THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Visual Management – on Communication in Product Development Organizations

LUDVIG LINDLÖF

Department of Technology Management and Economics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

Visual Management – on Communication in
Product Development Organizations
LUDVIG LINDLÖF
ISBN 978-91-7597-077-6

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 3758
ISSN 0346-718X

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Printed by
Chalmers Reproservice
Gothenburg, Sweden 2014

Till Stina och Moa

ABSTRACT

Product development implies a need for information processing capability due to its uncertain and ambiguous nature. Uncertainty is troublesome as it limits an organization's ability to plan for, and make decisions about, the activities that need to be made in order to reach the objectives of the organization. Ambiguity stems from individuals having differing interpretations of a situation, which further complicates communication and decision making. This thesis discusses visual management as a way of improving an organization's information processing capability. Visualization seems to be able to provide a support for information processing in R&D organizations, but the research on visualization in management is not as advanced as in other fields, such as marketing and education. Thus, the overall purpose of the research presented in this thesis is to explore visual management and its use in product development organizations. Visualizations in product development are typically related to the communication of products and design concepts. However, this thesis is primarily focused on task communication, i.e., how the process, the tasks and the deliverables are communicated. The purpose is further concretized through three research questions: 1) What are the implications of using visual management in product development? 2) How can visual management be implemented and evaluated in product development? 3) How can the accessibility of information be increased to support information processing in product development?

These questions are answered by three empirical studies and a conceptual study. The empirical data is primarily collected through 99 interviews at six large product development organizations. The findings show that the cognitive benefits of visualization can support managerial tasks, and that visual management can play a role in supporting communication between individuals. The thesis argues that visualizations trigger and support the teams' information processing capability through an improved overview together with the use of rich, synchronous and frequent communication using non-canonical boundary objects based on real-time information. Such objects used for task communication increase the team's information processing capability, thereby reducing uncertainty and ambiguity. The thesis contributes to theory on Visual management with empirical evidence of the link between using Visual management and more purposive means of communication. It also discusses the accessibility of information as a prerequisite for information processing, and suggests strategies for improving the accessibility. It also discusses how Visual management can be implemented and evaluated.

KEYWORDS: Visual management, Information processing capability, Task communication, Boundary object, Product development management

Acknowledgements

I am very grateful for the opportunity I have had to work with something I find so interesting and for all the great people I met along the way that I hope will be there also in upcoming adventures. Some people, I owe a big "thank you":

A big, big thank you to Lars Trygg, who inspired me to start researching and has given me continuous support ever since, you have taught me a lot about research, teaching and life. Thanks for your persistent optimism and your faith in me.

Thank you co-supervisors Magnus Persson, Hans Löfsten and Anna Moses. I have always felt your support in whatever I have been up to. Magnus, thank you for all the constructive feedback on this thesis, the great collaboration we had writing one of the papers, and all the support you have given me being my boss. Hans, thank you for teaching me in the art of writing a thesis and really pushing the work towards deadlines. Anna, you are such a source of energy, thanks for all the feedback and inspiration!

Björn Söderberg, you have a big part in this thesis being finished. I am so glad for the time we had at OM. It was epic. I miss you as a colleague, but I am glad to have you as a friend.

Thanks to all the great people I got to know during my time in the industry. Jörgen Furuhjelm, Johan Tingström, Peter Palmer, Per Malmborg, Roine Lundström, Mårten Jansson and Anders Svantesson. Thank you for sharing your experiences, for being interested in my research, and for all the good times. I am sure we meet again. And thank you Stefan Bükk, you really inspired me and challenged my thinking every time we met. I wish we could have done more of that before you left.

I owe a big thank you to Bengt Berglund, Dan Paulin, Lars Holmdahl and Mats Magnusson, who all provided insightful and extremely valuable input on earlier drafts of this thesis.

Thanks to all the great colleagues at Operations Management: Anders Isaksson, Birgitta Engrell, Björn Lantz, Cecilia Åberg, Dan Paulin, Hanna Rydehell, Jan Eklind, Jan Lindér, Jan Möller, Kaj Sunesson, Lise Aaboen, Mats Winroth, Max Pasche, Naghmeh Taghavi, Nina Edh and Torbjörn Jacobsson, I have always looked forward to our tisdagsfika! Thank you Marcus Assarlind, Lisa Carlgren, Marcus Holgersson, Ahmet Sezer and Shahin Mohklesian for all the laughs and interesting conversations.

I am also grateful to Birgitta Engrell and Yvonne Olausson for great support, Göran Gustafsson for a great PhD program at ProViking, Vinnova for funding parts of the research, and Anja Schulze at ETH Zürich for inspiring discussions and an enjoyable and insightful visit in Japan.

Finally, thank you Anette and Lennart for being the absolute best parents possible and my brothers Otto and Filip for being outright awesome. And Stina and Moa, you are my buoy in the bay, my everything.

Göteborg, November 2014

Ludvig Lindlöf

List of appended papers

PAPER 1

Lindlöf, Ludvig; Söderberg, Björn; Persson, Magnus (2012). Practices supporting knowledge transfer - an analysis of lean product development. *International Journal of Computer Integrated Manufacturing,* 2012 s. 1-8. ISSN 1362-3052

PAPER 2

Lindlöf, Ludvig; Söderberg, Björn (2011). Pros and cons of lean visual planning: experiences from four product development organizations. *International Journal of Technology Intelligence and Planning*, 7 (3/2011) s. 269-279. ISSN 1740-2832

PAPER 3

Lindlöf, Ludvig; Trygg, Lars; (2012). Task visualization in product development - improved communication for development teams. *The R&D Management Conference 2012, May 23-25, Grenoble, France.*. s. 153. ISBN 978-0-9559367-4-6

PAPER 4

Lindlöf, Ludvig; Söderberg, Björn (2011). Towards Lean product development – prerequisites for implementing Visual planning. *18th EurOMA Conference, Cambridge, UK.* 2011. *(Currently under review for an international journal.)*

PAPER 5

Lindlöf, Ludvig; Furuhjelm, Jörgen; Tingström, Johan (2012). Increased Flow in the Innovation Process - an Assessment Tool. *The 5th ISPIM Innovation Symposium - Stimulating Innovation: Challenges for Management, Science & Technology*, Seoul, Korea on 9-12 December 2012. ISBN 978-952-265-317-8

PAPER 6

Lindlöf, Ludvig (2014). The "documentation paradox" – on knowledge reuse through document repositories in R&D organizations. *The R&D Management conference – Connecting high value solutions with future markets,* Stuttgart, Germany on 3-6 June 2014. *(Currently under review for an international journal)*

Contents

1 Introduction

This thesis contributes to how product development organizations can improve their ability to handle uncertainty. Uncertainty is troublesome as it limits an organizations ability to plan for and make decisions about the activities that need to be done to reach the objectives of the organization (Galbraith, 1977). The thesis looks at *visual management* as a way to improve an organizations *information processing capability*. This capability is regarded as central to the product development organization (Brown and Eisenhardt, 1995), primarily because it reduces uncertainty (Daft and Lengel, 1986). Ulrich and Eppinger define product development as "*an information processing system that concludes when all the information required to support production and sales has been created and communicated*" (Ulrich and Eppinger, 2008 p.13), and the link between information processing and performance is well established (Keller, 1986; Ancona and Caldwell, 1992). Further, the use of visualization in management has not become as prevalent as in other fields such as marketing (Barry, 1997; Lurie and Mason, 2007) and education (Wall et al., 2005). This can be considered unexpected, especially since management tasks often imply complexity and ambiguity, which requires information processing capability. Additionally, management decisions are often made under time pressure, with high risk of information overload and a need to integrate different expertise. Several researchers acknowledge that visualization seems underutilized in the field of management (Meyer, 1997; Zhang, 2012; Eppler and Bresciani, 2013; Al-Kassab et al., 2014).

1.1 Drivers of uncertainty in product development

The product development context is inherently uncertain. The uncertainty typically stems from both the complexity and novelty of the product or technology that is to be developed, and from organizational complexity, typical in larger companies with many functions and competences that need to be integrated (Tatikonda and Rosenthal, 2000; Lawrence and Lorsch, 1967). Uncertainty can be defined as the

"*inability to predict future outcome*s" (Shenhar and Dvir, 1996) or as "*the difference between the amount of information required to complete a task and the amount of information already possessed by the organization*" (Galbraith, 1977 p.5). Therefore, Galbraith equals uncertainty with the absence of information.

Galbraith further argues that an organization possesses a certain amount of information which is drawn from previous experiences, be it from services, products, customers or process technology. Nevertheless, the organization will need more information in any development project than it currently possesses. It is this gap (between the current and needed information) that the development project aims to close by creating enough information to be able produce and sell a product (Ulrich and Eppinger, 2008; Wheelwright and Clark, 1992). Therefore, with this view of uncertainty, product development becomes an activity of creating and processing information.

Knight (1921) identified an important distinction between *uncertainty* and *risk*. According to Knight, risk refers to an unknown outcome of a situation, but one where the odds of different outcomes can be quantified. Uncertainty, on the other hand, refers to an unknown outcome of a situation, in which we also lack the knowledge to estimate the odds of different outcomes. Knight refers to this "true uncertainty" and elevates it to the level of being the foundation for the organization of an enterprise:

> *"It is this true uncertainty which by preventing the theoretically perfect outworking of the tendencies of competition gives the characteristic form of "enterprise" to economic organization as a whole and accounts for the peculiar income of the entrepreneur."* (Knight, 1921 ch 7, section 48)

This "Knightian uncertainty" is the foundation for the view on uncertainty in this thesis. So what drives uncertainty? Research on uncertainty in product development points out two main internal drivers of uncertainty: *complexity and novelty* (Griffin, 1997; Tatikonda and Rosenthal, 2000). The uncertainty is then further amplified by external uncertainty – a customer changing its mind or new competing or supplementing technologies emerging (Wheelwright and Clark, 1992; Song and Montoya-Weiss, 2001).

Definitions of *complexity* often include the interrelation between different parts of a system; Webster defines complexity as "the state or quality of having many interrelated parts or aspects" (Merriam-Webster.com, 2014a). Therefore, in line with this, system theorists define complexity as a result of 1) the number of elements in a system (for example the number of components in a product), 2) the number of relationships between the elements in a system and 3) the organization and behavior

of the relationships (Flood and Carson, 1993)[1]. Wheelwright and Clark (1992) point out complexity as the main driver of uncertainty:

> *"The problems that uncertainty creates – e.g. the different views on the appropriate course of action, new circumstances that change the validity of basic assumptions and unforeseen problems – are compounded by the complexity of the product and the production process." (Wheelwright and Clark, 1992 p. 8)*

Thus, in a product development setting, the complexity can have several causes such as the quantity, magnitude and type of subtask interactions in a project (Tatikonda and Rosenthal, 2000), the scope of the project (Maylor, 2010), the number of components (Hobday, 1998; Novak and Eppinger, 2001), and organizational complexity (Lawrence and Lorsch, 1967; Baccarini, 1996; Damanpour, 1996). Nightingale (2000) argues that because of the high failure rate, highly complex product development needs to be regarded as something conceptually different to that of less complex product development. Research confirms that with increased complexity, product development becomes more challenging to overview and lead times increase (Clark and Fujimoto, 1991; Chen et al., 2010). The level of complexity associated with product development is the foundation for the need of coordination mechanisms, especially in industries where there is a high demand for innovative and capital intensive products. Companies operating in such industries are dependent on internal coordination mechanisms both technically and organizationally.

Complexity is thus a substantial driver of uncertainty. *Novelty* is the second driver, and it can be defined as "*the newness, to the development organization, of the technologies employed in the product development effort*" (Tatikonda and Rosenthal, 2000 p. 77). Tatikonda and Rosenthal further divide this novelty into product related novelty, i.e., the newness of the product or technology under development, and the process related novelty, i.e., the newness of products or technologies employed to enable the development. Shenhar and Dvir (1996) discusses the relation between "the technological uncertainty dimension" and the nature of product development activities. They draw on Roussel et al's (1991) classification of technologies into base, key, and pacing technologies, and define four types of projects with different technological novelty; they call them projects with low, medium, high and super high technological uncertainty. This is related to the work by Wheelwright and Clark (1992) who classify projects along the same dimension of novelty, referring to it as

[1] Please note, "Complex" can be confused with "complicated", but complicated is often regarded as the opposite of simple, while complex is the opposite of independent; it is related to how easy or difficult it is to overlook the system and foresee the effects of interventions in the system (Lane and Maxfield, 1996).

the level of product change[2]. This is further underlined by Tatikonda and Rosenthal (2000) who also connect the level of uncertainty with the notions of "radical" and "incremental" innovation, again emphasizing novelty as a characterizing aspect of product development. They further argue that practitioners would rather use the term "technology risk" than "technology novelty", and that the risk is closely related to whether they are at the beginning of a project or closer to the end, i.e., it is related to the level of knowledge acquired within the project so far (Tatikonda and Rosenthal, 2000). Griffin (1997) takes this characterization further and argues that the level of novelty as well as complexity must entail strategic implications due to its relation to performance.

Therefore, in handling this uncertainty, the processing of information is a viable strategy. However, sometimes relevant information might be accessible to the individuals of an organization without them acknowledging it. Information must therefore be communicated to where it is actually needed and this, especially in larger, more complex organizations, can be very challenging. Moreover, the mere existence of information might not be the problem, but rather the internal communication of it (Greif, 1991). Thus stimulating such internal communication is considered one of the most important managerial challenges in product development (Allen, 1977; De Meyer, 1991). One of the things discovered in a study from the early 90's on communication within factories, was that

> *"the challenge in a factory of today is not to communicate much and over large distances, but to communicate well within a group of people that work close together" (Greif, 1991 p.16).*

One reason for this statement might be that Galbraith's view of uncertainty is further complicated by the fact that teams and organizations suffer from equivocal information. This means that not only is some information lacking, but the information that does exist is interpreted differently across individuals (Daft and Lengel, 1986).

1.2 Ambiguity in product development

Revisiting Galbraith's definition of uncertainty, it can be argued that the definition does not sufficiently describe the uncertainty experienced in product development projects. The Knightian uncertainty does not refer to uncertainty based only on lack of information, or even a lack of understanding of what a good solution to a

[2] In addition to product change, Wheelwright and Clark describe a second dimension; the process change (referring to the production process) which must not necessarily be related to the product change (Wheelwright and Clark, 1992).

problem might be, but rather a lack of understanding of what the problem really is. Daft and Lengel (1986) elaborate on Galbraith's definition by discussing both 1) uncertainty; which is due to absence of information and 2) ambiguity; which is defined as "*the existence of multiple and conflicting interpretations about an organizational situation*" (Daft and Lengel, 1986 p. 556). It is not only the lack of information that causes uncertainty, but also inconsistent or ambiguous information. Daft and Lengel refer to this as equivocality[3] (Daft and Lengel, 1986). Unlike uncertainty based on lack of information, ambiguity leads to confusion and lack of understanding[4]. It is no longer sufficient to acquire the missing information through asking questions, but one must first understand what questions to ask. This relates well with the nature of the early stages of product development projects, i.e. "the fuzzy front end" (Reinertsen, 1999; Nobelius and Trygg, 2002; Reid and De Brentani, 2004; Brun and Saetre, 2008). Daft and Lengel propose a framework of uncertainty and ambiguity as two complementary forces that influence the information processing of an organization. In the framework, the two forces are clearly distinguished from each other; however the authors acknowledge that they in reality are undoubtedly related. A key concept in Daft and Lengels framework is *information richness,* which they define as "*the ability of information to change understanding within a time interval"* (Daft and Lengel, 1986 p. 560). Thus, in situations with high levels of ambiguity, a capability to process rich information is needed, while in those of low ambiguity, media with less capability to process information is typically considered more efficient.

Schrader et al (1993) studied the technical problem solving process, and in their research, they underline the importance of distinguishing between uncertainty and ambiguity as the concepts imply different use of communication channels and problem solving processes. Consequently, they propose that uncertainty reduction and ambiguity reduction are two different activities in structure and content; uncertainty reduction involves gathering of information and ambiguity reduction

[3] The terms "equivocality" and "ambiguity" are in this thesis considered synonymous; for clarity, the term ambiguity will be used throughout the text. However, it can be noted that a difference in nuance of the two concepts can be seen in Weick's studies, where he defines ambiguity as the combination of equivocality (as a result of confusion) and lack of clarity (as a result of ignorance) (Weick, 1995).

[4] Although ambiguity is typically seen as something negative, it should be noted that some researchers argue for the opposite, that ambiguity is actually providing flexibility and maneuverability in volatile environments, (Eisenberg, 1984; Brun et al., 2008), and that it is a prerequisite for innovation (Ahmed, 1998). Brun et al. (2008) identify several benefits of sustaining ambiguity in product development projects, but they also contend that although ambiguity is a "natural companion" to innovation, sooner or later during a product development project, reducing the ambiguity will become necessary. Thus, this thesis assumes that ambiguity reduction is favorable.

involves constructing and evaluating models to frame the problem in order to bring clarity (Schrader et al., 1993). However, in both cases, the information processing capability is central.

Brun and Saetre (2008; 2009) argue that ambiguity emerges in the understanding of an event. As previously discussed, Knight proposed that risk is when the outcome of an event is unknown, but the probability distribution is known or can be estimated while "true uncertainty" is when the outcome of an event is unknown as well as the probability distribution (typically because the event is unique). Brun and Saetre adds one more level to this argumentation by asking: "*What happens if there is no agreement on what the events are?*" (Brun and Saetre, 2008 p. 577). Thus, ambiguity refers rather more to the formulation of a problem while uncertainty relates to how proficient different solutions to the problem might be.

Further, Brun et al. (2009) suggest a classification of ambiguity into two dimensions; subjects of ambiguity and sources of ambiguity. Subjects of ambiguity refers to what the ambiguity pertains and which includes product, market, process and organizational resources, while sources of ambiguity include multiplicity (when multiple alternative interpretations exist), novelty (when interpretations change over time), validity (whether the interpretations are representative) and reliability (whether the interpretations are consistent). Furthermore, in relation to this thesis, the process ambiguity is of greatest relevance. Process ambiguity refers to ambiguity relating to the development process and its tasks; the tasks themselves, dependencies between them, sequence of them and their input and output. Brun et al. presents several examples of process ambiguity from their empirical studies, such as confusion about the internal process and different terms used, different interpretations of the process due to the introduction of a new process and inconsistent information about the process (Brun et al., 2009). Although uncertainty is a key concept in research on product development, Brun and Saetre argue that research on the nature and management of ambiguity in product development projects specifically, is lacking (Lester and Piore, 2004; Brun and Saetre, 2008).

Thus far, uncertainty and ambiguity have been presented as a foundation to the main problem this thesis is addressing. Previous research points to information processing as a strategy in managing this problem. Next, visualization is discussed as a way of supporting information processing in an organization.

1.3 Visual management

The use of visualizations to communicate between people has existed at least since the cavemen made drawings in the caves. Thanks to the IT-revolution at the end of

the last century, the possibilities of visualizing content through for example computer aided technologies have been substantially improved. The use of visualization in society as well as in business is today both extensive and diverse. Bell and Davison (2013) argue that "*contemporary society has seen an explosion in the prevalence of the visual*" (Bell and Davison, 2013 p.167).

Furthermore, within research on human cognition, visualization plays an important role for central cognitive functions such as finding patterns (Glenberg and Langston, 1992), problem solving (Rieber, 1995), reasoning (Bauer and Johnson-Laird, 1993) and memory (Glenberg and Langston, 1992; Bell and Davison, 2013). Visualization can also play an important role in efficient knowledge transfer (Nonaka, 1994; Nonaka and Takeuchi, 1995). Despite these well-known properties of visualized information, visualization seems underutilized in the field of management (Meyer, 1997; Zhang, 2012; Al-Kassab et al., 2014; Eppler and Bresciani, 2013). However, as previously mentioned, this can be considered somewhat puzzling, as management tasks often include complex problem solving under time pressure with a high risk of information overload and a need to integrate the knowledge of several different experts. Therefore, in this kind of environment, visualization seems to be an attractive communication strategy.

Returning to the product development context, ambiguity is often managed through visual tools such as, e.g., CAD technology and prototyping, which are powerful in reaching consensus, communicating ideas and making decisions (Wheelwright and Clark, 1992; Baba and Nobeoka, 1998; Carlile, 2002; Subrahmanian et al., 2003). The development team typically develops these "scale models" of the current version of the product in order to create good conditions for communication regarding the product. This is often referred to as *technical communication* (Tushman, 1978). However, a development team also use *task communication* extensively (Hirst and Mann, 2004), i.e., the communication regarding the development process and the activities and objectives entailed by that process. When it comes to visualization, task communication has not received as much attention as that of technical communication. Contemporary research on visualization in product development is typically focused either on the visualization of products and concepts, or on the visualization technology itself, including topics like rapid prototyping, rendering, and virtual reality (Card et al., 1999).

Turning to literature on how product development processes are typically represented, one finds that such visualizations are often representations of the conceptual, or ideal process, rather than "scale models" of the actual process. Examples of this include Gantt charts (Ulrich and Eppinger, 2008), process visualizations (Fagerström, 2004) and roadmapping (Barker and Smith, 1995).

