective ways to

[3]From internal document 3, see Appendix A
[4]From internal document 4, see Appendix A

transfer their knowledge to encourage them to contribute to knowledge sharing within ASML.

However, at the moment ASML lacks such a structural approach to assess the efficiency and effectiveness of its intra-organizational knowledge flows. Currently, ASML measures only once per year in a large survey on employee engagement, amongst others, the degree of inter-team communication[5]. However, measuring only the frequency of communication may give an inaccurate indication of the efficiency and effectiveness of how knowledge is exchanged. For example, two teams may have to communicate very frequently, especially because their ways of transferring knowledge to one another are inefficient and ineffective. Therefore, measuring only the frequency of communication between teams falls short of delivering the quantitative insight within the flow of knowledge to assess and improve the flow of knowledge. All in all, it can be concluded that:

ASML lacks a measurement approach to quantify the efficiency and effectiveness of knowledge flows, which limits guiding employees towards the best ways to exchange knowledge and the ability to demonstrate return on investment of knowledge management interventions.

[5]From internal document 5, see Appendix A

Appendix B

Consulted internal documents and interviews KM-experts

Table B.1: An overview of all referenced internal documents in the problem analysis

Entry	Document name	Source	Consultation date
1	Knowledge management Day @ ASML 151119	Intranet	22-09-2021
2	Knowledge sharing to field	Intranet	22-09-2021
3	ReportInvestigatingKnowledgeCapturingAndLoss	Intranet	22-09-2021
4	Learning&KM_roadmap2025	Intranet	22-09-2021
5	Results We@ASML	Meeting with CS CE	11-10-2021

Table B.2: An overview of conducted exploratory interviews with KM-experts within ASML. For reasons of confidentiality, the names of the interviewees are left out.

Nr.	Function of interviewee(s)	Duration
1	Program manager knowledge management	30 minutes
2	Change manager competence centers	35 minutes
3	Competency maturity manager	30 minutes
4	Program manager continuous improvement	35 minutes
5	Cross-sectoral knowledge strategy manager	55 minutes

Appendix C

Questions semi-structured interviews study I

Before starting with the questions of the interview a short introduction to the project was provided. The introduction of the project included the goal of the project, the method, and how the data would be handled. Furthermore, it was pointed out to interviewees that at any given moment they had the right to stop the interview or request their data to be deleted. During the interview, the following questions were used:

Job responsibilities

1. What are your main job responsibilities?

Knowledge utilization

1. What knowledge do you need from others to be effective in your job and why?
2. From whom or where do you obtain this knowledge and through which channels do you obtain this knowledge?
3. How much time on average per week are you busy with searching and obtaining knowledge?
4. How applicable is the knowledge you obtain? Does it require significant effort to adapt it to what you need?
5. Do you feel that you miss knowledge that should be coming from others to be effective in your job?
6. Are there barriers to finding and obtaining knowledge?

7. What do you find the most useful ways to search and obtain knowledge?

Knowledge contribution

1. For who is your knowledge relevant, which teams or people depend on receiving knowledge from you?
2. What knowledge do you provide to them and why?
3. How much time on average per week are you busy with sharing your knowledge?
4. How do you make your knowledge available to others, which channels do you use? And why do you use these channels?
5. Is knowledge sharing encouraged in your department and if so how? Are there incentives or KPIs which encourage this?
6. Do you encounter barriers in sharing your knowledge?
7. What are for you the most effective ways to share your knowledge?
8. How could knowledge sharing be improved within CE?

General information

1. Age
2. Tenure at ASML
3. Tenure in current function
4. Educational background

Appendix D

Summary and comparison of the results of the interviews and diary study

Table D.1: Summary and comparison of the interview results with the diary data analysis

