THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Effective Sharing of Information and Knowledge in Production Systems

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in Production Systems
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Cover:
A stylized rendition of the MEET model from Fig. 2.8 and 4.5 occupies centre stage of the cover illustration. It is orbited by three icons that represent both the title of this thesis as in Fig. 1.1 and its conclusion as in Fig. 6.1.

The three icons were originally designed by Freepik (left and bottom) and geotatah (top) from www.flaticon.com.

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ABSTRACT

The ongoing paradigm shift of the manufacturing industry, Industry 4.0, creates many new opportunities for companies to become more agile with increased automation, and thus gain a competitive advantage. This development of automation increases the manufacturing complexity, and subsequently also the complexity of the work tasks performed by people. Yet human operators remain as the most important resource in modern production systems. However, to manage the increased complexity, people working together in the manufacturing industry need to effectively communicate and share information and knowledge with each other, especially for Operator 4.0 in a future Industry 4.0 context. Therefore, the purpose of this research is to explore how more effective sharing of information and knowledge can be achieved, with the aim of this thesis to propose, evaluate, and develop a framework for effective sharing of information and knowledge.

This framework, the MEET model, was applied at four different companies with varying mixed-methods research designs. In general, the MEET model emphasizes harmonization between a company's Organization System and Information System, which together support the activities where information and knowledge are shared by operators. In this thesis and its appended papers, the MEET model has been applied for the structural development for both a group of meetings in general and specific meetings in particular. Further, the use of the MEET model itself has been developed to focus on individual needs and preferences for sharing information and knowledge.

The outcome of this thesis suggests that when designing effective activities for sharing information and knowledge, it is important to focus on individual needs and preferences for information and knowledge, which the MEET model has been developed to support. This holistic approach towards effective sharing of information and knowledge is based on individual needs and preferences. Thus, this approach places an emphasis on consolidating how people want to work with the addition of technological possibilities to support the effective sharing of information and knowledge.

Conclusively, when designing and implementing effective sharing of information and knowledge, it is important to keep a human-centred perspective and to include the operators in the design process. By first identifying individuals' needs and preferences for information and knowledge, development of organizational and technological aspects can support sharing of the aforementioned information and knowledge effectively because, in the end, it is all about how people want to work.

Keywords: MEET, information, knowledge, manufacturing, Industry 4.0, Operator 4.0.

ACKNOWLEDGEMENTS

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My research activities have been parts of three research projects: *Global Assembly Instruction Strategies 2*, *MEET*, and its successor *MEET-UP*, all with funding from the *Swedish Agency for Innovation Systems – Vinnova*. This contribution is gratefully acknowledged. Within these projects, I have had the pleasure to work with many people who have been of importance for my research. Thank you for the collaboration, and special thanks to everyone involved in the appended and additional papers of this thesis.

In my position as a PhD student, I want to direct special thanks to *Sandra Mattsson* and *Magnus Åkerman* for opening up paths before me. I hope that I will be able to be as inspiring to latter PhD students as you have been to me. You are my role models. *Anna Landström* and *Daniel Nåfors*, from the first stumbling steps of our undergraduate studies, your camaraderie has been a delight to me. Now that I embark on this onwards journey, I rejoice in keeping your company as we venture into quests of future research.

My dear family – my father *Martin Li*, my mother *Liya Sang*, and my brother *Sten Li* – I am very grateful and happy to enjoy your unconditional love and support in my endeavours. Lastly, I am humbled by the fortunate circumstances of my upbringing in this small corner of the world that enjoys this level of prosperity and peace, a free education, good healthcare, and freedom of movement. Even though my scientific contribution may be rather minor by comparison, it is my sincerest hope that my work contributes to making everyday life a little bit better for some people.

Dan Li
Gothenburg, April 2019

LIST OF APPENDED PAPERS

The five appended papers in this thesis are listed here, along with the distribution of work.

Paper I Towards an Assessment Approach Promoting Flexible Value-Adding Meetings in Industry

Ulrika Harlin, Åsa Fast-Berglund, **Dan Li**, and Leif Funke (2016)

Presented at the *7th Swedish Production Symposium*, Lund, 25-26 October.

Åsa Fast-Berglund initiated and wrote the paper with contributions from Ulrika Harlin and Dan Li. Ulrika Harlin, Åsa Fast-Berglund, and Dan Li planned the study, collected and analysed the empirical data. Leif Funke provided an industrial perspective. Ulrika Harlin presented the paper.

Paper II Identifying Improvement Areas in Production Planning Meetings by Assessing Organisation and Information Systems at a Small Production Company

Dan Li, Åsa Fast-Berglund, Per Gullander, and Lars Ruud (2016)

Presented at the *7th Swedish Production Symposium*, Lund, 25-26 October.

Dan Li initiated and wrote the paper with contributions from Åsa Fast-Berglund and Per Gullander. Dan Li and Åsa Fast-Berglund planned the study. Dan Li collected and analysed the empirical data. Lars Ruud provided an industrial perspective. Dan Li presented the paper.

Paper III Digitalization of Whiteboard for Work Task Allocation to Support Information Sharing between Operators and Supervisor

Dan Li, Åsa Fast-Berglund, Anna Dean, and Lars Ruud (2017)

Presented at the *20th World Congress of the International Federation of Automation Control*, Toulouse, 9-14 July.

Published in *IFAC PapersOnLine*, vol. 50, no. 1, pp. 13044-13051.

Dan Li initiated and wrote the paper with contributions from Åsa Fast-Berglund and Anna Dean. Dan Li and Anna Dean planned the study, collected and analysed the empirical data. Lars Ruud provided an industrial perspective. Dan Li presented the paper.

Paper IV Supporting Individual Needs for Intra-Organisational Knowledge Sharing Activities in Pre-Industry 4.0 SMEs

Dan Li, Dan Paulin, Åsa Fast-Berglund, Per Gullander, and Lars-Ola Bligård (2018)

Presented at the *15th International Conference on Intellectual Capital, Knowledge Management & Organisational Learning*, Cape Town, 29-30 November.

Published in Pather, S. (eds.) *Proceedings of 15th International Conference on Intellectual Capital, Knowledge Management & Organisational Learning*, pp. 160-170.

Dan Li initiated and wrote the paper with contributions from Dan Paulin and Åsa Fast-Berglund. Dan Li, Dan Paulin, and Dan Fast-Berglund planned the study. Dan Li collected and analysed the empirical data. Dan Li presented the paper. Per Gullander contributed to the body of knowledge and Lars-Ola Bligård supported the methodology.

Paper V Current and Future Industry 4.0 Capabilities for Information and Knowledge Sharing: Case of Two Swedish SMEs

Dan Li, Åsa Fast-Berglund, and Dan Paulin (2019)

Manuscript submitted to *the International Journal of Advanced Manufacturing Technology*, under review, minor revision.

Dan Li initiated and wrote the paper with contributions from Åsa Fast-Berglund and Dan Paulin. Dan Li, Åsa Fast-Berglund, and Dan Paulin planned the study. Dan Li collected and analysed the empirical data.

LIST OF ADDITIONAL PAPERS

This list of additional papers includes papers with related work, important for the content of this thesis but outside of the scope for answering the research questions.

Paper 1 How Changes in Cognitive Automation Can Affect Operator Performance and Productivity

Dan Li, Anna Landström, Sandra Mattsson, and Malin Karlsson (2014)

Presented at the *6th Swedish Production Symposium*, Gothenburg, 16-18 September.

Paper 2 Testing Operator Support Tools for a Global Production Strategy

Dan Li, Sandra Mattsson, Åsa Fast-Berglund, and Magnus Åkerman (2016)

Presented at the *6th CIRP Conference on Assembly Technologies and Systems*, Gothenburg, 16-18 May.
Published in *Procedia CIRP*, vol. 44, pp. 120-125.

Paper 3 Evaluation of Guidelines for Assembly Instructions

Sandra Mattsson, Åsa Fast-Berglund, and **Dan Li** (2016)

Presented at the *8th IFAC Conference on Manufacturing Modelling, Management and Control*, Troyes, 28-30 June.
Published in *IFAC-PapersOnLine*, vol. 49, no. 12, pp. 209-214.

Paper 4 Measuring Operator Emotion Objectively at a Complex Final Assembly Station

Sandra Mattsson, **Dan Li**, Åsa Fast-Berglund, and Liang Gong (2017)

Presented at the *7th International Conference on Applied Human Factors and Ergonomics*, Orlando, Florida, 27-31 July (2016).
Published in Hale, K. and Stanney, K. (eds.) *Advances in Neuroergonomics and Cognitive Engineering*, part of the series Advances in Intelligent Systems and Computing, vol. 488, pp. 223-232, Springer, Cham.

Paper 5 The Comparison Study of Different Operator Support Tools for Assembly Task in the Era of Global Production

Liang Gong, **Dan Li**, Sandra Mattsson, Magnus Åkerman, and Åsa Fast-Berglund (2017)

Presented at the *27th International Conference on Flexible Automation and Intelligent Manufacturing*, Modena, 27-30 June.
Published in *Procedia Manufacturing*, vol. 11, pp. 1271-1278.

Paper 6 Application of Design Principles for Assembly Instructions – Evaluation of Practitioner Use

Sandra Mattsson, **Dan Li**, and Åsa Fast-Berglund (2018)

Presented at the *7th CIRP Conference on Assembly Technologies and Systems*, Tianjin, 10-12 May.
Published in *Procedia CIRP*, vol. 76, pp. 42-47.

Paper 7 Testing and Validating Extended Reality (xR) Technologies in Manufacturing

Åsa Fast-Berglund, Liang Gong, and **Dan Li** (2018)

Presented at the *8th Swedish Production Symposium*, Stockholm, 16-18 May.
Published in *Procedia Manufacturing*, vol. 25, pp. 31-38.

Paper 8 Design Concept towards a Human-Centered Learning Factory

Sandra Mattsson, Omkar Salunke, Åsa Fast-Berglund, **Dan Li**, and Anders Skoogh (2018)

Presented at the *8th Swedish Production Symposium*, Stockholm, 16-18 May.
Published in *Procedia Manufacturing*, vol. 25, pp. 526-534.

Paper 9 Effects of Information Content in Work Instructions for Operator Performance

Dan Li, Sandra Mattsson, Omkar Salunkhe, Åsa Fast-Berglund, Anders Skoogh, and Jesper Broberg (2018)

Presented at the *8th Swedish Production Symposium*, Stockholm, 16-18 May.
Published in *Procedia Manufacturing*, vol. 25, pp. 628-635.

Paper 10 Forming a Cognitive Automation Strategy for Operator 4.0 in Complex Assembly

Sandra Mattsson, Åsa Fast-Berglund, **Dan Li**, and Peter Thorvald (2018)

Accepted for publication in *Computers & Industrial Engineering*, in press, available online.

Paper 11 Creating Strategies to Improve the Use of IT- and IS-Systems in Final Assembly

Åsa Fast-Berglund, **Dan Li**, and Magnus Åkerman (2018)

Presented at the *16th International Conference on Manufacturing Research*, Skövde, 11-13 September.
Published in Thorvald, P. and Case, K. (eds.) *Advances in Manufacturing Technology XXXII*, part of the series Advances in Transdisciplinary Engineering, vol. 8, pp. 177-182, IOS Press, Amsterdam.

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1

INTRODUCTION

This chapter introduces the research area of production systems, placing emphasis on human operators and arguing for the importance of cognitively supporting them. It then addresses the aim and questions of the research that are presented in this thesis.

1.1 BACKGROUND

The increased competitiveness of the manufacturing industry has for the past decades moved the paradigm for manufacturing companies from a focus on mass production to mass customization, and further towards personalized production (Jovane et al., 2003; Hu et al., 2011; ElMaraghy et al., 2013). While mass production on dedicated manufacturing lines is cost-efficient for high volume products, flexible and reconfigurable manufacturing systems enable mass customization, where product variety and customization deliver products catering to customers' needs and options (Jovane et al., 2003; ElMaraghy, 2006; Koren and Shpitalni, 2010). Product variety and customization increase complexity, both in regards to the manufacturing systems themselves and to the assembly work (Hu et al., 2011; ElMaraghy et al., 2012). However, instead of mitigating the effects of complexity, confronting difficulties that may improve the performance of the factory can create a competitive advantage (Guimaraes et al., 1999; ElMaraghy et al., 2012). In this context, human operators remain as important stakeholders that contribute to the overall success of manufacturing systems (Guimaraes et al., 1999; ElMaraghy, 2006; Griffin et al., 2007; Hu et al., 2011; Toro et al., 2015).

As a result of workplace automation, the work tasks of humans in the future are predicted to require more problem-solving capabilities to perform (Autor, 2015). The combination of increasingly automated and complex manufacturing systems necessitates the problem-solving humans at work to be flexible and to manage a variety of tasks and technologies (Jensen and Alting, 2006; Toro et al., 2015). In addition to managing this complexity (ElMaraghy et al., 2012), human operators are vital for interaction and initiatives (Kagermann et al., 2013), coordination and problem-solving (Brettel et al., 2014), and decision-making (Stankovic, 2014). These skilled human operators of the future shop-floors, Operator 4.0, can and should be aided both cognitively and physically (Romero et al., 2016).

To cognitively support operators, the dissemination of data, information, and knowledge is important (Romero et al., 2016; Bortolini et al., 2017). Recent technological development has enabled the sharing of more data, information, and knowledge (Inkinen, 2016) between actors and resources in the manufacturing industry (Kagermann et al., 2013; Lasi et al., 2014). Industry 4.0, and its associated enabling technologies, drive this paradigm shift (Lasi et al., 2014; Yao and Lin, 2016; Liao et al., 2017).

However, the emergence of new technologies does not translate directly to a direct implementation of them (van Lente et al., 2013); effort needs to be put into promoting their use (Dedehayir and Steinert, 2016). While some aspects of production systems are often managed by digital software applications, such as MES or ERP systems that support human decision-making in production systems, the use of pen and paper or word of mouth is still the prevalent approach for sharing of information and knowledge on many shop-floors. For a successful implementation of automation, a certain amount of trust in the reliance on the automation needs to be instilled in the intended user (Dzindolet et al., 2003), which can be manifested through the operators' own dispositions, the work situation, and the learning process of using the automation (Hoff and Bashir, 2015). However, Industry 4.0 enabling technologies need to be implemented in a working organization strategically and with a purpose (Mattsson et al., 2018a) and the intended user in mind. Otherwise the organization risks disuse or misuse of the implemented automation (Parasuraman and Riley, 1997). In addition to the aforementioned trust in automation, the implementation of the new technologies also requires an interpersonal trust within an organization (Hoffman et al., 2013). A high level of trust between people is especially important for the sharing of information and knowledge to be effective (Riege, 2005). This sharing should be supported by both information technologies and organizational processes (Goh, 2002). Together, these two aspects of effective sharing of information and knowledge among people at work have the opportunity to facilitate work processes.

