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Getting Work Done

The Significance of the Human in Complex Socio-Technical Systems

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Abstract
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This thesis aims to deepen the understanding of the role and relevance of the worker in the functioning of complex socio-technical systems. The perspective adopted is profoundly human-centred and the worker is considered as a resource. This stands in stark contrast to the performance-related measurements and accident investigations which have typically formed much research on work in complex safety-critical systems and conveyed a perspective of the human as merely a system cog. The empirical material in this thesis is based on ethnographic fieldwork in the shape of workplace studies conducted across two distinct work domains: manufacturing and operational train traffic. The studies are informed by distributed cognition (DCog) and activity theory (AT) as prominent theoretical approaches for developing in-depth understandings of how work activities are accomplished in situations where the interplay between humans and their socio-cultural and material environment is of interest. The findings are illustrated by empirical work that provides detailed accounts of work practices derived from a total of four work settings. It is illustrated how acquired experiences and skills allow the workers to simultaneously use and create resources in the socio-material environment. The findings also reveal novel characteristics of adaptations as driven by a human agency rather than being a result of external demands, which is the common view in literature on work in safety-critical domains. Based on the findings, the role of the worker is illustrated as a meaning-making actor – not only participating in, but also actively contributing to the system and its functioning. In that capacity, the worker is acting as a driving force for a process of continuous development, allowing the system to continue to function although frequently exposed to uncertainties and unexpected events. This thesis contributes to a deepened understanding of the role of human workers in socio-technical systems, highlighting how workers are an invaluable asset when it comes to managing large variations and unexpected events in technology-mediated complex work. This contribution is complementary to the current understanding of how to uphold system safety and provides insight into what underlies a mutually beneficial relationship between humans and technology to which both parties can contribute with what they do best.

Keywords: work, work practice, socio-technical system, workscape, workplace studies, ethnography, distributed cognition, activity theory, operational train traffic, manufacturing, human-computer interaction, HCI, safety-critical domain

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Till Noelia och ‘Humlan’

List of Papers

Papers written as part of this thesis are listed below and are referred to by their Roman numerals. Papers I, II and III were published prior to my name change from Andreasson to Cort.

I Andreasson, R., Lindblom, J. & Thorvald, P. (2017). Tool use and collaborative work of dock assembly in practice. *Special Issue in Production and Manufacturing Research*, *5*(1), 164–190. https://doi.org/10.1080/21693277.2017.1374890

Author contributions: I am the main author of this paper and hold the primary responsibility for the data collection and analysis. All the authors shared joint responsibility for writing the paper.

II Andreasson, R., Lindblom, J. & Thorvald, P. (2017). Interruptions in the wild: Portraying the handling of interruptions in manufacturing from a distributed cognition lens. *Cognition, Technology & Work*, *19*(1), 85–108. https://doi.org/0.1007/s10111-016-0399-6

Author contributions: I am the main author of this paper. Data collection was performed as a joint activity among the co-authors, but I had the overall responsibility for the analysis. I also had the main responsibility for the process of writing the paper; that is, I led and coordinated the manuscript preparations in collaboration with my co-authors.

III Andreasson, R., Jansson, A. A. & Lindblom, J. (2019). The coordination between train traffic controllers and train drivers: A distributed cognition perspective on railway. *Cognition, Technology & Work*, *21*(3), 417–443. https://doi.org/10.1007/s10111-018-0513-z

Author contributions: I am the main author of this paper. I was solely responsible for collecting and analysing the data and had the overall responsibility for the writing of the paper. My co-authors took part throughout the process in regular discussions on ideas and results and by providing continuous feedback on the manuscript in progress.

IV Cort, R. (2020). ”We’re doing this together”: An in-depth analysis of the teamwork between train traffic controllers and train drivers. In: A. Holzinger, H. Plácido Silva, M. Helfert, & L. Constantine (eds.). In: *Proceedings of computer-human interaction research and applications (CHIRA)*, 96-103. https://doi.org/10.5220/0010058000960103

Author contribution: I am the sole author of this paper.

V Cort, R. & Lindblom, J. (accepted with revisions). At the centre of coordination for train traffic: Activity theory and distributed cognition in times of digitalisation. *Submitted to a scientific journal*.

Author contributions: I am the main author of this paper and solely responsible for the data collection. The additional analysis and the writing of the manuscript were done in close collaboration with my co-author.

VI Cort, R. & Lindblom, J. (under review). Managing complexity at the railway: Sensing the breakdown. *Submitted to a scientific journal.*

Author contributions: I am the main author of this paper. Aside from collecting and analysing the data, I had the overall responsibility for writing the manuscript. My co-author provided continuous feedback and took part in the finalisation of the manuscript.

Papers I–IV have been published in scientific outlets, while Paper V has been resubmitted after being accepted with revisions. Paper VI is currently under review.

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Publications Not Included

The following publications are not included in the thesis but granted me valuable learning experience and influenced me as a researcher:

1. Jansson, A. A. & Cort, R. (2020). Assessment of openness as a dynamic team skill in order to counteract "free-riding". In: *Proceedings of IEEE frontiers in education conference (FIE)*, 1–6. https://doi.org/10.1109/FIE44824.2020.9274004
2. Thorvald, P., Lindblom, J. & Andreasson, R. (2019). On the development of a method for cognitive load assessment in manufacturing. *Robotics and Computer Integrated Manufacturing*, *59*, 252–266. https://doi.org/10.1016/j.rcim.2019.04.012
3. Andreasson, R., Jansson, A. A. & Lindblom, J. (2019). Past and future challenges for railway research and the role of a systems perspective. In: S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander & Y. Fujita (eds.). *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018): Volume VII: Ergonomics in design, design for all, activity theories for work analysis and design, affective design*. Cham: Springer, 1737–1746.
4. Alenljung, B., Andreasson, R., Lowe, R., Billing, E. & Lindblom, J. (2018). Conveying emotions by touch to the Nao robot: A user experience perspective. *Multimodal Technologies and Interaction*, *2*(4), 82. https://doi.org/10.3390/mti2040082
5. Lowe, R., Andreasson, R., Alenljung, B., Lund, A. & Billing, E. (2018). Designing for a wearable affective interface for the NAO robot: A study of emotion conveyance by touch. *Multimodal Technologies and Interaction*, *2*(1), 2. https://doi.org/10.3390/mti2010002
6. Andreasson, R., Alenljung, B., Billing, E. & Lowe, R. (2018). Affective touch in human-robot interaction: Conveying emotion to the Nao robot. *International Journal of Social Robotics*, *10*(4), 473–491. https://doi.org/10.1007/s12369-017-0446-3
7. Alenljung, B., Lindblom, J., Andreasson, R. & Ziemke, T. (2017). User experience in social human-robot interaction. *International Journal of Ambient Computing and Intelligence*, *8*(2), 12–31. https://doi.org/10.4018/IJACI.2017040102
8. Thorvald, P., Lindblom, J. & Andreasson, R. (2017). CLAM – A method for cognitive load assessment in manufacturing. In: J. Gao (ed.). *Advances in manufacturing technology XXXI*. Amsterdam: IOS Press, 114–119.

9. Alenljung, B., Andreasson, R., Billing, E. A., Lindblom, J. & Lowe, R. (2017). User experience of conveying emotions by touch. In: *Proceedings of the 26th IEEE international symposium on robot and human interactive communication, (RO-MAN),* 1240–1247.
10. Andreasson, R., Lindblom, J. & Thorvald, P. (2016). Distributed cognition in manufacturing: Collaborative assembly work. In: Y. M. Goh & K. Case (eds.). *Advances in manufacturing technology*. IOS Press, 243–248. https://doi.org/10.3233/978-1-61499-668-2-243
11. Lindblom, J. & Andreasson, R. (2016). Current challenges for UX evaluation of human-robot interaction. In: C. Schlick & S. Trzcieliński (eds.). *Advances in ergonomics of manufacturing: Managing the enterprise of the future*. Springer International Publishing, 267–277. https://doi.org/10.1007/978-3-319-41697-7_24
12. Andreasson, R., Lindblom, J. & Thorvald, P. (2015). Towards an increased degree of usability work in organizations. *Procedia Manufacturing*, *3*, 5739-5746. https://doi.org/10.1016/j.promfg.2015.07.814
13. Andreasson, R. & Riveiro, M. (2014). Effects of visualizing missing data: An empirical evaluation. In: *Proceedings of the 18th international conference of information visualisation,* 132–138.

Acknowledgements

As a child, I heard my older sister talk about this thing called ‘research’. I had no idea what it meant, but it sounded cool, and the 5-year-old me decided to become a researcher one day. It was either that or pursuing a singing career. Today, I am a tad older and somewhat wiser, and I have come to terms with the fact that I cannot sing. Research, however, was a childhood dream that stuck with me, and today I know that my initial thought was correct – research *is* cool.

Writing a doctoral thesis is, in many ways, a collective and social experience, and many people were essential parts of this process. First and foremost, my deepest gratitude goes to my supervisors: *Anders Arweström Jansson*, you are a visionary and – although many of our ideas have not yet seen the light of day – it has always been inspiring to discuss future research endeavours with you. Thank you for always believing in me and for giving me the freedom to grow and develop as an independent researcher, while always being there when I needed you. I also want to thank you for always looking out for the person behind the graduate student. *Jessica Lindblom*, you are not just my co-supervisor but also a great mentor and friend. We met in 2009, when I entered the Bachelor’s Programme in Cognitive Science and, from that day on, you have always managed to create a safe space for me – a learning arena in which we have had many inspiring discussions. I tremendously appreciate how you so generously share your knowledge. I am grateful to both of you for many interesting discussions and for your never-ending support and guidance, and I have truly benefited from your enthusiasm and commitment throughout these years.

I am grateful to my colleagues in the Human, Technology & Organisation (HTO) group. In this context, I would particularly like to thank *Åsa Cajander* and *Lars Oestreicher* for their guidance and support. In addition, I want to express my warmest gratitude to my former colleagues, *Thomas Lind*, *Ida Löscher* and *Gerolf Nauwerck*. Aside from creating a supportive environment with much-appreciated advice and continuous encouragement, you made going to work so much more enjoyable. Thank you for the many (and much needed) laughs.

I would also like to take this opportunity to acknowledge the importance of the people who inspired me early on, long before I became a PhD student. Once again, *Jessica*, you played a pivotal role in this, but I also want to men-

tion *Beatrice Alenljung*, *Erik Billing*, *Paul Hemeren*, *Ari Kolbeinsson* and *Peter Thorvald*: without you, I would probably never have embarked on this journey. Thank you for believing in me and persuading me to pursue my dreams of a doctoral degree. Others who deserve my deepest gratitude are my study participants: I am thankful to all of you for welcoming me into your community. This thesis would not exist without you so generously sharing your immense knowledge and work practices with me.

Last, but certainly not least, I want to express my deepest gratitude to my family for their never-ending support and encouragement. To my mother, *Inga-Lill*, who taught me early on to love learning and who always inspires me to pursue my dreams: thank you for always having my back, no matter what, and for all the times you so patiently listened to me go on and on about my research. *Victoria*, thank you for being the best sister one could have and for keeping me sane through this rollercoaster called life. *Leon*, you have been by my side through thick and thin, and no words can express the gratitude and love I feel for you. Thank you for being there and for sharing your life with me. *Noelia*, my beloved daughter, you are the true joy of my life; you inspire me to dream big and to never give up. I love you more than you will ever know. And to the little one, the youngest in our family, '*Humlan*' – although you are not even born yet, you have still contributed greatly to this thesis. In fact, you have been with me for large parts of the writing process, and so I want to thank you for being a terrific writing companion and for giving me something to look forward to. I love you and cannot wait to meet you in person.

As can be seen, this thesis is truly the product of distributed cognition and arose from numerous discussions with the people mentioned above. Although it was not in my original dream to write large parts of this thesis sitting by my kitchen table in the middle of a pandemic, I now appreciate more than ever the experience of being a part of a vibrant academic environment, and I hope the future holds opportunities for us to continue our rewarding discussions and collaborations. I truly appreciate all of you for being part of my journey. Thank you!

Uppsala, October 2021
Rebecca Cort

Summary in Swedish

Den forskning som presenteras i den här avhandlingen handlar om arbete i komplexa sociotekniska miljöer och syftar till att bättre förstå människans roll för att få det dagliga arbetet i sådana miljöer att fungera. Intresset för att förstå arbete är stort, och arbetspraktiker har tidigare studerats utifrån diverse olika forskningsansatser. Trots detta är det mycket vi ännu inte vet, och den tekniska utveckling vi ser i samhället bidrar dessutom till en konstant pågående förändring som drastiskt påverkar hur arbete genomförs i många olika tillämpningsområden. I min forskning ligger fokus på arbete i säkerhetskritiska miljöer. Det innebär miljöer där arbetsutförandet får stora konsekvenser om något går fel: ofta i form av skada på människa, miljö eller utrustning. Den forskning som ligger till grund för avhandlingen är utförd inom två sådana arbetsområden, närmare bestämt tillverkningsindustri och operativ tågtrafik. Trots sina uppenbara olikheter kännetecknas arbetet i båda tillämpningsområdena av höga krav på arbetaren i form av tidspress och uppgifter som kräver snabba beslut och god problemlösningsförmåga. Dessutom består arbetet av svåra uppgifter som kräver ett nära samarbete mellan den yrkesskicklige arbetaren och olika typer av verktyg och teknologier.