height**Topics**	Interviews at CE	Diary study
Types of knowledge sought	Technical knowledge (16 out of 16) Organizational knowledge (15 out of 16)	Technical knowledge: 38% of all knowledge sought Organizational knowledge: 62% of all knowledge sought
Types of knowledge shared	Technical knowledge (14 out of 16) Organizational knowledge (15 out of 16)	Technical knowledge: 27% of all knowledge shared Organizational knowledge: 73 % of all knowledge shared
Channels sourcing knowledge	1. Global KRs (15 out of 16) 2. E-mail (15 out of 16) 3. Meetings (14 out of 16) 4. Chat (6 out of 16) 5. Local KRs (5 out of 16)	1. Global KRs: 37% of all cases 2. E-mail: used in 21% of all cases 3. Local KRs: used in 19% of all cases 4. Meetings: used in 12% of all cases 5. Chat: used in 11% of all cases
Channels sharing knowledge	1. Meetings (16 out of 16) 2. Email (13 out of 16) 3. Global KRs (6 out of 16) 4. Local KRs (6 out of 16) 5. Chat (5 out of 16)	1. Meetings: used in 27% of all cases 2. Local KRs: used in 18% of all cases 3. E-mail: used in 17% of all cases 4. Global KRs: used in 13% of all cases 5. Chat: used in 3% of all cases Undefined: 22% of all cases
Knowledge sought from	1. D&E (16 out of 16) 2. 2nd line engineers (14 out of 16) 3. MAN (4 out of 16) 4. GSC (2 out of 16) 5. Others (1 out of 16)	Not applicable
Knowledge shared with	1. 2nd line engineers (14 out of 16) 2. D&E (12 out of 16) 3. GSC (7 out of 16) 4. MAN (2 out of 16) 5. Others (3 out of 16)	Not applicable
Antecedents of knowledge flow performance	1. Physical proximity (11 out of 16) 2. Work experience (10 out of 16) 3. Inter-departmental tie strength (9 out of 16) 4. Network size (8 out of 16) 5. Time pressure (8 out of 16) 6. Complexity of knowledge (6 out of 16) Psychological safety (4 out of 16) Corporate language proficiency (1 out of 16)	Identified priorly by Broeken and Verhaar (2021) Time pressure Complexity of knowledge Work experience Network size

Appendix E

Measurement scales study II

In the questions below the CE survey and non-CE survey differed slightly in formulation. Therefore, the following should be read:

- CE survey: [source unit], [recipient unit] = [2nd line engineers, GSC, DE]
- Non-CE survey: [source unit], [recipient unit] = [CE]

E.1 Time spent sharing knowledge

1. How much time on average per week do you spend on sharing your knowledge to [recipient unit] via local knowledge repositories in hours?
2. How much time on average per week do you spend on sharing your knowledge to [recipient unit] via global knowledge repositories in hours?
3. How much time on average per week do you spend on sharing your knowledge to [recipient unit] via written communication in hours?
4. How much time on average per week do you spend on sharing your knowledge to [recipient unit] via virtual verbal communication in hours?
5. How much time on average per week do you spend on sharing your knowledge to [recipient unit] via physical verbal communication in hours?

E.2 Time spent sourcing and acquiring knowledge

1. How much time in hours do you spend on average per week on sourcing and acquiring knowledge made available by [source unit] via local knowledge repositories?

2. How much time in hours do you spend on average per week on sourcing and acquiring knowledge made available by [source unit] via global knowledge repositories?

3. How much time in hours do you spend on average per week on sourcing and acquiring knowledge made available by [source unit] via written communication?

4. How much time in hours do you spend on average per week on sourcing and acquiring knowledge made available by [source unit] via virtual verbal communication?

5. How much time in hours do you spend on average per week on sourcing and acquiring knowledge made available by [source unit] via physical verbal communication?

E.3 Frequency of knowledge utilization

Indicate per channel how frequently you use and apply the knowledge made available by [source unit] via that specific channel. Seven-point Likert scale with (1) Never, (2) Very rarely, (3) Rarely, (4) Occasionally, (5) Frequently, (6) Very frequently, or (7) Always.

E.4 Knowledge flow effectiveness

Indicate for each channel the extent to which the receipt of knowledge from [source unit] through that specific channel contributes (or is likely to contribute) to:

- Reducing the meantime to repair
- Reducing the occurrence of extreme long downs
- Decreasing labor hours per machine
- Improving machine availability

Based on a 7-point Likert scale of Levin and Cross (2004) ranging from (1) Contributed very negatively, (2) Contributed negatively, (3) Contributed somewhat negatively. (4) Contributed neither negatively nor positively, (5) Contributed somewhat positively, (6) Contributed positively, to (7) Contributed very positively.

E.5 Knowledge complexity

Complexity of shared knowledge. Self-developed one-item measurement of the complexity of the knowledge shared via a specific channel.

Indicate for each channel the extent to which you agree or disagree with the statement that the knowledge you received from [source unit] via those channels is complex. Ranging on a 7-point Likert scale from (1) Strongly disagree to (7) Strongly agree.

Complexity of sought and acquired knowledge. Self-developed one item measurement of the complexity of the knowledge sought and acquired via a specific channel

Indicate for each channel the extent to which you agree or disagree with the statement that the knowledge you received from [source unit] via those channels is complex. Ranging on a 7-point Likert scale from (1) Strongly disagree to (7) Strongly agree.