Conceptually, the effective sharing of information and knowledge in production systems can be visualized as in Fig. 1.1. To the left, the effective sharing is supported by the human use of technology. In the centre, the information and knowledge that exists to be shared. To the right, the production systems where people work.

Fig. 1.1: Effective sharing of information and knowledge in production systems.

1.2 AIM AND RESEARCH QUESTIONS

The purpose of the research is to explore how companies in the manufacturing industry can achieve more effective sharing of information and knowledge through the development of their Information System and Organization System.

Hence, the aim of this thesis is to propose a framework, the MEET model, for assessing and evaluating the conditions for effective sharing of information and knowledge and then to develop its application.

The use of this framework will identify the information and knowledge needs of individuals and prioritize areas within the Organization System and the Information System as enabling mechanisms for sharing information and knowledge on shop-floors effectively. This effectiveness will reduce the number of misunderstandings, and ensure the correct understanding of conveyed information and knowledge.

To support the aim, two research questions are formulated.

RQ1: How can effective sharing of information and knowledge be supported?

For companies in the manufacturing industry, sharing of information and knowledge focuses on the structures and people that uphold and facilitate the information and knowledge sharing activities, which can range from daily meetings to browsing through assembly instructions. The digitalization, or computerization and connectivity, of such activities, with the use of digital support tools, has the possibility to support operators and managers on shop-floors cognitively. This research question explores, from an organizational perspective, how digitalization technologies can be implemented.

RQ2: What are the effects of effective sharing of information and knowledge?

This effectiveness stresses the quality of the shared information and knowledge, which differs from a process efficiency perspective that puts emphasis on faster communication. This research question explores, from a human-centred perspective, the perceived circumstances of activities for the sharing of information and knowledge among operators and managers on shop-floors.

1.3 DELIMITATIONS

Since this thesis is scoped to focus on how the proposed framework, the MEET model, has been applied and developed, the following delimitations have been made:

- Work instructions are a common approach to share information with shop-floor operators. The design of such instructions is important for operators to perform the prescribed work tasks but is not included in this thesis.
  - The design of work instructions is further studied in Additional Papers 1, 3, and 6.
- The carriers of the work instructions are also an important factor that affects the operators' performance. New technologies have the possibilities to change how work instructions are shared, but the evaluation of such new technologies is excluded from this thesis.
  - The use of new technologies to carry work instructions is further studied in Additional Papers 2, 5, and 7.
- Data from objective quantitative measurements can provide operators with faster feedback relevant for their work but are outside the scope of this thesis, which emphasizes information and knowledge.
  - The measuring of physiological data as a source of information for operators is further studied in Additional Paper 4.
- Varying the information content in work instructions can support the operators with different individual needs but is left out of this thesis.
  - Different levels of information and knowledge content in work instructions are further studied in Additional Papers 8 and 9.
- This thesis does not differentiate whether the situation of information and knowledge sharing is in a learning, an operational, or a disruptive phase.
  - Strategies for cognitive automation solutions are further studied in Additional Paper 10.

1.4 OUTLINE OF THE THESIS

After this first chapter where the importance of this research is introduced, this thesis is structured into five subsequent chapters with different information and knowledge content.

Chapter 2 Frame of Reference starts with an epistemological discourse on knowledge, how it is used in this thesis, and its difference from information and data. Communication - or sharing and dissemination of data, information, and knowledge - is detailed within the framework of the MEET model. The chapter continues with a description of how the MEET model was applied around the time of Paper I and ends with an account for how Industry 4.0 is related to this re.

Chapter 3 Research Methodology continues from the epistemological statement in the previous chapter, connecting it to a pragmatic mixed-method research approach, which was used for this thesis as a whole, as well as motifs for the selection of the specific applied methods in the five appended papers.

Chapter 4 Summary of Appended Papers recapitulates the main outcomes from the five appended papers and their contributions towards answering the research questions.

Chapter 5 Discussion combines the contributions from the five appended papers, arriving at elaborations on the research questions. The quality of research and its limitations are reflected upon, and possible future research directions are staked out.

Chapter 6 Conclusion summarizes the major points of interest, providing final remarks on the research questions. Implications for academic research, the manufacturing industry, and societal development are finally connected.

2

FRAME OF REFERENCE

This chapter starts with presenting different definitions and characteristics of knowledge before moving on to elaborating on how different kinds of information and knowledge can be shared within an organization. With this baseline in place, the MEET model for the sharing of information and knowledge is introduced, and finally, its niche within the future of the manufacturing industry is explained.

2.1 DATA, INFORMATION, AND KNOWLEDGE

It can be difficult for organizations to distinguish the concepts of data, information and knowledge from each other (Davenport and Prusak, 1998). Data and information can appear similar, so does information and knowledge, but data and knowledge are quite different.

From Data to Information

Data is a set of discrete and objective facts about events or objects (Davenport and Prusak, 1998; Tuomi, 1999). On itself, data is quite uninteresting since it bears no interpretations of these properties. However, the importance of data lies in its role as the foundation for creating information (Drucker, 1988) through contextualization, categorization, calculation, correction, and condensation (Davenport and Prusak, 1998). In this sense, information is data that has been endowed with purpose and relevance (Drucker, 1988). This conversion of data to information requires that knowledge is applied (Drucker, 1988; Tuomi, 1999).

From Information to Knowledge

While information builds on data, knowledge can be viewed to be built on information (Ackoff, 1989; Rowley, 2007) by mixing it with experiences, values, and insights (Davenport and Prusak, 1998). This concept of relating data, information, and knowledge can be visualized as a hierarchy, as in Fig. 2.1. Unlike information that is descriptive, knowledge is prescriptive (Ackoff, 1989) and heavily dependent on commitment and the belief of humans to understand the specific knowledge piece (Nonaka, 1994). Hence, knowledge is based on human understanding, and, within an organization, it can only be created by individuals (Nonaka, 1994; Crossan et al., 1999) through comparisons, consequences, connections, and conversations (Davenport and Prusak, 1998).

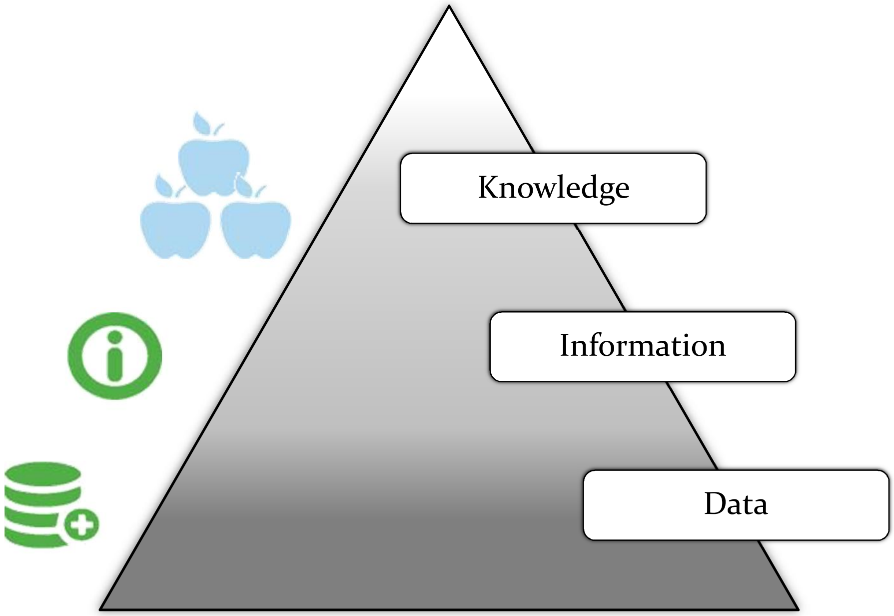

Fig. 2.1: Hierarchy of data, information, and knowledge.

Definitions of Knowledge

The concept of *justified true belief* that is often ascribed to Plato (360 B.C.E.) in his dialogue *Theaetetus*, illustrated in Fig. 2.2 as a Venn diagram, can be used to define knowledge (Lehrer and Cohen, 1983): subject ***S*** knows that proposition ***P*** is true, if and only if:

- P is true,
- S believes that P is true, and
- S is justified in believing that P is true.

This definition of knowledge has been criticized, for example, the individual may be justified in believing that a specific knowledge piece is true based on false premises (Gettier, 1963). In relation, defining knowledge as a higher level of understanding that is derived from human minds at work, built on information, experiences, values, and insights (Ackoff, 1989; Davenport and Prusak, 1998) offer explanations to what the justifications and beliefs are based on.

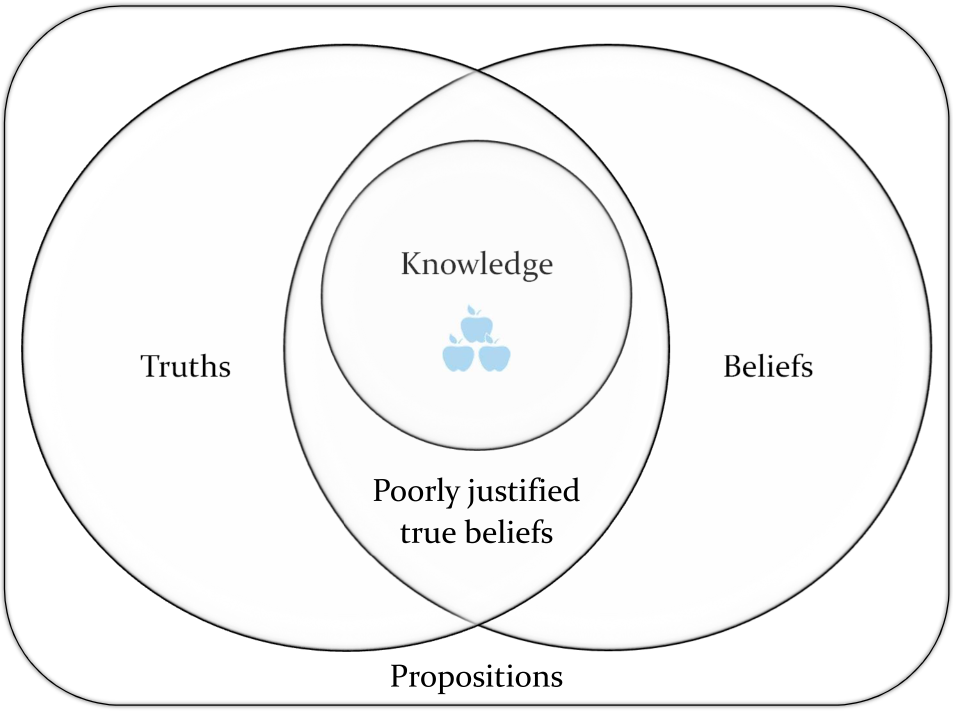

Fig. 2.2: Venn diagram of knowledge as justified true belief.

Whether knowledge is justified true belief or based on enriched information, both approaches to defining knowledge point toward the same substances. The justification and belief correspond to the uninterpreted facts that have been given meaning and context mixed with experiences and insights. Both definitions of knowledge encompass a variety of concepts that fit into either definition, forming cross-section subsets regarding the concept of knowledge:

- tacit and explicit (Polanyi, 1966; Smith, 2001), covered here
- individual, group, and organization (Crossan et al., 1999), covered in 2.2, sharing of information and knowledge

These definitions of data, information, and knowledge form the bedrock of this thesis.

Tacit and Explicit Dimensions of Knowledge

Knowledge can be characterized as tacit or explicit, which can either be opposites or complementary to each other (Smith, 2001). Polanyi (1966, p. 4) points out that "we can know more than we can tell", thus introducing knowledge within the tacit dimension. The tellable knowledge, or the explicit dimension of knowledge, can be summarized as transmittable with a formal and systematic language (Nonaka, 1994).

While Polanyi (1966) holds tacit knowledge as something that is not possible to tell, Grandinetti (2014) scopes tacit knowledge as something that is very difficult to articulate rather than impossible, which is a more useful conceptualization when studying how knowledge is shared. Nonetheless, based on its characteristics, tacit knowledge can be recognized as the knowledge that is:

- complex and abstract (Reber, 1989)
- difficult to formalize, document, and communicate (Zack, 1999; Lam, 2000; Shariq and Vendelø, 2006; Goffin and Koners, 2011; Gascoigne and Thornton, 2013)
- gained by experience and observation (Zack, 1999; Lam, 2000; Gertler, 2003; Gascoigne and Thornton, 2013)

On the other hand, explicit knowledge is:

- easy to formulate, document, and communicate (Goffin and Koners, 2011; Ribeiro, 2013)
- possible to articulate clearly and precisely (Zack, 1999)

Tacit knowledge is more difficult to manage than explicit knowledge but if successful, it presents a possibility for competitive advantage (Drucker, 1988). For humans to internalize explicit knowledge shared from others, the shared knowledge piece needs to be tacitly understood and applied, but it comes at a cost of losing some knowledge in the process (Goffin and Koners, 2011; Gascoigne and Thornton, 2013). This internalization of explicit knowledge to tacit knowledge was introduced by Nonaka (1991; 1994) as one of four modes of transforming knowledge, also visualized in Fig. 2.3:

- socialization, tacit to tacit: based on observations and experiences, often informal
- externalization, tacit to explicit: based on metaphors, analogies, and models, often by reflection
- combination, explicit to explicit: based on adding, sorting, and categorizing, often formal
- internalization, explicit to tacit: based on practice and usage, often through learning-by-doing

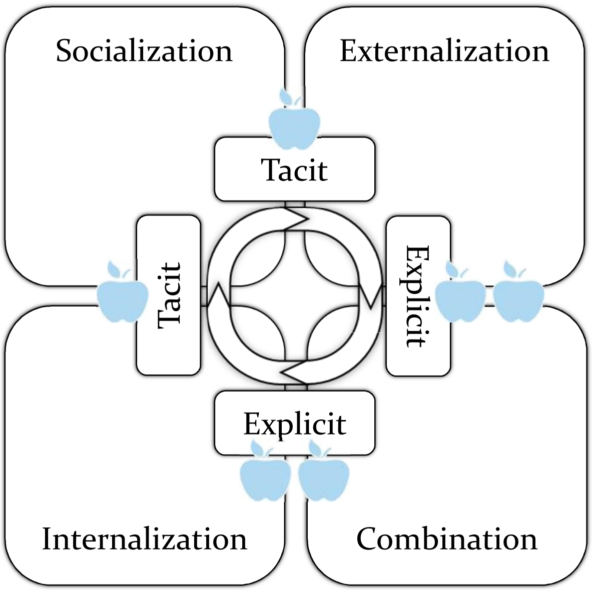

Fig. 2.3: Four modes of transforming tacit and explicit knowledge, adapted from Nonaka (1994).