Både tillverkningsindustri och operativ tågtrafik har traditionellt sett studerats inom ett forskningsfält som går under benämningen Human Factors. Detta är ett stort forskningsfält med omfattande betydelse för vad vi idag vet om arbetsutförande och utformning av arbetsmiljöer. I miljöer där säkerheten är en avgörande faktor har fokus huvudsakligen varit på att utreda olyckor och incidenter samt att beräkna riskfaktorer för att i förlängningen kunna upprätthålla en hög säkerhet i verksamheten. Trots dess relevans har detta fokus medfört ett flertal nackdelar. För det första är det ett faktum att olyckor och incidenter hör till ovanligheterna och att det dagliga arbetet allt som oftast leder till önskade resultat. Likväl har det dagliga arbetet inte studerats i detalj och det återstår många frågor att besvara när det kommer till att förstå vad som kännetecknar arbetet när allt går bra, det vill säga det arbete som *inte* leder till incidenter och olyckor. För det andra har uppmärksamheten mot misstag och saker som går fel resulterat i en syn på människan som en riskfaktor och i många sammanhang har människan pekats ut som den felande systemkomponenten. För det tredje har fokus på incidenter och olyckor lett till en syn på arbetssystemet som bestående av ett flertal separata delsystem och att man i en olycksutredning kan peka ut vilken del som brustit. Detta synsätt förminskar den tätt sammanvävda relation som finns mellan människan och hennes

sociala, kulturella och materiella miljö där det omöjligt går att distinkt separera dem och dess påverkan på varandra. För att hantera den ökande komplexiteten i dagens arbetsliv behövs en helhetssyn på arbetspraktiker och på människans roll i systemet. Det är här som den här avhandlingen tar sin utgångspunkt och ger ett bidrag.

Det finns flera teoretiska perspektiv att använda när man studerar arbete med ett helhetsperspektiv. Forskningen som presenteras i den här avhandlingen utgår ifrån två sådana perspektiv, nämligen distribuerad kognition (DCog) och aktivitetsteori (AT). Trots olikheter dem emellan är ett centralt antagande inom både DCog och AT att mänsklig kognition och aktivitet är ett resultat av interaktion mellan sociala, materiella och kulturella aspekter i den miljö där människan verkar. Båda perspektiven har blivit väl etablerade utgångspunkter för att förstå arbete som utförs i komplexa sociotekniska system där det sociala och det tekniska är så sammanflätat att de omväxlande informerar och formar varandra.

Studierna som presenteras i avhandlingen innehåller resultat från sex vetenskapliga artiklar baserade på etnografiskt fältarbete i form av arbetsplatsstudier utförda i totalt fyra olika miljöer inom tillverkningsindustri och operativ tågtrafik. Samtliga artiklar bidrar till en ökad förståelse för arbetspraktiker i verkliga miljöer och illustrerar människans roll och relevans för att få det dagliga arbetet att fungera. Studierna visar hur arbetarna använder förvärvade erfarenheter och kompetens på sätt som möjliggör användning av tillgängliga socio-materiella resurser, samtidigt som de bidrar till en konstant utveckling av dessa resurser för att bättre anpassa dem till verksamheten. Resultaten belyser också hur arbetarna gör anpassningar till de dagliga arbetspraktikerna, och att dessa anpassningar är internt drivna av arbetarens vilja och motivation att omsätta sina kunskaper i praktiken. Detta skiljer sig från hur anpassningar vanligtvis framställs i litteraturen, där de ofta ses som ett resultat av omgivningens krav.

Avhandlingens övergripande bidrag utgörs av resultat i form av illustrativa exempel av arbetspraktiker som belyser den yrkesskicklige arbetaren som en meningsskapande agent. Arbetaren deltar inte bara i det socio-tekniska systemet utan bidrar aktivt till dess möjlighet att fungera. På så sätt agerar arbetaren som en drivkraft för systemet och för en process av kontinuerlig utveckling som på många sätt är nödvändig för att det sociotekniska systemet ska bestå och fungera i en värld där oförutsägbara händelser är vanligt förekommande. Utifrån dessa insikter om arbetarens roll i det sociotekniska systemet framhävs arbetaren som oerhört central då denne kan hantera osäkerhet, oförutsägbara händelser och stor variation på ett sätt som dagens teknologi inte kan. På så sätt bidrar arbetaren, människan, med något kvalitativt annorlunda än tekniken och spelar således en essentiell roll för att systemet ska kunna fungera. I förlängningen förväntas detta bidra till nya perspektiv på systemsäkerhet samt ge insikter kring hur arbete bäst fördelas mellan människa och teknik.

Contents

1. Setting the Scene

The technological development of modern times has been fast, bringing dramatic changes to work conditions across all domain types. However, the increasing interactions between humans and technologies have not been entirely free of friction, and the technologies and their functionality have not always met the expected or hoped-for outcomes (e.g. Bainbridge, 1983; Fitzpatrick & Ellingsen, 2013; Fortune & Peters, 2005; Orlikowski, 1992; Suchman, 1987; Vicente, 2006; Woods & Branlat, 2010). Still, on a societal level, we see a strong push towards technology as the solution to a variety of problems. Despite the many benefits and potential of this technology push, the position advanced herein is instead a push for the human perspective in the interaction with technology. I hope to highlight the role humans play in the successful functioning of complex socio-technical systems. With a deepened understanding of the human contribution to such systems, it is possible to mitigate the common friction between humans and technology and create a mutual relationship between them to which both parties can contribute what they do best.

The constant stream of emerging technologies gives rise to increased interactions between humans, technologies and processes, such that they pile up in a way that increases the level of complexity. Humans and technologies are becoming increasingly intermingled, and a multitude of interconnected and interdependent systems are giving rise to new challenges, introducing ambiguity and uncertainty into our workplaces. This thesis explores the role of the worker in everyday work practices in complex domains; it also examines how the interactions with social and material resources affect the workers' enactment of these work practices. This research takes place across various domains in order to provide examples of real-world work in complex socio-technical systems. By doing so, it indicates the generalisability of human contributions to work in such systems.

Although work has been a long-standing research topic in a number of disciplines, the main perspectives on work in complex work domains have emphasised aspects of safety and efficiency first and foremost (e.g. Grundgeiger et al., 2021; Lee et al., 2017; Norros, 2014). Less attention has been paid to workers and the 'human capital' (Wilson, 2000, 2014). With technological innovations changing the ways in which we live and work, the perception of the worker has often been too limited in scope, connoting a passive *factor* – that is, a fragmented and unmotivated individual – instead of an *actor* who is

active and in control, while having underlying values and motivations (Bannon, 1991). More than 20 years ago, Luff and colleagues stressed that 'we need not only further technological developments … but also a better understanding of the nature of workplace activities that are being intended to support, transform or replace' (Luff et al., 2000, p. 1). Due to increased complexity and the constantly changing nature of work, there is still a prevailing need for additional insights into and a deepened understanding of how work gets done 'in the wild'. While taking both the social and the technical into account and focusing strongly on the relations between them, this thesis sets out to highlight what characterises the role of the human to everyday work in complex socio-technical systems.

1.1 Research problem

Most of us are familiar with work[1] of some kind; yet, although it is a part of our everyday lives, we rarely stop to scrutinise how we accomplish our work. To paraphrase Nike's famous trademark: we just do it. Our work might entail collaborative practices, coordination, meetings and interactions, phone calls, machinery, computer systems, workarounds, documentation, performance reports, tacit knowledge and much more. Under the surface of us 'just working' lies an intricate net of activities and work practices. Most of it is routine, streamlined by the technical systems we use and organised by organisational procedures and instructions. Nonetheless, it is work and, as I will argue, it is essential for the functioning of a complex socio-technical system in a world of growing complexity.

The central theme of this thesis relates to work in complex socio-technical systems. A socio-technical system (hereafter referred to as a 'system') consists of humans and technologies; it can be described as an approach to the organisation of work that highlights the interaction between humans and technologies in the workplace, with an emphasis on the interrelatedness of the social and the technical (c.f. van Eijnatten, 1997; Trist, 1981). From this perspective, the unit of analysis is broadened beyond the historically more common focus on the interaction between individual and artefact, towards a more encompassing view of human activity and practices in a setting of multiple humans and a wide array of technologies (c.f. Kuutti & Bannon, 2014). This

[1] Work, work practices and work domains are central concepts. For the sake of clarity, I make the following distinction: 'work' is used to refer to the activities people perform to accomplish a certain goal or motive in a certain professional context – that is, *what* people do. 'Work practice' relates to *how* work is done in practice, including activities and procedures. It is governed by traditions, norms, rules, policies and regulations and is often shaped by the organisation's visions and goals, together with the workers' skills, experiences and social interactions. Finally, 'work domain' refers to the context in which professional workers are situated while conducting work and work practices.

perspective corresponds well with how work is carried out in most complex domains: by team members working on overlapping tasks and making use of both digital and analogue artefacts to successfully cooperate, collaborate and coordinate with each other[2].

Over the years, technology has claimed a central position in most workplaces, and technical developments have brought about a new set of system abilities, revolutionising the ways in which we work and communicate. Some scholars believe that the term 'technology' directs too much attention to hardware or software components (e.g. Orlikowski, 2007), as human thought and intention lie behind all technology. We usually pay more attention to the users of technology than to the designers and developers of a technical system; however, it is relevant to acknowledge that technology is a human construct that is both designed and used by humans. Due to modern technological advancements, the number of system components is increasing, along with the interdependencies and couplings between components, making systems more complex (Hollnagel, 2012a; Perrow, 2011). Although the term 'complexity' is difficult to define, it is often concerned with discussions on the number of interrelated parts and unexpected behaviours of a system, or even on the number of possible states a system can take (e.g. Hollnagel, 2012a; Perrow, 2011) (see Section 2.2). The growing complexity of most systems has traditionally been studied from the perspective of safety, especially in safety-critical domains in which incidents and accidents can result in damage to humans, equipment and/or the environment. Publicly announced accidents, e.g. the nuclear accident at Three Mile Island in 1979, or the two Boeing 737 MAX plane crashes in 2018 and 2019, have received far more attention in both research and public debates than the smaller breakdowns that occur in everyday disruptions of work in most work settings. Lee et al. (2017) describe safety as a constant critical concern in high-risk systems, closely followed by attempts to enhance performance rates without jeopardising safety; in contrast, satisfaction – including comfort and well-being in the workplace – is rarely emphasised. A similar conclusion is made by Grudin (2017) in a comprehensive historical summary of human-computer interaction, albeit in reference to power plant operation as a safety-critical domain. Grudin states that 'error reduction is critical, performance enhancement is good, and other goals are less important' (pp. 92–93). The fact that we only tend to hear about dramatic events – and usually only when such events have unsuccessful outcomes – has brought about a common understanding that safety lies in the absence of things gone wrong (Hollnagel, 2014). This perspective on safety has led to at least two problems. First, a great deal of blame has been put on the humans involved

[2] The concepts of cooperation, collaboration and coordination are commonly used but rarely defined (see e.g. Castañer & Oliveira, 2020). Here, I make the following distinction: 'cooperation' involves working separately yet for a common benefit, 'collaboration' involves working jointly, and 'coordination' involves working independently but consciously adjusting to the work of others.

in such accidents, which has resulted in humans being seen as error-prone system components whose performance variability is considered a hazard. This variability should instead be considered essential for learning purposes and for laying the necessary foundation for the development of the desired situated knowledge and skills. Second, investigating accidents in retrospect with the aim of understanding what went wrong implies that incidents and accidents are anomalies whose origin can be traced back to a failing component within the system. This viewpoint is problematic, as it conceptualises the functioning of a system as the result of a collection of individual components rather than as a result of the system (e.g. Bannon, 1991, 2011; Leveson et al., 2009). It also disregards the possibility that a deepened understanding of the relations and interconnections between the parts that make up the system might be necessary in order to enhance our understanding of work practices and of how they uphold safety in complex domains.