E.6 Type of knowledge

Knowledge can be distinguished into two main types:

- Technical knowledge: knowledge related to (the working of) technical products, systems, subsystems, modules, or other technical parts
- Organizational knowledge: knowledge related to projects, processes, procedures, troubleshooting, ways of working, who is responsible for what, etc.

Type of knowledge shared. The self-developed scale of the type of knowledge shared:

Indicate for each channel the extent to which the knowledge you shared to [recipient unit] through that channel consists predominantly of technical or organizational knowledge. Ranging on a 6-point scale from (1) 100% technical knowledge, (2) 80% technical knowledge and 20 organizational knowledge, (3) 60% technical knowledge and 40% organizational knowledge, (4) 40% technical knowledge and 60% organizational knowledge, (5) 20% technical knowledge and 80% organizational knowledge, or (6) 100% organizational knowledge

Type of knowledge utilized. The self-developed scale of the type of knowledge sought and acquired:

Indicate for each channel the extent to which the knowledge you sought and acquired from [source unit] through that channel consists predominantly of technical or organizational knowledge. Ranging on a 6-point scale from (1) 100% technical knowledge, (2) 80% technical knowledge and 20 organizational knowledge, (3) 60% technical knowledge and 40% organizational knowledge, (4) 40% technical knowledge and 60% organizational knowledge, (5) 20% technical knowledge and 80% organizational knowledge, or (6) 100% organizational knowledge

E.7 Physical proximity

Select the most applicable option. The people from [source unit/recipient unit] with whom I exchange knowledge are predominantly working:

- On the same floor in the same building as me
- In the same building, but on a different floor than me
- In a different building, but on the same office location as me
- At a different office location, but in the same country (could apply to working from home)
- At a different office location in another country, but on the same continent
- At a different office location and on a different continent

Slightly adjusted from physical proximity by Levin and Cross (2004) to fit the context

E.8 Inter-departmental tie strength

Indicate the extent to which you agree with the following statements:

1. During the last year I interacted frequently with people from [source/recipient unit].
2. The working relationship between myself and people from [source/recipient unit] is close.

On a 7-point Likert scale ranging from (1) strongly disagree to (7) strongly agree. Based on inter-unit tie weakness of Hansen (1999).

E.9 Level of experience

Self-developed to measure the experience of participation within ASML and within their current function.

1. How many years have you already worked for ASML?
2. How many years have you already worked for ASML in your current function?

E.10 Corporate language proficiency

Indicate to what extent you agree or disagree with the following statements:

1. I am proficient in speaking English
2. I am proficient in writing in English
3. I am proficient in understanding English

The corporate language proficiency scale was based on corporate language proficiency (Peltokorpi, 2015). In this survey, the corporate language is made explicit to be English.

E.11 Perceived psychological safety

Indicate the extent to which you agree with the following statements with respect to your communication with people from [source/recipient unit]:

1. I feel like people from [source/recipient unit] would judge me on the things I say (R)
2. I have the impression that people from [source/recipient] want to hear what I have to say
3. I have the impression that people from [source/recipient] would appreciate discussion
4. I expect people from [source/recipient unit] to react positively when I disagree with them
5. I feel like people from [source/recipient] would think more positively of me when I agree with them
6. I expect people from [source/recipient unit] to appreciate it when I mentioned new information

Ranging on a 7-point Likert scale ranging from (1) strongly disagree to (7) strongly agree. Based on psychological safety of van Ginkel and van Knippenberg (2008).

E.12 Perceived time pressure on knowledge sharing

Indicate the extent to which you agree with the following statements:

1. During a week, I have plenty of time to share my knowledge with [source/recipient unit]
2. I am constantly running out of time to make my knowledge available to [source/recipient unit]

3. I do not have the time to focus on making my knowledge available to [source/recipient unit]
4. Sharing my knowledge with [source/recipient unit] takes up time I don't have
5. I don't have much time to share my knowledge to [source/recipient unit] - I am too busy with other things

Ranging on a 7-point Likert scale from (1) strongly disagree to (7) strongly agree. The first three items are based on items 1,2 and 3 of the perceived time pressure of Madjar and Oldham (2006), while items 4 and 5 are based on the items of the experienced creative time pressure of Baer and Oldham (2006).