Wheelwright and Clark (1992) use the funnel as a metaphor for the development process. Further, in an experiment, they ask managers to draw the funnel that they perceive actually exists in practice in their respective organization. Not surprisingly, their funnels differ substantially from each other and from the "ideal" funnel. This indicates a communicative problem when trying to understand the development process at a company. This is further complicated if we turn from canonical practices – the formal work descriptions and conceptual models of the process to the non-canonical practices – the actual activities and deliverables of the development team (Brown and Duguid, 1991). Thus, there is a need for visualization of non-canonical processes.

1.4 Main research purpose

In summary, product development implies a need for information processing capability due to its complex and uncertain nature. Visualization seems to be able to provide a support for information processing in R&D organizations, but the research on visualization in management – especially when it comes to task communication in teams – is not as developed as in other fields. Thus, the overall purpose of the research presented in this thesis is:

to explore visual management and its use in product development organizations.

The research presented in this thesis focuses on the visualization of the information needed for R&D managers and teams to communicate and coordinate tasks and activities. The thesis intends to discuss visual management from a theoretical perspective as well as from a practical perspective.

1.5 Thesis outline

After this short introduction to the subject and presentation of the overall purpose, this thesis will present the frame of reference used to address the purpose. The frame of reference consists of two main parts; a review of the information processing capability of an organization, and a review of the field of Visual management, with a focus on the R&D context. The first part on information processing provides both a central organizational capability for Visual management to relate to, and also a description of the context of the studies; the R&D organization. The frame of reference is directed towards the formulation of three research questions, which aim to concretize the overall purpose.

The research questions provide important input to the methodology chapter, which discusses the research design and overall methodological considerations as well as

the relations between the research questions and the appended papers. Executive summaries for those papers are compiled in chapter 4.

Chapter 5 provides an analysis of the findings presented in the appended papers on the basis of the frame of reference presented in chapter 2. The chapter provides answers to the three research questions. Finally, the sixth chapter concludes the thesis by summarizing the main findings in relation to the overall purpose and pinpoints the main contributions and directions for future research.

2 Frame of reference

This chapter presents the frame of reference for this thesis, which provides a structure of concepts and definitions that are relevant to the overall research purpose. The chapter consists of the review of two main theoretical fields that are considered central. First of all, a review on *information processing* in a product development organization is presented. This includes a discussion on existing literature on information processing and its relation to communication within product development organizations. The review leads into the second part dealing with *visual management* as a research domain. Visual management is distinguished, and a review of literature is presented to emphasize and justify the research and the need for further contributions. Furthermore, within the chapter, some areas in need of development are identified, which serve as the primary input for the formulation of the three research questions that are presented towards the end of the chapter.

2.1 Information processing in product development

Product development is characterized by uncertainty and ambiguity as discussed in the introductory chapter. Every new product development project implies that new information is needed. This happens in an environment that is constantly changing. Moreover, in such an environment, methods for proficient execution of tasks are highly relevant. Obviously, the reduction of uncertainty or ambiguity along any strategy will not only require acquisition of information, but also transfer of that information to individuals and teams making decisions. However, in many cases, important information might be accessible to the people in an organization, without them being aware of it. This implies that the existing information in the organization must be communicated to the right place at the right time. For example, the extensive research on concurrent engineering (e.g. Wheelwright and Clark, 1992; Ford and Randolph, 1992; Song et al., 1997; Loch and Terwiesch, 1998; Ernst et al., 2010) shows that this is a very challenging task; especially in large complex organizations. Nevertheless, the existence of information is not necessarily the problem, but rather the internal communication of it (Greif, 1991). Thus, a general definition of information processing in organizations typically includes gathering of

data, transformation of data into information and the communication and storage of information in the organization (Galbraith, 1973; Tushman and Nadler, 1978).

When discussing organizational information processing, a conceptualization of information should be helpful. A rather pragmatic view is represented by the conventional data-information-knowledge hierarchy (Davenport and Prusak, 1998) in which knowledge derives from information and information derives from data. Information in this model is described as a message; i.e. it has a sender and a receiver, and the purpose of it is to impact the receiver, and it can come in the form of documents or audible or visible communication (Davenport and Prusak, 1998). The data-information-knowledge hierarchy is subject to much criticism as it does not capture the complexity of knowledge and neglects interpretation. Braganza (2004) and Tuomi (1999), for example, suggest that the hierarchy should be inverted; i.e., data is derived from information and information is derived from knowledge, as knowledge must exist before information can be formulated and data collected. Further, Alavi and Leidner (2001) point out that knowledge is more than an abstraction of data and information, as knowledge is personalized and therefore relative. Nevertheless, the view of information as presented by the data-information-knowledge hierarchy should be sufficient for use in this thesis[5].

Also, organizational information processing theory can relate both to the individual organizational participants' processing of information, and the organizational systems and structures that contribute to information processing (Choo, 1991). This thesis focuses on the latter.

2.1.1 Why organizations process information

The *information processing* approach to analyzing organizations constitutes a stream of organizational research. One of the purposes of the approach is to better understand the information needs of an organization; how and why is information used? According to Daft and Lengel (1986) and Choo (1991), two streams of research on organizational information processing are predominant and they, to some extent, correspond to the distinction between uncertainty and ambiguity. Daft and Lengel (1986) argue that a common answer as to why organizations process information is: they do it to reduce uncertainty. The stream of research building upon that assumption views organizations as rational decision making systems (Choo, 1991). According to Daft and Lengel, the logic is based on the work of organizational researchers such as Burns and Stalker (1961), Lawrence and Lorsch (1967) and Galbraith (1977). However, some researchers provide a different answer to why organizations process information: they do it to reduce ambiguity. According

[5] Also, see paper 1 for a conceptualization of *knowledge*.

to Daft and Lengel (1986), this stream of research builds upon Weick's (1979) argument that ambiguity reduction is a basic reason for organizing. The organization in this case is viewed as a loosely-coupled system or as an interpretation system (Choo, 1991)[6].

Daft and Lengel (1986) combine these two views by describing organizational information processing as containing two types of organizational activities; obtaining data to reduce uncertainty, and interpreting ambiguous situations. They base their view of organizational information processing on three basic assumptions: 1) organizations are open social systems that must process information, but have limited capacity, 2) interpretation on an organizational level as opposed to an individual level includes the convergence and compromise of several individual interpretations, and 3) the organizational division of labor increases the need for organizational information processing. The information processing perspective of product development conceive organizational units as social networks that have information-processing capabilities (Galbraith, 1977; Emmanuelides, 1993). This view relates effectiveness to the fit between available information-processing capabilities and information-processing requirements of the task at hand. Nevertheless, an organization must have enough capability to handle increased information requirements (Galbraith, 1977). Both Galbraith (1977) and Tushman and Nadler (1978) argue that there must be a match between the information processing requirements of the organization and the information processing capability. Thus, organizations need to develop these information processing capabilities. Premkumar et al. (2005) investigated the fit between these capabilities and requirements and found that it significantly affects performance in an inter-organizational supply chain context. The more complex and interconnected the tasks in product development are, then the higher the information processing requirements (Tushman and Nadler, 1978). Therefore, in order to manage these requirements in product development, the capability to process information in the organization is of high importance (Leifer and Mills, 1996). For example, the richness and timing of information affect the product developers' ability to act and make quick decisions on accurate and real-time information (Wheelwright and Clark, 1992; Zirger and Hartley, 1994). Zirger and Hartley (1994) present a framework in which information processing capability is divided into three components: 1) the extent of information sharing, 2) the timeliness of information processing and 3) the speed of decision-making.

[6] See Daft and Weick (1984) for reading on the view of organizations as interpretation systems.

The extent of information sharing is proved to be related to the performance of the development teams (Allen, 1977). The more complex the tasks are, the more information needs to be processed (Tushman and Nadler, 1978). Clark and Fujimoto (1991) point out the need for what they refer to as intensive communication in product development projects, with "rich, bidirectional information flows". Allen (1977) identified that not only a higher frequency of contacts with colleagues, but also the number of colleagues contacted contributed significantly to richness of communication and performance of product development efforts. Further, the richness of the communication affects the extent and quality of the information being shared, where for example, face-to-face communication is a richer mode of communication than information sharing through documents and IT systems (Wheelwright and Clark, 1992; Becker-Beck et al., 2005). Face-to-face is also considered a two-way communication mode to a greater extent, since the feedback is direct both verbally and also through body and facial expressions (Daft and Lengel, 1986). It is a form of dialogue, whereas documents such as e-mails, reports and memos are one-way communication tools and less rich in format (Ivanvevich et al., 1977; Wheelwright and Clark, 1992; Timmerman and Madhavapeddi, 2008).

The timeliness of information processing is very important for product development success, especially in a complex environment. Without accurate information at critical decisions points, the product designs might later have to be modified, reworked or re-created, causing an extensive prolonging of the process (Zirger and Hartley, 1994). Further, if information is received at the right time, the processing of this information becomes a performance driver in the organization (Hultink et al., 2010). Wheelwright and Clark (1992) specifically discuss the aspect of timing in cross-functional integration, where upstream engineers need to find the right timing for the release of information so that other functions within or outside the development function can start preparing their own decision making processes. Decisions are made constantly in an organization, and they directly affect the speed of completing product development tasks.

Thus, in a fast-moving and complex setting, *the speed of decision making* could be the difference between success and failure (Ireland and Miller, 2004). Eisenhardt (1989b) identified two characteristics of fast decision-makers. 1) the fast decision-makers were often using more information than the slow decision-makers and relied more on richer media such as face-to-face communication. They also use a large number of indicators and data. 2) the use of real-time information was emphasized to a higher extent by the fast decision-makers. Zirger and Hartley (1994) argue that time can be saved in product development through making decisions on the lowest

practical level. This argument is supported by Galbraith's model arguing that decentralization will make the point of decision closer to the source of the information (Galbraith, 1977).

Galbraith emphasizes certain strategies based on his view that organizations strive to improve their ability to process information (cf Tushman and Nadler, 1978). The strategies are based on the level of task uncertainty to which the organization is exposed. Furthermore, in an environment with low task uncertainty, three basic strategies are recommended: 1) rules for decision making 2) organizational hierarchy and 3) goal setting. All three strategies aim to support the individual in decision making, and are regarded as the basis for further work. However, these strategies will become insufficient as uncertainty continues to rise. At this point, the organization can choose whether to further increase its ability to process information, or reduce the amount of information that needs to be processed, or both. These two strategies are illustrated in Figure 1.

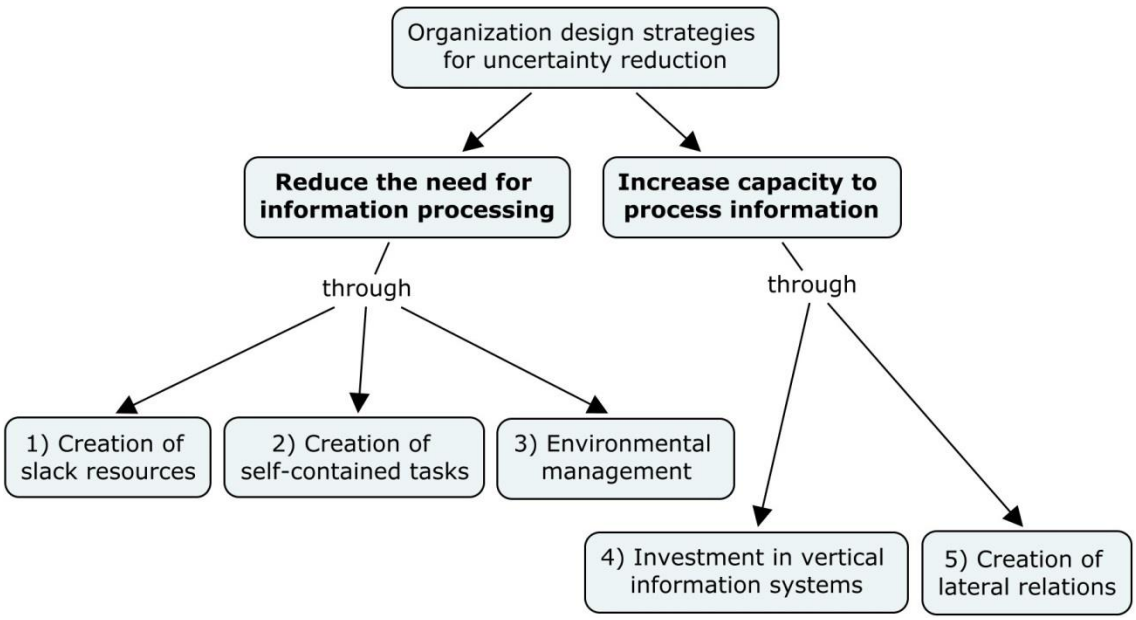

Figure 1: Organization design strategies, from Galbraith (1977)

Furthermore, in order to reduce the information processing need, the organization can 1) create slack resources, reducing the performance level, 2) create self-contained tasks, i.e., isolated teams that have all the resources needed to perform their specific and delimited task, or 3) attempt to modify the environment in which it operates. If the organization instead chooses to increase its information processing capability, two other strategies are recommended; 4) create vertical information systems to improve the flow of information in that dimension, or 5)

create lateral relations. Lateral relations move the point of certain lateral decisions lower in the organizational hierarchy, which is assumed to be more efficient because this is where the information needed for the decision exists. Both Galbraith's strategies for increased information processing capability imply more communication throughout the organization.

2.1.2 Accessibility of information

A prerequisite for information processing is that the information is accessible. O'Reilly (1983) argues that "*Before information can have an impact, however, it must both reach and be processed by the relevant decision makers."* (p. 117) Thus, there is a distinction between making the information accessible, and processing it. Accessibility can be related to the effort required by the individual who wants to access it. The most accessible information requires the least effort (Anderson et al., 2001). This is arguably the reason why accessibility is the most prominent factor affecting the use of information (Leckie et al., 1996; Fidel and Green, 2004). Further, research on accessibility shows that decision makers are biased in their procurement of information. O'Reilly (1982), for example, found that decision makers preferred information that was more accessible even though they knew of information sources with higher quality, but less accessibility. He also found that managers prefer oral as opposed to written information, and argues that it is a consequence of the bias towards accessible information.

An important distinction which is according to Fidel and Green (2004) often overlooked is the one between *ease of access* and *ease of use*. Ease of access relates to the physical accessibility, i.e., "can I search for and find what I am looking for?", while ease of use relates to intellectual accessibility, i.e., "can I make sense of what I find?". These two components of accessibility are not always easily distinguished. Fidel and Green (2004), for example, discuss the finding that engineers use their co-workers as a primary information source and conclude that it is from their data impossible to tell if that is due to ease of access (co-workers are physically or organizationally in close priximity) or due to ease of use (co-workers are familiar and established relations which lowers the intellectual effort to use the information).

2.1.3 Task communication in R&D

Brown and Eisenhardt (1995) identify, in their comprehensive review of product development literature, the view of the development organization as a communication web as one of three dominating views. This view is closely related to the view of an organization as an information processing entity (Allen, 1977; Galbraith, 1977). This information processing view emphasizes among other things that

> *"frequent and appropriately structured task communication (both internal and external) leads to more comprehensive and varied information flow to team members and, thus, to higher performing development processes"* (Brown and Eisenhardt, 1995 p.358).

A lot of research has been done on team communication within this stream of research, and as expected several studies show that team communication is related to improved project performance (Keller, 2001; Brodbeck, 2001; Hirst and Mann, 2004). Engineers spend a substantial part of their time communicating with each other (Tenopir and King, 2004; Gopsill et al., 2013). Several researchers have appreciated the portion of time spent on communicating, and they typically end up in the region 40-75% (Vest et al., 1996; Dyke and Wojahn, 2000; Hertzum and Pejtersen, 2000; Tenopir and King, 2004).

Two types of communication are dominating the communication within product development teams; *technical communication* (Tushman, 1978; Morelli et al., 1995) which regards communication around the products and concepts, and *task communication*[7] (Hirst and Mann, 2004) which regards the process itself and the planning and execution of tasks. This type of communication has not been treated as rigorously as the technical communication in management research, and in particular the visualization of such information is partially neglected.

Task communication is about communicating information regarding the planning and execution of tasks, rather than the content of them, i.e., problems regarding who does what and when are discussed, rather than problems regarding the design or customer requirements. Research on task communication shows that it is a strong predictor of project performance (Hirst and Mann, 2004; Koufteros et al., 2005). Hirst and Mann operationalize task communication as a combination of 1) clarity of objectives, 2) feedback regarding the projects performance, 3) circulation and accessibility of relevant information and 4) clarity of customer requirements. Hirst and Mann's (2004) framework for team communication describes communication as a mechanism to translate, share and integrate information. They relate their model of team communication with different project performance measures, and find strong support for the relationship between task communication and a high rating of the project performance from the teams. However, they do not deal with the actual mechanisms of how these aspects are managed in the teams.

[7] A third type of communication is the *social communication* (Tenopir and King, 2004), which proves to be of great importance to for example building trust in a team (Jarvenpaa and Leidner, 1999). Social communication is however not treated as a central topic in the thesis.

2.1.4 Boundary object as a means of communication

Communication is sometimes seen as a transactional process between a sender and a receiver. The transaction employs some kind of channel, and things that hinder the transaction are labeled noise. Feedback from the receiver back to the sender can also occur. This basic view of communication can be traced back to the 40's (Shannon and Weaver, 1949). Their model is often considered simplistic because of its neglect of interpretation of the sent message, but is nevertheless a dominating model of communication in management literature (Boland and Tenkasi, 1995). The following section presents a means of establishing a channel for communication; the boundary object.

Boundary object theory presents a potential for managing the ambiguity in product development teams. Boundary objects are objects, often physical artifacts that mediate communication between individuals or groups of individuals with different perceptions of the topic or content that is communicated, e.g., a prototype of a product can serve as a center of attention for individuals with different agendas or perspectives, for example, based on their level of knowledge or organizational identity. The idea of a boundary object dates back to Star and Griesemer (1989) and their seminal work on the sought after balance between heterogeneity and cooperation in a team. They describe the process of creating and managing boundary objects as a "*key process in developing and maintaining coherence across intersecting social worlds*" (Star and Griesemer, 1989 p. 393). Star defined boundary objects as "*objects that are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites*" (Star, 1989 p. 46). This means that boundary objects can have different interpretations to different individuals, but still entail a structure that is common enough to facilitate a translation between these interpretations.

Star and Griesemer discuss boundary objects as something that enables collaboration between individuals despite their differing viewpoints (Star and Griesemer, 1989). Their initial example of a boundary object is the dead bird, used for different purposes by individuals with different interpretations; the amateur bird watcher and the professional scientist. Brown and Duguid (1998) subscribe to this view of boundary objects, arguing that boundary objects are of interest to different stakeholders, but are viewed and used differently by them; the role of a boundary object is to clarify other stakeholders' attitudes and make own presuppositions apparent to oneself (Brown and Duguid, 1998). Later, the use of boundary objects in theory seems to have shifted towards not only bringing different viewpoints together in one object, but also to create a common viewpoint of the individuals. For example, Koskinen (2005) and Bechky (2003) argue that boundary objects make

it possible to arrive at common understanding. This can be seen as a development of the concept, but it has also raised criticism towards the usefulness of the concept being overly including (Zeiss and Groenewegen, 2009; Star, 2010; Nicolini et al., 2012). Further, the theory of boundary objects is criticized for being rather descriptive and taxonomic rather than explaining how a boundary object functions (Fox, 2011). Boland and Tenkasi (1995) present a solution to this problem in their comprehensive discussion on boundary objects as an enabler of "perspective taking". They argue that the opportunity for knowledge work is dependent on an individual's ability to take on other individuals' perspectives. To do that, his or her own perspective needs to be made explicit, or even visible. They state that:

> *"Once a visible representation of an individual's knowledge is made available for analysis and communication, it becomes a boundary object and provides basis for perspective taking".* (Boland and Tenkasi, 1995p. 362)

Thus, members of a community cannot reach full consensus, or a common understanding, but they can create conditions under which the perspective taking process can take place. This means that boundary objects do not necessarily convey a common understanding on which collaboration can build, but enable a conversation without enforcing a shared understanding (Boland and Tenkasi, 1995).

Many scholars in different fields of research use boundary object theory as a mechanism for communication. Medical records in healthcare, for example, can be considered effective boundary objects that enhance communication between different roles both within and outside the hospital (Berg and Bowker, 1997). Eppler and Pfister (2013) find the use of boundary objects in police investigations and military operations. Other examples of the application of boundary objects include business models (Doganova and Eyquem-Renault, 2009), narratives (Bartel and Garud, 2009) and IT systems (Pawlowski and Robey, 2004). All of these examples show that boundary objects are a powerful means of communications in settings where individuals with different perceptions of the communicated content need to work together.