Nevertheless, the emphasis on errors and things gone wrong is slowly shifting towards a focus on how things 'go right', how work activities succeed and how work is organised relative to the available resources and current demands (Hollnagel, 2012b; Hollnagel, et al., 2015; Leveson, 2020; Woods et al., 2010). Along with an increasing interest in understanding the achievements of everyday work, another perspective of human variability is now being considered: a perspective in which humans play an important role in keeping systems safe and functioning (e.g. Dekker, 2004; Reason, 2008; Woods et al., 2010). Hollnagel et al. (2015) highlight this with the words 'things do not go right because people behave as they are supposed to, but because people can and do adjust what they do to match the conditions of work' (p. 4). Although humans' ability to adapt has been informally recognised by many, the role adaptations play in work practices is scarcely understood in organisations and in research. Thus, there is a knowledge gap between what Hollnagel (2012b) describes as 'work-as-imagined' and 'work-as-done'; in other words, the imagined work practices that are prescribed in procedures and formal documentation rarely reflect the reality of how work is done in practice. This gap gives rise to a classical issue in technology development: the finalised product reflects the developers' understanding of the work that the technology is intended to support rather than the actual work that is conducted in practice. Furthermore, technology use makes up an increasingly large part of everyday work activities influencing how work is done, as well as job satisfaction, motivation and employee well-being (Bhutkar et al., 2019). Therefore, it is essential to gain a deeper understanding of what role(s) humans and technologies respectively play in a well-functioning human-technology interaction.

This thesis aims to explore and explain how humans accomplish work tasks – that is, how work actually gets done – in order to gain a deepened understanding of work in general and of the role of the worker in complex work domains in particular. Using ethnographically based studies of work, this the-

sis highlights human contributions to everyday work practices, with an emphasis on the interrelatedness between the social and the technical in settings where work is time-critical and where coordination and cooperation are demanding yet essential for a successful outcome. The empirical settings in which this research is conducted comprise two domains that are traditionally studied in human factors research: the domain of manufacturing and the domain of operational train traffic. In contrast to human factors research, which uses traditional cognitive psychology as its foundation, this thesis takes the perspective of embodied, situated and distributed views on cognition; it emphasises that cognition is for action, and it demonstrates how the mind, body and socio-cultural and material environment can never be separated (e.g. Barsalou et al., 2003; Clark, 1997, 2005; Gallagher, 2006; Hutchins, 1995a, b; Lindblom, 2015a; Suchman, 1987). Accordingly, the embodied, situated and distributed approaches contrast with the traditional view on cognition as something that is internal to the individual mind and offer complementary viewpoints from which to view and analyse aspects of work practices as they unfold *in situ*.

Instead of focusing on incidents and accidents, this thesis is committed to a holistic understanding of work, meaning that the focus is on entire 'workscapes' (Suchman, 1995; Szymanski & Whalen, 2011). To gain such a holistic understanding, attention is paid to the workers, to the practices they enact in order to organise and accomplish their work, to the environments in which their work is done, and to the artefacts and tools that populate these settings in a way that makes them intimately involved in the work achievements (Szymanski & Whalen, 2011). From this perspective, I am just as interested in the ordinary, mundane work of an ordinary day as I am in incidents and accidents. Given that work is often achieved in situations governed by a certain degree of ambiguity and uncertainty, and that everyday disruptions, interruptions, breakdowns and workarounds are always on the horizon, I view systems as neither safe nor unsafe, and as neither functioning nor broken down, but rather as something that falls in between the two, in a constantly ongoing process. A system must be *made* to function and make use of its intricate complexity, which provides both system opportunities and constraints. As Willems (2018, p. 18) so vividly expresses it: 'Issues pop up. Disruptions come and go. Some are explosive, many are contained, and most reside somewhere beneath or within the system as an enduring possibility.' This thinking is in line with that of Graham and Thrift (2007), who stress a continuously ongoing process of simultaneous breakdown and repair. While safety is not explicitly on the agenda here, an underlying assumption is that an understanding of how work gets done and what makes the system function in real work situations will inevitably provide insights that contribute to creating and upholding system safety.

In summary, in a world of growing complexity, humans are faced with a multitude of interconnected and interdependent systems that give rise to increased ambiguity and uncertainty at work. A technology push is often made in order to mitigate these challenges; however, there is little understanding of how to create a mutually beneficial relationship between humans and technology. This lack of understanding jeopardises functioning interactions and – in the long run – the safe and efficient execution of work. It is here that this thesis makes its contribution: by deepening our understanding of workers and the role they play in how systems are made to function I hope to contribute with nuances of the intricate interplay between workers and technology, which – in the long run – may provide insights into what underlies a mutually beneficial relationship between them.

1.2 Aim and research questions

The focus on risks, incidents and accidents in complex safety-critical domains has led to a common view of work in such domains as something of a dichotomy: either it is safe or it is not; either it is functioning or it is broken down. However, this approach cuts away most of what lies between these two extremes. This thesis examines the work practices involved in making complex work domains function – that is, how they are being *made* to function by workers acting in the socio-material and cultural work environment. In light of this, the aim is to *deepen the understanding of the role and relevance of workers in the functioning of complex socio-technical systems.*

A naturalistic and empirically driven research approach makes it possible to explore this aim (Rawls, 2008). More specifically, the six appended papers are designed as workplace studies (Heath et al., 2010; Luff et al., 2000), informed by two theoretical approaches from the embodied, situated and distributed perspectives on cognitive work: distributed cognition (DCog) and activity theory (AT) (e.g. Engeström, 2015; Hollan et al., 2000; Hutchins, 1995a, b; Kaptelinin, 2013). The analyses presented in each paper respectively aim to investigate what constitutes true work practices when they unfold naturally in complex socio-technical systems; this is done by studying work *in situ* across four empirical settings belonging to two distinct work domains. The overall argument for adopting such a research approach is that it makes it possible to explore the role and relevance of the worker in the functioning of a system across multiple domains. It also allows such exploration to occur from within work settings that pose distinct challenges and opportunities for task achievement in everyday work practices. All of the selected work settings are considered to be complex socio-technical systems characterised by frequently

occurring breakdowns, interruptions, unexpected events and a continuous coordination between the workers and different kinds of tools and technological artefacts[3]. This aim is further addressed by the following research questions:

- What characterises adaptability to work practices in complex socio-technical systems?
- How do workers engage with the complex socio-technical environment in their everyday work practices?

The research questions explore two aspects of human contributions to work: the ability to adapt and the use of resources in the socio-technical environment. The perspective adopted is profoundly human-centred, as it promotes meaningful control in the workspace in support of the social organisation of situated and contingent activities; it also supports workers' learning, creativity and well-being. An overarching claim of this thesis is that a deeper understanding of the human as an active contributor to work practices (c.f. Bannon, 1991) and to the functioning of the socio-technical system is needed in order to understand what underlies a mutually beneficial relationship between humans and technology and how to enable both parties to contribute with what they do best (c.f. Grundgeiger et al., 2021; Stephanidis et al., 2019). Much research on work in complex safety-critical domains (e.g. manufacturing and operational train traffic) has been influenced by the classical information-processing view on cognition. According to this view, cognition resides within the individual, and the socio-technical environment is considered to have little or no effect on cognition. The setting and nature of cognitive activities, as distributed in the socio-material and cultural environment, are thus often disregarded in studies on work in such complex systems, where the focus more commonly has been on safety and performance-related issues (Grudin, 2017; Lee et al., 2017; Norros, 2014). Accordingly, this thesis offers a complementary way of thinking about work – and, more specifically, the human contribution to work – in complex, safety-critical socio-technical systems. Furthermore, it does so with the use of a theoretical stance from within the embodied, situated and distributed perspectives on cognition.

1.3 Guiding perspectives

This thesis takes ethnographic studies of work practices in manufacturing and operational train traffic as its starting point. These domains are characterised

[3] It is not within the scope of this thesis to give a thorough account of what constitutes tools and artefacts, both of which have been given numerous definitions in the literature (c.f. Susi, 2006). I will use the terms in a general sense, meaning that tools are manually operated and artefacts are human-made.

by tasks that require professional teams with highly skilled and trained workers to control complex work processes, often challenged by time pressure and the need for rapid decision-making. Such work is cognitively demanding, with tasks that require the workers to coordinate actions and solve problems that are complex and often distributed over time and space. This work involves many tasks that are – and need to be – supported by various kinds of artefacts, both analogue and digital. Within such complex domains, everyday work is characterised by continuously varying conditions caused by, for example, breakdowns, deviations, workarounds and interruptions. In the following, I will refer to these varying conditions as 'unexpected events'. The term 'unexpected' should not be interpreted as meaning that the event is rare; however, it does imply low predictability in system variations. Accordingly, I see this term as being closely related to the workers' expectations and timing, as well as to the overall context of the event. Although such events may be unexpected, their handling is a natural part of everyday work in the aforementioned domains and should not be considered as out of the ordinary.

Considering the nature of work in the domains under study, a research approach with a cognitive starting point that places emphasis on the social and cooperative constitutions of work was considered to be appropriate. With an interest in how cognition emerges in the interaction between humans and their environments, I write this thesis from the point of departure that cognition is situated, embodied and distributed (e.g. Gallagher, 2006; Hutchins, 1995a, b; Lindblom, 2015a). In other words, cognition involves external resources that are available in the social, cultural and material environment in which the human is situated. Taking this as a guiding principle, I use two theoretical lenses, DCog and AT (e.g. Engeström, 2015; Hollan et al., 2000; Hutchins, 1995a, b; Kaptelinin, 2013), to study the complex work practices at play in the high-pace, high-risk domains of manufacturing and operational train traffic. My main underlying perspective is DCog, which works well with complex and ill-defined problems while providing flexibility to the unit of analysis. DCog has been used in multiple dynamic environments and has yielded highly interesting results in such environments. Although my research is mostly empirically driven, the theoretical perspectives adopted act as a filter, pulling some aspects into sharper contrast while making others fade away. Accordingly, they have been helpful in guiding me and helping me to maintain focus during data collection and analysis (see Section 3.4.1–3.4.2).

It is worth mentioning that research in the domains of transportation and manufacturing has predominantly been undertaken from within the discipline of human factors and ergonomics[4], in which approaches such as embodied,

[4] Historically, these were two distinct fields, and human factors originate from the field of ergonomics. However, the two are now often grouped together and are considered to be a single scientific discipline that is known as human factors and ergonomics (HF/E) or just as human factors. I use the latter term here.

situated and distributed cognition (e.g. Barsalou et al., 2003; Clark, 1997, 2005; Gallagher, 2006; Hutchins, 1995a, b; Lindblom, 2015a; Suchman, 1987) have yet to be fully adopted (e.g. Norros, 2018; Savioja et al., 2014; Wilson, 2014). It is only natural that research fields differ in their underlying theories, methods, tools, level of analysis and perspectives, and it falls outside the scope of this thesis to review and compare the fields related to the research problems addressed herein. However, by not considering the modern theories of human cognition, studies of work in safety-critical domains risk missing out on general progress in relation to a holistic understanding of cognitive work as shaped by the reciprocity and interactions between the human and the environment (Savioja et al., 2014). I do not intend to diminish the well-justified research previously carried out within these domains, but I do seek to demonstrate how the modern understanding of cognition complements the tool box of available theories and methods used for this type of research. Accordingly, I will commit to the perspective of cognition as situated, embodied and distributed, which has been proven useful for studies in domains where the demands are high and the problems are complex and ill-defined – just as they are in manufacturing and operational train traffic (e.g. Hutchins, 1995a; Lindblom, 2015a; Suchman, 1987).

Along with this theoretical positioning comes the perception of the human as a cognitive agent actively taking part in, and contributing to, the cognitive system she or he engages with. In my view, this also entails that the human being has values, motivations, goals and beliefs about things of importance to that individual (c.f. Bannon, 1991). The concept of 'human' is continuously used throughout this thesis, based on the abovementioned meaning. A related concept – and one of great importance – is that of the 'worker'. Here, 'worker' refers to a human being acting in a professional role and within a professional setting. In this context, the worker brings her or his values, motivations, goals and beliefs to work, which – as will be seen in later chapters – shapes and structures the work practices. Across both of the domains represented here, most of the workers have many years of experience and show great engagement and agency in how they perform their work. They do not just do what is asked of them; they invest themselves in the task and care about its outcome. These are the implications behind my use of the concept of 'worker', which I hope shine through in the descriptions of my study participants and the work practices they employ.

1.4 Research projects

The studies comprising the empirical part of this thesis are based on data collected in two work domains. The research presented in Papers I and II was performed as part of a larger EU project named Sense & React. This was a Seventh Framework project funded by the EU grant FP7-314350 that involved

a total of 12 industry and academic partners. The project aim was to increase the flexibility of how information is presented in manufacturing by developing a context-aware and user-centred information distribution system. Such a system should 'sense' and 'react' to surrounding conditions and present information accordingly.