Appendix F

Measurement of knowledge flow effectiveness

In this appendix, the items of the perceived receipt of useful knowledge of Levin and Cross (2004) are mapped onto the newly developed items to fit the context of the study. The original items of Levin and Cross (2004) are measured how the receipt of knowledge contributed to increasing customer satisfaction, increasing value to the organization, increasing quality, and reducing time and costs activities take. Furthermore, their items were tailored to fit the context of project-based working, so for instance revolved around the impact the receipt of knowledge had on the costs or time a project took. Within the customer service department of ASML however, the work is less scheduled around projects. Moreover, when the original items were tested with individuals within ASML, it proved difficult for them to answer these questions. Therefore, it was decided to adapt the original items to better fit the context of this research, while still measuring the impact on the aforementioned constructs of the original items.

The main value proposition of ASML is offering its customers not only highly accurate lithography machines but also all the services around them to ensure the reliable and continuous production of chips. In service agreements, ASML provides its customers with various packages to guarantee the uptime of the lithography machines. To measure the performance of the service delivered by ASML to its customers, there are four key performance indicators, or so-called 'workstreams'. These indicators are (i) reducing the mean-time-to-repair a machine (MTTR), (ii) reducing the occurrence of extreme long downs (XLDs) of machines, (iii) reducing labor hours (LH) needed to support the machines, and (iv) increasing machine availability (MA). Therefore, the participants in the survey were asked to indicate the extent to which the knowledge they received via a certain channel contributed to these four indicators.

A quick overview of how each new item maps onto the original items of Levin and Cross (2004) can be observed in Table F.1. Firstly, the original item 'increasing client satisfaction is covered by 'reducing the MTTR', 'reducing the occurrence of XLDs' and 'increasing machine availability. When the machines of customers are repaired faster, experience shorter downtimes, and are in general more often available, the customers of ASML can produce more chips, which contributes to their satisfaction.

Table F.1: Relation between items of Levin and Cross (2004) and newly developed items

	MTTR	XLDs	LH	MA
Original items perceived receipt of useful knowledge				
1. Client satisfaction with the project	✓	✓		✓
2. Overall performance of the project	✓	✓	✓	✓
3. Project's value to the organization	✓	✓	✓	✓
4. The project's quality	✓	✓		✓
5. This project's coming in on budget		✓	✓	
6. Reducing costs on this project		✓	✓	
7. Spending less time on the project			✓	
8. Shortening the time this project took				

Secondly, the items measuring how the receipt of knowledge contributed to the overall performance and the value delivered to the organization are covered by all four workstreams. Reducing the MTTR, reducing the occurrence of XLDs, as well as decreasing the required labor hours, and improving machine availability all contribute to ASML's performance to their customers. Thirdly, the quality delivered by ASML can be mapped onto the items measuring the uptime of the machines, so the MTTR, XLDs, and MA. The higher performance on these indicators, the higher the quality of service and products delivered by ASML to its customers.

Fourthly, the original items measuring costs are covered by the new items which measure the reduction of XLDs and the reduction of labor hours. XLDs are very costly for ASML's clients as well as for ASML itself as it has to dedicate a large number of resources to fix the problem as quickly as possible. Therefore, reducing the occurrences of XLDs contribute to reducing costs for ASML. Furthermore, a reduction of labor hours means fewer labor costs for ASML and thus also maps onto items five and six of Levin and Cross (2004).

Fifthly, the reduction of the number of labor hours maps onto item 7; 'Spending less time on the project' of Levin and Cross (2004). One could argue that a reduction in the MTTR or even the reduction of XLDs also imply that less time was required to maintain the machines. However, from a holistic point of view, it may cost ASML more labor hours to design solutions to reduce the MTTR or occurrence of XLDs than these solutions reduce the time spent on maintenance. Such design solutions may drive down the costs of maintenance but do not necessarily reduce the service times needed to keep the machines up and running. The only item which was not covered by the newly developed items was item 8 of Levin and Cross (2004); 'Shortening the time this project took'. As mentioned prior, the work of the departments of interest is not focused on a project basis, thus making it difficult to measure this item as there were no start and end dates for the work of the departments of interest.