This model of transforming knowledge between tacit and explicit suggests that it is not black and white. Such a mix of tacit and explicit knowledge is explored by Wong and Radcliffe (2000) in a knowledge spectrum, visualized in Fig. 2.4, where each knowledge piece has different degrees of tacitness and explicitness.

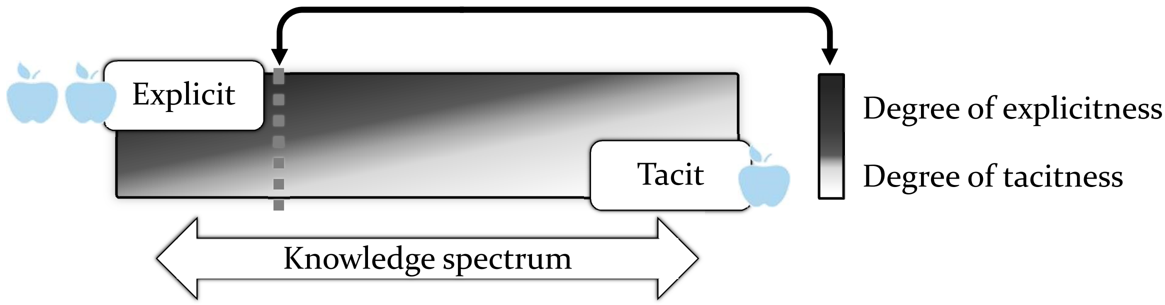

Fig. 2.4: Spectrum of explicitness and tacitness of knowledge, adapted from Wong and Radcliffe (2000).

2.2 SHARING OF INFORMATION AND KNOWLEDGE

Shannon and Weaver's (1949) model for communication explains how information and knowledge are shared between individuals, emphasizing the sender and receiver without attention given to feedback loops between the individuals during the activity of sharing information and knowledge. In Fig. 2.5, a model for sharing information and knowledge by Paulin (2013) is presented. This model synthesizes other models by Lindkvist (2001), Cummings and Teng (2003), Paulin (2006), Minbaeva (2007), and Duan et al. (2010) and is adapted for activities of sharing information and knowledge in a manufacturing context.

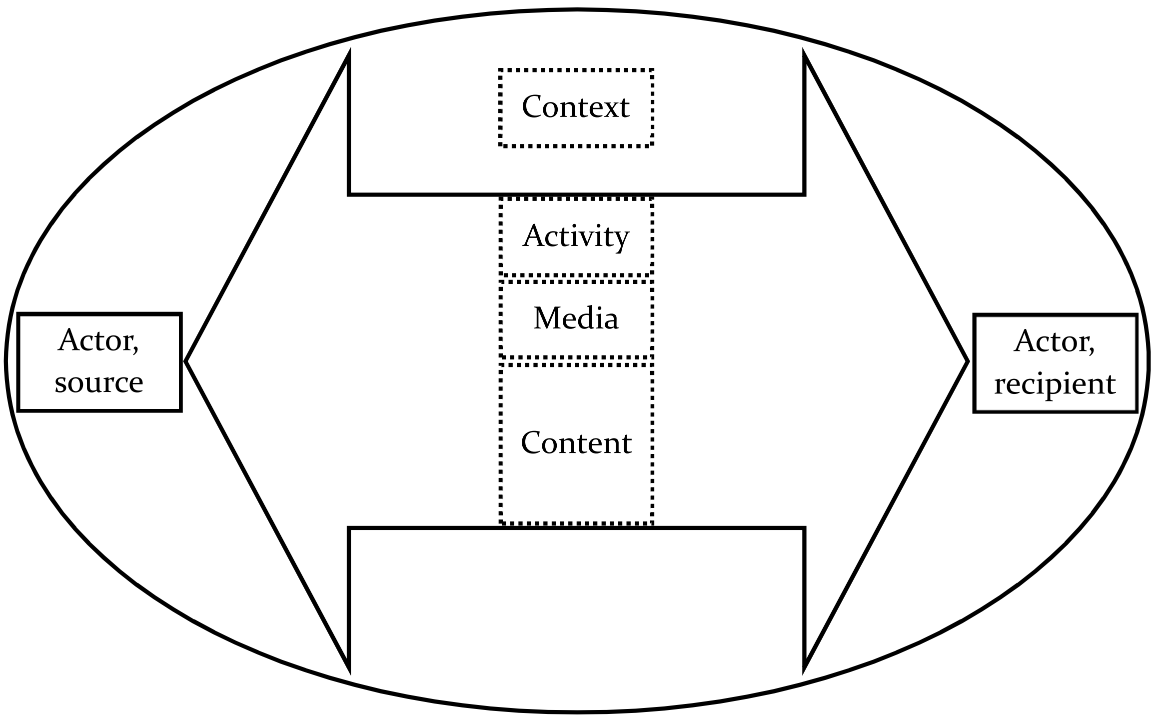

Fig. 2.5: Model for sharing information and knowledge, adapted from Paulin (2013).

In this model, the individuals participating in the *activity* for sharing information and knowledge are referred to as *actors*. The information and knowledge *content* is shared through a *medium*, which encompasses channels or carriers by which information and knowledge are shared, e.g. face-to-face conversation or e-mail correspondence. *Context* explains the situation in which information and knowledge are shared. The five components in this model, i.e. activity, actors, content, context, and media, have associated factors that influence the sharing of information and knowledge (Paulin and Winroth, 2013).

When sharing information and knowledge, the actors that participate in the activity may perceive the content differently. To be of help for the actors, the quality of the information and knowledge content is important (DeLone and McLean, 2003; Petter et al., 2013). Kehoe et al. (1992) present six different attributes that affect the quality of shared information and knowledge:

- relevance – is it useful?
- timeliness – is it presented when needed?
- accuracy – is it correct?
- accessibility – is it easy to find?
- comprehensiveness – is it enough to act on?
- format – is it easy to understand?

Individual, Group, and Organizational Levels of Knowledge

Nonaka (1994) and subsequently Nonaka and Takeuchi (1995) focus on the tacitness and explicitness of the knowledge sharing output on individual and group levels. This is criticized by Crossan et al. (1999), who implores the importance of emphasis on the interaction levels within an organization, visualized in Fig. 2.6. Four processes help organizational learning and the dissemination of information and knowledge between the individual, group, and organizational levels within an organization (Crossan et al., 1999):

- intuiting: experiences, images, and metaphors
- interpreting: language, cognitive map, and conversations and dialogues
- integrating: shared understandings, mutual adjustments, and interactive systems
- institutionalizing: routines, diagnostic systems, and rules and procedures

Tacit and explicit knowledge are shared differently, both with regards to the tacitness and explicitness (Nonaka, 1994) and to the individual or group levels (Crossan et al., 1999) of the knowledge output (Cook and Brown, 1999). Based on the proposal by Cook and Brown (1999) to study the intersections of tacit-explicit and individual-group knowledge, Small and Sage (2005) give examples of the four knowledge types that are typical for each intersection, as squared in Fig. 2.7.

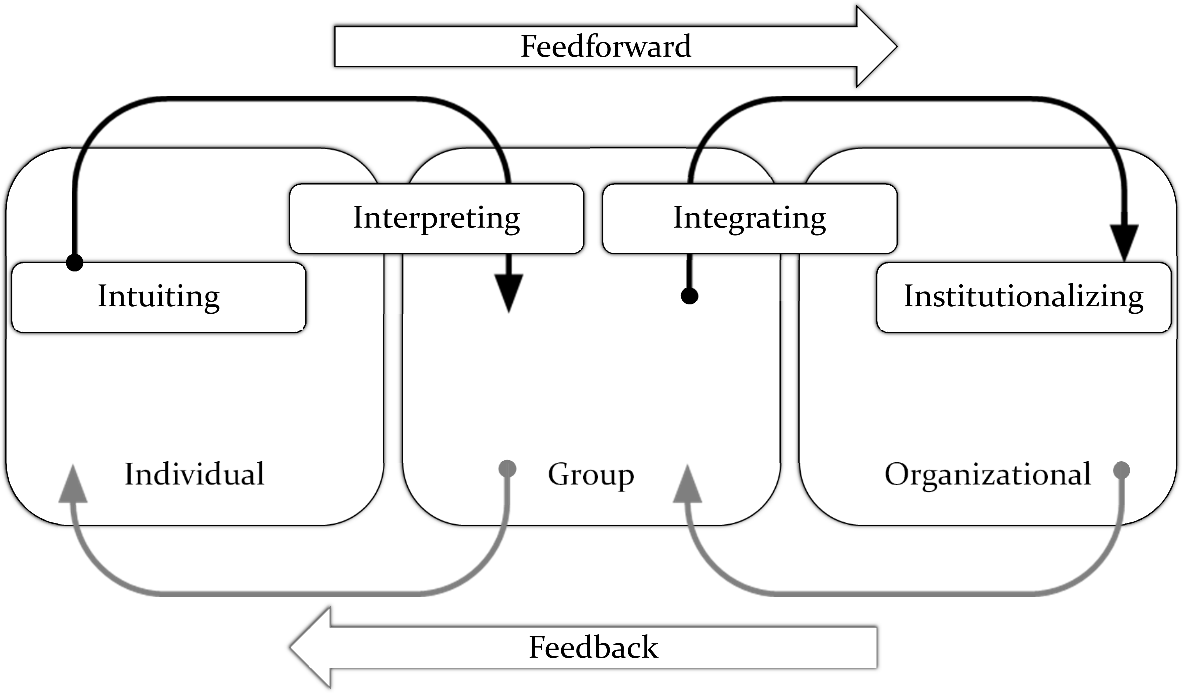

Fig. 2.6: Organizational learning as a dynamic process, adapted from Crossan et al. (1999).

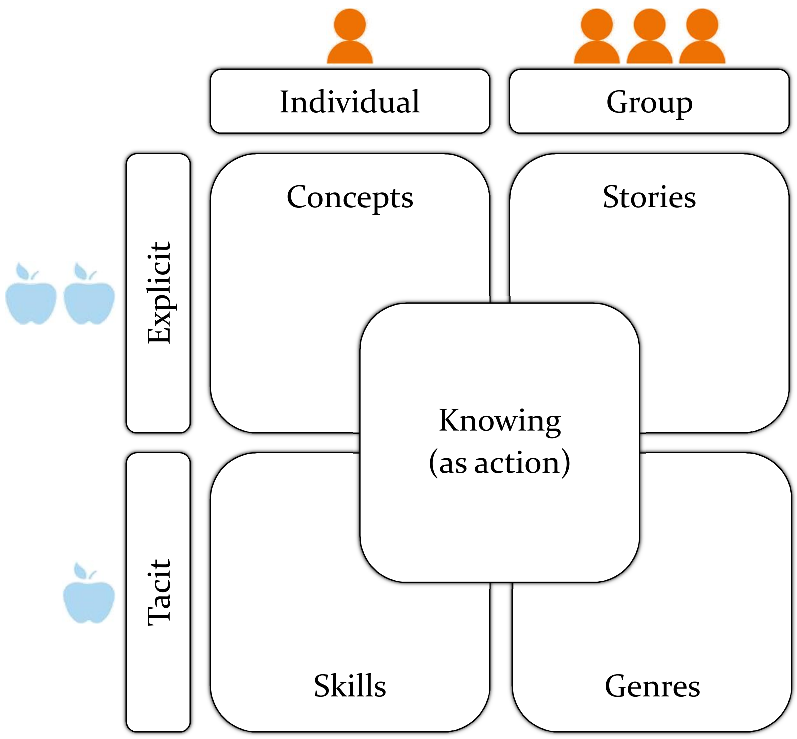

Fig. 2.7: Crossing dimensions and levels of knowledge, combined and adapted from Cook and Brown (1999) and Small and Sage (2005).

Codification and Personalization Strategies

Sharing different kinds of information and knowledge can take different forms or shapes for different people, as previously presented. Whether it is socialization, externalization, combination, and internalization, as in Fig. 2.3 (Nonaka, 1994), or if it is intuiting, interpreting, integrating, and institutionalizing, as in Fig. 2.6 (Crossan et al., 1999), these approaches focus on the individual source and recipient actors, earlier depicted in Fig. 2.5 (Paulin, 2013). Hansen et al. (1999) offer insights to managing information and knowledge within organizations with a focus on the components of activity and media from Fig. 2.5, by introducing two strategies: codification and personalization, with their respective characteristics listed in Table 2.1.

Table 2.1: Codification and personalization strategies with their respective characteristics, adapted from Hansen et al. (1999).

Characteristics	Codification strategy	Personalization strategy
Strategic focus	People-to-documents: Develop IT systems that codify, store, and disseminate information and knowledge.	Person-to-person: Develop networks, communities and arenas for people to share information and knowledge.
Information technology requirements	Need to make it simple for people to find relevant information or documents.	Need to make it simple for people to connect to each other.
Anthropocentricity	People need to develop skills in finding information in IT systems. People who are actively documenting in the IT systems are rewarded.	People need to develop skills for social interaction. People who are actively interacting with other people are rewarded.
Potential benefits	Process control, visibility, traceability, etc.	Collaboration, participation, problem solving, etc.

The codification strategy relies on documentation, which requires a system for people to store predominately explicit knowledge accessibly. This strategy provides “high quality, reliable, and fast information-systems implementation by reusing codified knowledge” (Hansen et al., 1999).

The personalization strategy relies on face-to-face interactions, which require a network of people that frequently exchanges predominately tacit knowledge. This strategy provides “creative, analytically rigorous advice on high-level strategic problems by channelling individual expertise” (Hansen et al., 1999).