Star and Griesemer argue that boundary objects are relevant in cases where both heterogeneity and cooperation are central (Star and Griesemer, 1989). Product development is such a case, where both different competences and an integration of those competences are needed. Boundary objects are often used as a method for knowledge integration, which is a central research stream within product development theory (Berggren et al., 2011). Several authors argue that successful product development is dependent on how individual knowledge bases are integrated (Enberg et al., 2006; Dougherty, 1992; Eisenhardt and Tabrizi, 1995;

Zollo and Winter, 2002). A boundary object is a way to achieve this knowledge integration. When developing products, boundary objects are often used in the form of prototypes and 3D models of the product (Henderson, 1999; Bechky, 2003). This is done with the intention of reducing the ambiguity about the product. The same mechanism may be useful for the development process, in order to improve task communication while at the same time lowering the ambiguity regarding the process. However, little is known about the use of boundary objects in relation to product development processes (Koskinen, 2005).

2.2 Visual Management

Following the review on information processing in organizations, this section will go into previous research on visualization in management and later more specifically in product development

2.2.1 Visual cognition

The effects of visualization from a human cognitive perspective is a well-populated research area, studies show that it plays an important role for central cognitive processes that help us function as thinking and communicating humans. Table 1 presents an overview of researchers highlighting different cognitive functions that are reinforced by the use of visualization.

COGNITIVE FUNCTION	AUTHORS
Information processing capacity	(Miller, 1956), (Larkin and Simon, 1987)
Identifying patterns ("Gestalt psychology")	(Koffka, 1935), (Ellis, 1938), (Glenberg and Langston, 1992)
Memory	(Kosslyn, 1980), (Shepard and Cooper, 1982)
Learning	(Mandl and Levin, 1989), (Weidenmann, 1989)
Problem solving	(Rieber, 1995), (Finke, 1990)
Reasoning	(Bauer and Johnson-Laird, 1993), (Novick, 2001),
Comprehend verbal information	(Kosslyn and Koenig, 1992)

Table 1: *Cognitive functions reinforced by visualization. Expanded from Burkhard (2005a)*

The *dual coding theory* formulated by the psychologist Allen Paivio is useful (Paivio, 1971; Paivio, 1991) in order to understand the very foundation of visualization. According to Paivio's theory, an individual processes information through two cognitive channels. One of the channels processes verbal information such as words, whether they are written or spoken. The information in this channel can be

characterized as arbitrary[8] (i.e., there is no logical reason why the object car is represented by the word "car") and sequential (i.e., the words in a text are presented in a certain order which is crucial for conveying meaning). The other channel processes non-verbal information such as images. The information in this channel can, on the other hand, be characterized as spatial, non-arbitrary (i.e., there is resemblance between the image and the reality), and continuous (i.e., an image is interpreted in its entirety, not sequentially). Paivio refers to the information as representation units, in the verbal channel the units are called logogens, and in the nonverbal channel the units are called imagens. Using Paivio's theory, Rieber defines visualization as: "… *representations of information consisting of spatial, non-arbitrary and continuous characteristics*" (Rieber, 1995 p. 45).

The two channels are interconnected so that a word can evoke pictures, and pictures can evoke words. Paivio presents three main types of information processing based on these two channels: 1) *Representational processing*, in which a certain channel is activated by its representing unit, e.g., when the word "car" triggers the car logogen, or seeing a car triggers the car imagen. 2) *Referential processing* is when a representation unit triggers the opposite channel, as when the word "car" triggers an image of a car – a logogen triggering the nonverbal channel. 3) *Associative processing* is when a representation unit triggers other units within the same channel, e.g., if the word "car" triggers associative words like "road" or "garage".

Information can also be processed in both channels at the same time, for example, when you see a car (imagen) and at the same time hear or read the word car (logogen). This kind of double processing improves the individual's ability to recall. Paivio refers to this as the *additivity hypothesis*. The hypothesis suggests that an individual can more easily recall information if it has been presented to them using both channels, as opposed to only using one of them.

Paivio also discovered that people are generally better at recalling a series of pictures than a series of words. This is also referred to as the *pictorial superiority effect* (Nelson et al., 1976), which might be related to the fact that meaning or semantic information is more readily accessible through pictures than through words (Smith and Magee, 1980).

Visualization enables so called *deictic gesturing,* or *deixis*, which can be described as "*The act of indicating something by pointing is called a deictic gesture in human communication theory. Often such a gesture is combined with speech so that it links the subject of a spoken sentence*

[8] Some languages use however pictograms in writing, in which case, the symbols are often not arbitrary but have some sort of resemblance with reality.

with a visual reference" (Ware, 2012 p. 334). Deictic gestures are a quite an elementary method, but provides a link between verbal and visual information, and makes referencing of objects and sequences of objects less ambiguous (Chapman, 2002; Ware, 2012). Tang studied team-based problem solving using "work surfaces" (large sheets of papers), and showed that gesturing was an important part of the work surface activity, as approximately 35 % of all work surface actions were gestures, and provided an aid in enacting ideas and focusing attention of the group (Tang, 1991). Bly (1988) also studied gesturing in teamwork, and found that in a face-to-face situation, more than half of the events she observed were gestures[9]. Both Bly and Tang call for more specific research into how tools can support deictic gestures.

2.2.2 Visualization for managerial purposes

Therefore, in the light of these findings regarding the relations between visualization and cognitive functions such as the ability to enhance the processing of information, one could expect that the use of visualization in management would be widespread. Management tasks often imply complexity and ambiguity, and management decisions are often made under time pressure, with high risk of information overload and a need to integrate different expertise. However, as already mentioned, several researchers acknowledge that visualization seems underutilized in the field of management (Meyer, 1997; Zhang, 2012; Eppler and Bresciani, 2013; Al-Kassab et al., 2014). Although there is a change happening, and the following quote serves as an indication that the emphasis on visualization in management might increase: "*It is an idea whose time has come: the use of visualization in management"*. (Eppler and Bresciani, 2013 p. 146). Such a research agenda with a shift from the verbal to the visual would for management research imply a similar trend as identified by Bell and Davison (2013) in other fields within the humanities and social sciences, but also in interdisciplinary studies and within management research itself, as suggested by Bell and Davison (2013).

Eppler and Burkhard identified a need to define a research field in the boundary region between Knowledge Management and Visualization (Burkhard, 2005a; Eppler and Burkhard, 2007). They saw that from a managerial perspective, there is a need for a platform to discuss visualization and its role in improving management communication and decision making. They refer to it as "Knowledge visualization" and they distinguish it from adjacent areas such as "information visualization" and "visual communication". Burkhard defines it as:

[9] Bly studied three types of events during teamwork; draw, write and gesture. She also found that gesturing was used during telephone meetings, although the team members couldn't see each other (Bly, 1988).

> *"Knowledge visualization examines the use of visual representations to improve the transfer and creation of knowledge between at least two persons"* (Burkhard, 2005b p. 242).

Further, they describe knowledge visualization as a broad set of purposes and methods which goes beyond the dissemination of information:

> *"Knowledge visualization designates all graphic means that can be used to construct, assess, measure, convey or apply knowledge (i.e. complex insights, experiences, methods, etc.). Beyond the mere transport of information or facts, people who employ knowledge visualization aim to create, assess, reference or transfer insights, experiences, attitudes, values, expectations, perspectives, opinions and predictions, and this in a way that enables someone else to re-construct, remember, find or apply these insights correctly"* (Eppler and Burkhard, 2007 p. 112).

According to Burkhard (2005a), the need to distinguish knowledge visualization from information visualization has at least three underpinnings: 1) in an era of intense digitalization, information visualization research tends to disfavor non-computer based visualization, in fact, in Card et al's definition of information visualization, the term "computer-supported" plays a prominent role: "*Information visualization is the use of computer-supported, interactive, visual representations of abstract data to amplify cognition* (Card et al., 1999 p. 637)." 2) Information visualization focuses primarily on explicit knowledge, while in Knowledge management, the distinction between explicit and tacit knowledge is acknowledged as central to Knowledge management activities. Research on visualization in management needs to include the tacit dimension of knowledge to a greater extent. 3) Knowledge about visualization relevant for management is dispersed over several knowledge domains, such as information management, cognition, communication science, learning, art and so forth. An alignment of relevant topics under one umbrella enhances the possibilities for further studies and knowledge development.

Burkhard suggests that the framework for knowledge visualization contains four central perspectives (see table 2): 1) the function of the visualization, i.e., what is the visualization used for? 2) the type of knowledge transferred, 3) the type of recipient, i.e., is it one or more individuals? Burkhard also argues that knowledge visualization could be used at all organizational levels, not only in the role of managers. 4) Type of visualization; Burkhard classifies knowledge visualizations into seven categories (Burkhard, 2005a).

FUNCTION	KNOWLEDGE TYPE	RECIPIENT	VISUALIZATION TYPE
Coordination Attention Recall Motivation Elaboration New insight	Know-what Know-how Know-why Know-where Know-who	Individual Group Organization Network	Sketch Diagram Image Map Object Interactive visualization Story

Table 2: *The four perspectives of Burkhard's knowledge visualization framework (Burkhard, 2005a)*

2.2.3 Visual management in product development

Taking a closer look at the use of visualization in product development, several findings of relevance for this thesis emerge. Indeed, ambiguity is to some extent handled through visualization tools and methods. However, it becomes clear that, literature discussing visualization from a management perspective is typically related to *product visualization*. Two dominating streams within contemporary research on visualization in product development are: 1) research focused on the visualization of products and concepts, and 2) research focused on the visualization technology itself, including topics like rapid prototyping, rendering, and virtual reality (Card et al., 1999).

Perhaps the most obvious examples of product visualization are CAD technology and prototyping, both being a powerful means of communicating and making decisions (Wheelwright and Clark, 1992; Baba and Nobeoka, 1998; Carlile, 2002; Subrahmanian et al., 2003). Thus, developers often construct "scale models" of products and concepts to establish good conditions for technical communication regarding the product or concept. However, a substantial portion of the communication in a development organization is regarding the planning and execution of tasks; the task communication

An example of a visualization that addresses task communication is the representation of the development process. These representations are often conceptual; they embody a role model of what the process should look like also in practice. A common visualization of a development process is using the funnel as a metaphor, where a broad input is converged through a series of strategic and design-related decisions into the narrower part of the funnel which symbolizes the project execution and delivery (Wheelwright and Clark, 1992). Depicting the process as a funnel provides a "…*graphic structure for thinking about the generation and screening of*

alternative development options…" (Wheelwright and Clark, 1992 p.111). However, using visualization like this is not necessarily unproblematic. Wheelwright and Clark conducted an experiment where managers are asked to draw the funnel as they perceive it in reality. They found that the visualizations made by the managers differed substantially from each other as well as from the "ideal" funnel.

Further, as mentioned in the introductory chapter, the problem of mismatches between conceptual and actual processes is described by Brown and Duguid (1991). They distinguish between canonical practices – the formal work descriptions and conceptual models of the process, and the non-canonical practices – the actual activities and deliverables of the development team. Brown and Duguid see a risk of using canonical practices, they "*can blind an organization's core to the actual, and usually valuable practices of its members*" (Brown and Duguid, 1991 p.41). Consequently, managers need ways to visualize and communicate the non-canonical practices.

Other visualizations rather aim at visualizing activities with a higher resolution, such as Gantt charts (Ulrich and Eppinger, 2008). The Gantt chart is a widely visual method used to describe the phases and progress of, for example, a project. It is able to present a large amount of information, which can be adapted to the users' information needs (Wilson, 2003). However, Taxén and Lilliesköld (2008) argue that in a complex and dynamic project environment, the Gantt chart might become too complex and overwhelming to use, and too static. They are less useful in highly volatile environments. Maylor (2001) criticizes the Gantt chart of being a blunt instrument for project management.

Perhaps one of the most obvious examples of visualization for task communication is the process map. Most organizations visualize their product development process in one way or another. Many of them are inspired by the stage-gate model (Cooper, 1993), but it can also be represented, for example, by a funnel (Wheelwright and Clark, 1992) or something more circular (Buijs, 2003), which is more common in software development. The purpose of such process modelling can be to map processes for improvement, better understanding of information flows, relations between processes, planning, coordination, and they are also often the basis for evaluation of quality systems (Negele et al., 1999; Fagerström, 2004). The process map is a typical example of what Brown and Duguid would call a canonical practice (Brown and Duguid, 1991).

2.2.4 Visual management in product development teams

Thus far, this chapter has discussed what visualization is, and how it is used in management in general, and in product development in particular. This section will discuss visualization from the perspective of the smallest organizational entity, the

team. There are several ways of visualizing information in product development teams. Furthermore, in Lean literature, the *Obeya*[10] is one of the most recognized methods (Morgan and Liker, 2006; Oosterwal, 2010). Morgan and Liker (2006) describe the Obeya as a large room with visualizations of both processes and products, and it is used by engineers to meet and have workshops on a certain design issue. The engineering team does not typically have meetings on a regular basis in the Obeya, but rather workshops based on the visualizations in the room focusing on the product. The Obeya can also contain additional information and tools that can be useful in the design process, such as CAD systems, simulations and test-results (Morgan and Liker, 2006). The Obeya is described primarily as a vehicle for technical communication.

2.2.5 Visual planning

A team must navigate through an uncertain environment in order to perform the tasks assigned to them and deliver products that are manufacturable and sellable. Ulrich and Eppinger (2008) describe projects as divided into two phases: the planning phase involves determining resource requirements and scheduling of those resources, and the execution phase involves execution, coordination and facilitation of the tasks required to fulfill the aim of the project. Ulrich and Eppinger claim that in the execution phase, "*many teams fail because they do not remain focused on their goals for the duration of the project*" (Ulrich and Eppinger, 2008 p.334). During the execution phase of a project, the team must make sure on a daily basis that tasks are assigned, resources are allocated, deliverables are assured and that the team stays focused on the common goal.

One method for development teams to handle this task coordination is to visualize tasks and deliverables to enhance their communication and coordination within the team. The method is sometimes called "*Visual planning*" (Lindlöf and Söderberg, 2011) or "*Visible planning*" (Hines et al., 2006). Briefly, Visual planning is a method where activities and deliverables are outlined and illustrated on a physical board and discussed at frequent meetings (Lindlöf and Söderberg, 2011). **Figure 2** shows an illustration of such a meeting.

The concept is sometimes confused with the Obeya, but it should rather be considered a possible component of an Obeya system (Oosterwal, 2010). The principle of establishing visual aid to enhance the communication of the team tasks is similar, but the timeliness and length of the meetings differ as well as the visualized content, which creates different communication patterns. The following sections will present and discuss previous studies on Visual planning.

[10] Obeya is Japanese for "large room".

Figure 2: *Illustration of a team using Visual planning (Illustration: Jimmy Wallin)*

Olausson and Berggren (2010) studied a product development organization in order to search for an approach to manage complexity and uncertainty simultaneously. They identified four key ingredients essential to such an approach. One of them is labeled "Transparent visual communication tools". The members of the studied project team used a visual iterative planning process similar to visual planning, and according to the study, the use of visual planning resulted in smoother workflows, clarified expectations and it supported the prioritization among tasks. The project manager also stated that in comparison to other projects, visual planning facilitated rapid interaction, revealed mismatches between the projects master plan and the subproject plans. It also supported spontaneous discussions.

Olausson and Berggrens study points out a drawback of using the method. The planning process became more time-consuming, as it involved around 100 team members simultaneously. Hence, the amount of team members seems to be an important factor when using interactive planning methods. The fact that the study does not explain what Visual planning in this context includes, how the Visual planning is used, or what kind of information is being visualized, leaves room for further research, and the claims about improved communication seem to be based solely on the statements of two project managers which calls for more rigorous research. However, in a previous study, Berggren et al. (2008) discuss the value of project management as a mechanism for knowledge integration. This knowledge integration could require images and artifacts, and the communication of these images and artifacts could be supported by a forum of some sort. Also in this study, Berggren et al leave out what kind of information is visualized and how. The case they have studied is a large Swedish electronics company. The company used a forum for detecting and handling deviations. The forum consisted of daily meetings described as hands-on problem solving and status checking. One of the main purposes with the forum in this case was to improve vertical communication; the presence of senior management was considered central in the forum. This is an important difference to the study from 2010 where the focus of the Visual planning was on lateral, intra-project communication.

Turning to the research on lean product development[11], Hines et al. (2006) provide a contribution to the knowledge on Visual planning. They present a six stage framework for Lean product development where KIVP – "Knowledge Innovation Visible Planning" is one of the steps[12]. Hines et al base their notion of Visual planning on the idea of KIVP developed by JMAC; a Japanese management consultancy. KIVP as a method starts with an assessment of current status. After the initial assessment, the "visible planning" part starts when the required project tasks are defined and illustrated on a board. The board is then used to plan, monitor and execute the project. Central to the KIVP method are the daily ten-minute meetings in which the team members can see what their tasks are, what other members are doing, and where in time the interactions and handovers occur,

[11] Visual planning along with other visualization methods is often treated as a component of the emerging framework for how Lean principles can be translated into a product development setting. Visualization itself is a prominent concept in literature on Lean through concepts like "Jidoka", "Andon" and "Gemba". For reading on Lean product development, refer to Morgan and Liker (2006), Ward, et al (1995) and Leon and Farris (2011).

[12] Hines et al's six steps are: 1) Understand customer needs, 2) Value stream mapping, 3) Improved end-to-end technical process (through for example Quality Function Deployment), 4) Improved end-to-end people process (through for example KIVP), 5) Develop the single project standard, 6) Develop the complete process standard (Hines et al., 2006).

internally and externally. Hines et al's assessment of this method is that it primarily increases staff motivation and improves identification and resolution of problems. They also identify other benefits such as improved teamwork through clearer directions for the work and improved capacity planning. Hines et al's contribution is somewhat schematic and does not explain why the effects of Visual planning occur. Added to that, there is very little empirical evidence, and the evidence that is presented does not seem to be supported by a scientific method.

A third study of interest is Parry & Turners (2006) study. They do not refer to Visual planning explicitly, but have a rather broad conception of what they call "visual process management tools". They base their study on site visits and discussions with senior management at three companies in the aerospace industry. The companies visualize slightly different information; one of them visualizes their ERP system, which provides them with schedules for production output, the second company visualizes project tasks in one of their divisions producing manuals for aircraft components and systems. The third one uses an extensive visualization of how tasks and resources are allocated and used on several organizational levels – from the board of directors to the shop floor. Parry and Turner suggest that visual control is a relevant tool for use also in areas other than manufacturing, and they conclude that visual tools can bring "process discipline" through transparency, which supports resource allocation and scheduling (Parry and Turner, 2006). However, the study does not define or investigate the implications of Visual planning, and they do not discuss implications for product development in particular.

Moreover, in addition to these scientific contributions, several examples of companies using Visual planning exist in one way or another. Oosterwal (2010) reports on the lean transformation at Harley Davidson. According to Oosterwal, the lean initiative cut the development time by half and quadrupled the product development throughput. Central to the lean initiative at Harley Davidson, is what Oosterwal calls an Obeya system that was implemented simultaneously at three levels; the management level, the project team level and the system level. Findings related to results from using Visual planning from the Harley Davidson case include increased team alignment, shortened development time and more focused problem solving.

In summary, Visual planning as a method has not been given much attention in research or in popular science texts, but some benefits of using the method have been identified and they relate to coordination and communication. However, more empirical evidence is needed to support these findings, both when it comes to confirming the implications and explaining their existence. This is one incentive for

writing this thesis. There is also a need to formulate a definition of Visual planning, as there is substantial discrepancy between descriptions of the method.

Figure 3: *Illustration of a Pulse meeting (Illustration: Jimmy Wallin)*

Using the same kind of logic as Visual planning, but focusing on the project portfolio level, instead of at the project team level, is sometimes referred to as "*Pulse board*", see figure 3. On a pulse board, activities and project status are visualized in a matrix (Kaya et al., 2014). Thus, in the intersections of the matrix, the project and the function have a common dot which represents the status of that function in that particular project. The statuses are often color-coded; green means "no problem", yellow means "we have a problem, but we have a plan to solve it" and red means "we have a problem, and we don't know how to solve it". The colored dots in the matrix provides a viewer with an instant insight into the status of the activities in the entire development organization (Oosterwal, 2010). The method can help functional managers and project managers gain a better overview of the organizations activities on an aggregate level.

To summarize, visualization supports important human cognitive functions, which is a well-researched area. The leverage of this knowledge is widespread in many

areas of the society and industry, but in management it seems to be underutilized. When it comes to visual management in product development, the focus is primarily to visualize the product; i.e., to support the technical communication. Knowledge on how to support task communication is, on the other hand, not as well developed. Examples of visual task communication methods exist, such as Gantt charts and process maps, but when it comes to supporting task communication based on non-canonical real-time information and rich face-to-face communication for teams, research is scarce. There is a method which is gaining traction in, for example, Swedish product development organization which is called Visual planning, which seems to have some of traits that are interesting for this research, but it is not well-researched as a method, and not put in relation to the task communication needs of a product development organization.

2.3 Research questions

The overall purpose presented in the introductory chapter is meant to set the stage for the research conducted during the four studies that this thesis builds upon. After having reviewed and discussed related research in this chapter, this section is meant to provide more specific formulations. This is done in the form of three research questions.