Appendix G

Reliability of constructs and tests for normality

Table G.1: The reliability of all multi-item scales reported by Cronbach alpha's

Variable	Data set sharing	Data set sourcing
Corporate language proficiency	0.98	0.98
Inter-unit tie strength	0.83	0.87
Perceived time pressure	0.87	NA
Psychological safety	0.78	0.79
Effectiveness LKR	NA	0.90
Effectiveness GKR	NA	0.90
Effectiveness WC	NA	0.87
Effectiveness VC	NA	0.87
Effectiveness PC	NA	0.91

Table G.2: Shapiro-Wilk tests for normality of the knowledge flow efficiency per channel

	CE - 2nd line		**2nd line - CE**	
Channels	Test-statistic	p-value	Test-statistic	P-value
LKR	0.967	0.14	0.892	0.005**
GKR	0.955	0.052	0.947	0.19
WC	0.943	0.10	0.860	0.039*
VC	0.977	0.41	0.967	0.49
PC	0.987	0.80	0.935	0.054
	CE - DE		**DE - CE**	
Channels	Test-statistic	p-value	Test-statistic	P-value
LKR	0.954	0.59	0.954	0.14
GKR	0.959	0.61	0.923	0.019*
WC	0.883	0.20	0.847	0.001**
VC	0.953	0.31	0.951	0.092
PC	0.938	0.18	0.950	0.10
	CE- GSC		**GSC - CE**	
Channels	Test-statistic	p-value	Test-statistic	P-value
LKR	0.943	0.27	0.889	0.030*
GKR	0.918	0.18	0.915	0.078
WC	0.840	0.13	0.769	0.008**
VC	0.922	0.16	0.962	0.48
PC	0.972	0.82	0.864	0.004**

Note: *p<0.05; **p<0.01; ***p<0.001

Table G.3: Shapiro-Wilk tests for normality of the knowledge flow effectiveness per channel

	CE - 2nd line		**2nd line - CE**	
Channels	Test-statistic	p-value	Test-statistic	P-value
LKR	0.959	0.04*	0.917	0.02*
GKR	0.957	0.03*	0.930	0.04*
WC	0.955	0.03*	0.847	4.39e-4***
VC	0.972	0.18	0.969	0.44
PC	0.972	0.19	0.966	0.381
	CE - DE		**DE - CE**	
Channels	Test-statistic	p-value	Test-statistic	P-value
LKR	0.905	0.05	0.872	2.68e-4***
GKR	0.896	0.04*	0.905	2.77e-3**
WC	0.947	0.38	0.899	2.04e-3**
VC	0.895	0.02*	0.847	6.45e-5***
PC	0.841	2.95e-3**	0.852	8.35e-5***
	CE- GSC		**GSC - CE**	
Channels	Test-statistic	p-value	Test-statistic	P-value
LKR	0.956	0.46	0.961	0.41
GKR	0.904	0.06	0.955	0.31
WC	0.851	0.01*	0.897	0.01*
VC	0.925	0.14	0.965	0.51
PC	0.870	0.01*	0.946	0.19

Note: *p<0.05; **p<0.01; ***p<0.001

Table G.4: Shapiro Wilk tests on the difference between the effectiveness of pairs to test the normality assumption and the results of the visual inspection of the histogram of the difference in effectiveness between the pairs to evaluate the assumption of symmetry around the median

Source-recipient couple	**Test-statistic**	**P-value**	**Symmetrical around the median**
LKR - GKR	0.803	2.76e-07	Yes
LKR - WC	0.825	1.16e-06	Yes
LKR - VC	0.877	3.81e-05	No
LKR - PC	0.781	1.01e-07	No
GKR - WC	0.833	1.96e-06	Yes
GKR - VC	0.930	3.11e-03	No
GKR - PC	0.859	1.03e-05	No
WC - VC	0.903	3.04e-04	No
WC - PC	0.816	8.46e-07	No
VC - PC	0.757	3.63e-08	No

Appendix H

Linear regression assumptions: testing for heteroskedasticity and multicollinearity

Table H.1: Autocorrelations and Breutsch-Godfry tests for lags 1 and 2 to test the assumption of independence of the error terms for the multiple regression models for the dataset with only related entries

	ρ **lag 1**	ρ **lag 2**	**Breutsch-Godfry test-statistic**	**df**	**P-value**
Efficiency					
LKR	0.22	-0.24	12.42	2	2.00e-3**
GKR	0.18	-0.12	4.95	2	8.40e-2
WC	0.11	-0.11	2.76	2	0.25
VC	0.16	-0.25	10.19	2	6.14e-4**
PC	0.14	0.01	1.70	2	0.43
Effectiveness					
LKR	0.07	0.07	0.86	2	0.65
GKR	0.16	0.13	3.76	2	0.15
WC	0.19	-0.14	6.23	2	4.36e-2*
VC	-0.06	0.079	0.835	2	0.66
PC	0.10	0.18	4.05	2	0.13

H.1 Variance inflation factors of the stepwise and full models

Table H.2: Variance inflation factors to evaluate the presence of multicollinearity