Papers III–VI relate to the domain of Swedish operational train traffic. This research was funded by the Traffic Administration Board (Swe. *Trafikverket*) via the research program KAJT (*Kapacitet i järnvägstrafiken*; Eng. Capacity in the Railway Traffic System), whose core activity relates to research for improved performance of the railway system. Papers III and IV are part of the results from a project called DIALOG, which aimed to gain a deeper understanding of the coordinative aspects of work in train traffic control and train driving. The FTTS2 project continued where DIALOG left off and aimed to widen the unit of analysis even further to include information officers and the role they play in operational train traffic. FTTS2 is a Swedish acronym that translates into 'Socio-technical system design of the train traffic system of the future' (Swe. *Socioteknisk systemdesign av framtidens tågtrafiksystem*). The project addressed the question of how responsibilities, information and knowledge are best shared among workers in order to maintain skills and best practices that enable the efficient handling of train traffic. This project contributed to Papers V and VI.

1.5 Reading directions

Following this introduction, Chapter 2 provides a frame of reference with an introduction to central concepts and definitions. It also gives an introduction to studies of work, along with a description of the theoretical perspectives underpinning this research. Chapter 3 introduces the two work domains and the four empirical settings that constitute the empirical part of this thesis and gives a description of some of the defining characteristics of these domains. It also motivates and discusses the research approach applied in the foundational papers. This includes a description of the methods used for data collection and analysis, and the ethical considerations that were made. Next, Chapter 4 summarises the six appended papers and briefly presents their main findings. Chapter 5 concludes and discusses the study results in terms of their relation to the aim and research questions posed; it also provides a discussion and reflection on the methodological and theoretical contributions and limitations of this research. The thesis ends with a discussion on ideas for future research and some concluding remarks.

2. Theoretical Background

This chapter provides a theoretical backdrop with definitions, descriptions and considerations of central concepts, as well as an introduction to the theoretical approaches influencing the research presented in this thesis.

2.1 Socio-technical systems

The term 'socio-technical system' refers to the interdependencies between humans and things (including both digital and analogue 'things'; i.e. artefacts such as IT systems, pen and paper, calendars, and mechanical tools such as hammers or drills). These 'things', objects, devices and artefacts come to have meaning only when they are enrolled in a social practice (Suchman, 1987), which implies that the objects themselves do not 'do' anything. Instead, they are dependent on the social practice in which they are implemented and used, in ways that shape the very nature of the practice itself (Benders et al., 2006; Bostrom & Heinan, 1977).

The term 'socio-technical system' was first coined as a concept in the 1950s by researchers at the Tavistock Institute of Human Relations in a series of field studies on the organisation of work in British mines (see e.g. Trist & Bamforth, 1951). They operationalised the work in the mines as consisting of two subsystems: one technical and one social. The technical subsystem included the technologies used and the tasks related to the artefacts and their usage, while the social subsystem was described as abstract and consisting of institutionalised ideas about communication patterns, status hierarchies and power relations. The findings by Trist and Bamforth (1951) suggest that the social and the material are overlapped and interdependent in ways that produce local practices of work. They considered the technical sub-system to be more than just the technological artefacts. It was 'a sociomaterial practice in which people's goals and the technology's materiality became, to use Orlikowski's (2007: 1437) term "constitutively entangled."' (Leonardi, 2012, p. 41). The studies in the coal mines highlighted the need for consideration of both technical and social factors when promoting change within an organisation, such as when designing and implementing new technologies. These findings, along with similar studies, resulted in the development of the socio-technical sys-

tems theory (van Eijnatten, 1997) to inform technology design and technology-led changes by emphasising that 'design is systemic' (Clegg, 2000, p. 465).

In the digital era, within modern time of rapid technological developments, it is well-known that a considerable amount of time, money and effort is invested in projects for developing technology that may ultimately fail to deliver the intended benefits (e.g. Doherty, 2014; Fortune & Peters, 2005). In light of this situation, adopting the socio-technical approach to system development has been proposed as a way to design technology that will achieve higher acceptability with end users and increased value to stakeholders (e.g. Baxter & Sommerville, 2011; Eason, 1982). However, it seems as if the general technology push seen in modern society brings about a slight separation between the social and the technical, sometimes making the social subsystem secondary. In my research, I want to move away from the view of the social and the technical as two side-by-side systems. This thesis does not focus on design, and the concept of a socio-technical system is used rather as an approach to work and to the work settings in which I have conducted my research. This viewpoint entails a holistic approach that emphasises the interdependent nature of technological and social aspects in the workplace (or 'workscape'; c.f. Suchman, 1995; Szymanski & Whalen, 2011). In this view, it should be emphasised that the social and the technical are seen as a single system in which the interaction between the two is considered to be the main factor in the system's performance.

2.2 Complexity

This thesis addresses work practices in complex work settings, so the term 'complexity' is important. Complexity – and complex systems – are referred to in a variety of scientific disciplines ranging from biology to philosophy; however, the concept is rarely properly defined. Hollnagel (2012a) has put forward multiple ways to define and understand complexity. He states that the most intuitive way may be to note complexity as the opposite of simplicity. Something is considered simple if it involves few parts and if the order and relationships among the parts are easily understood. The opposite – when something involves many parts and the relationships between them are not straightforward and cannot be understood in simple analytic or logical ways – would then constitute complexity. Complexity has been defined more formally as the number of possible states a system can take, in an idea that goes back to early works in cybernetics (e.g. Wiener, 1948). Many of the suggested definitions have one thing in common: something is considered to be complex if it is difficult or impossible to predict what will happen and what outcomes specific actions will result in (Hollnagel, 2012a). This is an important feature that distinguishes complex systems from complicated ones – two concepts that

are sometimes used interchangeably although they have quite different meanings. Poli (2013) aptly describes what distinguishes 'complex' from 'complicated' problems and systems:

> Complicated problems originate from causes that can be individually distinguished; they can be addressed piece-by-piece; for each input to the system there is a proportionate output; the relevant systems can be controlled and the problems they present admit permanent solutions. On the other hand, complex problems and systems result from networks of multiple interacting causes that cannot be individually distinguished; [they] must be addressed as entire systems, that is they cannot be addressed in a piecemeal way; they are such that small inputs may result in disproportionate effects; the problems they present cannot be solved once and for ever, but require to be systematically managed and typically any intervention merges into new problems as a result of the interventions dealing with them; and the relevant systems cannot be controlled – the best one can do is to influence them, learn to "dance with them". (Poli, 2013, p, 142).

It is a common misunderstanding that complexity is a higher order of complicatedness; however, complicated and complex systems should be viewed as different types of systems. As 'learning to dance' with a complex system is fundamentally different from solving the problems that arise from the system, it is relevant to recognise system complexity and to cope with it, rather than to avoid, hide or try to 'solve' it (Andersson et al., 2014; Poli, 2013). This thesis draws on examples from complex systems as its empirical material. Although the domains under study are seemingly different, both place high demands on their workers in terms of performance, efficiency, how they uphold safety, timeliness, communication, cooperation/collaboration and coordination, while largely depending on the successful use of and interaction with tools and (technological) artefacts. Accordingly, the term 'complexity' as used in this thesis refers to the intricate relationship between the humans, tools and artefacts involved in the realisation of work practices. This relationship contains a richness of information that is central to (and often given by) the process that the workers aim to control. The properties of this information commonly introduce interdependencies, time delays, disruptions and unpredictable behaviours into ordinary work practices.

2.3 Studies of work

Work plays a central role in most peoples' lives, which is reflected in the interest in work of a number of research disciplines, some of which may be argued to be partly overlapping (Rogers, 2012), such as human-computer interaction (HCI), computer-supported cooperative work (CSCW), human factors, cognitive science, sociology, psychology and anthropology. Although they

have somewhat varying foci and scope, all of these fields have devoted substantial research efforts to investigate and analyse how humans carry out work. Despite this great interest, many questions still remain to be explored, some of which are addressed in this thesis.

One relevant aspect of work that has received significantly increased interest in the last few decades is the human-technology relationship and the role it plays in work and workplaces. This increased interest may stem from at least two rudimentary reasons. The first reason has to do with where we draw the bounds of cognition – that is, the boundary between human cognisers and their environment. Since the inception of cognitive science in the mid-1950s, mainstream research in this field has focused on understanding the unaided, isolated mind; thus, it explains cognition in terms of states and processes that are internal to the individual (in a research tradition called cognitivism)[5]. This focus has resulted in the cognitive abilities of individuals, such as memory, attention and perception, receiving a great deal of attention, with little or no regard to the interactions between humans and their environment (Clark, 1997; Dourish, 2001; Lindblom, 2015a). In many ways, viewing human cognition as a process that is internal to the brain as an ultimately rational symbol-processing machine (e.g. Simon, 1996; Vernon, 2014; Wilson, 2002) has proven successful. However, it is a problematic view for explaining actions and tasks performed in ill-defined spaces and for complex problems coloured by the 'messiness' of the real world (e.g. Barsalou et al., 2003; Rogers & Marshall, 2017; Vernon, 2014). This insight has caused multiple academic disciplines to expand the bounds of cognition and start to pay attention to the close coupling between humans and their environment and the central role of this coupling in cognitive processes (e.g. Dreyfus, 1972; Norman, 1980; Rogers, 2012; Vicente, 1999). Today, academic interest in the study of human cognition situated within a socio-cultural and material environment is rapidly growing in many of the abovementioned disciplines. However, the classic information-processing view still dominates the fields of human factors and cognitive science.

The second reason for this increased interest in the human-technology relationship and the role it plays relates to the current rapid technological developments. The so-called 'digital revolution' has transformed the ways in which we communicate, coordinate, divide labour, perform teamwork and much more. However, we still encounter difficulties in developing computer systems that support users and meet their needs. This issue has prompted research interest in a more refined understanding of how humans work with and through varying kinds of technical artefacts. These questions have led to the

[5] It falls outside of the scope of this thesis to provide an exhaustive review of the historical development of cognitive science. I will use cognitivism, computationalism, information processing, the computer metaphor of mind and the more loosely worded expression 'traditional view of cognition' interchangeably. This should not be interpreted as a suggestion that the concepts are synonyms but should rather be seen as a way to create nuances in the writing.

development and establishment of some of the abovementioned research fields – especially HCI and CSCW, both of which have contributed to the study and analysis of work and workplace activities.

At the core of this thesis lies the intention to further develop an in-depth understanding of how workers make use of their socio-material and cultural environment to cope with varying conditions and unexpected events in their everyday work. For this purpose, a workplace study approach is considered to be appropriate. Before further exploring workplace studies, this chapter provides a backdrop to the history of studies of work by highlighting a few prominent research contributions that have had great impact on this type of research.

2.3.1 Situating work in socio-cultural and physical-material spheres

The movement towards a more situated[6] view on cognition, which has been seen across disciplines, has given rise to various directions for studies of work[7]. Most of it is concerned with ethnographic fieldwork, often with an emphasis on distinct features of (cognitive) work. Jens Rasmussen's studies on problem-solving from the late 1960s and early 1970s are a noteworthy example. As opposed to the laboratory tasks that were at the centre of much research at that time, Rasmussen strongly committed to the relevance of carrying out real-life observations of work while encouraging the workers to provide verbal reports of their thought processes (also known as 'think-aloud'). Among other things, he studied technicians diagnosing problems with electronic instruments and found that they used a number of recurrent search routines. The physical layout of the electronic circuitry organised an iterative search process that the technicians engaged in until they could identify the problem. Rasmussen found that the search routines were highly opportunistic, meaning that the workers did not follow a strict search procedure but rather took 'shortcuts' whenever possible. Although it involved redundancy in tests, the opportunistic

[6] With the 'situated' concept, I refer to the human as situated within socio-cultural and physical-material spheres. Although the social, cultural, physical and material aspects of situatedness are interwoven, my general view on these concepts is that the social relates to the social relations and interactions taking place here and now within the community of practice or organisation. The cultural relates to the cultivation of work practices, the historical perspective and the time horizon during which a work practice has developed. Moving on to the physical versus material, I view the physical as the physical space in which the work takes place, encompassing the design of the room and its physical layout, while the material refers to the things, tools and artefacts within the physical space. To ease readability, I will hereafter avoid the long and rather awkward phrase 'socio-cultural and physical-material spheres' in favour of the word 'situated', which I will use as an umbrella term encompassing the social, cultural, physical and material setting in which the human operates.

[7] See Salembier and Wagner (2021) for an excellent historical summary on the field study tradition in work practice research.

approach made the search strategies fast and efficient (e.g. Rasmussen & Jensen, 1974). These observations could not be accounted for solely by the traditional information-processing models that were dominant at that time, which relied on internally stored representations of the problem (e.g. Newell & Simon, 1972; Lindsay & Norman, 1972). Instead, the work by Rasmussen and colleagues acknowledged the role of external representations in structuring the problem space (Waterson et al., 2017).