Research question 1:

- *What are the implications of using visual management in product development?*

This question relates to what implications[13] can be expected when using visual management methods in a product development setting. The question is addressed both from a theoretical and from an empirical perspective. The types of implications that are sought are implications that relate to the product development team and its ability to fulfill their requirements.

Research question 2:

- *How can visual management be implemented and evaluated in product development?*

The second research question serves as an extension of the first. After implications have been identified, more practical questions arise regarding the nature and proficiency of both the implementation and the evaluation of the methods used. Implementation in this case is delimited to concern mainly the prerequisites for

[13] The word "implication" can have at least two meanings; "a possible future effect or result", or "something that is suggested without being said directly"(Merriam-Webster.com, 2014b). In this context, the first meaning is intended.

implementing visual management. It is implied that the implementation of visual management aims to deliver the implications identified in research question 1. Evaluation refers to the assessment of the expected benefits of an implementation of visual management.

Research question 3:

- *How can the accessibility of information be increased to support information processing in product development?*

The third question addresses the fact that existing information is not automatically readily accessible. The question implies the assumption that information accessibility is an enabler of information processing; information must be accessible to be able to be processed. The research question emerged from the discussion in answering research questions 1 and 2 on the usefulness of visualization for information processing, but it addresses both the semantic and the visual information channels. The reason for this is that the insights from studying visual methods spurred a curiosity as to why the non-visual methods, such as document repositories, does not seem to function satisfactory. Thus, the decision to study non-visual information processing was partly a result of the close collaboration with the companies.

3 Research design and methodology

This particular research process is best described as an evolving process in which earlier findings have served as an important input to the formulation of new questions. An overarching ambition to contribute to topics related to the efficient use of information in product development organizations has guided the research. Each appended paper has however had its own individually focused purpose, albeit that there are prominent inter-study relations. The studies have been performed in close collaboration with a number of companies, and their current agendas of problems regarding different aspects of efficient use of information have been allowed to shape the research process and purpose along the way. In total, 99 formal interviews have been conducted at 6 companies. The appended papers are listed along with their content in terms of studies, data, and contribution to the research questions in table 3.

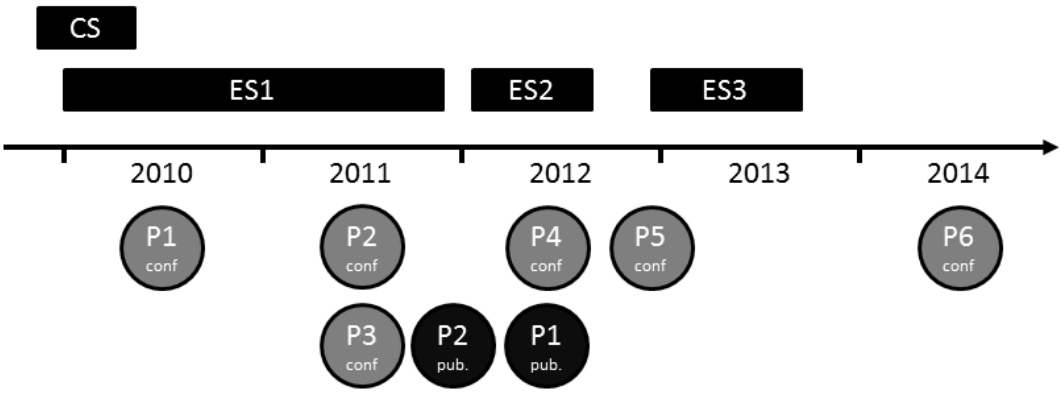

***Figure 4**: Timeline for the research process. CS = Conceptual study, ES = Empirical study, P = Paper*

Figure 4 is an illustration of the four different studies on which the research is based. It shows both the studies and the papers in a chronological order. The studies are illustrated as bars above the timeline, and the papers are illustrated as

circles below the timeline. The first study (CS) is a comparative analysis of two theoretic models – Lean product development, in which visual management is a central topic, and a knowledge management framework – the SECI-model (Nonaka, 1994; Nonaka and Takeuchi, 1995). Following this theoretical paper (P1), a second study (ES1) was designed. The purpose of this study was to collect empirical data on the use of visual management in product development organizations. Study two (ES2) consisted of two stages, where company Alpha was studied in the first stage. Therefore, in the second stage, the study was extended to a multiple case study including also Beta, Gamma and Delta. Common for all the four companies was the implementation of "Visual planning", which was identified as a study object suitable for the overall research purpose. Based on study 2 (ES1), three papers were written and are appended to this thesis (papers 2-4). Study 2 provided ample insights on the use of visual management, including implications and implementation challenges, but questions regarding the evaluation of the results arose, and therefore study 3 (ES2) was designed around these types of questions and involved two case companies in paper 5.

Papers	Empirical study	Data	Case companies	Number of interviews	Contribution to research questions
1		Theoretical paper	-	-	RQ1 + RQ3
2	1	Multiple case (four cases)	Alpha, Beta, Gamma, Delta	42	RQ1
3					RQ1
4					RQ2
5	2	Multiple case (two cases)	Scania, SAAB Aeronautics	22	RQ2
6	3	Multiple case (four cases)	Beta, Delta, Epsilon, Zeta	35	RQ3

Table 3: *Table of appended papers*[14]

[14] A note on the contributions from the author of this thesis to the (empirical) papers respectively: Papers 2-4: The author and Björn Söderberg jointly designed the study and gathered and analyzed the data (In paper 4, Lars Trygg provided additional analysis). Paper 5: The author designed the study together with the coauthors of paper 5, and gathered and analyzed the data. Paper 6: The author designed the study and gathered and analyzed the data.

Finally, study four (ES3) was conducted focusing on documentation of information in order to get a contrast to visualization. Partly as a result of the discussion around visualization of information that was initiated in study 2 (ES1), questions regarding the accessibility and dissemination of information were discussed, in product development organization in general, and in the role of document repositories in particular. The challenges with document repositories were considered substantial at the companies, and study four (ES3) was designed to address those challenges. Semantics are central to a company's information processing capabilities. Pictorials are arguably not able to nor aim to replace semantics, rather are they both parts of an important balance. Possibly, the emphasis on visualization in the companies' implementation spurred a growing dialogue also regarding verbalized information. The relations between the studies and the research question as well as the appended papers are presented[15] in Figure 5.

Furthermore, in papers 1 to 5, the concept of Lean product development appears with varying frequency. This has a practical as well as a contextual explanation. Lean product development has from the outset appeared as an attractive research topic, as the practices seemed well ahead of the theoretical conceptualization and the scientific inquiry. The ambition to engage in the study of Lean product development as a whole can be recognized in paper 1. However, as the studies progressed, it became advisable to delimit the research to the visualization part of Lean product development, then as a result of that, it later became abundant to relate to whether visualization is "Lean" or not. Effectively, it can be argued that visual management is a central topic in Lean product development and companies working with Lean product development often start their Lean initiative with visualization (Wangwacharakul et al., 2014; Gamme and Aschehoug, 2014), but that does not necessitate visual management being exclusively a "Lean concept". This said, the context in which the research is conducted is related to Lean product development, as all of the case companies studied have been engaged in a Lean product development implementation at the time of the studies, and the topics investigated have been considered by the companies as components of that implementation.

[15] Note that the purpose of paper 5 is formulated as a research question, but should not be confused with the research questions of the thesis.

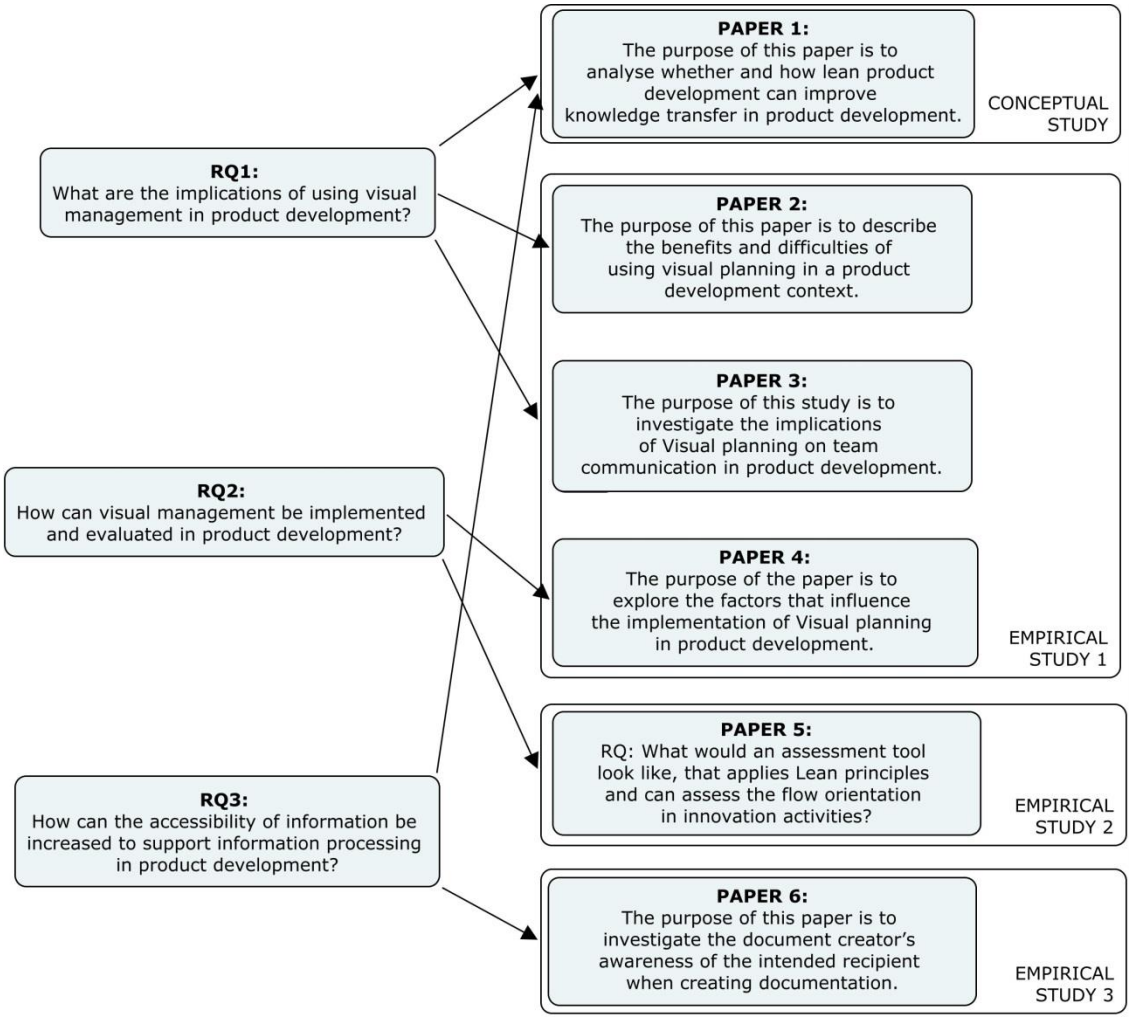

Figure 5: Relations between the research questions and the appended papers.

3.1 The case study approach

The nature of the purposes in the papers – to describe, explore and identify – suggests that the research can be labeled exploratory. This is undoubtedly also a result of the immaturity of the research field. The fact that the research is exploratory has led to that it is fairly inductive in its approach, considering that the empirical material has been the foundation for the analysis. Exceptions from that are paper 1 and paper 5, both of which are based on literature reviews. Thus, to be strictly inductive can be considered impossible, since the decision to study certain cases or phenomena is in itself based on something; being completely unprejudiced is not possible (Dubois and Gadde, 2002). The progress of the different studies was evolutionary. This means that the different research questions have been formulated successively, and that the formulation of each research question has been individually adjusted over time. Eisenhardt argues that even though a prioi

formulations of research questions are helpful, they are typically considered tentative in case studies (Eisenhardt, 1989a).

Since the research is exploratory, a case study is generally considered suitable[16]. The basic line of thinking behind doing case studies is that "*to truly understand how and why events play out over time, we must examine them directly*" (Langley, 1999 p. 691)[17]. In-depth case studies can provide powerful examples of cases that can prove important when the research field of the study object is relatively new (Siggelkow, 2007). Case study is argued (e.g. by Brunsson, 1982) to be appropriate when dealing with "theory development" or "theory building" which is the purpose of this research. Case research is a versatile methodology that can be used in a number of different areas such as psychology, sociology, anthropology, history, economics, management, and education (Yin, 2008). It can also be used in a number of different maturity levels of the research area being studied. Case research investigates a past or current phenomenon and can use a large diversity of different evidence. "*In fact, any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important*" (Leonard-Barton, 1990 p. 249). Even though case study research is a highly valid method to use in the creation of knowledge, there are some possible weaknesses that a researcher needs to be aware of. First, there is always a risk of information overload, that a researcher has so much rich data that it can be hard to sort through what really is suitable for the particular study, and might cause unfocused reasoning (Eisenhardt, 1989a). Another common criticism is that it is hard to generalize the findings from the context of the cases studied. (Yin, 2008).

Dubois and Gadde argue that "*Learning from a particular case (conditioned by the environmental context) should be considered a strength rather than a weakness*" (Dubois and Gadde, 2002 p. 554), since the case study approach is the most efficient way of understanding a phenomenon in its context. The context is generally considered highly important for the *explaining*, *understanding* and *describing* of a problem (Arbnor and Bjerke, 2009). The use of case study approach is further emphasized by Karlsson: "*Case research has consistently been one of the most powerful research methods in Operations Management*" (Karlsson, 2009 p. 162). One of the reasons for that is the possibility of collecting a full variety of evidence such as e.g. interviews, direct observation, documentation and artifacts, which enhances the possibilities of grasping the problem as a system problem (Yin, 2008).

[16] Case studies are however increasingly accepted also in research dealing with more mature research questions and purposes (Yin, 2008).

[17] See also Mintzberg (1979)

3.2 The selection of case companies

Comparing quantitative and qualitative reasoning when it comes to sampling reveals a fundamental difference. In sampling for quantitative research, the random sample is the ideal, there is no reason to believe that one case is more or less important than another (Dubois and Araujo, 2007). However, in qualitative sampling, the researcher is out to look for a specific phenomenon, and therefore the case must provide the possibility of studying that phenomenon – the sampling must be "purposeful" (Patton, 1990). The criteria for selecting a case are therefore a central argument in case studies.

The empirical evidence are collected at six Swedish technology based companies, referred to as Alpha, Beta, Gamma, Delta, Epsilon and Zeta. The single most important selection criterion is related to the access to the object of study. Thus, in the case of the first empirical study, for example, a study object suitable for the study of Visual management was sought, and when the Visual planning method was chosen as that study object, only companies that were using the method were eligible for studies. According to Yin, this is a valid way of choosing a case – the decision to study a unique case that is known to the researcher does not leave room for further considerations. However, it can be discussed in this case whether or not the companies studied because they used the method of interest, were unique – surely there are other companies somewhere using the method. Reasons to believe that other companies would be more suitable than the chosen ones were however considered few. Or as Bryman and Bell formulate it: "*With a case study, the case is an object of interest in its own right*" (Bryman and Bell, 2007 p. 60).

Another important criterion for the selection of the case companies was the fact that they conduct technical development with a high technical and/or organizational complexity. This means that the companies have a certain size; they range from 120 to 3500 employees in the organization, or that they have a seemingly complex product; for example vehicles and aerospace equipment.

The last, but nonetheless important, criterion was based on the access to data, and as the research design builds on qualitative studies, good access to interviewees and company contacts was considered important. In the case of the six companies, they were all at some point connected to a network of companies run by the Swedish research agency Swerea IVF. The network aimed to exchange knowledge on Lean product development between the participating companies. The fact that the companies were engaged in the network made it likely for them to be interested in the research questions of this thesis, and thereby also grant access to the respective organizations.

3.3 Level of analysis

When conducting case research, the *unit of analysis* is central to the research design. Easterby-Smith et al. (2012) define unit of analysis as "*the entity that forms the basis of any sample*" (p.65), i.e., it is related to what species of observations that will be analyzed in a particular research design (Gerring, 2007). Bryman and Bell (2007) suggest four different types of units related to organizational level: individuals, groups, organizations and societies. These levels can be used either exclusively or in combination. It is considered preferable by some methodologists to relate to one unit of analysis within the context of a particular research design (Gerring, 2007; Yin, 2008), while some argue that an ex ante definition of the unit of analysis is not necessary in exploratory research, although it could be helpful to the initial analysis (Easterby-Smith et al., 2012), and that the unit of analysis may change in the course of a given study (Gerring, 2007)[18]. It is also possible to use subsidiary units of analysis, also referred to as "embedded cases" (Easterby-Smith et al., 2012). Moreover, in this thesis, different units of analysis have been addressed in the three empirical studies. However, within each study, the unit of analysis is consistent.

Thus, in empirical study 1, the unit of analysis is the development team. This means that the relevance of the aspects of visual management identified are primarily in relation to the team and not, for example, to the individuals or the organization. Interviews were held with individuals, as they are considered representatives of the team, and the questions were related to the team level. In addition, during the participating observations made during the study, the team was observed rather than the individual. It could be added that at the outset, the four companies involved in the study were expected to be the units of analysis, but as the study progressed, the analysis of the data showed that the team would be a more appropriate unit of analysis. However, in study 2, the assessment tool is directed towards individuals in order to capture their perceptions of the flow orientation of the organization. The development of the assessment tool was based on a literature study and an interview series, but the assessment tool is intended for analysis on the organizational level. Thus, the unit of analysis in this study is the organization. Further, in study 3, individuals were interviewed to capture their individual behavior, and individuals' behaviors were compared to each other. Thus, the unit of analysis is the individual. Implicitly, using different units of analysis in the studies means that the research questions that are addressed by those studies were answered through analysis on

[18] Gerring (2007) assumes that a "study" can contain several different research designs, alternatively the research design can change during a study.

different levels[19]. This is considered a strength as it provides differing perspectives on the answers to the questions. Also, the research questions are formulated on an aggregate level in relation to the studies and the papers, which in turn are internally consistent when it comes to the unit of analysis.

3.4 Data collection

This section on data collection aims to provide a complementary view of the data collection in addition to the more detailed and focused descriptions provided in the respective papers. Empirical data was collected for the papers 2 to 6, so this chapter relates to the studies underpinning those papers. Generally speaking, the data collection was made with interviews as the main method, but observations such as participation in meetings and informal conversations also provided important input.

3.4.1 Interviews

A total of 99 semi-structured interviews were conducted at the companies. The semi-structured interviews provided an important opportunity to capture perceptions of the interviewees that were not anticipated beforehand (Bryman and Bell, 2007). It also allows following up emerging relevant topics and change the direction of the data collection according to the new insights gained (Edmondson and McManus, 2007). The questions were generally open-ended to allow the interviewee to formulate their opinions and answers by themselves (Silverman, 2011). The exact design of the interviews varied slightly between the three empirical studies, but they were all approximately one hour in duration; this was the amount of time that the discussion allowed in order to reach a certain level of detail while simultaneously not losing momentum because it was too long. The interviews typically took place in a conference room or meeting room at the company and were recorded with a dictaphone. Two interviewers conducted and analyzed the data together throughout the first study; this was done in order to increase the confidence in findings and the richness of the data (Eisenhardt, 1989a), and to reduce personal bias (Karlsson, 2009). The interviews were held in Swedish; the native language of both the interviewers and interviewees.

Sharing templates in the shape of questionnaires with the interviewees during the interviews were used more intensively as the studies evolved. Therefore, in the cases were this was used, the interviewees were asked to evaluate (using Likert scales) a number of statements that were sent to them before the interview. These statements

[19] The overall purpose of the thesis relates to the organizational level, this wording is chosen because it captures both the organizational level and the organizational entities, i.e. the teams and the individuals.

then formed the basis for the discussion. As the interviewees were forced to position themselves more clearly rather than providing universal and/or ambiguous answers, the chosen rating provided a basis for a discussion around the topic. It was found that the use of such a questionnaire provided the interviewer with better possibilities of understanding how the interviewee was reasoning and why, and in addition, the compiled results from the interview questionnaires provided a good foundation for the analysis and the validation workshops with the companies.

The selection of interviewees is of great importance to the quality of the research. Therefore, in the qualitative research, the "sampling" of respondents must be purposeful rather than random, just as with the selection of case companies. According to Morse (1991), a small random sample "*violates both the quantitative principle that requires an adequate sample size in order to ensure representativeness and the qualitative principle of appropriateness that requires purposeful sampling and a 'good' informant*" (Morse, 1991 p. 127). A good informant, Morse argues, is one who is articulate, reflective, and willing to share with the interviewer. Thus, effort has been put on using a purposeful[20] sample with "good" informants. The sampling strategy has been similar in the three studies. The most important criterion for the purposeful sampling is whether the respondent is likely to have the answers to questions in the interview guideline. Furthermore, other criteria such as organizational spread, experience of working in the organization, role, attitude towards the topic and more were taken into consideration[21]. Therefore, in the identification of purposeful respondents, a contact person familiar with the organization was used.