McMahon et al. (2007) conclude that the knowledge management needs of any organization cannot be satisfied by either strategy on its own since their benefits are dependent on the situation, and each strategy should be deployed and adapted to each situation. An example of the interplay between codification and personalization can be found in face-to-face meetings, in which proper documentation can be supported with visualizations which in turn are supported with narration. This activity for the sharing of information and knowledge is supported by visualization of information as well as verbalization of knowledge, which can help to make work-task coordination more efficient (Lindlöf and Söderberg, 2011).

2.3 THE MEET MODEL

Meetings are an important subset of all activities where information and knowledge are shared. However, often meetings can be perceived as ineffective, mostly because the meetings are not purposefully designed (Leach et al., 2009; Rogelberg, 2019). Hence, there is a sense of urgency to improve meetings in the manufacturing industry.

The MEET model is pivotal for this thesis. Originally developed by Gullander et al. (2014) and Fast-Berglund et al. (2014) as a strategic framework for designing flexible meetings that are both efficient and innovative, the MEET model aims to purposefully support individuals' work activities cognitively as well as encourage progress for organizational learning. As illustrated in Fig. 2.8, the MEET model brings together three systems: the *Organization System* with its five areas to the left, the *Information System* with its five areas to the right, and the *Meetings* in between with the four time-place flexibility categories that connect the two systems.

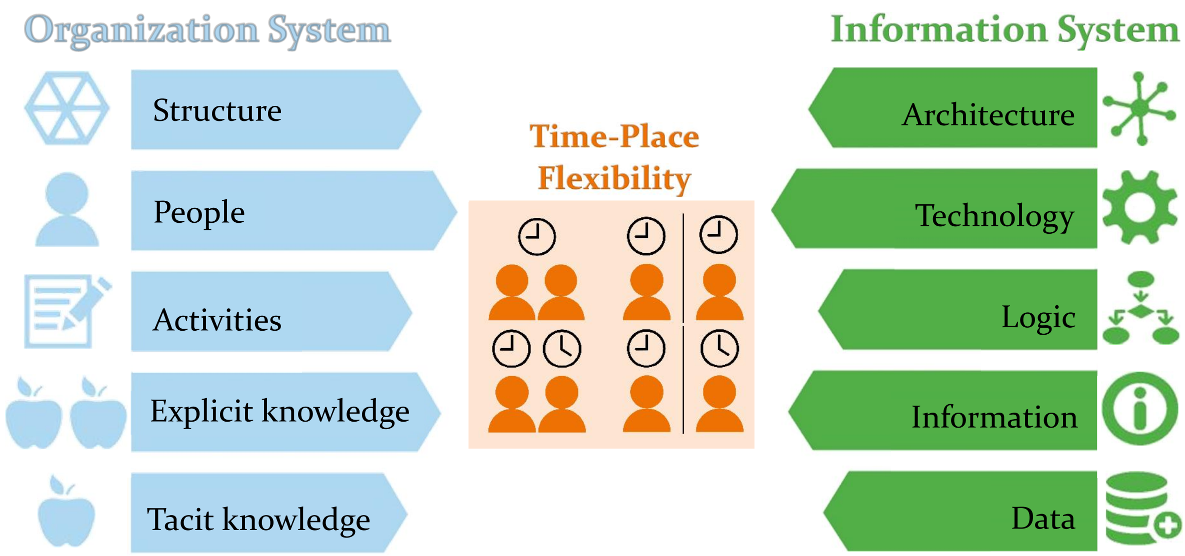

Fig. 2.8: The MEET model, as introduced by Gullander et al. (2014) and Fast-Berglund et al. (2014).

Apart from this thesis and its five appended papers, three papers, including the aforementioned two, have been published on the MEET model. These three papers are listed in Table 2.2.

Table 2.2: Previously published papers where the MEET model has been applied.

Authors (year)	Title of paper
Gullander et al. (2014)	Meetings – The Innovative Glue Between the Organisation System and Information System
Fast-Berglund et al. (2014)	Creating a structured MEETing arena for knowledge-sharing
Fast-Berglund et al. (2016)	Digitalisation of meetings –from white-boards to smart-boards

The MEET model was developed with the purpose of providing a holistic approach towards aspects that are important to consider when designing meetings where the Organization System and the Information System provide structural support (Gullander et al., 2014). The MEET model can be used to support analysis of the current state of meetings, provide inspiration for work with continuous development, and guide improvement efforts (Fast-Berglund et al., 2014). In Fast-Berglund et al. (2014), the MEET model is applied to both individual meetings and companies' structure of meetings.

Meetings and Time-Place Flexibility

In general, meetings between people are characterized by location and the rules and norms for the exchange of data, information, and knowledge (Purser et al., 1992). In the MEET model, meetings are the central part of the model, as depicted in Fig. 2.8, where the components of the Organization System and Information System are integrated (Gullander et al., 2014).

Conceptual development of computer-supported cooperative work, or groupware, originated in the 1980s when computerization enabled people to communicate and cooperate at work in new ways that transcended the same time-same place facilitation of traditional face-to-face meetings (Grudin, 1994).

In the MEET model, a simplified version of Grudin's (1994) groupware matrix is incorporated. Baecker's (1993) groupware matrix focus on the flexibility in designing meetings with regards to the time and place, instead of detailing the predictability of communication.

The time-place flexibility of Baecker's (1993) groupware matrix is represented by two dimensions, which companies should consider when designing meetings. A time dimension (same or different time) and a place dimension (same or different place) crosses the matrix, generating four different types of meetings (Baecker, 1993), visualized in the centre of Fig. 2.8:

- same time - same place: people physically meet to share data, information, or knowledge, e.g. traditional face-to-face meetings
- different time - same place: data, information, or knowledge are stored for later use by others, e.g. on a whiteboard, either conventional or digital
- same time - different place: data, information, or knowledge are shared remotely, e.g. via telephone or video conference
- different time - different place: data, information, or knowledge are stored and later accessed by others at a different location, e.g. mail or use of databases

These four time-place flexibilities have different conditions, requirements, and opportunities (Baecker, 1993). While meetings do occur as one of these four types, often the content of a meeting can extend to cover several categories (Grudin, 1994).

Organization System and Information System

The Organization System involves the organizational aspects of the model that support the sharing of information and knowledge. It consists of five areas (to the left in Fig. 2.8) that are interrelated: the organization's *structures* and where meetings fit in these, the *people* participating in the meetings, the *activities* performed during the meetings, and the *knowledge*, either *explicitly* shared or *tacitly* possessed by the participants.

The Information System is important in its supporting role for the sharing of information and knowledge in organizations (von Krogh, 2002). The Information System also consists of five areas (to the right in Fig. 2.8): the *architecture* of the IT system that upholds digitalization, the *technology* which encompasses the physical resources that enable or facilitate the sharing of information or knowledge, and the *logic* that explains how *data* and *information* are managed and processed.

To make the transformation from data, via information, to knowledge, as made visual in Fig. 2.1, the connection and integration between the Organization System and the Information System, i.e. the interrelations between the ten areas listed in Fig. 2.8, are important (Brancheau and Wetherbe, 1987; Rowley, 2007).

Technology is an important enabler for collaboration between people (Blankenburg et al., 2013), and recent development has greatly benefitted a faster sharing of information and knowledge (Inkinen, 2016). Apart from technologies specifically designed for communication, the incoming paradigm shift of the manufacturing industry – Industry 4.0 - will also create new sources for valuable data, information, and knowledge (Lasi et al., 2014). In this context, it is becoming increasingly important for companies to have purposeful strategies for the management of data (DalleMulle and Davenport, 2017), information (Petter et al., 2013), and knowledge (Toro et al., 2015)

2.4 INDUSTRY 4.0

Not yet a fully consolidated term (Pereira and Romero, 2017), Industry 4.0 has gained attention from practitioners and researchers alike (Liao et al., 2017; Xu et al., 2018). In this context, the manufacturing industry is proactively (Almada-Lobo, 2015) undergoing a technology-driven (Lasi et al., 2014) paradigm shift (Yao and Lin, 2016) towards increased digitization, automation, and communication (Oesterreich and Teuteberg, 2016). In this Industry 4.0 context, data is becoming more and more valuable as it supports better decision-making (Bärring et al., 2018; Berinato, 2019), especially because information and knowledge build upon data (Ackoff, 1989; Davenport and Prusak, 1998; Rowley, 2007). This will lead to greater integration of data and information vertically, horizontally, as well as digitally end-to-end across a product's value chain (Kagermann et al., 2013; Leyh et al., 2016). However, it is still difficult for many companies to implement digital technologies related to Industry 4.0 for such purposes (Bittighofer et al., 2018; Chengula et al., 2018; Stentoft et al., 2019).

Operator 4.0

Despite increased digitization and automation in Industry 4.0 (Oesterreich and Teuteberg, 2016), humans continue to be as important as ever in the history of manufacturing industry (Brettel et al., 2014; Stankovic et al., 2014; Longo et al., 2017; Taylor et al., 2018). However, most research regarding Industry 4.0 concerns the technological aspects and possibilities (Kagermann et al., 2013; Lasi et al., 2014; Liao et al., 2017). To underline the importance of designing the manufacturing industry to support human operators, Romero et al. (2016) propose to emphasize Operator 4.0, which has gained attention from other researchers as well (Mattsson et al., 2018a; Taylor et al., 2018; Kaasinen et al., 2019). Romero et al. (2016) exemplify eight typologies where Operator 4.0 may be supported, listed in Table 2.3.

Table 2.3: Operator 4.0 typology, adapted from Romero et al. (2016).

Operator 4.0	Interaction	Short description
Super-Strength Operator	Physical	Exoskeletons that allow operators to do some otherwise impossible heavy lifting.
Augmented Operator	Cognitive	Augmented Reality technology that overlays information for the operator.
Virtual Operator	Cognitive	Virtual Reality technology with immersive simulations that can support decisions.
Healthy Operator	Physical and cognitive	Wearable trackers that measure physiological data help operators' health.
Smarter Operator	Cognitive	Intelligent Personal Assistants can help operators in managing tasks and interaction with automation.
Collaborative Operator	Physical	Collaborative robots allow operators to interact with robots in the same workspaces.
Social Operator	Cognitive	Social networks help operators create communities, which promote sharing information and knowledge.
Analytical Operator	Cognitive	Big data analytics help operators to make better data-driven decisions.

As the manufacturing industry gets more complex (Hu et al., 2011; ElMaraghy et al., 2012), the work of the operators does, too (Jensen and Alting, 2006; Toro et al., 2015). This is especially true because a strategic consensus between operators and managers is important for the manufacturing strategy content (Edh Mirzaei et al., 2016). Applying a human-centred approach to production development by involving operators encourages continuous improvement efforts (Longoni and Cagliano, 2014; Lam et al., 2015), especially if the valuable knowledge and experience can be elicited and disseminated (Tamayo-Torres et al., 2014; Brennan et al., 2015).

Operator 4.0 can and should be supported cognitively (Romero et al., 2016; Mattsson et al., 2018a), for example, training by using Virtual Reality technology (Gorecky et al., 2017) or personalized instructions based on work experience (Johansson et al., 2018). Even though many new technologies are being developed and off-the-shelf solutions are available, it is still difficult to implement technologies to support operators (Stentoft et al., 2019). Often, it is because the automation solution is not implemented in a way that is optimal for how people want to work with automation (Parasuraman and Riley 1997). Aspects for companies to consider when implementing support systems for operators are individual needs and preferences of information (Haghi et al., 2018). Thereafter must be a concern for visualization and the presentation of information in an appealing manner for the operators (Thoben et al., 2017), which in turn sets demands on the organization to involve the operators in design processes (Bauer et al., 2017).

Industry 4.0 Maturity Index

In order for companies to assess its proficiency towards Industry 4.0, Schuh et al. (2017) introduced a maturity index that supports an Industry 4.0 roadmap journey, where functional areas of a company, e.g. production or logistics, are assessed. Thus, different parts of a company may have different maturity towards Industry 4.0. Within this model, four structural areas to assess are proposed, each with two guiding principles:

- resources
    - digital capability
    - structured communication
- information systems
    - self-learning information processing
    - information system integration
- organizational structure
    - organic internal organization
    - dynamic collaboration within the value network
- culture
    - willingness to change
    - social collaboration

The companies' maturity with regards to the structural areas' guiding principles is assessed based on the maturity stages in the Industry 4.0 development path, as illustrated in Fig. 2.9. While Schuh et al. (2017) include stages 1-6, each one needs to be accomplished before moving onto the next stage. Stage 0 is also included in Fig. 2.9 because of the outcome of Paper V, where many of the cases haven't reached stage 1 yet.

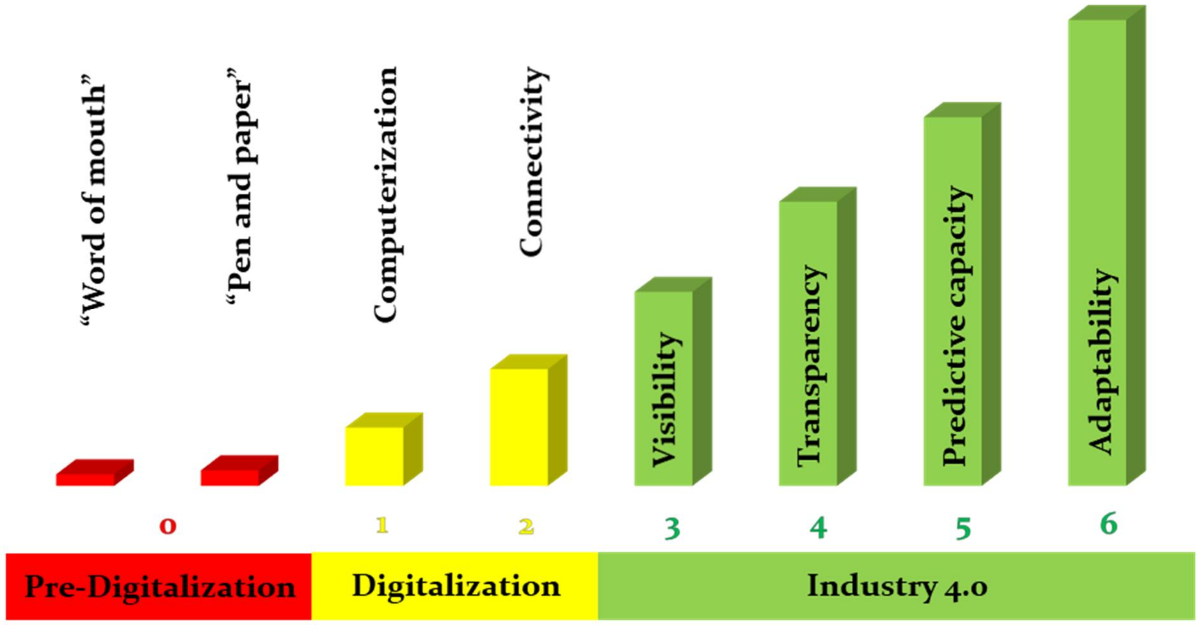

Fig. 2.9: Industry 4.0 Maturity Index, adapted from Schuh et al. (2017).