The insights derived from Rasmussen's early research laid the foundation for his widely recognised decision ladder (Rasmussen, 1974) and the cognitive work analysis (CWA) framework (Vicente, 1999). The latter has been extensively applied to complex systems with the overarching aim of improving system design. Through a process of five iterative phases of analysis, CWA identifies behaviour-shaping constraints from the structure of the work tasks, strategies, social and organisational factors, and so forth within the system. The phases start with an ecological perspective and an analysis of the ecology of work, before focusing on tasks, strategies and an analysis of the social organisation and cooperation. Finally, the necessary competencies are identified (Vicente, 1999). With these steps of analysis, the framework has been used to inform both interface design and design of the work system as such (Read et al., 2012).

Another prominent example of studies of work is the research by Gary Klein and colleagues (e.g. 1986), who studied expert decision-making in situations characterised by time pressure and repeatedly changing goals. They employed a research approach similar to that of Rasmussen, with an emphasis on ethnographic fieldwork and verbal protocols, and studied how fire ground commanders made critical decisions during non-routine cases. Their analysis revealed that the fire ground commanders rarely engaged in analytical processes such as specifying possible options and contrasting their advantages and disadvantages. Instead, they relied on their experience and their ability to recognise and classify the situation. Based on the classification made, they selected a course of action that was typical for this type of situation. These findings initiated the development of the recognition-primed decision (RPD) model, which emphasises the use of recognition rather than calculation or analysis in the decision-making process (Klein et al., 1986). This perspective on human decision-making stood in stark contrast to the (at that time) dominant view of humans as non-rational and incompetent decision-makers (Klein, 1998). The research was received well by scholars questioning the traditional paradigm of decision research for its lack of explanatory or predictive power in real-world settings (Zsambok, 1997) and firmly established what is referred to as the naturalistic decision-making (NDM) community.

Yet another noteworthy example of this line of research is the early work by Lucy Suchman (1987), in which she analysed office workers' interactions with photocopiers and found that the interactions did not match the ways prescribed by models and procedures for how human-technology interactions

were assumed to play out. By observing the users trying to figure out how to use the double-sided copying function, Suchman showed how novice users deviate from the anticipated procedure to instead engage in a situated interaction with the machine based on what they consider to be the appropriate next action. The observed activity grew directly out of the immediacy of the situation, revealing that such action had an emergent character (Suchman, 1987). Given that most technologies at that time were designed based on preconceived, abstract models of users, Suchman argued that designers would benefit from insights into the details of actual work practices to understand how humans use technology in a specific setting. Her research (Suchman, 1987) criticised the cognitive model suggesting that actions derive from plans, which implied that plans are a prerequisite and an underlying mechanism for action. When plans are viewed as determining actions, the plans need to be closely related to prior knowledge and to an understanding of which situations are most likely to occur. In contrast to this view, Suchman describes plans as loose templates for action. What these templates are filled with – that is, human action – is contingent on the circumstances in which the action takes place. To further make her point, Suchman referred to the Trukese navigators as an illustrative case:

> The Trukese navigator begins with an objective rather than a plan. He sets off toward the objective and responds to conditions as they arise in an ad hoc fashion. He utilizes information provided by the wind, the waves, the tide and current, the fauna, the stars, the clouds, the sounds of the water on the side of the boat, and he steers accordingly. His effort is directed to doing whatever is necessary to reach the objective. If asked, he can point to his objective at any moment, but he cannot describe his course. (Berreman, 1966, in Suchman, 1987, p. VII)

What this quote so elegantly captures is that the answer to how the navigator's course of action has been put together is found in the socio-cultural materials of the situation. In line with this perspective, Suchman's research situates human actions in their social, material and cultural world and shows how intelligent behaviours are productions of socio-cultural contingencies that cannot be covered in full by a predetermined plan.

These examples of research represent prominent directions for studying work in its natural setting; thus, they have contributed to the movement out of the laboratory to contextualise work in its true environment. It is, however, worth acknowledging that Suchman's (1987) influential work was in fact conducted in an artificial setting. This may seem contradictive, considering that her research agenda highlights the situatedness in human activity, but her argument is that *everything* is situated, including the interactions made inside a laboratory. The users interacting with the photocopier may have had access to a reduced number of social and material scaffolds when in an artificial setting, but they were still engaged in a situated activity (c.f. Rooksby, 2013). Human

cognition – human thinking – is not different in the laboratory than in 'the wild'; therefore, there are no situations where cognition should be considered to be 'non-situated'.

Rasmussen, Klein and Suchman all acknowledge that the carefully controlled settings of most laboratory-based research on cognitive work do not properly inform our knowledge on the strategies used in real life and under less controlled conditions. Although they all agree on this point, they differ in terms of the role they assign to the social, material and cultural environment of the cognitive process under study. Rasmussen and Klein put emphasis on mechanisms such as pattern recognition and selective search. This choice indicates that the setting is considered to have a restricted impact on the cognitive work, which they still consider to be based on knowledge representation concepts such as schemas and mental models. Thus, these scholars still rely on the traditional view of cognition, which explains cognitive work as processes that are internal to the mind – albeit with external input from the environment in which the human is situated. This is also visible in the methods they favour, with both Rasmussen and Klein relying a great deal on verbal reports from their participants. Such knowledge-elicitation techniques capture only those aspects of performance that the workers themselves can easily verbalise; therefore, these techniques can only provide insights into the individual's explicit thoughts, desires and needs. The result is a restricted level of understanding; in fact, concerns have been raised regarding the difficulty of verbalising information about automated work processes (e.g. Polanyi, 1966). It should be noted that more recent research has addressed these challenges: for example, Jansson et al. (2015) suggest a method in which an independent observer – a colleague who is knowledgeable about the tasks of interest – verbalises about recorded material of a person performing the tasks. The method has the very fitting name of collegial verbalisation (for more details, see Erlandsson & Jansson, 2013; Jansson & Axelsson, 2017; Jansson et al., 2015).

Instead of relying on verbal reports, Suchman relies on observations that are documented through video, which offer complementary insights into underlying assumptions or tacit practices – that is, what the participants do not (or cannot) verbalise. In fact, the revelations hidden in unspoken words have often proven to be valuable for understanding a particular practice (e.g. Agar, 1996; Patton, 2002). Suchman moves further away than the others from the traditional view on cognition by suggesting that all activity is contingent on the social and material context, which makes all action situated at all times. She has publicly criticised iconic figures in cognitive science for their inability to understand the implications of the fact that human activity is not driven by the rational execution of plans but rather emerges from the social and cultural world, which then holds the explanation for that action (Button & Sharrock, 2009). By doing so, she has distanced herself from the prevailing view on cognition even more than Rasmussen and Klein, who have mainly pointed out

limitations in the scope and practical usefulness of the traditional cognitive view.

Around this time – that is, the late 1980s to early 1990s – the term 'in the wild' arose as a movement rejecting the then-current approach to studies of cognition in HCI (Rogers, 2012) and arguing for a broader unit of analysis to take the conceptualisation of human cognition out of the individual's head and into the world of body, environment and culture (Rogers & Marshall, 2017). Lucy Suchman's work in *Plans and Situated Actions* (1987), which was mentioned above, along with Jean Lave's book on arithmetic problem-solving in everyday situations such as grocery shopping, called *Cognition in Practice* (1988), and Ed Hutchins' studies of navigation practices onboard a U.S. Navy ship, reported in *Cognition in the Wild* (1995), were in the forefront of this movement. Lave reached a similar conclusion to Suchman: namely, that it is impossible to separate the individual from the environment, since dynamic encounters between the two shape cognition, which in turn shapes both humans and the world within which they act (Lave, 1988). Hutchins agrees with this but adds another dimension by arguing that cognition is not only inseparable from our material and social surroundings, but also *arises* in the interactions between the brain, body and world. Thus, rather than being evidence of underlying cognitive processes, such interactions are the actual cognitive processes themselves (Hutchins, 1995a, b, 2008). Hutchins' work is discussed further later in this chapter.

At this point, it should be noted that the study of (cognitive) work and workplace activities is a diverse and vaguely defined research quest, with a high interdisciplinary factor and few defined guidelines to follow. My interest is in all aspects of work – not just exceptional cases and high-stakes situations, but primarily the mundane, everyday aspects of work. I am also interested in the interaction between the human and the socio-cultural environment in the sense that they together form a system that consists of more than the sum of its parts. With this viewpoint in mind, I will now move on to workplace studies, which draw on the paradigmatic shift described above, informed by both the social and the 'in the wild' approach.

2.3.2 Workplace studies

At the core of this thesis lies the wish to develop an in-depth understanding of how humans make use of their socio-material and cultural environment to cope with varying conditions and unexpected events in their everyday work. For this purpose, a workplace study approach is considered to be appropriate. Rawls (2008, p. 710) describes workplace studies as follows:

> a cross between research and work. Performed by trained researchers, the questions they raise orient toward the problems and taken-for-granted competences

> workers manage in doing their work. They are different from 'applied research', which takes its problems and questions about how the world is ordered from disciplinary interests with no immediate practical relevance to the worksite, and then attempts to 'apply' them.

Workplace studies are concerned with studying, discovering and describing details of how activities are accomplished in natural, real-world workplaces (Luff et al., 2000). They offer holistic understandings of the characteristics of work practices and provide 'thick' descriptions of human conduct and cooperation through naturalistic, ethnographic studies and analyses of work activities. Workplace studies have been put forward as a prominent approach for highlighting the interactional organisation of a workplace and for examining how tools and (technological) artefacts are used to support work tasks, cooperation and coordination (Heath et al., 2000). It should be noted that, although implications derived from workplace studies can inform design recommendations and provide input into the development of novel technologies to support workplace activities, this is not within the true scope of workplace studies, nor should it be their main contribution (Bannon, 2000; Dourish, 2006; Dourish & Button, 1998; Halverson, 2002; Luff et al., 2000; Plowman et al., 1995).

In a workplace study, the worker – not the researcher – is the expert. The importance of this perspective can be explained with Goodwin's (1994) concept of 'professional vision', which implies that professional training and experience make workers able to see objects and relations that an untrained individual (i.e. the researcher in this case) cannot see. In order to capture the details of how activities are accomplished in a work setting, it is necessary to acknowledge the workers' expertise in order to reveal the true challenges and contingencies of the work situation. If we fail to do so, the research will lack practical application and will 'become a model of a theory rather than a model of a worksite' (Rawls, 2008, p. 714).

With roots in sociology, cognitive science, social anthropology and – to some extent – computer science, workplace studies have emerged as a response to academics and practitioners acknowledging that problems with technologies often stem from a lack of understanding of how everyday work activities are accomplished (Luff et al., 2000). Today, workplace studies have been applied to a multitude of contexts with the aim of better understanding the socially situated organisation of work. Regardless of the setting, the objective of such studies is to understand work practices and explore human-technology interactions as they naturally unfold, along with the complexities surrounding these interactions (Heath et al., 2010). This objective requires an empirically driven research approach – meaning that the analysis begins with the empirical material, rather than with the intention of testing a set of previously determined theoretical assumptions (e.g. Rawls, 2008).

Numerous theoretical orientations can be taken for an analysis of the situated organisation of work. The majority of them were developed from cognitive psychology and cognitive science as a response to the mainstream orientation of studying cognitive work as something contained within the individual. This response emphasised a focus on developing methods and approaches to explore the social, material, and cultural aspects of work and to better understand what role various aspects of the social setting play in how humans work with and through technologies (Dreyfus, 1972; Luff et al., 2000; Norman, 1980). Accordingly, the theoretical orientations associated with workplace studies focus on naturally occurring workplace activities, although they bring different conceptions to the domain of study.

Examples of the theories, perspectives and approaches put forward as suitable for studying the social and situated nature of activities include ethnomethodology (Garfinkel, 1967), conversation analysis (Sacks, 1992), (cultural-historical) activity theory (Engeström, 2015; Kaptelinin & Nardi, 2012), situated action (Suchman, 1987), and DCog (Hutchins, 1995a, b, 2008). The role of theory can be debated and in regard to HCI, Rogers (2012) describes how theories have been stretched out, from being part of the scientific method to being more broadly used 'to describe, explain, predict and argue with' (p. 17). This view is in line with Halverson's (2002) analogy of theories being like dark glasses: when you put them on, they tint the world in a way that brings some objects into sharper contrast while causing others to fade away. Thus, the value of a theory does not lie in its objective representation of reality, but rather in how well it can 'shape an object of study, highlighting relevant issues' (Barthelmess & Anderson, 2002, p. 14).

The rich array of theoretical orientations available for workplace studies may sometimes complicate the process of committing to a single suitable approach, since they all have somewhat different scopes and theoretical constructs for understanding and describing the practices under study. The research described in this thesis is undertaken from two such theoretical perspectives: DCog (Hutchins, 1995a) and AT (Engeström, 2015; Kaptelinin & Nardi, 2012). Both can be seen as cognitive theories but have, in the HCI context, mostly been applied as frameworks in the sense that they put forward a set of interrelated concepts that have been used to inform particular aspects related to the interaction between humans and technologies (Rogers, 2012). In the following sections, I will describe and discuss these frameworks and briefly outline their main characteristics and how they have been applied to studies of work. While none are described in full, as that would be enough material for a number of theses, my emphasis rests on DCog, since it is the main underlying perspective of my research.