3.4.2 Observations

Moreover, in an effort to increase the validity of the findings aside from the survey, the data were triangulated with direct observations, i.e., participation in Visual planning meetings and through documents such as implementation plans (Yin, 2008). The combination of interviews and observations proved to be an important way of understanding, for example, the use of Visual planning, as the interview answers provided an input in understanding what was going on during the observed Visual planning meetings, and respectively, the observed meetings provided input to the interview series.

[20] In literature on qualitative sampling, the terms "selective sampling" (Schatzman and Strauss, 1973), "purposeful sampling" (Patton, 1990), and "theoretical sampling" (Glaser and Strauss, 1967) are used interchangeably, albeit with some differences. See Coyne (1997) for a review of these different terms.

[21] For deeper explanation, refer to the respective appended paper.

3.4.3 Workshops

Furthermore, in the first empirical study, two half-day workshops with the participating companies were held. The first one included only company Alpha, and the second one included all four companies. Also, at the end of the second and third empirical study, half-day workshops were held with the participating companies. The members of the workshop were two or three from each of the companies. The purpose of the workshops was to present the findings from the interview series to primarily get feedback for verification of the results, but also to get input on further research. The workshops proved to be an effective communication channel between the researchers and the companies.

3.5 Data analysis

Typically, exploratory research is an iterative process, where data is collected and analyzed in parallel. New empirical findings demand more literature review, which in turn demanded more empirical data, referred to as an abductive approach (Eisenhardt, 1989a), systematic combining (Dubois and Gadde, 2002), or successive induction (Alvesson and Sköldberg, 2009). This way of doing research allows the research to explore, i.e., make new decisions about the direction in which to proceed, based on the hitherto results. This means that some emerging topics and aspects are more closely looked into, and some are neglected (Edmondson and McManus, 2007). Miles and Huberman (1999) establish three concurrent flows of activity in the process of analyzing qualitative data: Data reduction, data display and conclusion drawing and verification. These activities all occur simultaneously with each other and before, during and after the data collection.

3.5.1 Data reduction

Data reduction is described as the process of selecting, simplifying and transforming the data collected, whether it is done consciously or not. Not all the data collected can or must be used for drawing conclusions. Data reduction occurs all the time throughout the research project. Selecting topics, methods, interviewees, writing the final report; it all affects the data reduction (Miles and Huberman, 1999). Data reduction in this research in terms of selection of data comes down to the processing of transcriptions and notes from the interviews. The transcriptions were essentially analyzed by the author and the co-interviewer individually but in close collaboration in order to avoid too much personal bias when it comes to what data to extract. Relevant statements were filtered for further analysis. The relevance of a statement was determined by its direct or close relation to the respective research questions pertaining to that study, and whether or not the statement contained an expression of the interviewee's perception of or attitude towards that particular

topic. Some statements were filtered for other reasons; be it that they were in contradiction to another statement, or irregular in relation to the bulk of statements. Thirdly, statements that served as an input to the mapping of the organizational context that was made initially were also filtered, even though they had no or little relevance to the research questions. These statements helped a lot in providing insights regarding the organizational context.

3.5.2 Data display

Data display is the process of making the data accessible for the researcher to do the analysis or draw conclusions. A lot of effort has been put on the display of data in the research work that is the foundation for this thesis. Large amounts of text such as transcriptions of interviews, and field notes are considered by Miles and Huberman as "display", but they also argue that humans are not "*very powerful as processors of large amounts of information*" (Miles and Huberman, 1999 p. 11) and as a result of that, they call for more visual displays such as matrices, charts and graphs. Also, Langley (1999) emphasizes the strengths of using what she calls a "Visual mapping strategy" to analyze process data. She describes the mapping of data as an intermediate step between the raw data and the more abstract conceptualization. This has been subscribed to in the display and analysis of the data in this research. The extracted statements were written down on sticky notes and clustered. Moreover, in the first empirical study, these notes were color-coded according to the following categorization; they were green if the statement was considered positive, pink if considered negative, and yellow if considered neutral or uncategorized. These statements were then clustered inductively and they were put up on a wall. New categories took form, for example; statements that had to do with implementation, the needs of the particular team, the interface to other methods used, the ability to faster respond to changes, the communication etc., ended up as different categories. This made it easy to see what categories had the most statements, and of which color they were. Taking one step closer to the wall revealed the detailed statements. This visualization formed the foundation for analyzing the statements.

Miles and Huberman (1999) also discuss conclusion drawing from the perspective that conclusions are drawn throughout the research and not typically as a final step as one might assume. From the very beginning, the researcher starts to decide what things mean – these early conclusions are then verified, rejected or altered during the project, e.g., looking at improved communication as the main finding from the interviews, it emerged quite soon as the statements on improved communication were both numerous and strong, and it was later continuously confirmed by the different cases and the survey.

3.6 Quality of data

Internal validity refers to the extent to which measures and research findings provide accurate representations of the things they are supposed to describe (Easterby-Smith et al., 2012). How exactly internal validity should be operationalized in qualitative research is not subject to consensus in the research community, but some established strategies for securing internal validity do exist (Onwuegbuzie and Leech, 2007).

First, triangulation is perhaps the most immediate strategy. Triangulation refers to the use of several methods, investigators, sources and theories in order to obtain supporting evidence (Guba and Lincoln, 1994; Easterby-Smith et al., 2012). Several such triangulations have been actively deployed during the research. First of all, the main method of interviews has been triangulated with observations, and in some cases documentation[22]. Furthermore, in all of the three empirical studies, several case companies have been studied to add depth to the study which is not entirely dependent on one case company, as advised by for example Eisenhardt (1989a). In addition, several types of respondents have been interviewed to reduce the risk of a too simplistic perspective. Finally, several investigators have been used throughout all of the three empirical studies.

Second, as described by Guba and Lincoln (1994), by using the strategy of *persistent observation*, i.e., by spending sufficient time close to the study object, the insight into the study object and its context is intensified and the data collected will assumedly become rich and deep (Onwuegbuzie and Leech, 2007). The importance of interviewing respondents that are reasonably probable to be *informed* is also emphasized, in line with Voss (2002).

A central purpose of research is the *generalization* of the findings. Guba and Lincoln (1994) discuss the epistemological differences between, on one hand, the generalizability of knowledge and, on the other, the context specificity of knowledge. Therefore, in the case of this research, considering the rather qualitative nature of the data and thereby also the rather small sample, generalizations of the findings in a quantitative sense are unfeasible[23]. Some authors argue that the generalization from case studies should be regarded as an analytical process rather than a statistical one (George and Bennett, 2005; Dubois and Araujo, 2007; Yin,

[22] The use of observations and documentation is only used in the first empirical study.

[23] However, there are exceptions; Flyvbjerg (2006) argues that falsification is a generalization strategy that can be based on case studies. He refers to Karl Poppers (1959) example of "the black swan" - only one observation of a single black swan is enough to falsify the general theory that all swans are white.

2008). A feasible strategy for such an analytical process related to extern validity seems to be *transferability* (Guba and Lincoln, 1994), i.e., to what extent it is feasible for other researchers to transfer the findings to different or similar contexts. The notion of transferability correlates with the notion of *naturalistic generalization*, which emphasizes the readers role in interpreting and adopting the findings to another context (Buchanan, 1999; Halldórsson and Aastrup, 2003). Central for transferability and naturalistic generalization is the possibility of comparing and evaluating how different the target context is from the context in which the knowledge was created. Thus, it is central for the author to provide rich descriptions of the context and object of study in order to enable that comparison. Guba and Lincoln refer to this as "thick description" (Guba and Lincoln, 1994). Therefore those kinds of descriptions are emphasized in this thesis as well as in the papers. Finally, it should be added that also non-generalizable findings typically stemming from exploratory research are important both for the establishment of a new field and for the formulation of further research inquiries in an emerging field (Edmondson and McManus, 2007).

4 Summary of appended papers

The purpose of this chapter is to provide extended summaries of the six papers appended to this thesis. Also, it intends to put the respective paper in the context of the thesis in addition to the context in which it was originally written - the target journal or conference. These summaries do not discuss method or findings in great detail; such details are discussed in the methods chapter or the analysis chapter of this thesis, and in the respective papers.

4.1 Paper 1

Title: Practices supporting knowledge transfer – an analysis of Lean product development. Published 2012 in International Journal of Computer Integrated Manufacturing. A previous version was presented at the International Product Development Management Conference in Murcia, Spain 2010.

The background to this paper was an identified increase of interest in questions regarding the applicability of Lean principles in product development. This increase could be noticed in research, but it was mainly identified in industry and popular scientific press. The question whether "Lean product development" ought to be an adapted version of Lean production or something rather more fundamentally different is still debated. The paper discusses these different views on the applicability of Lean in product development. One of the views focuses on the capture, transfer and use of knowledge, with the logic that product development is knowledge intensive, and that the goal of a product development organization is to create enough knowledge about the product and the market to be able to produce and sell the product with a profit. A field where a similar discourse is central is the field of Knowledge Management. Thus, there seems to be synergies to gain from integrating the two fields of Lean product development and Knowledge Management.

Lean product development is therefore analyzed from a knowledge transfer perspective in this paper. This is done through a review of literature on Lean

product development and a mapping of this review towards an established knowledge transfer-model – the SECI model (Nonaka and Takeuchi, 1995), in which both tacit and explicit knowledge is considered important, and the knowledge is transferred in four different conversion modes (Socialization, Externalization, Combination, and Internalization).

The findings show that the Lean product development concepts from the literature review correlates well with the conversion modes of the SECI-model. This is especially true for the visualization methods analyzed; the trade-off curve, the A3-report and the Obeya, which seemed to represent at least three of the modes. The paper discusses the fact that all the visual management methods seem to support knowledge transfer through making the knowledge accessible. The paper concludes by stating that Lean product development fits into the conversion modes, and therefore forms a methodical foundation that promotes knowledge transfer. Implications include that in relation to the SECI-model, Lean product development is potentially rewarding for product development organizations aiming to improve the knowledge transfer within the organization. The paper also calls for empirical studies of companies that use Lean product development to confirm the connection to knowledge transfer.

4.2 Paper 2

Title: Pros and Cons of Lean Visual Planning: Experiences from four product development organizations. Published 2011 in International Journal of Technology Intelligence and Planning. A previous version was presented at the R&D Management Conference in Norrköping, Sweden 2011.

This paper, in comparison to paper 1 which deals with Lean product development as a framework, deals with one of the ingredients that were identified as central to the case companies' Lean product development implementation programs – Visual planning. The use of visualization in management was identified as an attractive research topic during the work with paper 1. However, a suitable study object was needed to start studying the implications of visual management. The method called Visual planning emerged as promising for that purpose. The paper thus explores the use of the method to identify both positive and negative implications of its use.

Four companies using Visual planning were identified and participated in the study. During the study, 42 interviews were conducted[24]. The interviews aimed to capture

[24] Page 272 in paper 2 states inaccurately that 41 interviews were conducted.

the perceptions of the users of the method, and a semi-structured interview guideline was used to enable an elaborate discussion.

The findings from the interviews could be clustered into two categories: communicational and coordinational aspects. Generally speaking, the interviewees perceive Visual planning as improving the communication within the team both in terms of efficiency, faster communication, and in terms of effectiveness, higher quality communication, indicated by, for example, a better overview of the team undertakings. The communicational aspects are strongly linked to the meeting, which becomes more focused, shorter, and more coherent. The coordination is also perceived to improve, with a better resource allocation and better tracking of resources. The coordination aspects are strongly linked to the visual board, as this is where the actual resource reallocation occurs. The paper also briefly discusses some difficulties of using the method, related to, for example, the composition of the team, reluctance towards transparency, and project planning aspects such as lack of documentation and causal links between activities.

4.3 Paper 3

Title: Task visualization in product development – improved communication for development teams. Presented at the R&D Management Conference in Grenoble, France 2012.

The division of perceived benefits into aspects regarding communication and coordination was an important finding in paper 2. Although the studied method – Visual planning – refers to *planning* as being visual, it can be argued that the visualization is rather a support for the communication needed for the short term planning in the teams. The finding that Visual planning can help the team with their task communication called for further analysis. Therefore, the purpose of paper 3 is to specifically investigate the implications of Visual planning on team communication. Paper 3 is thus a further development of some of the reasoning in paper 2, and is also based on empirical data from the same study as paper 2.

The paper uses a framework for team communication developed by Hirst and Mann (2004) to analyze the Visual planning as a method for team communication. The paper also introduces boundary object theory as a model in explaining the function of Visual planning in terms of communication. The paper shows that certain factors of team communication such as participative communication, reflective communication and clarity of objectives are enhanced by the visualization. This can in its turn, according to Hirst and Mann's framework, have a positive impact the performance of the team. The paper also formulates a definition of the Visual planning method, as a response to the rather scattered descriptions that exist in

previous research. The definition is discussed in the paper as well as in the contribution section of this cover paper. Additionally, the paper starts with a prologue in the format of a story that illustrates how a meeting at the board can be carried out. The short story provides, together with the definition, a picture of what Visual planning can be. The definition is:

> *Visual planning is when development teams use frequent meetings and physical representations of tasks in order to manage deliverables and tasks throughout the execution of a project* (Lindlöf and Trygg, 2012 p.4).

This definition emphasizes the importance of the two components of Visual planning; the visualization itself, and the meeting. They are both crucial for the team to be able to capitalize on the benefits of Visual planning, and they underline that it is primarily a communication method, as the meeting without the visualization and the visualization without the meeting makes less sense than the two combined.

4.4 Paper 4

Title: Towards Lean product development - prerequisites for implementing Visual planning. Presented at the European Operations Management Association Conference in Cambridge, UK 2011. Currently under review for an international journal.

Furthermore, as study 1 unfolded and the implications of Visual management in the study context became clearer, questions regarding the implementation emerged. The study included 17 teams, and all of them were using the method in a rather similar way, but they perceived the method somewhat differently with regards to its implications. This sparked an interest in studying the differences between the teams in identifying the prerequisites for an implementation that rendered positive perceptions of the method. This paper aims to cover just that, and it is based on empirical data from the same study as papers 2 and 3.

The purpose of the paper is to explore the factors that influence the implementation of Visual planning. It does this by using the distinction between communication and coordination introduced in paper 2. Thus, implementation factors that are prerequisites for communication are distinguished from factors that are prerequisites for coordination. A third section discusses factors that are related to the fact that the method is limited as a result of its physical nature. Therefore, as with other studies of implementation, the role of management is also identified in this paper and discussed as a crucial factor, although it is not considered specific for the method of Visual planning.

The findings relating to communication include two factors. First, the importance of a need for intra-team communication, teams that have less need for intra-team communication and thus probably have a higher need for external communication, do not find the method essential. Second, the high frequency of meetings is perceived as a prerequisite for the visualization to be of effect. If too much time passes between the meetings, team members will communicate without the support of the visualization, and when they meet at the board, the discussions will be preempt. The findings relating to coordination include three factors; 1) the need for coordination complexity to perceive a need for continuous resource planning, 2) the need for redundant competencies to be able to reallocate activities, and 3) an openness to share information among team members. Another factor relating to both communication and coordination is the distance between team members, the method build on rich communication between individuals, which is highly dependent on the team members' possibilities of meeting in person.

Paper 4 thus contributes to the knowledge on *how* visual management can be implemented, in relation to *what* it is and what its implications are, as covered by papers 2 and 3.

4.5 Paper 5

Title: Increased flow in the innovation process - an assessment tool. Presented at the International Society for Professional Innovation Management Conference in Seoul, South Korea 2012.

The background to this paper was an identified need to be able to evaluate the use of visual management. Together with two companies working extensively with visual management, an assessment tool was developed based on a literature review. The paper describes what this assessment tool looks like and how it was developed. The title relates to "flow" in the innovation process, which indicates that the assessment tool attempts to capture a slightly wider array of questions than just visual management. Flow as a concept is recognized as central to Lean production and Lean product development, and here it is used to describe a product development process adhering to Lean principles. Moreover, in this context, visual management is central, theoretically but also practically, for the two companies involved in the study.

The paper is based on a literature study of Lean product development theory, and an interview series of 22 interviews divided on the two case companies. The literature study served as an input to the development of the assessment tool, and the interview series served as an evaluation of the assessment tool. The assessment tool was designed in three steps; 1) identification of items, 2) selection of items, and

3) design of the assessment tool. The result of these steps is a tool that consists of 10 items categorized under four headings; 1) Flow in the value chain, 2) Visual management systems, 3) Continuous improvements, and 4) Knowledge management. The purpose of the tool is to provide product development managers with a way to assess the flow-orientation in the product development projects, but also to trigger awareness and a dialogue around the topic. The findings presented in the paper are twofold; first the ten items that constitute the assessment tools is a theoretical finding. Secondly, findings of a more practical nature suggest that the assessment tool is perceived as easy to comprehend by the respondents, and it provides good conditions for a dialogue on the flow orientation in the organization.

4.6 Paper 6

Title: The "documentation paradox" - on knowledge reuse through document repositories in R&D organisations. Presented at the R&D Management Conference in Stuttgart, Germany 2014, nominated for the best paper award. Currently under review for an international journal.

The background to this paper is the perceived inadequacy of non-visual information processing identified in the previous studies. An important method for non-visual information processing is the creation, storage and retrieval of documents. This happens mainly through document repositories; large databases in which information is stored for later use. From an engineering perspective, the leverage from such document repositories is not always obvious. Challenges of using document repositories include for example finding, assessing, using and trusting information. Extensive research is focused on the searchability of information and the search patterns of users of repositories. However, for knowledge transfer to occur successfully, it is important to be aware of the recipient at the time of the creation of the document. Hence, the study focuses on the creator of documents and its awareness of the recipient.

Furthermore, for the purpose of the paper, 35 interviews evenly distributed at four companies were conducted. The interviews included users of document repositories such as design engineers, functional managers and project managers. During the interviews, the perceptions of current document repositories and incentives to document were inquired as well as the use of different knowledge transfer strategies in relation to different situations.

The paper concludes that the awareness of an intended recipient of the documentation is not necessarily considerable at the time of the document creation. This is in itself not a surprising finding; that there is a trade-off between qualitative (directed, purposeful and with a clear recipient) and quantitative (general,

opportunistic and with several and/or unspecified recipients) documentation can be expected. However, the findings also show that the creation of documents occur not only *despite* that the recipient is unknown, but *because* it is unknown. Thus, it is not sufficient to describe this relation as a trade-off but also as a paradox.

5 Analysis

This chapter addresses the three research questions of the thesis. It discusses the findings in the papers in relation to the respective research question and the frame of reference presented in chapter 2.

5.1 Implications of using visual management in product development

The first research question has been answered both theoretically and through empirical evidence. The first three papers address different aspects of the question; paper 1 formulates a theoretical answer drawn from the conceptual study, and papers 2 and 3 present answers based on the first empirical study. Therefore, as previously presented, the method of Visual planning, which in this thesis is regarded as an example of a Visual management method, has been at the center of the studies. The collection and analysis of the data in study one rendered a division of implications into three categories: 1) benefits related to communication, 2) benefits related to coordination, and 3) challenges of using the method in general. This categorization is discussed in paper 2, and then in the following sections, further analysis on the communication aspect is provided as this is considered the most prominent finding, and is therefore selected as a main perspective of this thesis. A brief section on difficulties and disadvantages with Visual planning is also provided, in order to expand the discussion in paper 2.

When analyzing Visual planning as a method for visual management through a comparison to other task communication methods in product development, a few similarities as well as dissimilarities appear. Table 4 presents a compilation of the four identified methods for task communication and how they relate to Burkhard's (2005a; 2005b) four perspectives of Knowledge visualization. Burkhard argues that these perspectives can be generally applied to visual representations of knowledge. The table shows that in the comparative analysis between the visualization methods, Burkhard's perspectives are generally very similar and therefore do not suffice to capture the fundamental differences between the task communication methods.

	Visual planning	Gantt chart	Process visualization	Pulse board
Function	Coordination Attention Recall	Coordination Attention Recall	Attention Recall	Coordination Attention Recall
Knowledge type	What/Who	What/Who	What/Who	What/Who
Recipient	Group	Individual Group Organization	Individual Group Organization Network	Group
Visualization type	Map	Map	Map	Map

Table 4: *Comparison of task communication visualizations*[25]

The empirical analysis of the method Visual planning indicates that there are other central dimensions of communication that differ, represented by the bottom five items in Table 5. These dimensions can be considered an extension of Burkhard's (2005b) model, in order to better explain the implications on task communication caused by visualization. The five dimensions include the fundamental differences between the methods that Burkhard's model neglects. They will now be scrutinized in more detail.