Stage 0 contains non-computerized means of communication dominated by word of mouth transferring information and pen and paper documenting information.

Laying the foundation for digitalization are stages 1 and 2 that consist of computerization and connectivity. The first step is digitizing information and storing it in computers instead of on papers. This is followed by the second step of connectivity where digitized information is no longer isolated but still requires manual work for transferring.

Moving towards Industry 4.0 are stages 3-6. Stage 3 is visibility, where information is easily accessible. Stage 4 is transparency, where information is descriptive and explains past events. Stage 5 is predictive capacity, where information is automatically analysed to provide prescriptive support for decision-making. Finally, stage 6 is adaptability, where information enables the automation to make its own decisions, for example, in the form of quick adaptations.

3

RESEARCH APPROACH

This chapter connects the epistemological considerations of the research to the pragmatic mixed-method approach that is applied in this thesis, as well as outlining the specific applied methods in the five appended papers.

3.1 EPISTEMOLOGICAL REFLECTIONS

In this thesis, knowledge has been defined as enriched information, visualized in Fig. 2.1 (Ackoff, 1989; Davenport and Prusak, 1998; Rowley, 2007) and justified true belief, visualized in Fig. 2.2 (Plato, 360 B.C.E.; Gettier, 1963; Lehrer and Cohen, 1983), complementary to each other. Both approaches contemplate a concept of knowledge that builds on some other substance, whether it is formalized data and information or informal experiences. Here, two distinct portrayals of knowledge appear.

First, there is the knowledge that the objects of the study possess, whether it is shop-floor operators, managers, or other stakeholders in the manufacturing industry (Drucker, 1988). The operators themselves often describe it as a gut feeling or that they just know how to perform certain work (Davenport and Prusak, 1998). This knowledge can be simplified as "experience-based tacit knowledge", which often can be subjective (Polanyi, 1966). It is this knowledge that people in production systems share with each other and the title of this thesis and its research questions refer to.

Second, there is the knowledge that is the result of research (Creswell and Plano Clark, 2018), formulated by studying how people on shop-floors interact. It can be described as formal knowledge or systematic insight into processes (Davenport and Prusak, 1998). This knowledge can be simplified as "fact-based explicit knowledge", which should be objective in its scientific context (Ribeiro, 2013). It is this general body of knowledge about production systems that this thesis aims to contribute to.

3.2 RESEARCH PHILOSOPHY AND APPROACH

In order to contribute to the general body of knowledge in production systems, a pragmatic approach of instrumentalism philosophy to applied research, with mainly abductive reasoning, has guided the selection of the used mix of quantitative and qualitative research methods.

Given the nature of the objects of study, in essence, how people and their behaviour can be supported in a production system, a pragmatic approach to the applied research is used. This is different from basic research, which focuses on theory-building and hypothesis-testing (Williamson, 2002) that upholds a coherence theory of truth with findings that rationally, logically, and consistently fit into existing truths and prior knowledge (Lehrer and Cohen, 1983). This thesis displays applied research that strives to solve specific problems in specific situations (Williamson, 2002). A pragmatic approach towards applied research denotes a "whatever works" attitude in explaining how the problems are solved (Creswell and Plano Clark, 2018), which shifts the focus of the research from asking "why" to asking "how" and "what". In this context, this thesis upholds an instrumentalism philosophy, where the scientific contribution does not aim to be judged on its ability to provide absolute truth, but rather on its effectiveness (Knowles, 2006), i.e. the usefulness of the frameworks and models in explaining events and generating predictions that can be confirmed with empirical data.

In the process of systematic investigation to acquire new knowledge, inductive and deductive reasoning describe two strategies of scientific inquiry. While inductive reasoning focuses on analyzing empirical data to build theory, deductive reasoning focuses on testing hypotheses to confirm or reject theory (Bryman and Bell, 2011). However, in the spirit of instrumentalism and pragmatism, this thesis has mainly been guided by a third strategy: abductive reasoning, or inference to the best explanation. Unlike deductive reasoning, abductive reasoning deals with plausibility and likeliness rather than outright confirmation or rejection (Knowles, 2006).

3.3 RESEARCH ACTIVITIES

The research activities in this thesis and its appended papers were conducted between 2016 and 2018 under the aegis of three research projects, all funded by the *Swedish Agency for Innovation Systems – Vinnova*: *MEET*, the subsequent *MEET-UP*, and *Global Assembly Instruction Strategies 2*. Papers I-V contributed to answering Research Question 1 and Papers I-III contributed to answering Research Question 2. The alignment of the appended papers and the research questions are visualized in Fig. 3.1, along with the course of the research projects. The boxes for Papers I-V represent when the empirical data was collected and when it was published.

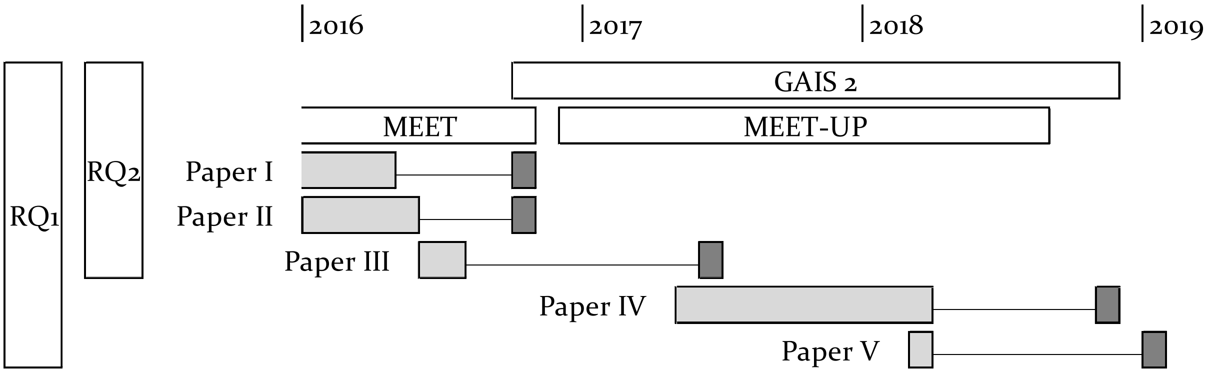

Fig. 3.1: Alignment of research projects, appended papers, and research questions.

3.4 RESEARCH DESIGN AND DATA COLLECTION

Based on the pragmatic approach and abductive reasoning, a methodology of mixed-methods research was applied to the methods in the research projects and their outcome in the form of the appended papers. Mixed-methods research combines qualitative and quantitative methods in different sequences (Creswell and Plano Clark, 2018), which are prevalent in Papers I-IV, as outlined in Table 3.1. In Paper V, thematic analysis was used as a procedure to quantify qualitative data (Braun and Clarke, 2006).

In Paper I, an exploratory sequential design was applied where qualitative observations of meetings were first conducted, followed by quantitative questionnaires, which were filled out by a selection of the meetings' participants.

In Paper II, convergent parallel design was applied where a quantitative questionnaire was filled out independent of 10 semi-structured interviews. The outcome of the questionnaire and the interviews were thereafter compared.

In Papers III and IV, explanatory sequential designs were applied. In Paper III, quantitative methods comprised of both questionnaire responses as well as opinion terminals where the questionnaire participants had the possibility to give feedback on a daily basis. Afterwards, semi-structured group interviews were held as support to explain the quantitative results. In Paper IV, questionnaire responses were followed up by semi-structured interviews.

In Paper V, a thematic analysis approach was applied. First, 15 structured interviews were conducted, followed by a thematic analysis where a quantitative assessment of the interview results was conducted.

Table 3.1: Research design and data collection for the appended papers.

Paper	Research design	Intent of research design	Data collection	Type of conclusion
I	Exploratory sequential: Qualitative, then quantitative, followed by interpretation	Use qualitative method to help develop or inform the quantitative method (Greene et al., 1989)	Observation of meetings 4 questionnaire responses	To develop a contextually appropriate feature
II	Convergent parallel: Quantitative and qualitative in parallel, followed by comparison and interpretation	To obtain different but complementary data on the same topic (Morse, 1991)	1 questionnaire response 10 interviews	To develop complete and corroborated conclusions
III	Explanatory sequential: Quantitative, then qualitative, followed by interpretation	Use a qualitative strand to explain initial quantitative results (Creswell and Plano Clark, 2018)	21 questionnaire responses and 418 opinion terminal responses in total by 23 people across 2 questions and 16 days 2 group interviews with 3 interviewees each	To develop a strong explanation
IV	Explanatory sequential: Quantitative, then qualitative, followed by interpretation	Use a qualitative strand to explain initial quantitative results (Creswell and Plano Clark, 2018)	33 questionnaire responses 16 interviews	To develop a strong explanation
V	Thematic analysis: Qualitative, followed by a quantitative assessment	To quantify qualitative data for comparisons (Braun and Clark, 2006)	15 interviews	To identify themes or patterns

3.5 RESEARCH QUALITY

Validity of research refers to whether the applied research methods do investigate what was intended or not (Yin, 2009). Internal validity was supported by first combining quantitative and qualitative findings and then studying their consistency. External validity was supported by first comparing the outcomes from the appended papers and then studying their consistency.

Reliability of research refers to the lack of serendipity of the collected empirical data, ensuring that the outcome did not occur by chance (Yin, 2009). This places requirements on methodical rigour in controlling the factors that may affect the outcome.

Trustworthiness

Trustworthiness of research refers to the establishment of its four aspects (Lincoln and Guba, 1985):

- credibility: confidence in the "truth" of the findings
- transferability: showing that the findings have applicability in other contexts
- dependability: showing that the findings are consistent and could be repeated
- confirmability: a degree of neutrality or the extent to which the findings of a study are shaped by the respondents and not researcher bias, motivation, or interest

Credibility, in similarity to internal validity, was supported by member checks throughout the appended papers where research outcomes were shown to the participants from whom the data was originally obtained (Lincoln and Guba, 1985). To further support the credibility, two other techniques were applied: prolonged engagement with sufficient time spent with the case companies in Papers I, II and IV and persistent observation with a focus on detailed problem-solving in Papers III and V.

Transferability, in similarity to external validity, was supported by thick descriptions (Lincoln and Guba, 1985) throughout the appended papers. By providing sufficient details in the descriptions of phenomena in Papers I-V, conclusions drawn in the earlier appended papers could be transferred to the latter appended papers, despite differences in times, settings, situations, and people.

Dependability, in similarity to reliability, was supported by inquiry audits throughout the appended papers. Such external audits provided an opportunity for non-involved researchers to evaluate the accuracy of the research and whether the research outcomes are supported by the data (Lincoln and Guba, 1985). Papers I-III were subject to a single-blind peer review process, and Paper IV was subject to a double-blind peer review process. At the time of the printing of this licentiate thesis, Paper V is undergoing a double-blind peer review process.

Confirmability, in similarity to validity, was supported by methods triangulation throughout the appended papers, with the use of both qualitative and quantitative methods (Lincoln and Guba, 1985).

4

SUMMARY OF APPENDED PAPERS

This chapter summarizes the five appended papers sequentially and recapitulates their contributions to the development of the MEET model as well as towards answering the research questions.

4.1 CONTRIBUTION OF THE APPENDED PAPERS

This thesis is scoped to focus on how the proposed framework, the MEET model, has been applied in Papers I-III. The application has focused on operators' needs for information and knowledge with an organizational mindset for solving issues. This focus on sharing information and knowledge is put into an Industry 4.0 context in Paper V, where the current situation extends to a future outlook. Table 4.1 summarizes the main outcomes from Papers I-V and their contribution to the research questions.

Table 4.1: Summary of main outcomes from the appended papers.

Paper	Application of the MEET model	Main contribution to RQ1	Main contribution to RQ2
I	Introduced the MEET model as an assessment tool for meetings with the use of the MEET questionnaire.	Different people may have different opinions on what is important for creating common understandings for the same activity.	For the Organization System, effective sharing of information and knowledge inspires continuous improvement efforts.
II	Compared the use of the MEET questionnaire with conducting interviews and observations.	Quantitative methods can support the qualitative discussion on how to develop activities where information and knowledge are shared.	For the Information System, effective sharing of information and knowledge inspires further development of other meetings.
III	Compared the use of the MEET questionnaire with conducting interviews and daily polls.	Implementation of technology can support person-to-person interaction with regards to information sharing.	Effective sharing of information and knowledge decreased perceived workload and improved social aspects of work.
IV	Applied the MEET model in supporting development along with the MEET questionnaire, interviews, and observations.	Individual needs and preferences for information and knowledge are important for effective sharing of information and knowledge.	-
V	-	Technologies that enable Industry 4.0 can support effective sharing of information and knowledge but can be difficult to implement.	-

4.2 PAPER I

Title: Towards an Assessment Approach Promoting Flexible Value-Adding Meetings in Industry

Short Description

The purpose of Paper I is to explore the use of the MEET model as an assessment tool for meetings. In this assessment approach, the MEET model was put in a continuous improvement context by applying a Plan-Do-Study-Act (PDSA) cycle at a case company, as visualized in Fig. 4.1. The case was set at Volvo Penta's factory in Vara, Sweden, studying the daily planning meetings for two PDSA cycles, corresponding to two years' time. Observations and semi-structured interviews were conducted to compile qualitative descriptions of the company's improvement efforts within the PDSA context. Afterwards, the MEET questionnaire was introduced and utilized to gather quantitative data on four different shop-floor stakeholders' (operator, group leader, production engineer, and maintenance) self-assessments of the studied daily planning meetings.