2.3.3 Distributed cognition

The foundation of distributed cognition (DCog)[8] is best understood in the light of the critique that has been directed against traditional cognitive science. In fact, DCog was introduced around the same time as the discussion of cognition being 'in the wild' was initiated (see e.g. Dreyfus, 1972; Hutchins, 1995a, b; Lave, 1988; Suchman, 1987). The theoretical framework was developed by the cognitive anthropologist Edwin Hutchins and his colleagues and presents a rather different conceptualisation of the nature of cognition than the traditional view. The main characteristics and concepts of DCog are carefully described in the appended papers. In the following, after a short summary of the framework, I will focus on its epistemological foundations and discuss its conceptual apparatus and underlying assumptions and interpretations. The introduction provided below is based on the description of DCog presented by Hutchins (1995a, b) and colleagues (Hollan et al., 2000), as some of the most prominent sources for Hutchins' original thoughts and DCog's application to HCI.

In his seminal book, *Cognition in the Wild*[9], Hutchins (1995a) presents a detailed analysis of the navigational work conducted onboard a U.S. Navy ship, the U.S.S. Palau. His extended analysis presents the trail of events surrounding the crew as they find their bearings and carry out calculations to determine the ship's location as it nears port. In contrast to the then-prevailing focus on individuals, Hutchins demonstrates that the ship, its crew members and the artefacts they use are best described as a socially distributed cognitive system (also referred to as a 'functional system'). He shows that no individual human could physically do all that must be done to complete the task of determining the ship's location within the required time interval. Although Hutchins' analysis is complex and highly detailed, his main conclusion is that the activities on the navigational bridge are successfully accomplished as a result of how information flows between the parts of the system (humans and artefacts) and how representations of information are transformed in the interaction between these parts. Accordingly, DCog views the human mind and environment as inseparable, making cognition fundamentally distributed in the socio-cultural environment that the human inhabits. By removing the focus from the individual, DCog broadens the unit of analysis and takes a systemic approach to cognition, considering cognition as an emergent property stemming from the interactions between humans and between humans and arte-

[8] To avoid confusion, I will hereafter abbreviate 'distributed cognition' as DCog when referring to Hutchins' (1995a) theoretical framework. When the term is written out in full, it will instead refer to the general phenomena of cognition being distributed (c.f. Halverson, 2002).

[9] Hutchins describes the meaning of the phrase 'cognition in the wild' as it referring to 'human cognition in its natural habitat – that is, to naturally occurring culturally constituted human activity' (Hutchins, 1995a, p. xiii).

facts. This perspective on cognition softens the boundary between what is considered to be internal mental processes and what is considered to be external socio-material structures (Hutchins, 1995a; Rogers, 1997). To summarise, the DCog perspective sees cognition as a result of interactions between the entities of the socio-cultural environment – that is, the individual's brain, body, and the social and material environment (Figure 1). From the combined efforts of these entities, the cognitive system creates a whole that is much greater than the sum of the individual efforts. With its primary focus on characterising the general information flow, which involves how various kinds of representations (internal and external) are propagated and transformed in the distributed socio-technical system, DCog provides a holistic view of human cognition (Rogers, 2012). Hutchins' (1995a) work on ship navigation is one of the most illuminating and influential pieces of research in the area of workplace studies, making DCog one of the most pertinent theoretical perspectives for such studies (Heath et al., 2000).

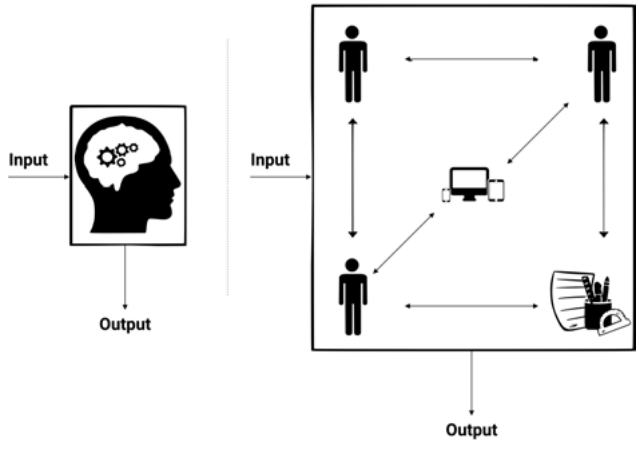

Figure 1: The traditional view on cognition is depicted to the left, suggesting that the unit of analysis is restricted to the mind of the individual. The image on the right depicts the unit of analysis from a DCog perspective, in which cognition is distributed across people and artefacts within the cognitive system. From this view, cognitive processes are the result of interactions between the entities in the system.

DCog can be distinguished from other post-cognitivist approaches by its commitment to two particularly important additions to studies of cognitive work. These two core principles are closely related; they concern (1) the boundaries of the unit of analysis for cognition; and (2) the range of processes considered to be of a cognitive nature (Hollan et al., 2000). DCog defines the boundaries for the unit of analysis by the functional relationships between different entities of a cognitive system. Accordingly, the focus of the analysis can range from the individual level to the organisational one, or beyond. This makes DCog especially fruitful for studies of whole socio-technical systems (Hollan

et al., 2000). With an expanded unit of analysis, the researcher is effectively forced to consider the socio-cultural environment as part of the cognitive processes under study and the environment is seen as a source of cognition rather than as a problem domain that must be handled. As the second principle, DCog views cognitive processes as interaction between internal processes, the manipulation of external objects, and the propagation and transformation of representations across the system's entities (Hollan et al. 2000). In a general sense, the human brain, body and external resources together result in the 'mind', and cognition is distributed across the agent, the situation and its resources (Hutchins, 1995a, b).

When the two core principles of DCog are applied to the observation of human activity, it is possible to observe the following processes of cognition being distributed (Hollan et al., 2000):

- across the members of a social group;
- between internal structures (mental) and external structures (material, physical and social environment); and
- over time in such a way that the products of earlier events can transform the nature of later events.

The idea that cognition emerges in the interaction between brain, body and the world has sometimes been misunderstood as meaning that thinking happens in the brain as a consequence of the individual interacting with the world (Hutchins, 2008). This is, however, not a correct interpretation of Hutchins' work, which rather claims that cognition, first and foremost, *is* interactions between the brain, body and world. Such interactions should therefore be considered not as evidence of underlying cognitive processes, but rather as the actual cognitive processes themselves (Hutchins, 1995a; 2008).

> Many cognitive outcomes produced by human activity systems are properties of our interactions with material and social settings, but we routinely mistake them for properties of ourselves (Hutchins 1995a, ch. 9). Our cultural practices guide us to direct our attention to aspects of our material and social surroundings in ways that produce powerful cognitive outcomes. (Hutchins, 2008, p. 2017)

Accordingly, socio-technical environments, including humans and their everyday work practices, should be viewed as a reservoir of resources for cognitive processes such as learning and decision-making (Hollan et al. 2000; Hutchins, 2008). This can be illustrated with a brief example from the control room of operational train traffic (for further details, see Paper III). Different kinds of representations are present in the control room; while some are observable (e.g. computers, graphs, verbal exchanges etc.), others are not (e.g. the memories of the traffic controllers). In DCog, the concept of 'representation' refers to the ways in which a functional system stores knowledge about

things or the organisation of things. They can be either internal (within the individual) or external (within the environment) (Perry, 2003). The time-distance graph is one of the main artefacts used in the train traffic control room and it is an external representation that the traffic controllers have close by and clearly visible at all times. This representation is thus relatively permanent and durable over time, while spoken representations, for example, are only sustained during their production. Still, spoken words play an important role in the control room, enabling the traffic controllers to create a distribution of information across the social space, contributing to the information flow. As information is distributed, both internal and external representations transform and propagate through the system and across different media, bringing different representations into coordination with one another. In this continual interaction with the world, the reservoir of cognitive resources is created and maintained, making the cognition of the control room system observable.

Since the inception of DCog in the mid-1990s, substantial research has been done using DCog in some form to support analyses of cognitive activity in various professional domains. Two examples of studied domains are part of this thesis: manufacturing and operational train traffic (see Papers I, II, III and V); other examples include ship navigation (e.g. Hutchins 1995a), aviation (e.g. Hutchins, 1995b), nuclear power plants (e.g. Mumaw et al., 2000) and healthcare (e.g. Grundgeiger et al., 2010; Hazlehurst et al., 2007), to name just a few. Within the HCI research community, DCog has been applied in studies aimed at gaining a deeper understanding of the interactions between humans and technologies (Rogers, 2012), although its general visibility in the field has been rather limited (Wright et al., 2000).

It is also worth mentioning that DCog has been used as a foundation for developing methods, of which the resources model (Wright et al., 2000) and distributed cognition for teamwork (DiCoT; Blandford & Furniss, 2006) are probably the most renowned. However, the former addresses single-user interaction and demonstrates DCog's applicability to software design as traditional HCI research. Therefore, it was not considered appropriate for studying the complex and highly coordinative work practices that are in focus here. Instead, DiCoT seemed likely to be more suitable for the studies reported in this thesis. Nevertheless, as a junior researcher, I wanted to learn the 'original version' of DCog above all. Besides, DiCoT is structured around principles of teamwork that are relevant for understanding how cognition is distributed in small teams (Blandford & Furniss, 2006). Thus, it has been framed as a method for studying teamwork activities, rather than as a perspective on cognition in general (c.f. Hutchins, 1995a). Accordingly, DCog was considered to be more in line with the purpose of the studies reported in the appended papers, even though DiCoT poses an interesting avenue for future research.

To truly grasp the implications of how Hutchins attempts to redefine the traditional view of cognition, it might be useful to see what he says about one

of the cornerstones of mainstream cognitive science – symbolic representation:

> Notice that when the symbols are in the environment of the human, and the human is manipulating the symbols, the cognitive properties of the human are not the same as the properties of the system that is made up of the human in interaction with these symbols. The properties of the human in interaction with the symbols produce some kind of computation. But that does not mean that that computation is happening inside the person's head. (Hutchins, 1995a, p. 361)

Here, an essential point is that the cognitive properties of a socio-technical system differ significantly from the cognitive properties of its constituent elements (i.e. its artefacts and individual members). This quote also raises questions on the use of the concept of computation, since it is heavily associated with traditional cognitive science and its focus on internal computational thought processes. In his book, Hutchins accuses this mainstream definition of cognition as being 'unhooked from interaction with the world' (Hutchins, 1995a, p. 367). As shown in the descriptions above, DCog attempts to establish a strong relationship between cognition and interaction with the world. This raises the question of why Hutchins still makes use of the 'cognition as computation' concept in his analysis of the operation of the ship navigation system. Simply put, as DCog analyses the input and output of a functional system (Hutchins, 1995a), it has similarities to the theories that consider cognition as information processing or computation (see e.g. Neisser, 2014). However, it is important to note that, while the traditional computational model maps out input and output to the brain, Hutchins (1995a) extends the model to include the whole socio-technical system and views cognitive processes as encompassing the cultural, material and social environment surrounding the individual. When investigating the navigational work onboard the U.S.S. Palau, Hutchins demonstrates the emergent properties of the information processing, which arise from activities that are distributed across several members of the crew and a variety of media. He does not reject the computation model, but he strongly questions the previous unit of analysis that focuses on the individual while stripping away culture, context and history. In other words, instead of moving in a brand-new direction, DCog takes mainstream cognitive science as its starting point and attempts to redefine the view on cognition from within the research field itself. As Hutchins himself explains (1995a, p. 49):

> I will attempt to apply the principal metaphor of cognitive science—cognition as computation—to the operation of this system [of ship navigation]. In so doing I do not make any special commitment to the nature of the computations that are going on inside individuals except to say that whatever happens there is part of a larger computational system. But I do believe that the computation

> observed in the activity of the larger system can be described in the way cognition has been traditionally described—that is, as computation realized through the creation, transformation, and propagation of representational states.

It is clear that Hutchins deliberately applies the same theoretical constructs that were used in studies of individual cognition; however, he widens the boundary of cognition to include any number of interdependent actors and their socio-cultural environment, emphasising the interactions between humans and the artefacts they use. Using the conceptual apparatus of mainstream cognitive science may seem unorthodox, and it has resulted in some criticism (e.g. Button, 2008; Nardi, 1996). However, the point Hutchins makes is that many representations are physically manifested in artefacts and do not require indirect methods of examination. With an expanded unit of analysis that includes the surrounding people and artefacts, it is no longer necessary to access the mental processes of an individual (Hutchins, 1995a; Perry, 2003). This expanded conception of cognition means that the cognitive system is larger than the individual, which makes it possible for the DCog analyst to physically 'enter' the cognitive system to observe the representations used and their transformation and propagation throughout the system. I believe this to be Hutchins' main point: the previous way of making assertions about unobservable, mental cognitive processes led to an attribution problem and to an understanding of the individual that is 'fundamentally flawed' (Hutchins, 1995a, p. 354). Through the rhetorical strategy of using the already established vocabulary from the classical cognitive science field, he makes his point even more clear: he does not aim to present a complementary perspective on cognition, but rather to correct the previous perspective. Hutchins does this by applying concepts that are well-recognised in the research community, but this time on a systems level. He then demonstrates the necessity of adopting a broader unit of analysis in order to reach a coherent account of cognition. This may be seen as a bold move on Hutchins' part; however, he points out that he uses the notion of 'cognition as computation' as a metaphor and explicitly states that there are elements of a cognitive system that cannot be fully described in computational terms (1995a, p. xv).