	Visual planning	Gantt chart	Process visualization	Pulse board
Function	Coordination Attention Recall	Coordination Attention Recall	Attention Recall	Coordination Attention Recall
Knowledge type	What/Who	What/Who	What/Who	What/Who
Recipient	Group	Individual Group Organization	Individual Group Organization Network	Group
Visualization type	Map	Map	Map	Map
Bidirectional	Yes	No	No	Yes
Organizational level	Team	Project leader	Organization	Management team
Synchronicity	Synchronous	Asynchronous	Asynchronous	Synchronous
Update frequency	Realtime	Delay	Fixed	Realtime
Canonical / Non-canonical	Non-canonical	Non-canonical	Canonical	Non-canonical

Table 5: *Comparison of task communication visualizations – extended*

5.1.1 Visualization in task communication

The studies show that from a task communication perspective, Visual planning is used in a bidirectional sense[26], i.e., the individuals using the visualization both send

[25] The items in the function category originate from Burkhard's six possible functions, i.e. Coordination, Attention, Recall, Motivation, Elaboration and New insight (Burkhard, 2005b).

[26] I.e. it supports what e.g. Wheelwright & Clark (1992) refers to as "two-way communication".

and receive information – the communication is a dialogue rather than a monologue. Thus, it is not typically used as a "presentation" of information from one sender to one or more receivers. This distinction appears when comparing to a Gantt chart, where it is typically the project manager who is compiling information for the project members, or the process visualization were typically development managers communicate their view of the desired process to an organization (Maylor, 2001; Wilson, 2003).

Also, the bidirectional aspect of Visual planning can be seen in the way the content is *negotiated*. Paper 3 discusses this as participative communication, which is a component of Hirst and Mann's team communication framework (Hirst and Mann, 2004). The individuals of the team all have the possibility of influencing the visualization so that it better fits with their perception of the project. When individuals do not agree on the content, this creates a representation of the uncertainty or even ambiguity present in the team. Nevertheless, the visualization triggers the differences in the individuals' perceptions of the project. Therefore, the visualization of the project in the way Visual planning presents can be considered a *boundary object* (Star and Griesemer, 1989; Henderson, 1991; Carlile, 2002).

Important for the negotiation to occur is the richness of the communication. Visual planning as a method builds upon two components; the visualization and the meeting. As the visualization functions as a boundary object, the communication through that boundary object must be facilitated. When it comes to Visual planning, this is done through face-to-face communication, which is the richest form of communication (Daft and Lengel, 1986).

Visual planning can be used on different levels; design teams as well as management teams use it. It seems however to be a distinct team communication method. Thus, it is not used for individual or organizational communication, but rather for the internal team communication. Moreover, the method primarily supports what Galbraith (1977) refers to as *lateral* communication. Further, in addition to bidirectional, the communication is also synchronous. Thus, the feedback on the content visualized is direct, in contrast to for example emails, which are asynchronous, i.e., they normally include a time lag between responses.

The idea of Visual planning as a method assumes that the communication is based on real-time information. The content (i.e., the information on the board) is therefore updated before every meeting, to make sure that the boundary object corresponds to the actual status of the project. Therefore, using the analogy of a prototype, the communication based on a prototype assumes that the prototype is a reasonably correct representation of the actual product or concept to which the

prototype refers. This is central for the decisions taken based on the prototype to be valid. The same goes for the visualization of the project status.

This line of reasoning relates to Brown and Duguid's (1991) distinction between canonical and non-canonical processes. Visual planning supports the communication of the non-canonical process, i.e., it focuses on the actual process taking place in the organization, not the canonical process; i.e., the ideal, intended process. Arguably, visualizations of both kinds of processes can serve as boundary objects, although the non-canonical process is in focus in the research underpinning this thesis.

The increased frequency of meetings identified during the first empirical study among teams using Visual planning plays an important role. Communicating real-time information requires a certain update frequency. The more frequent meetings, the more up-to date is the information. Too low a frequency of meetings will probably imply a need to communicate certain things outside the meeting, which has also been observed at the case companies. However, the benefits of frequent meetings are assumedly best described as an inverted u-shape, as maximizing the meeting time is clearly not the answer[27]. Therefore, as identified in paper 2, the visualization seems to help the team to hold efficient meetings, which in turn helps them to increase the frequency of meetings, as the total time spent on team meetings is still reduced.

Complementing this view of Visual management as a way of improving certain aspects of communication based on empirical findings from paper 2 and 3 are the findings from the conceptual study presented in paper 1 (Lindlöf et al., 2012). Paper 1 supports the idea of visualizations supporting knowledge transfer, on the basis of an analysis of Visual management using the SECI-model (Nonaka, 1994; Nonaka and Takeuchi, 1995). Lean product development, in which visual management is a prominent ingredient as previously argued, clearly emphasizes the importance of knowledge transfer. It does so both when it comes to explicit and tacit knowledge. The principles and methods of Lean product development correspond to the conversion modes of the SECI-model. This means that working with visual management supports the internal transfer of knowledge.

5.1.2 Challenges

Paper 2 discusses the challenges of Visual planning in terms of "difficulties". These challenges include leveling of workload when team members have different

[27] Finding a breaking point regarding an optimal meeting frequency is out of the scope for this thesis, but is assumedly contingent on several factors, including the nature of team's activities and the complexity and volatility of the team's environment.

competences; i.e., the higher degree of specialization within the team, the more difficult it becomes to reallocate tasks within the team. Thus, the coordination benefit identified in paper 2 becomes difficult to leverage[28]. Also, the degree of specialization is believed to be one of the explaining factors as to why teams have different foci in their use of Visual planning. Some teams focus clearly on the communication aspect; everything that is visualized on the board is done because there is a need to communicate. "*As long as people talk to each other, the planning board fills its purpose*" is a quote from one of the project managers with a team focusing on the communication aspect. Other teams focus more on the coordination aspect of Visual planning, and this often translates into quite rigorous work tracking time estimated versus time spent[29].

Other problems relate to the limitations of the board. Certain functions are difficult to provide on the board with its current rather physical configuration. Furthermore, in this research, only physical boards with physical representations of tasks, deliverables and critical issues are studied. Three limitations are particularly troublesome. First, the difficulty of using Visual planning in teams distributed over more than one site is a common criticism. Second, the historical data is cumbersome to save; it is not uncomplicated to look back at what the board looked like a couple of weeks ago. Third, sequential dependencies between activities are difficult to visualize, and are therefore often not monitored at the board.

Also, problems with individuals being reluctant to be as transparent as needed for the Visual planning to work has been identified, although it does not appear to be a substantial hindrance. Reasons for such behavior are not analyzed as a part of this research, as it is considered rather peripheral. Nevertheless, such aspects of social psychology related to visualization and transparency should not be underestimated, and further studies in such an interdisciplinary area are certainly called for.

In summary, the implications of using Visual management in product development within the scope of this research can be summarized in three categories; 1) benefits related to communication; these benefits include improved knowledge transfer, improved overview, rich and frequent communication, accessibility of real-time information, participative communication, reflective communication and clarity of

[28] Several interviewees point out however, that if this happens, Visual planning has actually highlighted the need for redundant competences, which is positive. In other words, the visualization does not affect whether or not tasks can be reallocated, it merely points to the need of such reallocation.

[29] This difference can also partly be explained by the way the method was communicated through the organization; the focus of the implementation coach assumedly transfers to some extent to the teams implementing Visual planning.

objectives, 2) benefits related to coordination; these benefits include support for leveling of workload, problems surfacing early, and coordination in itself becoming a team effort, and 3) challenges of using the method in general, which include difficulties of workload leveling in teams with diverse competences, difficulty to estimate time needed for individual activities and deliverables, reluctance among individuals to expose the information needed, difficulty to use the method on distributed teams, and not being able to easily store and access historical information and causal links between activities. When analyzing the communicational aspects of Visual management, which is the focus of this thesis, several findings are identified. They include Visual planning being a method for task communication on a team level that is bidirectional and synchronous. This communication is based on real time information and a non-canonical representation of the development process. This representation (i.e. the visual board) is considered to serve as a boundary object for the communication between team members, which reduces ambiguity regarding processes and tasks.

5.2 Implementation and evaluation of Visual management

Following the first research question regarding the implications of using visual management which is of a rather descriptive nature, research question 2 is of a more prescriptive nature. The question regards two aspects; the implementation of visual management, represented by paper 4, and the evaluation of the implementation of visual management which is represented by paper 5.

5.2.1 Implementation of Visual management

The question of how the implementation can be carried out aims to provide more details about the circumstances under which the implications found when answering research question 1, are expected[30]. Therefore, research question two functions as an extension to the contribution provided by the answers to research question 1. Questions regarding the implementation arguably follows after the nature of the phenomena have been established. Thus, in the case of Visual planning, there is a need to also look at the implementation issues, which are confirmed by the studies made by Leon and Farris (2011). Paper 4 presents four factors that influence the implementation of Visual planning. All of them are related to the team; i.e., it is assumed that certain teams are more likely to reap the benefits of Visual planning than other teams.

First of all, the need for intra-team task communication is a prerequisite for the team members to perceive the method as beneficial. Obviously, any team needs to

[30] I.e., the study does not focus on the implementation process itself.

communicate activities and deliverables, but the extent of that need differs. Some teams consist of individuals that are autonomous, have isolated tasks, and are in little need of task communication. Task communication in such teams is typically low or taken care of with individuals outside the team.

The need to communicate is also partly based on the coordination complexity within the team. Teams with highly interrelated tasks and deliverables and/or are operating in a volatile environment have a higher need for task communication, and thus see a greater potential in visualizing the complexity they are experiencing. The third factor is the difficulty of leveraging from the coordination benefits of Visual planning in teams with a variety of specialists. Teams with generalists typically imply redundant competences, making it easier to move activities between individuals.

The fourth factor is the distance between team members. The most common criticism towards the Visual planning method is that the method assumes co-located teams, which is not a reality for many product development teams. Being a method for communication between individuals, Visual planning does not offer support for distributed teams without further effort. As pointed out in papers 2 and 3, the meeting between the individuals in the team with a boundary object as a trigger for rich communication is the focus of the method. Thus, it does assume that the team is able to exercise rich communication. However, it can be assumed that distributed teams have an even higher need for boundary objects for their task communication, as it is probable that the ambiguity within the team is amplified by additional individual differences such as language and culture.

How to design boundary objects for communication in such teams is therefore a highly relevant question for further research. There are IT-based versions of Visual planning in existence, and studying the implications in that setting and comparing them to the studies in this thesis would be an important challenge for development organizations using distributed teams.

5.2.2 Evaluation of Visual management

An assessment tool has been developed based on existing literature on lean product development. It covers four areas: 1) Flow in the value chain, 2) Visual management system, 3) Continuous improvements and 4) Knowledge management (focus on capturing knowledge). Based on the test of the assessment tool at two companies, the assessment tool seems to be able to capture the state of a visual management initiative at a company. The matters concerning how such an implementation can be evaluated has been answered through the design of the assessment tool presented in paper 5. The assessment tool includes the four different areas presented above. Visual management is mainly represented in the second area; visualization.

However, it can arguably also play an important role in the other three areas. Further, as discussed in the section on implications of Visual management, visualization can be used to reduce the ambiguity regarding the development process. This means that visualization can play a role in assessing and improving the flow-orientation in the value chain (i.e. the first topic of the assessment tool). Also, visualization can support the identification and awareness of deviations and potential problems. This can then support the third area – continuous improvement. The fourth area; knowledge management, is related to visualization through its potential of improving knowledge transfer, as discussed in the previous section on implications, and which will also be discussed in the next section addressing research question 3.

The assessment tool presented in paper 5 should be considered as an initial model. The design has so far been tested on a small scale, and still needs validation in terms of test runs on companies with differing flow orientation, in order to make sure that the tool captures relevant differences between organizations. It could also be validated towards other already existing performance measures that could be relevant for the assessment of flow-orientation. Developing methods like this to assess the implications of visual management on a more quantitative basis is considered an important next step on the research agenda.

In summary, research question 2 addresses rather practical issues when it comes to implementing and evaluating Visual management. Certain team characteristics have been identified in the implementation process, as prerequisites for a positive perception of the use of the method. These team characteristics include 1) the need for intra-team task communication, 2) the coordination complexity, which drives a need to coordinate, and thus also to communicate, 3) competence redundancy, which improves the possibilities of using visualization for identifying the need for, and the execution of, workload leveling, 4) the co-location of team members is a prerequisite for the rich communication needed to leverage on the benefits of the Visual planning as a method.

When it comes to evaluation; the corresponding part of the research question is answered through the assessment tool in paper 5. The evaluation is based upon the compilation of the perceptions of members of the part of the R&D organization at focus. Thus, through the use of the assessment tool, the organization is evaluated along 10 dimensions divided into 4 categories regarding the effects of Visual management. This evaluation provides the company with a reference with which one can compare the use and implications of Visual management over time and/or between organizational units.

5.3 Increasing the accessibility of information

Uncertainty can as we have seen be defined as lack of information. An important task for the development organization is to close this gap between needed and existing information. This could mean that information needs to be gathered or created. But it could also mean identifying and seeking out information within the organization. The mere existence of information in an organization does not guarantee its use. Thus, accessibility of information is a prerequisite for the information processing to take place. The key to this is to make the information accessible to whoever needs it whenever it is needed, which is a challenging task. Research question 3 is addressed by looking at two aspects of information accessibility, one of them relates to visual communication, and the other relates to non-visual communication.

5.3.1 Accessibility in visual communication

The first aspect regards creating accessibility through visualization of information. The visual format, leveraging on the cognitive benefits of imagery, makes the information easier for recipients to digest. Accessibility is thus in this respect regarded as a characteristic that enhances the recipients ability to digest information, rather than accessibility as a characteristic of information that is easy to find. The examples of visual management methods in paper 1 are examples of making information more accessible to recipients. The paper analyzed three methods from a knowledge transfer perspective: the trade-off curve, the A3-report and the Obeya. Here, they are analyzed from an accessibility perspective in relation to *ease of access* and *ease of use* as discussed by Fidel and Green (2004).

A tradeoff-curve is a method of visualizing how design parameters relate to each other (Ward, 2007). The visualization is often based on data from testing activity, and could, for example, be the fuel consumption of different engines running at different rpm. The data exists in the organization and it can probably be retrieved fairly easy, but the ease of use when it comes to raw data is limited. Visualizing the test data makes it more intellectually accessible, i.e., it is easier to use. The A3-report has a similar purpose, but typically visualizes problem solving processes rather than data. The idea with A3 is to force the author to condense the information into a standard format which is very limited (Sobek and Smalley, 2008; Raudberget and Bjursell, 2014). In order to do this, the author of the A3 must carefully select and delimit the arguments and present them with high accuracy. This makes the information more accessible to a reader than long elaborate texts, and it makes it easier to interact with the author if further data or argumentation is wanted. A3's clearly emphasize the ease of use, and when it comes to ease of access, it is dependent on a search function, either for the A3 itself or for the authors of the

A3's. Finally, the Obeya is a method of visualizing all the information that is relevant for the execution of a specific project (Morgan and Liker, 2006). The idea is to keep the information in one place in order to make sure it is accessible when decisions are to be made[31]. The information in the Obeya can be visualized through methods like A3's and trade-off curves, to combine Fidel and Greens two components of accessibility; ease of access and ease of use (Fidel and Green, 2004).

All three methods represent ways of visualizing information in order to support team communication. Thus, in essence, the methods make the information, which already exists in the organization, also accessible. This means in the case of trade-off curves and A3's that accessibility is primarily in terms of ease of use increased, and in the case of the Obeya that accessibility in terms of ease of access is also increased. Therefore, in all three cases, this means that the team is able to use the information to make informed decisions. The methods therefore contribute to an organizations information processing capability.

5.3.2 Accessibility in non-visual communication

The second aspect regards the accessibility of information that is non-visual. All information is not easily visualized; a lot of information is documented in pure text. Thus, in product development organizations, the typical channel for such non-visual communication is the document repository. The starting point of the analysis in paper 6 is the perceived low reuse rate of documents stored in documentation repositories; the leverage of such depositories are not always convincing to the product developers using them. Although they add information to the repository, they are often not satisfied with how to find and use information in the system. Again, as in the example above with the test data, this is a case of existing information not being accessible for communication and decision making. Paper 6 shows that a problem causing a reduction of the accessibility of information in document repositories is *the documentation paradox*. The paradox refers to the fact that even though a known recipient is important to successful knowledge reuse, document creators may write documents without being aware of the recipient – in fact *because* they are unaware of the recipient, hence the paradox. This paradox arguably lowers the chances of documents being accessible for the recipient.

Here, the identified potential for increased accessibility is related to the extent to which the creator of a document is aware of the recipient of that document. The

[31] In paper 1, the related term "availability" is used for accessibility. However, Fidel and Green (2004) make an important distinction between the two; they refer to availability as information being "not busy", i.e. it is related to the possibility to use an information resource at a particular time, which is only a subset to accessibility. Therefore, accessibility is used in this cover paper.

findings show that in many cases, this awareness is low or nonexistent; i.e., documents are sometimes created without a clear recipient. Consequently, this presumably hampers the accessibility of the information, both when it comes to ease of access as well as ease of use. Markus (2001) showed that there are three types of recipients of a document; 1) the creator (some documents are created for own personal use) 2) similar others and 3) dissimilar others. This distinction is important in explaining how different document and linguistic structures, jargon, and contextual information are used when documenting. Thus, who the recipient is affects how the documentation is created. However this assumes that the recipient is known. Therefore, in cases where the recipient is unknown, questions regarding structure and context become difficult to handle. Assumedly, most of those documents are written to dissimilar others, as the recipient is obviously known if the document is written for personal use (albeit for a future version of that person), and if the recipient is a similar other, the recipient is probably either known or can be estimated, as contextual differences should be small. But in the case of documenting for dissimilar others, which is the category of recipients where it is of greatest importance to know the recipient to be able to adapt the document to those specific needs, it is assumedly more likely that the recipient is unknown. Finally, an extension of Markus' framework to also include a dimension of familiarity would perhaps describe the recipient more accurately. It should be noted that the study presented in paper 6 would benefit from complementing studies regarding, for example, the extent of and reasons for, creating documents for unknown recipients, in order to better understand why this occurs and how it can be reduced or managed.

In summary, the accessibility of existing information in an organization plays an important role for the information processing capability of the organization. This thesis suggests two strategies for increasing the accessibility of information in order to improve the information processing capability. The first strategy is using methods for visual communication which makes the information accessible primarily through the ease of use. The second strategy is to increase the document creators' awareness of the recipient of documents in order to make the content and form of the document adapted to the context of the recipient, thus increasing the accessibility through both ease of use and ease of access.

5.4 Discussion

An important distinction, on which this thesis builds, is that visualization can be used to process information in at least two different ways. Visualization can be used to process information for one or more individuals to better understand and make

use of data, as in the example with the trade-off curves, or it can be used to process information between individuals, as in the case of Visual planning. Typically, visualizations that are used in management are of the first type (see e.g. Zhang, 2012), i.e., the support that managers need to make informed decisions could be based on visualization of information that reduces uncertainty. But in order to handle ambiguity depending on different individual interpretations of information, then rich communication is needed between those individuals. This is where the boundary object comes in. Using boundary objects is a way of supporting the communication between the individuals rather than the communication between an individual and the data that individual is trying to understand.

In addition, but neglected by these studies, the process in which the visualization is created seems to be of central importance. It is in the creation of a visualization which is dependent on the input from several individuals that the negotiation of the content occurs (see e.g. Eppler and Bresciani, 2013), not only from the visualization itself. Although it can be argued, that in the example of Visual planning, the visualization is constantly created, as it is frequently updated. Every change in the visualization would ideally make the visualization a better representation of the "collected mental models" of the members of the team.

When it comes to ambiguity, this thesis specifically addresses *process ambiguity*, defined by Brun et al. (2009) as *"…related to the work process to be followed in the NPD project: tasks to perform, dependencies among them, sequences in which to perform them, their inputs, and their outputs"* (p. 74). Brun and Saetre argue that research that addresses ambiguity in general as something distinct from uncertainty in product development projects is missing. This thesis aims to contribute to that discourse focusing on process ambiguity. Relating to Brun and Saetres sources of ambiguity, visualization seems to address primarily *multiplicity* (ambiguity originating from multiple and conflicting interpretations) and *novelty* (ambiguity originating from new interpretations over time) where multiplicity is the most evident one, as interviewees typically perceive the team becoming more coherent and with less conflicting interpretations. Novelty is also highly relevant, as the visualized content is constantly changing and requires frequent updating.

Another factor that is not directly studied, but has emerged as a potentially important aspect of Visual planning is the *delimitation* of the visualization. The fact that the board which is used is delimited in size (although the team can decide what size it should have) makes the visualization process also a process of delimitating what content should be visualized. This has several implications. First, the content needs to be carefully selected to avoid an overcrowded board, which means that a cognitive process has to take place where information is evaluated based on its use

for task communication within the team[32]. Secondly, the board is possible to remember for the individual team members, at least "the big picture". However, compared to, for example, a PowerPoint presentation which can indeed be highly visual, the big picture is difficult to capture in several slides as opposed to one big board. This means that the team members can have a chance of keeping the process of the project in the back of their minds. Third, the delimited size of the board can create a "sense of control" of the project. Even though the sense of control might not be real control in effect, research shows that a sense of control makes people more focused, efficient and confident which is positively related to performance (Eisenhardt and Brown, 1997).

[32] Related to the idea of A3-communication discussed earlier.