Model	AR	EXAR	EXFR	ER	PP	TS	TK	CK	PE
Effectiveness									
Final model LKR	2.48	2.86	1.39	1.13		1.05	1.03	1.06	
Initial model LKR	2.48	2.91	1.44	1.14	1.07	1.05	1.06	1.15	1.13
Final model GKR	2.65	2.99	1.39	1.12		1.03		1.04	
Initial model GKR	2.62	3.08	1.46	1.17	1.06	1.03	1.09	1.11	1.12
Final model WC	2.68	3.07	1.45	1.15		1.03		1.06	
Initial model WC	2.66	3.14	1.54	1.16	1.05	1.03	1.06	1.09	1.10
Final model VC	2.70	3.05	1.38	1.12		1.02			1.07
Initial model VC	2.63	3.01	1.46	1.14	1.07	1.03	1.06	1.05	1.07
Final model PC	2.64	3.06	1.40	1.12		1.02		1.04	
Initial model PC	2.54	3.02	1.49	1.15	1.17	1.02	1.14	1.07	1.05
Efficiency									
Final model LKR	2.65	2.97	1.34	1.12					
Initial model LKR	2.48	2.86	1.43	1.15	1.11	1.08	1.10	1.12	1.11
Final model GKR	2.82	3.26	1.49	1.13					1.06
Initial model GKR	2.70	3.16	1.52	1.16	1.06	1.03	1.08	1.10	1.12
Final model WC	2.75	3.18	1.46	1.13		1.00			
Initial model WC	2.65	3.21	1.59	1.18	1.05	1.03	1.08	1.10	1.09
Final model VC	2.60	2.93	1.54	1.08		1.00			
Initial model VC	2.54	3.01	1.73	1.11	1.05	1.02	1.06	1.05	1.10
Final model PC	2.91	3.31	1.35	1.12			1.01		
Initial model PC	2.73	3.33	1.51	1.22	1.16	1.09	1.07	1.16	1.12