There is undeniable importance in having descriptive power (c.f. Halverson, 2002) – that is, a conceptual framework that properly supports the researcher in the task of describing and explaining the observations made – and it is my experience from applying the DCog framework that, although its core concepts work quite well, they are insufficient. For this reason, I have added concepts to my analyses, such as professional vision, tool-mediated seeing and actionable knowledge, in order to properly make sense of and describe the context of study. The conceptual restrictions of DCog can be seen as an opportunity to further develop the framework, but it is no secret that the few explicitly named theoretical constructs in DCog lack the rhetorical force that

can be found in frameworks such as AT, to which we now turn (see also Halverson 2002; Rogers 2012).

2.3.4 Activity theory

In the 1930s, almost 70 years prior to the development of DCog, the Russian psychologist Vygotsky presented a view of human thinking as a product of social interaction, situated within the social and cultural context. He argued that mental processes were derived from external actions through a process of internalisation (Cole & Engeström, 1993). Based on these thoughts, Leontiev (1978) developed the research framework that is commonly referred to as cultural-historical activity theory, or activity theory (AT) for short, in the 1960s and 1970s. AT is a conceptual framework that focuses on understanding human activity as the interaction between the actor(s) and the world. Accordingly, the emphasis lies on individuals, the artefacts used in everyday activities, and the close interrelatedness between them (Kaptelinin & Nardi, 2006; Kuutti, 1996). Multiple versions of AT exist but the description here is primarily focused on the way the framework has been applied in HCI research. In fact, AT is firmly established in the theoretical landscape of HCI, CSCW and interaction design, and has been used with emphasis on technology use and the role of technology for collaborative work activities (see e.g. Barthelmess & Anderson, 2002; Bødker,1991; Bardram & Doryab, 2011; Clemmensen et al., 2016; Collins et al., 2002; Halverson, 2002; Kaptelinin & Nardi, 2006; Korpelainen & Kira, 2013). Below, I will introduce the AT framework, with a focus on its basic features, the structure of activity and the activity system model as used in the HCI community. Additional information is available in Paper V of the appended papers; for a more extensive review, see the work of Engeström (2015).

In AT, the basic unit of analysis is the activity, which is seen as an interaction between an actor (subject) and the context of the activity: the world (object). The interaction has a purpose and will transform and develop the world, the actor or the relation between them (Kaptelinin & Nardi, 2006, 2012). In other words, all activity consists of a set of intentionally performed and goal-directed actions, which can be described as an interaction between a subject and an object with the aim of transforming that object through the use of mediating artefacts. Leontiev (1978) stressed that subject, object and artefact are the essence of activity and that we, therefore, can never pull them apart without violating this very essence. Accordingly, understanding human activity requires a true commitment to this complex unit of analysis (Kaptelinin & Nardi, 2012).

To help guide the analysis, AT is framed by five principles or main features: the hierarchical structure of activity, object-orientedness, tool mediation, internalisation-externalisation and development. These are associated

with various aspects of activity and should be considered as an integrated system (Kaptelinin, 2013). *The hierarchical structure of activity* organises activities into three levels: activity, action and operation, which are respectively related to motive, goal and condition (Figure 2; Kaptelinin & Nardi, 2012; Rogers, 2012):

- Activity: This is the primary unit of analysis. Activities are undertaken in order to fulfil a motive, which is something that drives the person to complete the activity.
- Action: This is subordinated to the activity. Actions are consciously goal-directed and correspond to what must be done to fulfil the motive of the activity. These goals can be decomposed into sub-goals, sub-sub-goals and so on, meaning that multiple actions may be needed to complete the activity.
- Operation: This concerns how the activity can be done and is defined by the circumstances or conditions under which it is carried out. Operations are lower-level units of actions that have usually been trained to such a level that they no longer require the subject's attention. As such, operations do not have their own goals, but are rather a result of prior actions that have been internalised into subconscious, automated operations (Kaptelinin & Nardi, 2012).

The activity levels make it possible to view human activity as a three-level system, which supports a flexible and broad unit of analysis that can vary from a relatively abstract level to individual operations as needed. However, it is important to acknowledge that the activity levels are far from static. Actions transform into operations when they are internalised; however, if the operations fail, they are again transformed into conscious actions. This continual transformation of skill that is taken into account within AT reflects its origin in Vygotsky's work on learning and development (Halverson, 2002; Kaptelinin et al., 1999; Rogers, 2012).

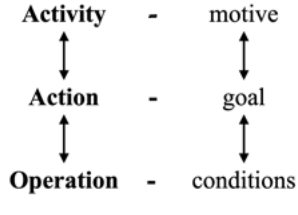

Figure 2: Activity levels in the hierarchical structure of activity (adapted from Rogers, 2012, p. 57).

The second principle of AT, *object-orientedness*, relates to the concept of activity as a 'subject-object' relationship. This principle states that the human subject's interaction with the world is always organised and structured around

objects – that is, something that objectively exists in the world. The notion of 'object' is understood in AT as including not only the physical aspects of things, but also properties that are socially and culturally defined, such as the grammatical structure of a language (Kaptelinin, 2013). As objects direct activities, the object-orientedness principle emphasises that we cannot understand human activities without properly analysing the objects involved.

The third principle, *tool mediation*, concerns how humans use tools to shape their interaction with the world. AT defines tools in a broad sense, embracing both physical tools (e.g. hammers, computers or calculators) and psychological tools (e.g. symbols, language or rules). As people have invented or modified tools in their efforts to solve certain problems, tool use reflects prior experiences of the community (Kaptelinin et al., 1999). Accordingly, experiences accumulate in the structural properties of the mediating tools as we use, modify and develop them (Susi, 2006).

The fourth principle is *internalisation-externalisation*, which refers to human activities being dynamically distributed between external and internal dimensions, with a constant transformation between them (Kaptelinin, 2013). It should be noted that the internal side of an activity (traditionally referred to as mental processes) cannot be analysed separately from the external side of that activity, since all activities have a dual nature with both an external and an internal side.

Development, the fifth principle, concerns how all practice is shaped and reformed by its historical development. This principle is closely related to tool mediation; as tool use unfolds and develops over time, AT emphasises that human activity always needs to be analysed in the context of this development (Kaptelinin et al., 1999).

During the years, several adapted versions of Leontiev's (1978) original framework have been proposed (Rogers, 2008). One of the most widely used versions was presented in the 1980s by the Finnish educational researcher Yrjö Engeström. While Leontiev's original work mainly examined individual activity, Engeström's activity system model (ASM) (also known as 'Engeström's triangle') is a model of collective activity and is an attempt to encompass the community level of an activity (Kaptelinin, 2013). To Leontiev's notion of activity as the 'subject-object' interaction with the world ('tools/artefacts'), Engeström added 'community', 'division of labour' and 'rules' (Engeström, 2015). Taken together, this version of the framework provides six interlinked elements that are part of the ASM (Figure 3). All six elements contribute to the outcome of the activity system, which in turn can be used as input for other activity systems (Engeström, 2015; Kaptelinin, 2013; Kaptelinin & Nardi, 2012).

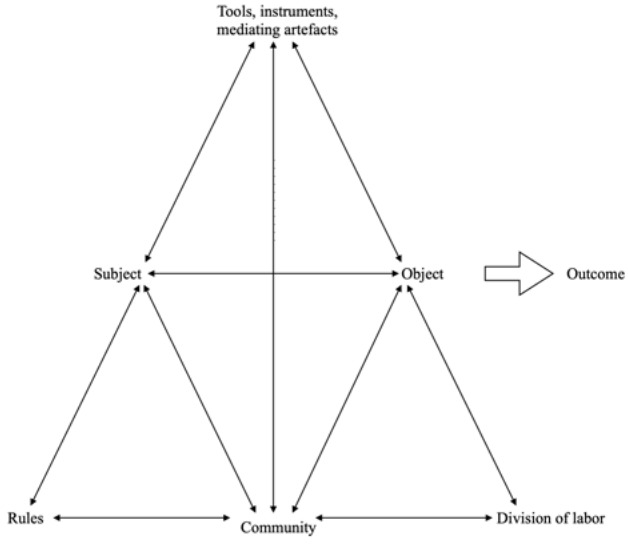

Figure 3: The activity system model (ASM) illustrating the interdependence of aspects of an activity (adapted from Engeström 2015, p. 63).

The concept of an activity system is not comparable with the notion of a socio-technical system (the unit of analysis in DCog). An activity system should instead be viewed as a self-developing dialectical system in which its elements mutually determine and define each other. Such a system carries its history within it, which is why Engeström (2015) emphasises the importance of searching for tensions and contradictions within the elements of the activity system. A contradiction can be described as a misfit within one of the elements of the activity system, between the elements, or between different activity systems (Engeström, 2015). Contradictions are commonly manifested as problems, interruptions, workarounds or breakdowns in the process of an activity; as such, they are often the source of development and learning as the human subject(s) handles the situation (Engeström, 2015; Kaptelinin, 2013; Kuutti, 1996). This is a key tenet of Engeström's framework – namely, that activity systems are under constant development, driven by their contradictions. This tenet has been put forward as one of the most distinct features of AT and is essential for understanding human use of technology (Bertelsen & Bødker, 2003).

2.4 Summary of background

The research presented in this thesis takes place in complex socio-technical domains and aims to deepen the understanding of how everyday work gets

done in practice in such domains. The research approach taken is firmly established in the tradition of workplace studies and informed by DCog and AT.

At first glance, the domains represented here – manufacturing and operational train traffic – may seem to be highly dissimilar; nevertheless, a look below the surface reveals similarities that classify both domains as complex socio-technical systems. The concept of complexity reflects the abundance of information, which often includes interdependencies, time delays, disruptions and unpredictable behaviours that the workers need to continuously handle and assess in their process of controlling production or executing train traffic. Such complex work processes require the workers to successfully coordinate their actions and to cooperate in such a way that they are enabled to solve the problems in a joint effort. Many – if not most – of the tasks they face in an ordinary workday are dependent on the use of artefacts of various kinds. It is clear that the workers form a tightly coupled system with their socio-material and cultural environment, revealing the interdependencies between the technological and social aspects that constitute the system. (See Sections 3.1–3.3 for more details on the empirical cases.)

Analysing work in manufacturing and operational train traffic, whose tasks typically require a series of interdependent decisions to solve problems in real time, requires theoretical perspectives that are compatible with these complex and ill-defined problems and the 'messiness' they bring. Cognitive science approaches that emphasise that cognition relies on a dynamic interaction between the human and the socio-material and cultural environment are helpful for understanding such complex socio-technical systems. From the historical walk-through presented in this chapter, it is clear that Rasmussen, Klein and Suchman (along with many others) have played an important role in the development that has pushed studies of work from their original focus on the isolated individual to a situated perspective addressing work from a holistic point of view. In this research tradition, DCog and AT are often highlighted as useful for the analysis of work in situations where the interplay between humans and their environment is of interest. DCog has been the main underlying perspective in my research and has proved to be a useful lens for studying work practices in manufacturing and operational train traffic. However, in later phases of my research, AT caught my attention; especially its focus on development, which I found to be missing in DCog (for a reflection on this, see Section 5.3). Throughout my empirical work, these theoretical frameworks have provided assumptions and initial conceptualisations in accordance with their descriptions above. In fact, the theoretical lenses they offer have been integral to my research and have guided me in approaching the study topic and designing the methodology and methods of the studies. They have also been necessary in the process of interpreting and explaining seemingly disparate data, allowing me to create a single analytic whole and to move beyond descriptions towards explanations. The next chapter provides more details on the research approach.

3. Research Approach: Empirical Settings and Methods

Drawing on the theoretical assumption that cognition is situated, embodied and distributed, this thesis studies work as constituted in situated, social and material practices. This chapter provides an overview of the empirical settings and work practices explored in the appended papers and of the research process. The latter includes the methods used, the analytical work and the ethical considerations made during the empirical process.

Papers I and II are based on the manufacturing domain, while Papers III–VI relate to the railway domain – especially the operational parts of work in the control room and within the train cab (hereafter collectively referred to as 'operational train traffic'). Across these two domains, the research that constitutes the empirical part of this thesis is derived from a total of four distinct work settings (Figure 4). In the next few sections, I introduce these four settings and reflect on the nature of the work taking place within them.