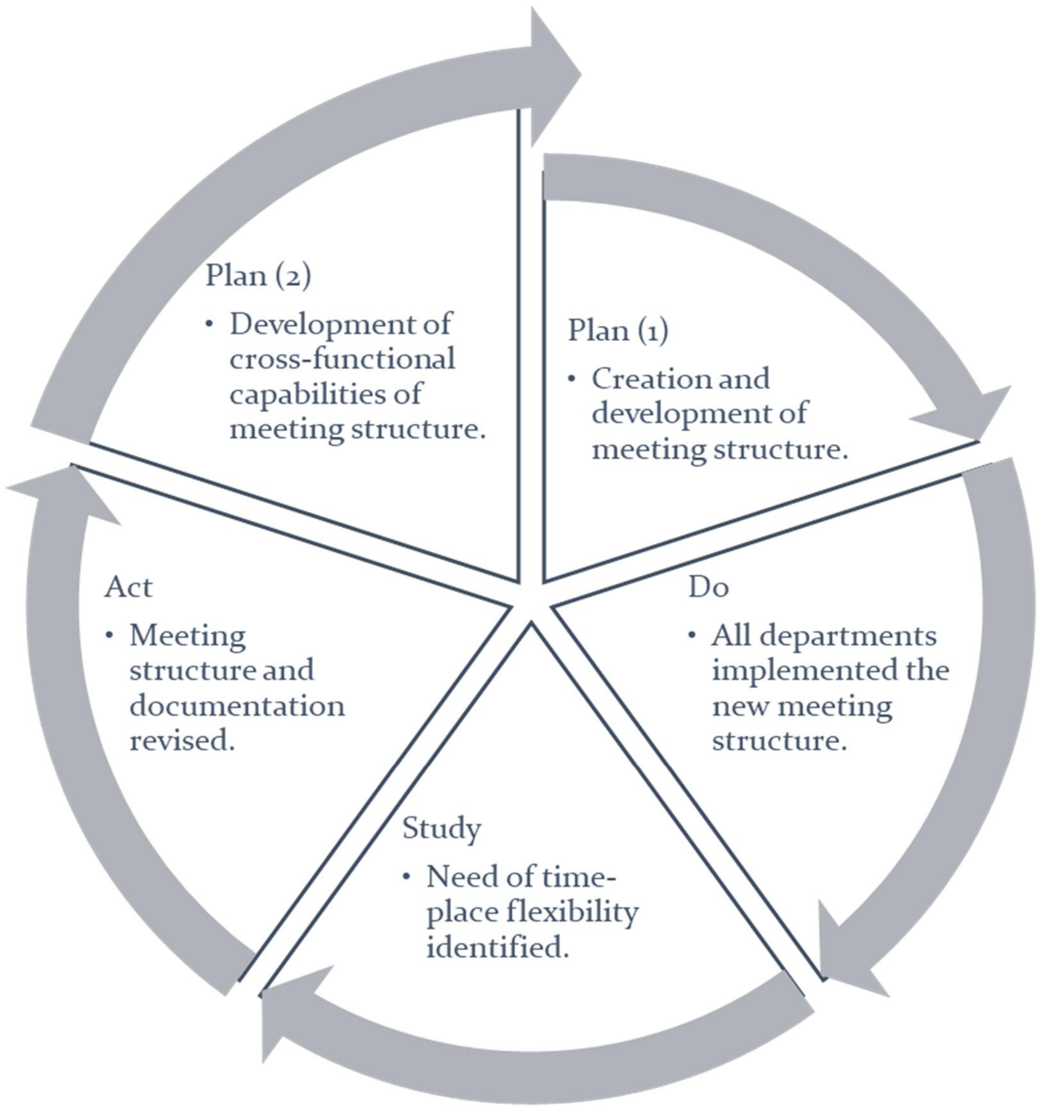

Fig. 4.1: MEET model applied in a PDSA cycle in Paper I.

Results

During the first round of the *Plan* stage, the company had developed and implemented a *structure* for daily production planning meetings, which aimed to support daily operations and transparency between different departments. During the *Do* stage, where the meetings structure was introduced, all departments became involved. Although meetings were perceived as time-consuming and inflexible at the beginning, the *logic* and *structure* of the meetings were appreciated by participants. During the *Study* stage, a need for future development to incorporate time-space flexibility was identified with the purpose of faster dissemination of information throughout the organization. The continuously structured agenda of the meetings became less time-consuming as the *logic* of the agenda became better established among participants. During the *Act* stage, some meetings in the structure have been removed and documentation from the remaining meetings has been subsequently revised. During the second round of the *Plan* stage, a clear focus towards the organization *structure* of meetings remained, and participants have developed their own information channels. With the daily production planning meetings established, a need for cross-functional sharing of information and knowledge to solve new problems arose.

The results from the MEET questionnaires were grouped to their questions' associated focus areas. Based on the observations and semi-structured interviews, the areas within the *Organization System* were expected to be assessed as less urgent for improvement efforts than the areas within the *Information System* due to the attention received from previous improvement work. This expectation was confirmed by the questionnaire results.

Discussion and Conclusion

Results show that the use of the MEET questionnaire within the framework of the MEET model could be used for self-assessments by stakeholders to evaluate the status of areas for directing improvement efforts. Further, the company's orientation towards information or organization in their approach for developing meeting arenas could be detected, which can be used for the improvement of flexibility and value of the meetings.

The periodic recurrent use of the MEET model as an assessment tool facilitated the continuous improvement efforts for the development of meetings. The MEET questionnaire supported this work by identifying the strengths and weaknesses of the studied meetings, which was used to prioritize improvement efforts.

4.3 PAPER II

Title: Identifying Improvement Areas in Production Planning Meetings by Assessing Organisation and Information Systems at a Small Production Company

Short Description

In Paper II, two approaches, both based on the MEET model, were employed to identify areas for possible improvement with regards to daily planning meetings at a company, LaRay, at their factory on Tjörn, Sweden. In the first approach, the CEO of the company used the MEET questionnaire to assess the current situation concerning the meetings, identifying focus areas with different levels of improvement potential. In the second approach, shop-floor operators were interviewed and the meeting was observed, resulting in a descriptive current state analysis and suggestions on actions for change. The current state and suggestions were categorized to the same focus areas and then compared to the results from the MEET questionnaire.

Results

The MEET questionnaire outputted a simple level of improvement potential: low, intermediate, or high, for the focus areas. It but does not make actual suggestions for improvements. The semi-structured interviews with the shop-floor operators and observations of the meeting resulted in descriptions of the meetings, which were categorized into the same focus areas. The current state analysis was assessed with regards to its improvement potential independent from the MEET questionnaire result. The result from the MEET questionnaire and a brief summary of the current state analysis for each focus area are listed and compared in Table 4.2. For most areas, there was a match between the two approaches, the area of *logic* being the exception.

Table 4.2: Comparison of improvement potentials from the two approaches in Paper II.

Focus areas	First approach: Questionnaire	Second approach: Operator interviews and meeting observation		
Organization System (OS)	Improvement potential	Brief summary of the current state	Improvement potential	Comparison
Structure	Low	Flat hierarchy, where management and operators work closely.	Low	Match
People	Low	All employees attend the daily planning meetings.	Low	Match
Activities	Low	Predetermined agenda on all the meetings.	Low	Match
Explicit knowledge	Intermediate	Based on concurrent events.	Intermediate	Match
Tacit knowledge	Intermediate	Resides within individuals and affect decisions.	Intermediate	Match

Table 4.2 (cont.): Comparison of improvement potentials from the two approaches in Paper II.

Focus areas	First approach: Questionnaire	Second approach: Operator interviews and meeting observation		
Organization System (OS)	Improvement potential	Brief summary of the current state	Improvement potential	Comparison
Architecture	High	Difficult for all employees to understand and use.	High	Match
Technology	High	Unusual. Most information is on paper.	High	Match
Logic	Intermediate	The activities don't match all the needs in the case company.	High	Mismatch
Information	High	Information from meetings is rarely saved for later use.	High	Match
Data	High	Most data is gathered manually, but some are automatically.	High	Match

Discussion and Conclusion

Based on the results, the company continued with an implementation of digital visualization of information, which is further studied in Paper III, and a revision of meetings and agendas, which are related to the focus areas of *people*, *activities*, *technology*, *logic*, and *information*. These actions cover several of the areas with high improvement potential. Paper II shows that both approaches can help with the identification of focus areas for improvement efforts; however, while the MEET questionnaire provides a quick assessment, it is less comprehensive than a more thorough current state analysis based on interviews and observations.

Revising meetings and agendas suggests that using the MEET model to study individual meetings may leave out other situations where information and knowledge may be shared. Hence, as a future research reflection, further development of the MEET model could emphasize work processes and individuals' needs for information and knowledge during various stages of their work processes rather than only studying formal meetings.

4.4 PAPER III

Title: Digitalization of Whiteboard for Work Task Allocation to Support Information Sharing between Operators and Supervisor

Short Description

The need for a digital visualization of information for the daily planning meetings that were identified in Paper II was implemented and evaluated in Paper III. At the company, LaRay, the daily meetings were held at 14:00 (2 p.m.) and were a combined follow-up meeting providing feedback for shop-floor operators with a planning meeting of work task allocation for the next day. However, often due to planning circumstances, this information was revised the next day, causing confusion and mistrust in the shared information by the shop-floor operators. A whiteboard for updated information on work task allocation had previously existed, but according to interviews with the operators, the whiteboard fell into disuse due to illegible handwriting, accidentally erased information, and non-standardized shorthand instructions.

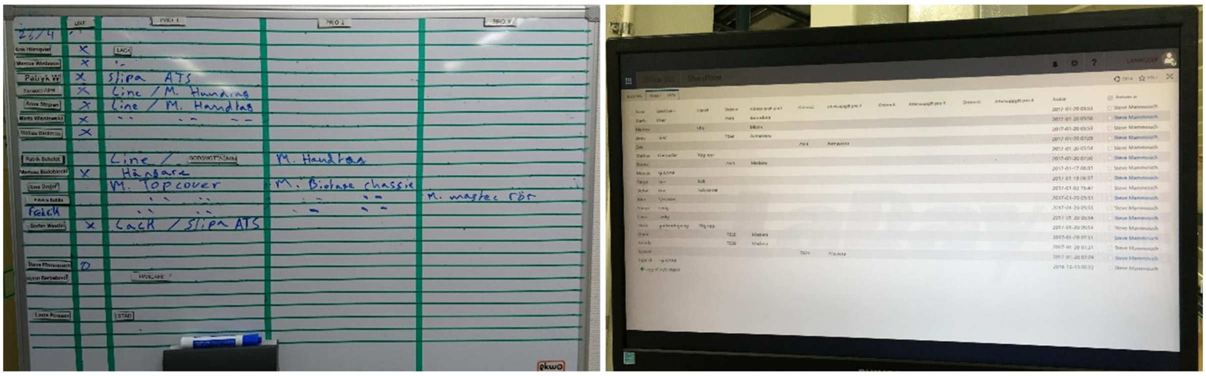

Fig. 4.2: Whiteboard before (left) and after (right) the change in Paper III.

The digital whiteboard was introduced at the company, which was a mobile interactive display that was mirrored to the company's content management system server on which a spreadsheet contained the same information content as the previously disused whiteboard. As depicted in Figure 4.3, seven work days before the introduction of the digital whiteboard, the shop-floor operators were introduced to the MEET model at a workshop that also resulted in additional information content that became included to the presentation of the digital whiteboard. These features include a timestamp of when information was last updated and a list of abbreviations of commonly written work tasks.

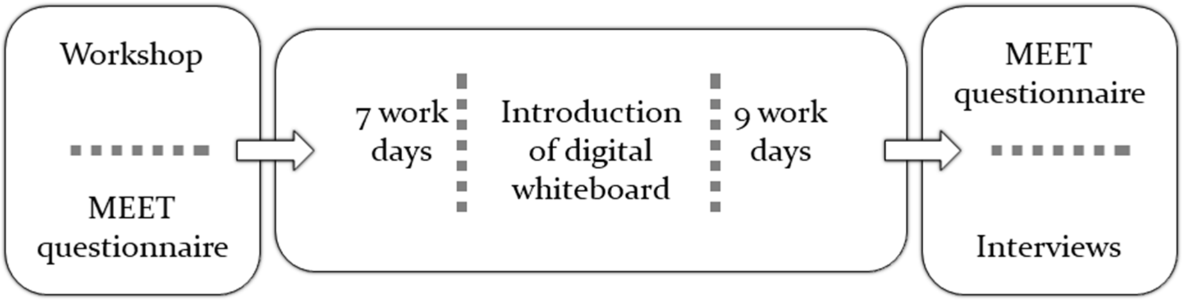

Fig. 4.3: Description of methods in research activities in Paper III.

Results

Three types of results were obtained in Paper III:

- MEET questionnaires, both 7 work days before the introduction of the digital whiteboard and 9 work days afterwards
- Opinion terminals, two questions on a daily basis from 7 days before the introduction of the digital whiteboard to 9 work days afterwards
- Semi-structured interviews, with both operators and supervisor 9 work days after the introduction of the digital whiteboard

At the start of this study, the MEET questionnaire showed that there was more improvement potential among the areas of *Information System* than the *Organization System*, where *technology* was the area with the most improvement potential. The *data* area was the most polarizing area, where the participants' views differed the most. The changes in the MEET questionnaire for each area at the end of the study showed that the *Organization System's* areas of *people*, *explicit knowledge*, and *tacit knowledge* have increased their improvement potential. For the *Information System*, improvement potentials in the areas of *technology* and *logic* have decreased, which was the intention of the introduction of the digital whiteboard, and thus expected. The decreased improvement potential for *Information System* and increased improvement potential for *Organization System* mean that after the digital whiteboard was introduced, the need for better *technology* and *logic* was satisfied, but the need for better organizational *structure* to support the use of the digital whiteboard has increased. Thus, the change of *Information System* requires a corresponding development of *Organization System*.

The question of the first opinion terminal was "Do you have enough information to do your job today?" Comparing the 7 days prior to the introduction of the digital whiteboard and the following 9 days, a slight improvement was registered, moving from 72% positive responses to 78%.

The question of the second opinion terminal was "How do you experience your workday today?" Again, comparing the 7 days prior to the introduction of the digital whiteboard and the following 9 days, a slight improvement was registered, moving from 63% positive responses to 72%.

In general, most shop-floor operators expressed during semi-structured interviews that they perceived improvement of information quality, which is confirmed by the results from the first opinion terminal. However, even more information concerning the work tasks was desired.