6 Conclusions and future research

This final chapter revisits the overall purpose of the thesis; to explore visual management and its use in product development organizations. The thesis has discussed how organizations can improve their capability to process information through visualizations, and thereby develop strategies for reduction of uncertainty and ambiguity. This chapter will present a compilation and synthesis of the conclusions drawn from both the analysis presented in this cover paper and the conclusions drawn in the appended papers. It will also pinpoint specific contributions, discuss implications for managers, and suggest topics for future research.

6.1 Conclusions

Visualization holds great promise when it comes to supporting a human's cognitive functions. These properties suggest a potential for supporting managerial tasks. This is also recognized in some areas of management. Moreover, in product development, visualization is used extensively for technical communication through e.g., CAD systems, prototypes and 3D models. However, it seems that the development of visual boundary objects for task communication of the non-canonical process on a team level is typically under prioritized in R&D organizations. This thesis presents an analysis of an example of such a boundary object. Several conclusions can be made on the basis of the analysis:

First, *Visual management supports an organizations information processing capability*. This thesis argues that the communication that is triggered and supported by Visual management methods, equips the organization with a capability to process information. This capability is key in handling 1) uncertainty, as acquiring and using information is one of the main strategies for uncertainty reduction; and 2) ambiguity, as it increases the awareness of ambiguities in R&D teams, and provides means for the teams to communicate and create strategies to reduce the ambiguity. The information processing capability based on visualization stems from the fundamental research on benefits of visualization, such as the dual coding theory,

the additivity hypothesis and the pictorial superiority effect, along with the possibility to use, for example, deictic gesturing. But the capability also stems from the identified implications of Visual management, such as improved overview, and the use of rich, synchronous and frequent communication through non-canonical boundary objects based on real-time information (see paper 2 and 3). A key to information processing capability is also the accessibility of information, which is enhanced by visualizations. This thesis argues that accessibility of information is central to information processing, and therefore also to the reduction of uncertainty and ambiguity. Accessibility can be improved by visualization (see paper 1), but also non-visual information can be made more accessible (see paper 6).

Therefore, in terms of visualization in product development specifically, experiences from using visualizations for technical communication seem to be transferrable to the task communication. Building physical and virtual prototypes of products and concepts is a key to creating good conditions for communication, thereby reducing both the ambiguity and the uncertainty regarding the product. The idea of "scale models" as boundary objects supports synchronous and rich communication that in turn provides conditions for making informed decisions. The same mechanism has been identified in this thesis, although for task communication. The main study object; Visual planning serves as a "scale model" of the project, providing the team with a boundary object that supports their communication of the tasks and deliverables in a project.

Second, *Visual management can play an important role in supporting communication between individuals*. This thesis argues that visualizations trigger and support synchronous and rich communication (see paper 3), discusses under what circumstances it does so (see paper 4) and also suggests how visual management can be evaluated (see paper 5). Visualizations can act as boundary objects between individuals with differing perspectives, knowledge and agendas. They trigger communication, but also "control" the communication, as the content of the visualization also becomes the content of the communication. Thus, it is crucial to consciously visualize exactly the content that needs to be communicated. This can be considered a strength, as communication gets focused on the topics of high priority, but it is also potentially a risk, as the communication relies on the input to and creation of the visualization.

Product development organizations and society at large have never produced such vast amounts of information as is being done today and analyzing and using all this information is becoming increasingly difficult. At the same time it is becoming increasingly important, as the speed and complexity of product development is increasing with globalization and technological advances. Visualization can provide a strategy in managing the flood of information, to increase the accessibility of

information and support team communication to be able to better handle uncertainty and ambiguity.

6.2 Contributions

This thesis contributes to the body of knowledge on visualization in management. Parker and Davis (1997) present four possible types of additive contributions of a dissertation: 1) new or improved evidence, 2) new or improved methodology, 3) new or improved analysis, and 4) new or improved concepts or theories. A combination of these types of contributions is possible. This thesis conveys four main contributions in terms of new evidence and new or improved concepts:

New empirical evidence is provided regarding the classification of Visual management methodology. Burkhard (Burkhard, 2005a; Burkhard, 2005b; Eppler and Burkhard, 2007) provides a framework for Knowledge visualization, where four perspectives are presented; the function, the type of knowledge, the recipient, and the type of visualization. From a communication perspective, this thesis expands on these four perspectives, by adding 1) whether visualization is used for mainly one-way or two-way communication, 2) the organizational perspective, i.e., at what organizational level is the communication taking place and whether it is lateral or vertical, 3) whether the visualization is used for mainly synchronous or asynchronous communication, 4) the update frequency of the visualization, i.e., whether the information is real-time, has a delay or is fixed, 5) whether the visualization represents canonical or non-canonical information.

New empirical evidence is also provided regarding the link between using Visual management and means of communication that are more purposive for task communication in teams. Product development teams typically have to handle uncertainty and ambiguity, and the communication therefore needs to address this challenge. This thesis provides empirical data from an example of such task communication, using visualization to reduce the uncertainty and ambiguity. This adds to previous theory on visualization for task communication (Brown and Eisenhardt, 1995; Hirst and Mann, 2004), previously mainly represented by one-way canonical visual communication tools such as process visualizations (Wheelwright and Clark, 1992; Cooper, 1993; Smith and Morrow, 1999) and one-way, asynchronous visual communication means such as Gantt charts and similar (Maylor, 2001; Wilson, 2003). Thus, the thesis provides new insight into visual task communication means that are two-way, synchronous and non-canonical.

The third contribution is the analysis of Visual management from a knowledge transfer perspective. The cluster of Visual management methods analyzed proves

theoretically to correspond to the requirements for knowledge transfer set by the analytical model; the SECI-model (Nonaka, 1994; Nonaka and Takeuchi, 1995). The analysis contributes to the research field of Visual management by establishing a theoretical implication of using Visual management; it supports the knowledge transfer in the organizational unit that uses it.

The fourth contribution is the introduction of a new concept; the documentation paradox, presented in paper 6. The concept adds to knowledge on the mechanisms of reuse of documented knowledge, a topic highly relevant for research fields such as Knowledge management and Information science. In short, the paradox captures a specific situation; although it is recognized that being aware of the recipient is vital to successful knowledge reuse, document creators use documentation as a communication channel not despite, but *because* the recipient is unknown.

Finally, the formulation of a definition of the main Visual management method under study in this thesis – Visual planning, is a contribution in itself. Although other authors have to different extents discussed Visual planning (Hines et al., 2006; Holmdahl, 2006; Parry and Turner, 2006; Olausson and Berggren, 2010; Oosterwal, 2010) a coherent definition has been lacking. The definition is formulated: "*Visual planning is when development teams use frequent meetings and physical representations of tasks in order to manage deliverables and tasks throughout the execution of a project"* (Paper 3). This definition adds to the previous literature on Visual planning by formulating what the central concepts of the method are. The definition contains an important finding from the case studies that deserves highlighting. Visual planning is a method that is dependent on both the visualization – the board, and the meetings that take place at the board. The combination of these two; physical representations and frequent meetings, compose the backbone of the method, which is evident at all of the case companies studied. This empirical finding is also supported by Hines et al (2006), and it is important in relation to the conclusions drawn from this work.

6.3 Managerial implications

The findings in this thesis are estimated to be of good practical use, and there are several implications for managers in product development organizations. Generally, managers need to find strategies to cope with the uncertainty and ambiguity that is constantly present in development activities. They also need to find methods to make sure information is made accessible at the time of decision making, to enable managers and product developers to make as informed decisions as possible. Within teams, communication of the processes they are a part of is of great importance to avoid multiple and conflicting interpretations of the situations the teams experience.

The thesis aims to provide support in these areas. The managerial implications of the thesis are of two types:

First, the *awareness of managers* that visualization can create a common base for communication, and that this common base sometimes needs to be actively created and maintained, is important in itself. The effectiveness of visual communication is intuitive to most people, but it does not seem as intuitive to visualize processes that are not naturally visual. For example, a production process is often visual as it is; you can physically walk through the process and see where the system boundaries are, collect metrics, communicate with people at certain sections of the process, etc. A development process is nothing like that. Instead, it needs to be actively visualized to reap all the benefits that a naturally visual process incorporates.

Second, once this awareness is in place, the question of *how to visualize the process* arises. This thesis has studied a few methods of doing this, but does not try to argue that they would be the only ones. Two basic recommendations when designing process visualizations emerge from the research. The purpose of the visualization is perhaps the most important aspect to consider. If the purpose is to stimulate communication, the content of the visualization has to be information that is of value to the team members to communicate. A visualization that is made for mapping purposes for example, provides little support for continuous communication. Another aspect is what the communication forum would look like; a visualization that does not have a communication forum attached to it will make little contribution to task communication. This could mean that the meetings around the visualization need to be purposefully designed when it comes to who should participate, how many, how often, etc.

Third, when it comes to accessibility a critical assessment of how accessible information in the organization really is could be useful. Undoubtedly, the use of IT in product development is of tremendous help when it comes to disperse information in global organizations, but overconfidence in such systems may prove dangerous. IT-systems increase accessibility of information in general, but that does not necessarily mean that information sent into the system is automatically more accessible. Both the ease of access and the ease of use need to be considered, i.e., the information must be easy to find, for which different search strategies could be applied such as tagging of content and intelligent search engines, but the information must also be easy to use. An important factor in making information easier to use is creating the document with a clear recipient in mind – one should probably ask oneself the question "why am I documenting this?" if it is unclear who the recipient of that particular document is.

6.4 Limitations and directions for future research

The research is based on case studies, which have been established in the methods chapter as being an appropriate methodology related to the research questions. However, all scientific methodologies have limitations. For further analysis of the implications, the implementation and the evaluation of visual management in product development, statistical analysis could be a viable strategy. This would make the findings generalizable, and using the qualitative findings from this study as a basis for a quantitative study would show how the two complement each other in formulating theory. Also, interviews have been used as the main method for data collection. Further data could be collected using other methods to triangulate the interview data to a greater extent. Observations are a good way of triangulating interview data, provided that the topic is observable. Visual planning proved to be very observable as it is delimited in time and space. Moreover, with hindsight, even more observations would perhaps have sharpened the analysis of the interview data. Experiments were also considered as a method, studying how visualizations affect team communication in a controlled lab like environment could have provided further insights, but the idea was never pursued due to time constraints. Both in observations and experiments, content analysis can be used to identify differences in nature and content of team communication with and without the support of visualizations.

On the basis of the results of the studies, several options for further research emerge. First, research on how to develop visual task communication further would complement the research up to the present day. Topics could include how to visualize the entire development process without compromising the real-time non-canonical process, reduce the redundancy with other planning methods in a development organization, and how different types of visualizations on different levels and places in the organization can interact in order to create a system of visualizations. Another topic of great interest would be to take the visualization even further, and study how the development process could be made more visual through how the organization is organized, how people in the process are physically located relative to each other, and how for example building layouts would be affected by such research. Also, other applications or contexts for visualizing activities and deliverables could be investigated. Fairly complex environments including different competences and where there is a need for resource allocation, planning and/or continuous communication and follow up on the deliveries of a team would be relevant contexts for such studies. Healthcare, the public sector, and the service sector are examples of such contexts.

Second, the understanding of how communication is affected by visualization in the product development context needs to be improved, e.g., what certain aspects of the visualization trigger the communication? If these aspects are identified, one might find other information that would benefit from visualization, for example, information that is now not communicated to a satisfactory extent. Also, this research focuses mainly on lateral communication. A possible extension of that could be to investigate if the ideas of communicating visually could also be extended to vertical communication in an organization or between organizational units. A question related to that is whether the implications of using Visual management could also be valid for use in globally dispersed teams, and how the methods would have to be adjusted to suit the needs of such teams.

Third, analyses of visualization of process information from an individual perspective would shed further light on how it affects the individuals and their ability and motivation to perform. This kind of research would border on behavioral science as it would look at how an individual reacts to increased transparency of activities and deliverables. Examples of similar topics could include visualization and its relation to power and influence, professionalism, and group dynamics (e.g. inclusion/exclusion).

Third, the design of boundary objects for communication in geographically distributed teams would be a relevant topic related to the findings in this thesis. Product development organization use distributed teams increasingly, and the need for boundary objects are even higher than in co-located teams. An important aid in achieving such boundary objects is undoubtedly IT-based solutions. Such solutions currently exist, and studying the implications in that setting and comparing to the studies in this thesis would be an important challenge for development organizations using distributed teams.

References

Ahmed, P. K. (1998). Culture and climate for innovation. *European Journal of Innovation Management,* 1**,** 30-43.

Al-Kassab, J., Ouertani, Z. M., Schiuma, G. & Neely, A. (2014). Information visualization to support management decisions. *International Journal of Information Technology & Decision Making*, 13(02), 407-428.

Alavi, M. & Leidner, D. E. (2001). Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS quarterly***,** 107-136.

Allen, T. J. (1977). *Managing the flow of technolog*. Boston: The Massachusetts Institute of Technology, MIT Press.

Alvesson, M. & Sköldberg, K. (2009). *Reflexive methodology: New vistas for qualitative research*, 2 ed. Los Angeles: Sage.

Ancona, D. G. & Caldwell, D. F. (1992). Demography and design: Predictors of new product team performance. *Organization science,* 3**,** 321-341.

Anderson, C. J., Glassman, M., Mcafee, R. B. & Pinelli, T. (2001). An investigation of factors affecting how engineers and scientists seek information. *Journal of Engineering and Technology Management,* 18**,** 131-155.

Arbnor, I. & Bjerke, B. (2009). *Methodology for creating business knowledge*. 3. ed. Thousand Oaks, Calif.: Sage

Baba, Y. & Nobeoka, K. (1998). Towards knowledge-based product development: the 3-D CAD model of knowledge creation. *Research Policy,* 26**,** 643-659.

Baccarini, D. (1996). The concept of project complexity—a review. *International Journal of Project Management,* 14**,** 201-204.

Barker, D. & Smith, D. J. H. (1995). Technology foresight using roadmaps. *Long Range Planning,* 28**,** 21-28.

Barry, A. M. (1997). *Visual intelligence: Perception, image, and manipulation in visual communication*, Albany: State University of New York Press

Bartel, C. A. & Garud, R. (2009). The role of narratives in sustaining organizational innovation. *Organization Science,* 20**,** 107-117.

Bauer, M. I. & Johnson-Laird, P. N. (1993). How diagrams can improve reasoning. *Psychological Science,* 4**,** 372-378.

Bechky, B. A. (2003). Sharing meaning across occupational communities: The transformation of understanding on a production floor. *Organization Science,* 14, 312-330.

Becker-Beck, U., Wintermantel, M. & Borg, A. (2005). Principles of regulating interaction in teams practicing face-to-face communication versus teams practicing computer-mediated communication. *Small Group Research,* 36, 499.

Bell, E. & Davison, J. (2013). Visual Management Studies: Empirical and Theoretical Approaches. *International Journal of Management Reviews,* 15, 167-184.

Berg, M. & Bowker, G. (1997). The multiple bodies of the medical record. *The Sociological Quarterly,* 38, 513-537.

Berggren, C., Bergek, A., Bengtsson, L., Hobday, M. & Söderlund, J. (red.) (2011). *Knowledge Integration and Innovation: Critical Challenges Facing International Technology-Based Firms*, Oxford: Oxford University Press

Berggren, C., Järkvik, J. & Söderlund, J. (2008). Lagomizing, organic integration, and systems emergency wards: Innovative practices in managing complex systems development projects. *Project Management Journal,* 39, 111-122.

Bly, S. A. (1988). A use of drawing surfaces in different collaborative settings. Proceedings of the 1988 ACM conference on Computer-supported cooperative work, 1988. ACM, 250-256.

Boland, R. J. & Tenkasi, R. V. (1995). Perspective making and perspective taking in communities of knowing. *Organization Science,* 6, 350-372.

Braganza, A. (2004). Rethinking the data–information–knowledge hierarchy: towards a case-based model. *International Journal of Information Management,* 24, 347-356.

Brodbeck, F. C. (2001). Communication and performance in software development projects. *European Journal of Work and Organizational Psychology,* 10, 73-94.

Brown, J. S. & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization Science,* 2, 40-57.

Brown, J. S. & Duguid, P. (1998). Organizing knowledge. *California Management Review,* 40, 91.

Brown, S. L. & Eisenhardt, K. M. (1995). Product development - Past research, present findings, and future directions. *Academy of Management Review,* 20, 343-378.

Brun, E. & Sætre, A. S. (2009). Managing ambiguity in new product development projects. *Creativity and Innovation Management,* 18, 24-34.

Brun, E. & Saetre, A. S. (2008). Ambiguity reduction in new product development projects. *International Journal of Innovation Management,* 12, 573-596.

Brun, E., Sætre, A. S. & Gjelsvik, M. (2008). Benefits of ambiguity in new product development. *International Journal of Innovation and Technology Management,* 5, 303-319.

Brun, E., Saetre, A. S. & Gjelsvik, M. (2009). Classification of ambiguity in new product development projects. *European Journal of Innovation Management,* 12, 62-85.

Bryman, A. & Bell, E. (2007). *Business research methods,* 2. ed., Oxford: Oxford University Press

Buchanan, D. A. (1999). The logic of political action: an experiment with the epistemology of the particular. *British Journal of Management,* 10, 73-88.

Buijs, J. (2003). Modelling product innovation processes, from linear logic to circular chaos. *Creativity and Innovation Management,* 12, 76-93.

Burkhard, R. (2005a). *Knowledge Visualization: The Use of Complementary Visual Representations for the Transfer of Knowledge: a Model, a Framework, and Four New Approaches.* (Doctoral dissertation, Swiss Federal Institute for Environmental Science and Technology).

Burkhard, R. A. (2005b). Towards a Framework and a Model for Knowledge Visualization: Synergies Between Information and Knowledge Visualization. *In:* Tergan, S.-O. & Keller, T. (eds.) *Knowledge and Information Visualization.* Berlin: Springer

Burns, T. E. & Stalker, G. M. (1961). *The management of innovation,* London: Tavistock Publications.

Card, S. K., Mackinlay, J. D. & Shneiderman, B. (1999). *Readings in information visualization: using vision to think*, San Francisco: Kaufmann

Carlile, P. (2002). A pragmatic view of knowledge and boundaries: Boundary objects in new product development. *Organization Science,* 13, 442-455.

Chapman, R. J. (2002). *Multimodal, Asynchronously Shared Slide Shows as a Design Strategy for Engineering Distributed Work in the National Airspace System.* (Doctoral dissertation, The Ohio State University).

Chen, J., Damanpour, F. & Reilly, R. (2010). Understanding antecedents of new product development speed: A meta-analysis. *Journal of Operations Management,* 28, 17-33.

Choo, C. W. (1991). Towards an information model of organizations. *Canadian Journal of Information Science-Revue Canadienne Des Sciences De L Information,* 16, 32-62.

Clark, K. B. & Fujimoto, T. (1991). *Product development performance: Strategy, organization, and management in the world auto industry* Boston, Mass.: Harvard Business School Press

Cooper, R. G. (1993). *Winning at new products: accelerating the process from idea to launch,* Massachusetts, 2. ed. Reading, Mass.: Addison-Wesley

Coyne, I. T. (1997). Sampling in qualitative research. Purposeful and theoretical sampling; merging or clear boundaries? *Journal of Advanced Nursing,* 26, 623-630.

Daft, R. L. & Lengel, R. H. (1986). Organizational information requirements, media richness and structural design. *Management Science,* 554-571.

Daft, R. L. & Weick, K. E. (1984). Toward a model of organizations as interpretation systems. *Academy of Management Review,* 9, 284-295.

Damanpour, F. (1996). Organizational complexity and innovation: developing and testing multiple contingency models. *Management Science,* 42, 693-716.

Davenport, T. & Prusak, L. (1998). *Working Knowledge,* Boston, Mass.: Harvard Business School Press.

Davis, G. B. & Parker, C. A. (1997). *Writing the doctoral dissertation: A systematic approach*, 2. ed. Happauge, N.Y.: Barron's

De Meyer, A. (1991). Tech talk: how managers are stimulating global RD communication. *Sloan Management Review,* 32.

Doganova, L. & Eyquem-Renault, M. (2009). What do business models do?: Innovation devices in technology entrepreneurship. *Research Policy,* 38**,** 1559-1570.

Dougherty, D. (1992). Interpretive barriers to successful product innovation in large firms. *Organization Science,* 3**,** 179-202.

Dubois, A. & Araujo, L. (2007). Case research in purchasing and supply management: opportunities and challenges. *Journal of Purchasing and Supply Management,* 13**,** 170-181.

Dubois, A. & Gadde, L. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research,* 55, 553-560.

Dyke, J. & Wojahn, P. (2000). Getting dissed: technical communicators in interdisciplinary engineering teams. Proceedings of IEEE professional communication society international professional communication conference and Proceedings of the 18th annual ACM international conference on Computer documentation: technology & teamwork, 2000. IEEE Educational Activities Department, 7-23.

Easterby-Smith, M., Thorpe, R. & Jackson, P. (2012). *Management research*, 4. ed. Thousand Oaks, Calif.: Sage Publications.