H.2 Residual plots

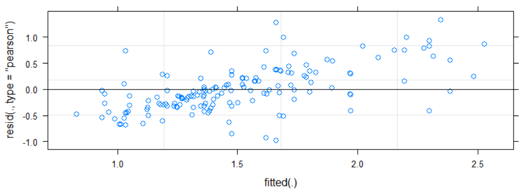

Figure H.1: Residual plot final model efficiency LKR

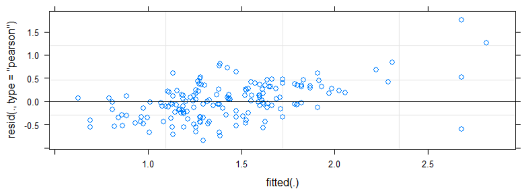

Figure H.2: Residual plot final model efficiency GKR

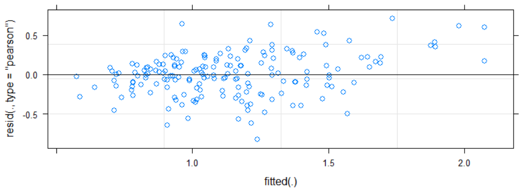

Figure H.3: Residual plot final model efficiency WC

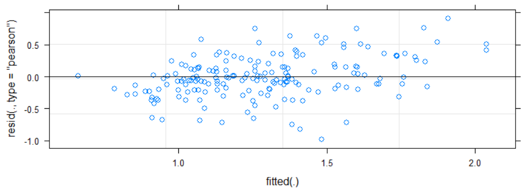

Figure H.4: Residual plot final model efficiency VC

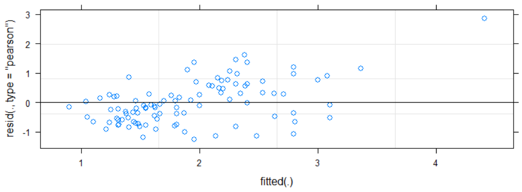

Figure H.5: Residual plot final model efficiency PC

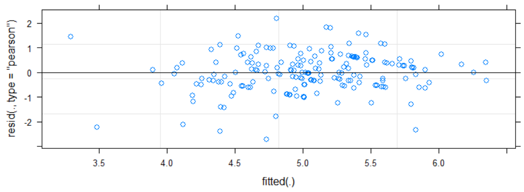

Figure H.6: Residual plot final model effectiveness LKR

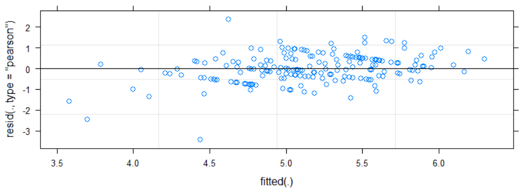

Figure H.7: Residual plot final model effectiveness GKR

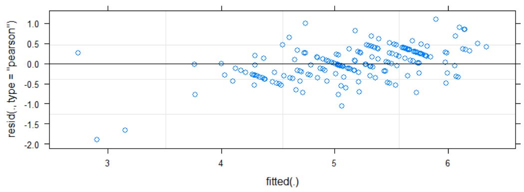

Figure H.8: Residual plot final model effectiveness WC

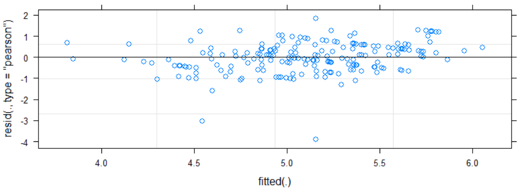

Figure H.9: Residual plot final model effectiveness VC

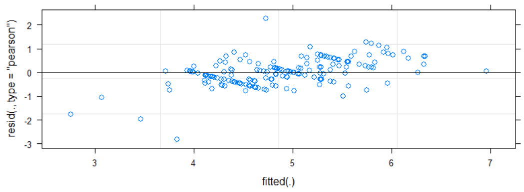

Figure H.10: Residual plot final model effectiveness PC

H.3 Initial regression models knowledge flow efficiency and effectiveness

Table H.3: Full regression models knowledge flow efficiency

	Dependent variable:				
	Efficiency LKR	Efficiency GKR	Efficiency WC	Efficiency VC	Efficiency PC
	(1)	(2)	(3)	(4)	(5)
Constant	0.522	0.009	0.148	0.366	−0.097
	(0.374)	(0.987)	(0.665)	(0.358)	(0.935)
Age recipient	0.020*	−0.003	−0.002	−0.002	0.006
	(0.038)	(0.694)	(0.651)	(0.732)	(0.765)
Experience ASML	−0.004	0.010	0.021**	0.017	0.069*
	(0.783)	(0.411)	(0.007)	(0.073)	(0.049)
Experience function	−0.022	0.008	−0.014	−0.005	−0.032
	(0.257)	(0.607)	(0.152)	(0.682)	(0.356)
Educational level	0.087	0.198**	0.135**	0.097	0.266
	(0.319)	(0.010)	(0.007)	(0.105)	(0.146)
Physical proximity	−0.034	−0.017	−0.014	0.013	−0.083
	(0.201)	(0.458)	(0.329)	(0.447)	(0.163)
Inter-departmental tie strength	0.040	0.053	0.075**	0.060	0.137
	(0.410)	(0.201)	(0.002)	(0.054)	(0.170)
Degree of organizational knowledge	−0.104	−0.090	−0.055	−0.051	−0.228*
	(0.084)	(0.063)	(0.077)	(0.148)	(0.036)
Complexity of knowledge	−0.010	0.012	−0.007	0.004	−0.032
	(0.809)	(0.724)	(0.746)	(0.849)	(0.689)
Proficiency in English	0.035	0.100**	0.044	0.041	0.114
	(0.471)	(0.008)	(0.079)	(0.151)	(0.204)
Observations	152	164	178	169	95
Marginal R^2	0.103	0.123	0.131	0.092	0.197
Conditional R^2	0.476	0.508	0.620	0.439	0.443
Log Likelihood	−155.513	−146.970	−77.733	−101.489	−139.278
Akaike Inf. Crit.	337.025	319.941	181.466	228.978	304.555
Bayesian Inf. Crit.	376.336	360.239	222.829	269.667	337.756

Note: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Table H.4: Full regression models knowledge flow effectiveness