The supervisor expressed during an unstructured interview that the implementation of the digital whiteboard was positive because of a reduced self-perceived workload since operators became more independent.

Discussion and Conclusion

Results show that the operators appreciated the introduction of a digital whiteboard due to an increase in information sharing with the supervisor and management. However, this impression varied depending on operators' work tasks, but it still contributed to a positive social aspect. The results from the self-assessment questionnaires showed that the improvements in *technology* and *logic* seem to have come at the cost of some of the *Organization System* areas. The interviews confirmed that the perceived improvement of the information quality has increased.

4.5 PAPER IV

Title: Supporting Individual Needs for Intra-Organizational Knowledge Sharing Activities in Pre-Industry 4.0 SMEs

Short Description

In Paper IV, two companies, Tamtron and Ventisol, located in Karlstad and Kristinehamn respectively, applied the MEET model to two activities each. These were two already existing activities for sharing information and knowledge with the purpose of improving the communication between employees.

During an introductory workshop at each company, a process mapping of operators was drawn, followed by identification of individuals' needs for information and knowledge to perform the prescribed work tasks during the various process steps. The mapping also showed how this information and knowledge was currently shared. The company participants of the workshop then subjectively prioritized which of the activities for sharing information and knowledge were more urgent for improvement efforts. Two of these activities were selected for each company. Then, using the introduced MEET model, supported by their own responses from the MEET questionnaire, the company participants themselves formulated possible changes to the four activities for sharing information and knowledge: A1, A2, B1, and B2.

After the companies had implemented changes to their selected activities for sharing information and knowledge, a new round of MEET questionnaires and follow-up interviews were conducted 6-9 months after the introductory workshop.

Results

The focus on the activities for sharing information and knowledge shifted the MEET model to be placed in a communication context rather than the previous focus on the meetings per se. In Paper IV, the MEET model from Fig. 2.8 has been put in the model for knowledge sharing from Fig. 2.5, where many similarities exist but different terminology is used. This relationship between the two models is presented in Figure 4.4.

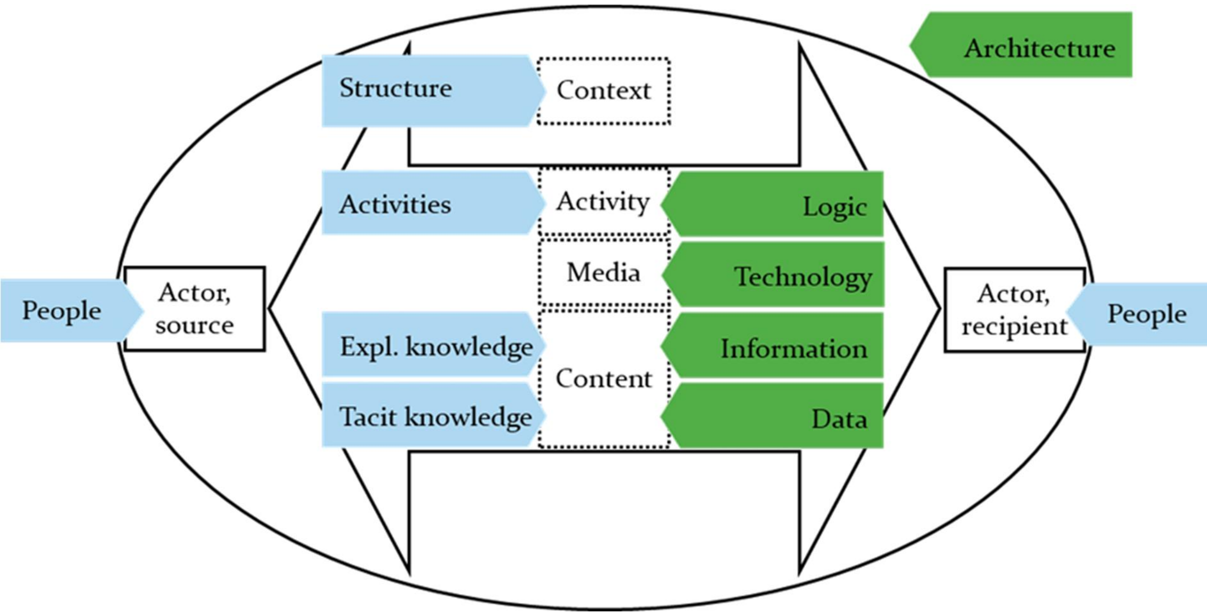

Fig. 4.4: Combination of the model from Paulin (2013) and the MEET model in Paper IV.

The outcome of the four activities for sharing information and knowledge is summarized in Table 4.3. Based on the interviews concerning the implemented changes at the companies, certain changes in the results from the MEET questionnaire were expected, and others were unexpected.

The MEET model was applied to different situations. While for A1, B1, and B2 group knowledge was shared, A2 solved specific problems for individuals. A2 and B1 contained more tacit knowledge based on experiences of the actors, while more explicit knowledge was shared in A1 and B2. Despite positive interview responses for A1 and B1, questionnaire results were lower than expected for *logic* and *activities*, respectively.

The MEET model supported the two companies' development of activities for sharing information and knowledge with regards to their *Organization Systems*. The questionnaire created an image for the participants concerning which areas to direct efforts of development, which was reviewed by the later round of questionnaires.

Table 4.3: Four activities for sharing of information and knowledge in Paper IV.

Activity	Type of shared knowledge	Time-place flexibility	Expected outcomes	Surprising outcomes
A1	Group knowledge. Explicit knowledge.	Same time, different place. Weekly phone meeting.	Activities: remain the same.	Logic: Increase is lower than expected.
A2	Individual knowledge. Tacit knowledge.	Same time, different place. Irregularly occurring phone meeting.	Logic and activities: increase.	-
B1	Group knowledge. Tacit knowledge.	Same time, same place. Daily face-to-face meeting, production preparation.	-	Activities: Increase is lower than expected.
B2	Group knowledge. Explicit knowledge.	Same time, same place. Daily face-to-face meeting, shop-floor planning and feedback.	Activities: small change. Technology and logic: increase.	

Discussion and Conclusion

Paper IV has shown that the MEET model can be used by SMEs for developing support for individuals' needs of information and knowledge by adopting a systematic approach that considers sub-processes of work tasks. It also indicates which related activities for sharing of information and knowledge should be focused on and developed. Since the companies were at a pre-Industry 4.0 stage, it was difficult to implement Industry 4.0 enabling technologies solely based on the MEET model. Still, parallels may help explain how sharing of information and knowledge in Industry 4.0 affects Operator 4.0 and how Organization 4.0 can be developed and subsequently implemented.

Novelty in the Development of the MEET model

This approach, to which the MEET model has been applied in Paper IV, is a novelty compared to how it was applied in Papers I-III and an important progression in the development of the use of the MEET model. This new approach to applying the MEET model is visualized in Fig. 4.5. Instead of focusing on a meeting or a group of meetings, as was the case of Gullander et al. (2014), Fast-Berglund et al. (2014), Fast-Berglund et al. (2016), and Papers I-III, the MEET model has in Paper IV been applied in a process context instead. The novelty is in that the organizations' development focus and effort have shifted towards prioritizing the individual needs and preferences of information and knowledge, rather than developing meeting arenas. By first identifying the needs and preferences of individuals in their work tasks and processes, the development of the activities where information and knowledge are shared can be planned.

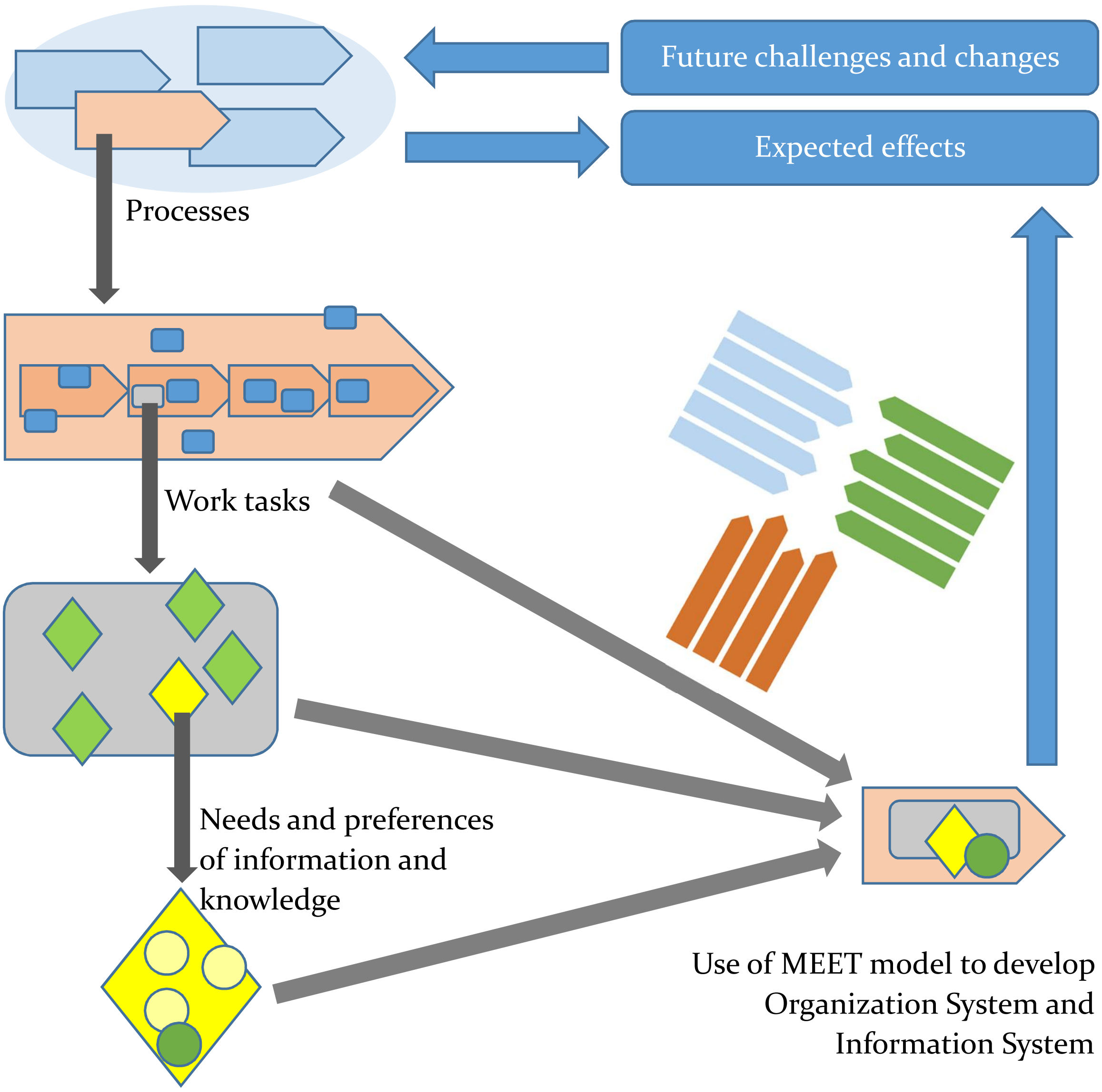

Fig. 4.5: New approach for applying the MEET model in Paper IV, with a stylized rendition of the MEET model to the centre-right.

4.6 PAPER V

Title: Current and Future Industry 4.0 Capabilities for Information and Knowledge Sharing: Case of Two Swedish SMEs

Short Description

Paper V provides insights into current digitalization efforts of SMEs and discusses possible near-future implementations of Industry 4.0 enabling technologies, placing both in an Industry 4.0 context that supports human-centred sharing of information and knowledge.

The current digitalization efforts are explored in terms of their Industry 4.0 maturity in four structural areas: resources, information systems, organizational structure, and culture. The perspective of Operator 4.0 in Assembly Systems 4.0 is assessed within the same Industry 4.0 maturity framework as an assessment of future capabilities.

Shop-floor operators and office workers at two Swedish SMEs, Ventisol and Tamtron, were interviewed to identify their current Industry 4.0 capabilities. The semi-structured interviews aimed at being able to make an assessment of the Industry 4.0 maturity index for each of the four structural areas and thus were centred around production-related sharing of information and knowledge with question areas aligned with the guiding principles.

Results

Results from the interviews are summarized in Table 4.4 with their respective maturity assessments. At Ventisol, shop-floor operators' work was predominantly communicated through word of mouth, complemented with some paperwork. Their office colleagues' activities for sharing information and knowledge were in a greater extent supported by computerized technologies, but manual work was necessary to transfer them. Tamtron's different locations necessitated a same time-different place approach in a larger extent; therefore, their *resources* have a level of connectivity, raising them in one structural area to a maturity level of 2.

Table 4.4: Summary of the results and assessment of Industry 4.0 maturity stages.

Resources			
Case	Digital capability	Structured communication	Stage
Ventisol: Shop-floor operators	Word of mouth, measurements with a yardstick	Word of mouth	0
Ventisol: Office workers	ERP system, emailing	Word of mouth, meeting notes on the computer	1
Tamtron: Office workers	ERP system, service system, and spreadsheets that are connected	ERP system, phone calls only for clarification	2

Organizational structure			
Case	Organic internal organization	Dynamic collaboration within the value network	Stage
Ventisol: Shop-floor operators	Word of mouth	Work orders on paper	0
Ventisol: Office workers	Word of mouth, emailing, phone calls	Word of mouth, emailing, phone calls	1
Tamtron: Office workers	Word of mouth, emailing, phone calls	Word of mouth, emailing, phone calls	1

Table 4.4 (cont.): Summary of the results and assessment of Industry 4.0 maturity stages.

Information systems			
Case	Self-learning information processing	Information system integration	Stage
Ventisol: Shop-floor operators	Work orders on paper	Word of mouth	0
Ventisol: Office workers	ERP system, own contextualization	Emailing, phone calls	1
Tamtron: Office workers	ERP system	Emailing, phone calls, meeting notes on the computer	1

Culture			
Case	Willingness to change	Social collaboration	Stage
Ventisol: Shop-floor operators	Show and tell	Work orders on paper, show and tell	0
Ventisol: Office workers	Spreadsheet and calendar on the computer	ERP system	1
Tamtron: Office workers	Word of mouth	Word of mouth	0

The proposed characteristics of Bortolini et al. (2017) suggest a developmental direction for companies. Most of the characteristics relate to the structural area of information systems, but resources and organizational structure are also affected. The studied companies in this paper are at stage 0 (pre-digitalization) for shop-floor operators and at stage 1 (computerization) for office workers. With an Assembly Systems 4.0, the companies may reach stages 3, 4, or 5 for the different structural areas, as displayed in Table 4.5, but stage 6 (adaptability) may yet be further off in the future.