Edmondson, A. C. & McManus, S. E. (2007). Methodological fit in management field research. *Academy of Management Review,* 32, 1246-1264.

Eisenberg, E. M. (1984). Ambiguity as strategy in organizational communication. *Communication Monographs,* 51**,** 227-242.

Eisenhardt, K. M. (1989a). Building Theories from Case Study Research. *The Academy of Management Review,* 14, 532-550.

Eisenhardt, K. M. (1989b). Making Fast Strategic Decisions in High-Velocity Environments. *The Academy of Management Journal,* 32, 543-576.

Eisenhardt, K. M. & Brown, S. L. (1997). Time pacing: competing in markets that won't stand still. *Harvard Business Review,* 76, 59-69.

Eisenhardt, K. M. & Tabrizi, B. N. (1995). Accelerating adaptive processes: Product innovation in the global computer industry. *Administrative Science Quarterly***,** 84-110.

Ellis, W. D. (1938). *A source book of Gestalt psychology,* New York: Harcourt, Brace & World.

Emmanuelides, P. A. (1993). Towards an integrative framework of performance in product development projects. *Journal of Engineering and Technology Management,* 10, 363-392.

Enberg, C., Lindkvist, L. & Tell, F. (2006). Exploring the Dynamics of Knowledge Integration Acting and Interacting in Project Teams. *Management Learning,* 37, 143-165.

Eppler, M. & Burkhard, R. (2007). Visual representations in knowledge management: framework and cases. *Journal of Knowledge Management,* 11, 112-122.

Eppler, M. J. & Bresciani, S. (2013). Visualization in management: From communication to collaboration. A response to Zhang. *Journal of Visual Languages & Computing,* 24**,** 146-149.

Eppler, M. J. & Pfister, R. Best of Both Worlds: Hybrid Knowledge Visualization in Police Crime Fighting and Military Operations. Proceedings of the 13th International Conference on Knowledge Management and Knowledge Technologies, 2013. ACM, 17.

Ernst, H., Hoyer, W. D. & Rübsaamen, C. (2010). Sales, marketing, and research-and-development cooperation across new product development stages: implications for success. *Journal of Marketing,* 74, 80-92.

Fagerström, B. (2004). *Managing Distributed Product Development. An Information and Knowledge Perspective*, (Doctoral dissertation, Chalmers University of Technology).

Fidel, R. & Green, M. (2004). The many faces of accessibility: engineers' perception of information sources. *Information Processing & Management,* 40, 563-581.

Finke, R. A. (1990). *Creative imagery: Discoveries and inventions in visualization,* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Flood, R. L. & Carson, E. R. (1993). *Dealing with complexity: an introduction to the theory and application of systems science*. 2. ed. New York: Plenum Springer

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry,* 12, 219-245.

Ford, R. C. & Randolph, W. A. (1992). Cross-functional structures: A review and integration of matrix organization and project management. *Journal of Management,* 18, 267-294.

Fox, N. J. (2011). Boundary objects, social meanings and the success of new technologies. *Sociology,* 45, 70-85.

Galbraith, J. (1973). *Designing complex organizations*, Reading, Mass.: Addison-Wesley.

Galbraith, J. (1977). *Organization design*, Reading, Mass.: Addison-Wesley.

Gamme, I. & Aschehoug, S. (2014). Assessing lean's impact on operational integration. *International Journal of Quality and Service Sciences,* 6, 2-2.

George, A. L. & Bennett, A. (2005). *Case studies and theory development in the social sciences*, Cambridge, Mass.: MIT Press.

Gerring, J. (2007). *Case study research*, Cambridge, Mass.: Cambridge University Press

Glaser, B. & Strauss, A. (1967). *The discovery of grounded theory: strategies for qualitative inquiry*. Chicago: Aldin

Glenberg, A. M. & Langston, W. E. (1992). Comprehension of illustrated text: Pictures help to build mental models. *Journal of Memory and Language,* 31, 129-151.

Gopsill, J., Mcalpine, H. & Hicks, B. The communication patterns of engineers within an SME. International Conference on Engineering Design (ICED'13), 2013.

Greif, M. (1991). *The visual factory,* Portland, OR: Productivity Press

Griffin, A. (1997). The Effect of Project and Process Characteristics on Product Development Cycle Time. *Journal of Marketing Research (JMR),* 34, 24-35

Guba, E. G. & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. *Handbook of Qualitative Research,* 2**,** 163-194.

Halldórsson, Á. & Aastrup, J. (2003). Quality criteria for qualitative inquiries in logistics. *European Journal of Operational Research,* 144, 321-332.

Henderson, K. (1991). Flexible sketches and inflexible data bases: Visual communication, conscription devices, and boundary objects in design engineering. *Science, Technology & Human Values,* 16**,** 448-473.

Henderson, K. (1999). *On line and on paper: Visual representations, visual culture, and computer graphics in design engineering,* Boston, Mass.: MIT Press.

Hertzum, M. & Pejtersen, A. M. (2000). The information-seeking practices of engineers: searching for documents as well as for people. *Information Processing & Management,* 36**,** 761-778.

Hines, P., Francis, M. & Found, P. (2006). Towards lean product lifecycle management: A framework for new product development. *Journal of Manufacturing Technology Management,* 17**,** 866-887.

Hirst, G. & Mann, L. (2004). A model of R&D leadership and team communication: the relationship with project performance. *R&D Management,* 34**,** 147-160.

Hobday, M. (1998). Product complexity, innovation and industrial organisation. *Research Policy,* 26, 689-710.

Holmdahl, L. (2006). *Complexity aspects of product development.* (Doctoral dissertation, Otto von Guericke University).

Hultink, E. J., Talke, K., Griffin, A. & Veldhuizen, E. (2010). Market Information Processing in New Product Development: The Importance of Process Interdependency and Data Quality. *IEEE Transactions on Engineering Management*. 58(2), 199-211

Ireland, R. D. & Miller, C. C. (2004). Decision-making and firm success. *Academy of Management Executive,* 18, 8-12.

Ivanvevich, J. M., Szilagi, A. D. & Wallace, M. J. (1977). *Organizational behaviour and performance,* Santa Monica: Goodyear publishing.

Karlsson, C. (2009). *Researching Operations Management,* New York: Routledge

Kaya, O., Stenholm, D., Catic, A. & Bergsjo, D. (2014). Towards Global Deviation Management in Product Development Using Pulse Methodology: A Case Study. *Procedia Computer Science,* 28, 265-274.

Keller, R. T. (1986). Predictors of the performance of project groups in R&D organizations. *Academy of Management Journal,* 29, 715-726.

Keller, R. T. (2001). Cross-functional project groups in research and new product development: Diversity, communications, job stress, and outcomes. *Academy of Management Journal***,** 547-555.

Knight, F. H. (1921). *Risk, uncertainty and profit*, Dover: Courier Publications.

Koffka, K. (1935). *The principles of Gestalt psychology,* London: Lund Humphries.

Koskinen, K. U. (2005). Metaphoric boundary objects as co-ordinating mechanisms in the knowledge sharing of innovation processes. *European Journal of Innovation Management,* 8, 323-335.

Kosslyn, S. M. (1980). *Image and mind,* Cambridge, Mass.: Harvard University Press.

Kosslyn, S. M. & Koenig, O. (1992). *Wet mind: The new cognitive neuroscience,* New York: Simon and Schuster.

Koufteros, X., Vonderembse, M. & Jayaram, J. (2005). Internal and external integration for product development: the contingency effects of uncertainty, equivocality, and platform strategy. *Decision Sciences,* 36, 97-133.

Lane, D. & Maxfield, R. (1996). Strategy under complexity: Fostering generative relationships. *Long Range Planning,* 29, 215-231.

Langley, A. (1999). Strategies for theorizing from process data. *Academy of Management review,* 24, 691-710.

Larkin, J. H. & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science,* 11, 65-100.

Lawrence, P. & Lorsch, J. (1967). *Organization and Environment: Managing Differentiation and Integration* Boston, Mass.: Harvard University Press.

Leckie, G. J., Pettigrew, K. E. & Sylvain, C. (1996). Modeling the information seeking of professionals: a general model derived from research on engineers, health care professionals, and lawyers. *The Library Quarterly***,** 161-193.

Leifer, R. & Mills, P. K. (1996). An information processing approach for deciding upon control strategies and reducing control loss in emerging organizations. *Journal of Management,* 22, 113-137.

León, H. C. M. & Farris, J. A. (2011). Lean Product Development Research Current State and Future Directions. *Engineering Management Journal,* 23**,** 29-51.

Leonard-Barton, D. (1990). A dual methodology for case studies: synergistic use of a longitudinal single site with replicated multiple sites. *Organization Science,* 1, 248-266.

Lester, R. K. & Piore, M. J. (2004). *Innovation - the missing dimension*. Cambridge, Mass.: Harvard University Press

Lindlöf, L. & Söderberg, B. (2011). Pros and cons of lean visual planning: experiences from four product development organisations. *International Journal of Technology Intelligence and Planning,* 7, 269-279.

Lindlöf, L., Söderberg, B. & Persson, M. (2012). Practices supporting knowledge transfer–an analysis of lean product development. *International Journal of Computer Integrated Manufacturing*. 26(12), 1128-1135.

Lindlöf, L. & Trygg, L. (2012) Task visualization in product development - improved communication for development teams. The R&D Management Conference 2012, May 23-25, Grenoble, France., 2012.

Loch, C. H. & Terwiesch, C. (1998). Communication and uncertainty in concurrent engineering. *Management Science,* 44, 1032-1048.

Lurie, N. H. & Mason, C. H. (2007). Visual representation: Implications for decision making. *Journal of Marketing,* 71, 160-177.

Mandl, H. & Levin, J. R. (1989). *Knowledge acquisition from text and pictures,* Amsterdam, Holland: Elsevier Science Publishers

Markus, M. L. (2001). Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success. *Journal of Management Information Systems,* 18, 57-94.

Maylor, H. (2001). Beyond the Gantt chart: Project management moving on. *European Management Journal,* 19, 92-100.

Maylor, H. (2010). *Project Management*. 4. ed. Harlow, England: Financial Times Prentice Hall

Merriam-Webster.Com. (2014a). *complexity* [Online]. Merriam-Webster. [Accessed 18 Feb 2014].

Merriam-Webster.Com. (2014b). *implication* [Online]. Merriam-Webster. [Accessed 19 Sep 2014].

Meyer, J.-A. (1997). The acceptance of visual information in management. *Information & Management,* 32, 275-287.

Miles, M. B. & Huberman, A. M. (1999). *Qualitative data analysis,* Thousand Oaks, Calif.: Sage Publications

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review,* 63, 81.

Mintzberg, H. (1979). An emerging strategy of "direct" research. *Administrative Science Quarterly,* 582-589.

Morelli, M. D., Eppinger, S. D. & Gulati, R. K. (1995). Predicting technical communication in product development organizations. *IEEE Transactions on Engineering Management,* 42, 215-222.

Morgan, J. & Liker, J. (2006). *The Toyota product development system: integrating people, process, and technology,* New York, NY: Productivity Press.

Morse, J. M. (red.) (1991). *Qualitative nursing research: a contemporary dialogue*. Rev. ed. Newbury Park, CA: Sage

Negele, H., Fricke, E., Schrepfer, L. & Härtlein, N. Modeling of integrated product development processes. Proceedings of the 9th Annual Symposium INCOSE, UK, 1999. 1-9.

Nelson, D. L., Reed, V. S. & Walling, J. R. (1976). Pictorial superiority effect. *Journal of Experimental Psychology: Human Learning and Memory,* 2, 523.

Nicolini, D., Mengis, J. & Swan, J. (2012). Understanding the role of objects in cross-disciplinary collaboration. *Organization Science,* 23, 612-629.

Nightingale, P. (2000). The product–process–organisation relationship in complex development projects. *Research Policy,* 29, 913-930.

Nobelius, D. & Trygg, L. (2002). Stop chasing the front end process—management of the early phases in product development projects. *International Journal of Project Management,* 20, 331-340.

Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science,* 5, 14-37.

Nonaka, I. & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*, New York: Oxford University Press

Novak, S. & Eppinger, S. D. (2001). Sourcing by design: product complexity and the supply chain. *Management Science,* 47, 189-204.

Novick, L. R. (2001). Spatial diagrams: Key instruments in the toolbox for thought. *The psychology of learning and motivation: Advances in research and theory,* 40, 279-325.

O'Reilly, C. A. (1982). Variations in decision makers' use of information sources: The impact of quality and accessibility of information. *Academy of Management Journal,* 25, 756-771.

O'Reilly, C. A. (1983). The use of information in organizational decision making: A model and some propositions. *Research in organizational behavior*. 5, 103-139

Olausson, D. & Berggren, C. (2010). Managing uncertain, complex product development in high-tech firms: in search of controlled flexibility. *R&D Management,* 40, 383-399.

Onwuegbuzie, A. J. & Leech, N. L. (2007). Validity and qualitative research: An oxymoron? *Quality* & *Quantity,* 41, 233-249.

Oosterwal, D. (2010). *The lean machine: how Harley-Davidson drove top-line growth and profitability with revolutionary lean product development,* New York, NY: AMACOM/American Management Association.

Paivio, A. (1971). *Imagery and verbal processes,* New York: Holt, Rinehart and Winston.

Paivio, A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology,* 17, 370-379.

Parry, G. & Turner, C. (2006). Application of lean visual process management tools. *Production Planning* & *Control,* 17, 77-86.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*, 2. ed. Newbury Park, Calif.: Sage Publications.

Pawlowski, S. D. & Robey, D. (2004). Bridging user organizations: Knowledge brokering and the work of information technology professionals. *MIS Quarterly,* 28, 645-672.

Popper, K. R. (1959). *The logic of scientific discovery*. London: Hutchinson.

Premkumar, G., Ramamurthy, K. & Saunders, C. S. (2005). Information processing view of organizations: an exploratory examination of fit in the context of interorganizational relationships. *Journal of Management Information Systems,* 22, 257-294.

Raudberget, D. & Bjursell, C. (2014). A3 reports for knowledge codification, transfer and creation in research and development organisations. *International Journal of Product Development,* 19, 413-431.

Reid, S. E. & De Brentani, U. (2004). The fuzzy front end of new product development for discontinuous innovations: a theoretical model. *Journal of Product Innovation Management,* 21, 170-184.

Reinertsen, D. G. (1999). Taking the fuzziness out of the fuzzy front end. *Research-Technology Management,* 42, 25-31.

Rieber, L. P. (1995). A historical review of visualization in human cognition. *Educational Technology Research and Development,* 43, 45-56.

Roussel, P., Saad, K. & Erickson, T. (1991). *Third generation R&D: Managing the link to corporate strategy*. Boston, Mass.: Harvard Business School Press

Schatzman, L. & Strauss, A. L. (1973). *Field research: Strategies for a natural sociology*, Englewood Cliffs, NJ: Prentice-Hall

Schrader, S., Riggs, W. M. & Smith, R. P. (1993). Choice over uncertainty and ambiguity in technical problem solving. *Journal of Engineering and Technology Management,* 10, 73-99.

Shannon, C. E. & Weaver, W. (1949). *A mathematical theory of communication*. Urbana, IL: Univ. of Illinois Press.

Shenhar, A. J. & Dvir, D. (1996). Toward a typological theory of project management. *Research Policy,* 25**,** 607-632.

Shepard, R. & Cooper, L. (1982). *Mental images and their transformations*. Cambridge, MA: MIT Press.

Siggelkow, N. (2007). Persuasion with case studies. *Academy of Management Journal,* 50, 20-24.

Silverman, D. (2011). *Interpreting qualitative data: a guide to the principles of qualitative research*. 4., [updated] ed. London: Sage Publications

Smith, M. C. & Magee, L. E. (1980). Tracing the time course of picture–word processing. *Journal of Experimental Psychology: General,* 109**,** 373.

Smith, R. P. & Morrow, J. A. (1999). Product development process modeling. *Design Studies,* 20, 237-261.

Sobek, D. & Smalley, A. (2008). *Understanding A3 Thinking: A Critical Component of Toyota's PDCA Management System,* New York, NY, Productivity Press.

Song, M. & Montoya-Weiss, M. M. (2001). The effect of perceived technological uncertainty on Japanese new product development. *Academy of Management Journal,* 61-80.

Song, X. M., Montoya-Weiss, M. M. & Schmidt, J. B. (1997). Antecedents and Consequences of Cross-Functional Cooperation: A Comparison of R&D,

Manufacturing, and Marketing Perspectives. *Journal of Product Innovation Management,* 14, 35-47.

Star, S. L. (1989). The Structure of Ill-structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving. *Distributed Artificial Intelligence,* 2**,** 37-54.

Star, S. L. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, Technology* & *Human Values,* 35, 601-617.

Star, S. L. & Griesemer, J. R. (1989). Institutional ecology, translations and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science,* 19, 387-420.

Subrahmanian, E., Monarch, I., Konda, S., Granger, H., Milliken, R. & Westerberg, A. (2003). Boundary objects and prototypes at the interfaces of engineering design. *Computer Supported Cooperative Work,* 12, 185-203.

Tang, J. C. (1991). Findings from observational studies of collaborative work. *International Journal of Man-machine Studies,* 34, 143-160.

Tatikonda, M. & Rosenthal, S. (2000). Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE Transactions on Engineering Management,* 47, 74-87.

Taxén, L. & Lilliesköld, J. (2008). Images as action instruments in complex projects. *International Journal of Project Management,* 26, 527-536.

Tenopir, C. & King, D. W. (2004). *Communication patterns of engineers,* New York, NY: John Wiley & Sons.

Timmerman, C. E. & Madhavapeddi, S. N. (2008). Perceptions of Organizational Media Richness: Channel Expansion Effects for Electronic and Traditional Media Across Richness Dimensions. *Professional Communication, IEEE Transactions on,* 51, 18-32.

Tuomi, I. Data is more than knowledge: Implications of the reversed knowledge hierarchy for knowledge management and organizational memory. Systems Sciences, 1999. HICSS-32. Proceedings of the 32nd Annual Hawaii International Conference on, 1999. IEEE, 12 pp.

Tushman, M. L. (1978). Technical communication in R & D laboratories: The impact of project work characteristics. *Academy of Management Journal,* 21, 624-645.

Tushman, M. L. & Nadler, D. A. (1978). Information Processing as an Integrating Concept in Organizational Design. *The Academy of Management Review,* 3, 613-624.

Ulrich, K. T. & Eppinger, S. D. (2008). *Product design and development*, New York: McGraw-Hill

Wall, K., Higgins, S. & Smith, H. (2005). 'The visual helps me understand the complicated things': pupil views of teaching and learning with interactive whiteboards. *British Journal of Educational Technology,* 36, 851-867.

Wangwacharakul, P., Berglund, M., Harlin, U. & Gullander, P. (2014). Cultural Aspects when Implementing Lean Production and Lean Product Development – Experiences from a Swedish Perspective. *Quality Innovation Prosperity,* 18, 125-140.

Ward, A. (2007). *Lean Product and Process Development,* Cambridge, Mass.: The Lean Enterprise Institute.

Ward, A., Liker, J. K., John J Cristiano & Sobek, D. K. (1995). The second Toyota paradox: How delaying decisions can make better cars faster. *Sloan Management Review,* Spring, 43-61.

Ware, C. (2012). *Information visualization: perception for design,* 3. ed. Boston: Morgan Kaufmann

Weick, K. (1979). *The social psychology of organizing,* Reading, Mass.: Addison Wesley.

Weick, K. (1995). *Sensemaking in organizations*, Thousand Oaks, Calif.: Sage Publ.

Weidenmann, B. (1989). When good pictures fail: An information-processing approach to the effect of illustrations. *In:* Mandl, H. & Levin, J. R. (eds.) *Knowledge acquisition from text and pictures.* Amsterdam, Holland: Elsevier Science Publishers.

Vest, D., Long, M. & Anderson, T. (1996). Electrical engineers' perceptions of communication training and their recommendations for curricular change: Results of a national survey. *IEEE Transactions on Professional Communication,* 39, 38-42.

Wheelwright, S. C. & Clark, K. B. (1992). *Revolutionizing product development: quantum leaps in speed, efficiency and quality*. New York: Free Press.

Wilson, J. M. (2003). Gantt charts: A centenary appreciation. *European Journal of Operational Research,* 149, 430-437.

Voss, C., Tsikriktsis, N. & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations* & *Production Management,* 22, 195-219.

Yin, R. (2008). *Case Study Research: Design and methods,* Thousand Oaks, CA: Sage Publications

Zeiss, R. & Groenewegen, P. (2009). Engaging boundary objects in OMS and STS? Exploring the subtleties of layered engagement. *Organization,* 16, 81-100.

Zhang, K. (2012). Using visual languages in management. *Journal of Visual Languages & Computing,* 23**,** 340-343.

Zirger, B. & Hartley, J. (1994). A conceptual model of product development cycle time. *Journal of Engineering and Technology Management,* 11, 229-251.

Zollo, M. & Winter, S. G. (2002). Deliberate learning and the evolution of dynamic capabilities. *Organization science,* 13, 339-351.