	Dependent variable:				
	Effectiveness LKR	Effectiveness GKR	Effectiveness WC	Effectiveness VC	Effectiveness PC
	(1)	(2)	(3)	(4)	(5)
Constant	2.659***	1.995**	2.371***	2.248**	1.588
	(<0.001)	(0.009)	(<0.001)	(0.002)	(0.068)
Age recipient	0.016	0.001	0.008	0.011	0.008
	(0.125)	(0.900)	(0.449)	(0.300)	(0.555)
Experience ASML	−0.013	0.015	0.006	−0.008	0.007
	(0.466)	(0.402)	(0.717)	(0.651)	(0.740)
Experience function	−0.052*	−0.015	−0.030	−0.019	−0.037
	(0.019)	(0.498)	(0.151)	(0.367)	(0.157)
Educational level	0.034	0.177	0.116	0.064	0.021
	(0.738)	(0.103)	(0.275)	(0.546)	(0.874)
Physical proximity	−0.001	0.039	0.025	0.015	0.041
	(0.975)	(0.243)	(0.354)	(0.656)	(0.283)
Inter-departmental tie strength	0.210***	0.243***	0.179***	0.226***	0.216***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Degree of organizational knowledge	−0.207**	−0.006	−0.041	−0.035	0.156*
	(0.004)	(0.932)	(0.504)	(0.606)	(0.043)
Complexity of knowledge	0.203***	0.173***	0.149***	0.064	0.166**
	(<0.001)	(<0.001)	(<0.001)	(0.152)	(0.003)
Proficiency in English	0.055	0.016	0.073	0.134**	0.075
	(0.319)	(0.771)	(0.163)	(0.010)	(0.251)
Observations	185	189	190	187	178
Marginal R^2	0.258	0.177	0.182	0.153	0.158
Conditional R^2	0.390	0.438	0.656	0.320	0.551
Log Likelihood	−259.446	−267.806	−242.900	−259.698	−270.443
Akaike Inf. Crit.	544.892	561.612	511.801	545.397	566.886
Bayesian Inf. Crit.	586.756	603.755	554.012	587.401	608.249

Note: *p<0.05; **p<0.01; ***p<0.001

Table H.5: Breusch-pagan test statistics to test for homoskedasticity for both the models with and without inter-departmental tie strength included with as dependent variable knowledge flow effectiveness

Model	BP	df	P-value
Effectiveness			
Model 1	14.21	11	0.22
Model 2	20.08	12	0.066
Model 3	23.55	11	0.015*
Model 4	23.56	12	0.023*
Model 5	12.90	11	0.30
Model 6	16.22	12	0.18
Model 7	10.31	11	0.50
Model 8	15.36	12	0.22
Model 9	11.91	11	0.37
Model 10	8.39	12	0.75

Table H.6: Variance inflation factors to evaluate the presence of multicollinearity for both the models with and without inter-departmental tie strength included, where knowledge flow effectiveness is the dependent variable

Model	RU	AR	EXAR	EXFR	ER	PP	PE	CK	TK	PS	TS
Effectiveness											
Model 1	1.53	2.93	3.01	1.74	1.28	1.24	1.20	1.34	1.14	1.17	
Model 2	1.68	2.89	2.98	1.75	1.28	1.24	1.22	1.25	1.15	1.36	1.39
Model 3	1.48	2.94	3.15	1.77	1.29	1.24	1.18	1.12	1.15	1.14	
Model 4	1.59	2.91	3.13	1.77	1.28	1.25	1.19	1.17	1.18	1.33	1.32
Model 5	1.48	2.82	3.08	1.88	1.35	1.24	1.23	1.19	1.18	1.18	
Model 6	1.58	2.80	3.07	1.88	1.35	1.24	1.24	1.29	1.19	1.34	1.35
Model 7	1.49	2.86	3.10	1.77	1.30	1.24	1.20	1.17	1.11	1.18	
Model 8	1.59	2.85	3.10	1.76	1.30	1.24	1.21	1.19	1.13	1.42	1.30
Model 9	1.43	2.92	3.10	1.81	1.35	1.30	1.15	1.26	1.10	1.25	
Model 10	1.53	2.92	3.07	1.80	1.34	1.31	1.16	1.30	1.13	1.48	1.29

Table H.7: Breusch-pagan test statistics to test for homoskedasticity for the regression of psychological safety on inter-departmental tie strength

Model	BP	df	P-value
Effectiveness			
Model 1	10.04	11	0.53
Model 2	5.47	11	0.91
Model 3	7.77	11	0.73
Model 4	3.26	11	0.99
Model 5	3.05	11	0.99

Table H.8: Variance inflation factors to evaluate the presence of multicollinearity for the regression of psychological safety on inter-departmental tie strength

Model	RU	AR	EXAR	EXFR	ER	PP	PE	CK	TK	PS
Effectiveness										
Model 1	1.54	2.89	2.98	1.74	1.28	1.24	1.20	1.16	1.15	1.18
Model 2	1.48	2.90	3.13	1.76	1.28	1.24	1.18	1.13	1.17	1.15
Model 3	1.48	2.79	3.05	1.87	1.35	1.24	1.23	1.20	1.18	1.19
Model 4	1.49	2.83	3.07	1.76	1.30	1.24	1.19	1.19	1.13	1.20
Model 5	1.43	2.92	3.07	1.80	1.34	1.30	1.15	1.29	1.13	1.28