Table 4.5: Assessment of Assembly Systems 4.0
in relation to Industry 4.0 maturity stages.

Assembly Systems 4.0 tool	Structural areas that were mainly affected	Stage of Industry 4.0 Maturity Index
Aided assembly	Resources Information systems	Stage 3 - Visibility
Intelligent storage management	Information systems	Stage 4 - Transparency
Self-configured workstation layout	Information systems	Stage 4 - Transparency
Product and process traceability	Information systems	Stage 4 - Transparency
Late customization	Resources Organizational structure	Stage 5 - Predictive capacity
Assembly control system	Information systems	Stage 5 - Predictive capacity

Discussion and Conclusion

The studied companies' current production-related practices for sharing information and knowledge are to date at a pre-Industry 4.0 maturity stage with regards to structural areas (resources, information systems, organizational structure, and culture), i.e. Industry 4.0 enabling technologies with a capability of visibility (stage 3) are not implemented to support activities for sharing information and knowledge. Digitalization (stages 1 and 2) capabilities have been implemented to various extents among the structural areas. However, shop-floor operators are working in a pre-digitalization stage.

For the studied companies, the future development concerning the sharing of information and knowledge in a human-focused Industry 4.0 context needs to start with digitalization for operators. In order to reach visibility (stage 3) and integrating IT systems, operators need to catch up to office workers in terms of availability of IT systems that support their information and knowledge needs. To further advance towards Operator 4.0, the characteristics of Assembly System 4.0 give hints of the possible outlook for a near future at stages 3 through 5.

5
DISCUSSION

This chapter elaborates the research questions with further reflections on the quality of research and its limitations. The discussion ends by staking out possible future research directions.

5.1 EFFECTIVE SHARING OF INFORMATION AND KNOWLEDGE

Both of the research questions regard the *effective sharing of information and knowledge*.

The concepts of information and knowledge can be interpreted differently in different contexts. In a production systems context, this thesis and its appended papers have adopted a similar stance to Davenport and Prusak (1998) where knowledge is built on information which in turn is built on data. In this sense, information is more concrete, while knowledge is more fluid. Production-related information and knowledge are important for people working in the manufacturing industry to perform at work. Purposeful activities are required for the sharing of information and knowledge between individuals.

In Papers I and II, information and knowledge about production performance and planning were shared during daily planning meetings at two different companies. In Paper III, information about work task allocation was shared via a whiteboard. In this sense, meetings are a subset of the activities for sharing information and knowledge that were conducted. While Papers I-III focused on how activities for sharing information and knowledge could be made more effective, i.e. sharing information and knowledge that are relevant and useful for the participants, Paper IV focused on individuals' needs of information and knowledge rather than on the activities themselves.

A common theme throughout Papers I-V is that the case companies have different approaches to share information and knowledge between people, but these approaches are often perceived as ineffective. While the meetings can be time-efficient, in the sense of being fast, the recipient actors often require additional aid or need to ask again for information or knowledge in order to be able to perform at work. In this thesis and its appended papers, the effectiveness of sharing information and knowledge relates to the perceived quality of the shared information and knowledge (Kehoe et al., 1999), whether it is shared through a socialization or a combination mode (Nonaka, 1994).

5.2 SUPPORTING EFFECTIVE SHARING OF INFORMATION AND KNOWLEDGE

Research Question 1 asked: *How can effective sharing of information and knowledge be supported?*

Effective sharing of information and knowledge can be supported in various ways, which has been exemplified by different approaches for applying the MEET model through Papers I-IV. Paper V continues to elaborate on new possibilities of such support within an Industry 4.0 context.

In Paper I, the MEET model in its questionnaire format was evaluated as to whether it could support continuous development for a series of meetings. It showed that for the same meetings, different participants may have different opinions about what is important when it comes to creating shared understandings. This is an example of difficulties in interpreting and integrating knowledge within an organization (Crossan et al., 1999). In Paper II, results from the MEET questionnaire were compared to a more comprehensive current state analysis based on interviews and observations. It demonstrated that both approaches can support the development of activities for sharing information and knowledge. Together, Papers I and II demonstrated that the MEET model could be used in different ways to support the assessment of meetings, and, used as a basis for developing meeting activities, validate the concepts presented by Gullander et al. (2014) and Fast-Berglund et al. (2014).

Based on the assessment made in Paper II, a change was made to the *technology* at that case company's meetings by introducing a digital whiteboard, which was studied in Paper III. This not only affected the Information System but also the Organization System (Gullander et al., 2014). While changes in how *information* is managed relate to *logic*, this change affected how people worked. Instead of operators needing to ask the supervisor for clarifications and double checking information, as was the case with the previous whiteboard, the information sharing became more effective since the information was more up-to-date, which increased the use of the digital whiteboard as medium (Parasuraman and Riley, 1997). Hence, this change also shifted the knowledge management strategy from one of *personalization* towards one dominated by *codification* (Hansen et al., 1999).

Meetings in general, and those studied in Papers I-III in particular, consist of individuals – source actors and recipient actors – sharing information and knowledge content with each other (Paulin, 2013). Colloquially, meetings may imply that sharing information and knowledge occurs at same time-same place face-to-face meetings (Baecker, 1993). However, the purpose of sharing information and knowledge can occur with time-place flexibility. Based on the work from Papers I-III, in Paper IV, the MEET model was applied to support individuals' need and preferences for information and knowledge rather than supporting the development of meetings.

By first considering the work tasks of individuals and then studying the required information and knowledge to perform these work tasks, Paper IV explored how the MEET model could be used to develop the activities to obtain such information and knowledge at two companies, with two cases each. The effective sharing of information and knowledge were supported by adjusting the areas in the MEET model's Organization and Information Systems (Gullander et al., 2014; Fast-Berglund et al., 2014) to better match individual needs and preferences. This adjustment concerns the balance between the codification or personalization strategies. Hansen et al. (1999) propose to focus on only one. However, the outcome from Papers III and IV suggest that both strategies are important to include, similar to McMahon et al.'s (2007) conclusion. From Papers III and IV, the participants of the five studied activities for sharing information and knowledge preferred some information and knowledge contents to be shared through digital repositories and other contents through person-to-person conversations – a matter that is supported by the Organization System of the MEET model. On the other hand, the Information System of the MEET model supports both approaches, either to host the aforementioned repositories or to facilitate the person-to-person conversations.

Together, in Papers I-IV, the MEET model has been developed from analyzing meetings to be used for developing support that accommodates individual needs and preferences for information and knowledge. However, the functional areas of the studied companies had a low maturity towards Industry 4.0 in general, not surpassing stage 2 – *connectivity* – as proposed by Schuh et al. (2017). When it comes to sharing information and knowledge, Paper V concludes that implementation of the Industry 4.0 enabling technologies could support effective sharing of information and knowledge. For example, implementation of intelligent storage management, self-configured workstation layout, or product and process traceability, as suggested by Bortolini et al. (2017), would reach an Industry 4.0 maturity of stage 4 – *transparency* (Schuh et al., 2017) - and support some information and knowledge needs of shop-floor operators. However, the effectiveness would lie in how well these are used by the operators (Parasuraman and Riley, 1997).

5.3 EFFECTS OF EFFECTIVE SHARING OF INFORMATION AND KNOWLEDGE

Research Question 2 asked: *What are the effects of effective sharing of information and knowledge?*

Effective sharing of information and knowledge can have different kinds of effects. Papers I and II focus on its impact on continuous improvement efforts. Paper III comes closer to how people who were participating in the activities for sharing of information and knowledge perceived their meeting situations. Paper IV elaborates on the effects between Organization System and Information System in the MEET model.

In Papers I and II, the assessment of the meetings raised awareness among the participating operators, supervisors, and managers concerning their meeting situation and what to consider when developing meetings with regards to the areas in the MEET model's Organization System and Information System. In the case of Paper I, the gained insight resulted in self-developed progress, mainly regarding the Organization System. In the case of Paper II, such self-reflection led to a wish to further develop another meeting, with changes mainly regarding the Information System, as explored in Paper III. Hence, in Papers I and II, an effect of effective sharing of information and knowledge is that it inspired further development of meetings that previously had received less attention.

In Paper III, the more effective information sharing contributed to a positive social aspect despite the *codification*, which transformed the same time-same place meeting to a different time-same place information sharing (Baecker, 1993; Hansen et al., 1999). This was because the information quality improved with regards to its timeliness, accuracy, accessibility, and format (Kehoe et al., 1992), which in turn decreased the perceived workload of the supervisor – source actor of the shared information. For the shop-floor operators – recipient actors of the shared information – a small improvement of perceived work situation was measured.

The systematic approach to support effective sharing of information and knowledge based on a large variety of individual needs and preferences, as reflected upon in Research Question 1, opens up for a large variety of new solutions that may be implemented, especially with the ongoing technological development of Industry 4.0 in mind. The effects of these are still to be further explored, whether it is the intended use of them (Parasuraman and Riley, 1997), lowered complexity (Mattsson et al., 2018), personalized instructions (Johansson et al., 2018), or the maturity of the companies (Schuh et al., 2017).

5.4 QUALITY OF RESEARCH

In Papers I-IV, the outcomes from the quantitative and qualitative methods were in general consistent with each other, which reinforce an internal validity for each of these papers. The small inconsistencies, in terms of unexpected outcomes, could be explained in the interviews. In Paper V, the outcome from the thematic analysis was in large consistent with the general frame of reference. Throughout Papers I-V, the outcomes were consistent with each other concerning the sharing of information and knowledge, which suggests an external validity.

Concerning the reliability of collected empirical data in Papers I-V, small inconsistencies were expected because human beings do not always behave as predicted. However, the outcomes from Papers I-V show that fulfilling the purpose to support effective sharing of information and knowledge has been consistent with the intentions of the pragmatic approach and instrumentalism philosophy of the research design.

Concerning the trustworthiness of the research, in general, the four aspects of credibility, transferability, dependability, and confirmability were established by applying techniques prescribed by Lincoln and Guba (1985) - to a certain extent. In the case of credibility, member checks were conducted throughout Papers I-V, but prolonged engagement and persistent observation were not applied to all of the appended papers.

5.5 FUTURE RESEARCH

While it may seem easy at first to implement digitalization technologies, as defined by Schuh et al. (2017), that either enable a codification or facilitate a personalization strategy to manage information and knowledge (Hansen et al., 1999), doing so requires consideration of how people want to work in order to avoid disuse of the implemented technology (Parasuraman and Riley, 1997). As the manufacturing industry becomes more complex (ElMaraghy et al., 2012), the way people prefer to share information and knowledge may also change. With incoming Industry 4.0 enabling technologies, this paradigm shift offers new possibilities for how effective sharing of information and knowledge can support people in their work in previously unimagined ways. Similarly, implementation of new technologies may have unforeseen implications that can be of interest for future research.

Future research into the development of effective sharing of information and knowledge in the manufacturing industry could focus on how an organization can implement Industry 4.0 enabling technologies to support both the needs and preferences that are known and expressed by individuals as well as good solutions as yet unimagined by the individuals. However, much Industry 4.0 research attention focuses on technological development, leaving research opportunities to explore the interaction between humans and organizations in the manufacturing industry.

Can maturity assessments of Industry 4.0 at companies be applied to facilitate the creation of a strategy for Organization 4.0 that enables an Industry 4.0 environment where Operator 4.0 is cognitively supported?

6
CONCLUSION

This chapter concludes this thesis by providing the answers to the research questions and some final remarks.

6.1 SUMMARY

This thesis proposes the design of a holistic framework that models the conditions for effective sharing of information and knowledge. Towards this backdrop, an extended version of the MEET model has been evaluated and developed where the application has been expanded from studying meetings to also encompass individual needs and preferences for information and knowledge.

The purpose of the research was explored by studying how companies in the manufacturing industry could achieve more effective sharing of information and knowledge through the development of their Information System and Organization System.

6.2 HOW CAN EFFECTIVE SHARING OF INFORMATION AND KNOWLEDGE BE SUPPORTED?

The progress throughout Papers I-IV suggests that when designing effective activities for sharing information and knowledge, it is important to focus on individual needs and preferences for information and knowledge during various stages of their work. The focus on individual needs and preferences helps keep the information and knowledge content relevant and useful for the participants. Based on these individual needs and preferences, a framework like the MEET model can support the design of activities where information and knowledge are shared by providing a basis for discussion where the participants can reconcile individual differences. The MEET model includes areas both within the Organization System and the Information System as well as including time-place flexibility. This holistic approach towards harmonization between organizational and informational capabilities also requires a balance between the general overarching themes of the organization and attention to details, which relate to individual needs and preferences. Hence, effective sharing of information and knowledge places an emphasis on consolidating how people want to work with technological possibilities to support it.

Conceptually, this conclusion can be visualized as in Fig. 6.1. To the left, a human-centred focus of production systems. In the centre, the individual needs and preferences of information and knowledge. To the right, the organizational and technological aspects that can support the effective sharing of the aforementioned information and knowledge.

Fig. 6.1: Individual needs and preferences of information and knowledge and how its effective sharing can be supported.

6.3 WHAT ARE THE EFFECTS OF EFFECTIVE SHARING OF INFORMATION AND KNOWLEDGE?

By emphasizing individuals' needs and preferences for information and knowledge, as prescribed in the answer to the first research question, the focus shifts from making meetings or instructions faster to making the shared information and knowledge more relevant and useful. In this thesis, the observed effects of effectively sharing information and knowledge are twofold. First, from a continuous improvement perspective in Papers I and II, effective sharing of information and knowledge inspired people to improve the effectiveness of how information and knowledge are shared in other situations. Second, from a personal experience perspective in Paper III, it improved the self-perceived work situation for the shop-floor operators as well as lowered the perceived workload of the supervisor.

6.4 FINAL REMARKS

To manage the increased complexity in the manufacturing industry, shop-floor operators share more and more information and knowledge that are necessary for the performance and completion of work tasks. Activities for effective sharing of information and knowledge need to be developed with a systematic and holistic approach, including both an organizational development of the activities where information and knowledge are shared and a technological outlook towards future possibilities. Such design and implementation need to be human-centred because, in the end, it is all about how people want to work.

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