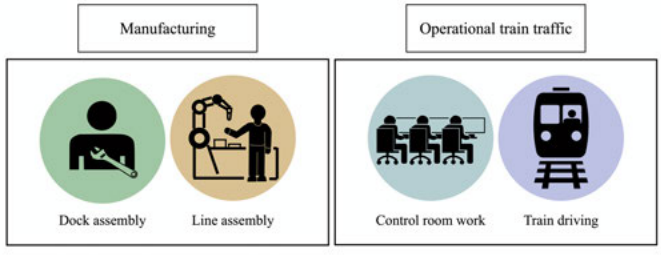

Figure 4: A visualisation of the four empirical settings (dock assembly, line assembly, control room work and train driving); the first two belong to the domain of manufacturing, while the latter two belong to the domain of operational train traffic.

3.1 Manufacturing and assembly

The word 'manufacturing' may conjure up an image of a long row of workers assembling a Ford automobile – perhaps the famous Model T – on a moving assembly line in the early 1900s. Henry Ford remains the classic example of mass production, which was later widely imitated across almost all product domains (Williams et al., 1992). Model Ts were all built exactly the same;

however, in today's manufacturing, large variations occur in the types of products produced and in the methods used for production. Methods range from custom manufacturing on a small scale based entirely on special orders, to mass manufacturing and the production of millions of identical articles. While some manufacturing processes are based on fully automated assembly lines, others rely heavily on the craftsmanship of the human workers (Chryssolouris, et al., 2009). In this thesis, both ends of the continuum are represented with the use of two different manufacturing settings, which are introduced below.

3.1.1 Dock assembly: small-scale production of forest machines

The research setting for Paper I is a medium-sized organisation that manufactures forest machines for cutting down trees and transporting timber. The number of products is small: 11 different models of forest machines and a total production of approximately 130 machines per year. Although the production is small in scale, every machine is built to special order, so numerous variations are available to customers.

The process for assembling the forest machines is called 'dock assembly', meaning that the whole product (or a large unit of it) is built by the same assembly workers and assembled at the same workstation. It could be described as individual workstation production. In this particular case, each forest machine is assembled by a pair of workers. They start with a chassis in the beginning of the assembly process; for a time period of approximately three weeks, they then mount around 3000 articles that together make up the machine.

A forest machine is a large and heavy vehicle and building one is a time-consuming and complex task that involves the assembly of articles, some of which are extensive in size and weight, while others are small and fiddly to handle or technically difficult to assemble correctly. No automatic assembly functions are used. Instead, the production relies heavily on the craftsmanship of the assembly workers. Each pair of workers is responsible for producing one – or at the most two – different models of forest machines, which gives the workers the opportunity to learn that exact model inside and out. In contrast to mass production, in which the goal is for every product to come out the same, the forest machines are all slightly different from each other. This is not only due to the variations ordered by the customers; it is also a result of individual adjustments that are made by the assembly workers – basically, a result of the machines being handmade. With time and experience, the workers learn how to make the assembly process smoother, more convenient and adapted to their particular way of working. This has resulted in instruction materials being made by the workers themselves (mostly in the form of detailed photographs of previously assembled machines), which they use as support for the assembly process. The workers rely more on these instruction materials than on the formal blueprints and assembly instructions provided by the

company. Clearly, the assembly process is highly dependent on the workers' skills, and the company deliberately acts to preserve the workers' unique experiences of building the machines. In fact, the company is in the process of creating new and improved instruction materials that are more closely related to the actual process of assembly.

Although the dock assembly of forest machines is very different from the production line most of us are somewhat familiar with, it is an example of complex manufacturing work being performed in a socio-technical system and distributed across a large number of people, tools and artefacts.

3.1.2 Line assembly: mass production of engine components

The research setting of Paper II is a manufacturing site that produces engines to be installed in cars, buses and trucks. At the time of the study, approximately 3000 employees were working at this manufacturing site. The production is active 24/7, and the production rate is high, producing 300 engines per day. The manufacturing site is divided into multiple production lines, among which this study focused on one line: the moulding line. This particular line is an automated production line that produces moulds for casting engine components. In brief, the process involves creating moulds and casting the engine components by pouring liquid iron into the moulds. Next, a cooling process causes the iron to solidify in the moulds. Finally, the iron components are removed from the moulds and assessed. Although this production line is automated, manufacturing workers actively monitor the process while continuously providing maintenance, adjusting the machines involved in the production and assessing the quality of the engine parts produced.

Much of the manual labour performed at this production line takes place in the control room. From here, the workers monitor the assembly process through a digital interface that shows the production line and the status of each machine involved in the production. The technologies used to monitor the machines along the production line enable the workers to see the production line from afar via the representations presented in the interface, in an example of what Goodwin and Goodwin (1996) describe as 'tool-mediated seeing'. This is done both with video-based surveillance and with displays of sensory-based data from the machines themselves. The monitoring task must be attended to at all times; while one worker shoulders this responsibility, the others monitor the production in a more hands-on way by physically walking along the production line, listening to the machines and noticing if anything looks, sounds or smells different than usual. They are skilled at what they do and can often detect a malfunction or other issues before the installed sensors warn about the problem. In many ways, the foundry is a harsh environment, with the machines creating constant noise and the melted iron resulting in elevated temperatures. I am told that there is a very low employee turnover in the foundry,

which may in part be due to the unique environment – new employees either leave within a few months or stay for the rest of their working lives.

Just as the engine can be seen as the heart of any vehicle, the foundry and its moulding line are the heart of this manufacturing site and the core of its production process. The moulding line is a so-called feeding line that produces the parts necessary for other lines to keep their production going. Accordingly, when the moulding line encounters a production stop, it can severely affect the efficiency and overall turnout of the whole organisation. Nevertheless, the workers handle approximately 100 production stops a day, mostly due to planned breaks for maintenance or, in more severe cases, machine failure or breakdown. As a result, the moulding line is a workplace with a fluctuating workload and work tasks that range from monitoring the status of the production to anticipating and preventing future breakdowns in the machinery, while handling production stops in a way that ensures that production can continue as soon as possible. The foundry and the moulding line are a highly distributed and complex socio-technical system that functions under harsh conditions and time pressure, while maintaining safety and upholding production speed and quality as the main priorities.

3.2 Operational train traffic

The train traffic system plays an important function in everyday life by facilitating a flow of both goods and people. Like most infrastructures, it plays an important role in modern society; although most people tend to take it for granted, there is a large organisation of work behind a functioning train traffic system. The Swedish train infrastructure consists of approximately 14 200 km of track lines on which around 4000 trains are running on a daily basis. Realisation of train traffic is a joint effort by the infrastructure manager, the Swedish Transport Administration (Swe. *Trafikverket*) and multiple railway undertakings. Due to traffic deregulation, train traffic currently comprises more than 50 private railway undertakings, which together organise a mixed type of traffic from local commuter trains to long-distance freight transportation (for more details, see e.g. Trafikverket, 2021).

This thesis relates to operational train traffic – that is, the organisation of work that lies behind the planning and execution of train traffic. More specifically, the work performed in traffic control, customer information and train driving.

3.2.1 Traffic control and customer information

The traffic controllers and information officers are distributed across eight traffic control centres. Each control centre is responsible for a predefined ge-

ographical area and for all train traffic within that area. This includes the platforms and stations within the area and the traffic information presented to travellers at those locations. Each geographical area is divided into smaller areas and each such area is manned by one traffic controller and one information officer.

The essence of traffic control can be described as an intricate problem-solving task that requires the controllers to make judgement calls and employ proactive strategies in order to optimise the timetable and free up resources for unanticipated events (Roth et al., 2001). Put differently, traffic control is like trying to put together a puzzle without knowing what the final picture is supposed to look like. Traffic controllers are responsible for managing and authorising movement on the track, with the overarching aim of coordinating the traffic flow. They remotely monitor running traffic and control train movements by manually controlling switches and signals to realise the pre-planned timetable. Disruptions and deviations occur frequently; when they cause delays in traffic, the controller needs to solve the situation so as to keep the delay to a minimum in terms of both time and the number of trains affected. To do this, traffic controllers continuously communicate with train drivers, maintenance workers and other traffic controllers to gather pieces of information that enable them to remain constantly updated on current traffic situations and to plan for potential future events.

Information officers play another important role in the control room. Their main task is to remotely update the information screens installed at train stations and platforms so that travellers are presented with accurate and updated information at all times. The original timetable is announced by default to the travellers; as soon as that information becomes obsolete, the information officer makes the necessary changes and updates. The traffic controllers and information officers work closely together to stay updated on the complex net of traffic both within and outside of the geographical area they are responsible for.

Because control room work is remote and aimed towards trains and travellers that are out of sight, both traffic controllers and information officers rely on technical artefacts to 'see' what is happening outside of the control room. Thus, the control room is a technology-dense environment characterised by continuous coordination among workers (both co-located and distributed) and intense collaboration between humans and technologies. Such environments have been described as 'centres of coordination' (c.f. Suchman, 1997), which nicely captures the essence of the work performed here. Although the division of labour makes each worker solely responsible for his or her geographical area, the workers are usually fast to offer each other help if needed. This is often the case when incidents and accidents occur, creating a sudden rise in workload for the workers in charge. In such situations, colleagues can take responsibility over certain parts of the geographical area so that the controller and information officer can stay focused on handling the incident. This type

of handover is common in the control room and is something the workers seemingly do without effort. They are constantly attuned to each other and are continuously oriented to aspects of coordination and cooperation.

3.2.2 Train driving

Each railway undertaking employs its own train drivers, who are responsible for operating the trains safely and in accordance with the signs and signals along the rail, while upholding the timetabled stops. The drivers should also consider energy consumption and the comfort of passengers, and adapt their style of driving accordingly. Furthermore, they need to be attentive to events outside the train and anticipate and react to, for example, passenger behaviours at platforms, weather conditions and obstacles on the rail. The train driver is alone while working and is completely dependent on the information presented by signals and signs along the rail and on the predefined timetable stating where the train should be at a certain time. To support drivers' ability to maintain awareness of the traffic situation around them, many railway undertakings have developed and implemented so-called driver advisory systems (DASs), which present the driver with real-time information about the timetable, its potential updates and the status of the surrounding traffic. The DAS also provides advice aimed at optimising traffic flow, improving punctuality and maintaining an energy-efficient style of driving. In many ways, the drivers' extended access to information has been positive; however, it has also caused concerns related to information overload and a 'heads up, heads down' type of driving in which drivers must constantly shift their attention from outside the train to the information presented inside (Naghiyev et al., 2014). Furthermore, the implementation of DASs has given rise to a situation in which the ways information is distributed between traffic controllers and train drivers are unclear – a lack of clarity that affects the division of responsibilities and challenges workers' ability to maintain smooth coordination and cooperation.

3.2.3 A holistic perspective on operational train traffic

It is relevant to acknowledge that traffic controllers, information officers and train drivers actively partake in the organisation of operational train traffic and are interdependent to the extent that it is difficult to distinctly separate the work of one role from that of another. For this reason, Papers III–VI argue (to different extents) for a systems perspective in which both control room work and train driving are considered as parts of the same socio-technical system. Therefore, I finish this subsection with a reflection on operational train traffic and the challenges involved, from such a holistic systems perspective.

Traffic controllers, train drivers and information officers are essential to Swedish operational train traffic; if they failed to cooperate, the results would

include dissatisfied passengers stuck somewhere across the country and unable to go to work or to return home at the end of the day – or much worse consequences. From this point of view, the functioning of the train traffic system plays an important societal role. However, the work is complex and includes challenges such as a fluctuating workload and time criticalness. The train traffic is a carefully planned network of trains; for the busiest hours of the day, there are just a few minutes between departures. Each train runs on its own distinct timetable, and the drivers and traffic controllers must act in a way that makes it possible to uphold that timetable. Due to the complex network of traffic, even the smallest deviations can have large effects on the overall traffic system. This creates time sensitivity in the sense that deviations to the original traffic plan must be solved as quickly as possible to avoid having the problem spread even further and affect more trains.

Operational train traffic is a highly complex system involving multiple roles with distinct responsibilities, a large variety of artefacts and tools, and interdependencies connecting them. Adding to the complexity of this socio-technical system is that much of the work takes place across time and space. For example, traffic controllers usually set switches and signals well in advance to distribute the workload and avoid unnecessary peaks. They do this to control train paths for the trains distributed across a large area, which are out of sight from the control room. As a result, it is difficult to take each train's situated aspects (e.g. weather conditions and geographic factors) into account, even though they may have an impact on the train's movements. In a similar manner, information officers and train drivers plan ahead and work proactively as much as possible. However, as soon as something deviates from what was expected, the workers' focus returns to the present time as they handle the situation. Afterwards, they once again shift to a focus on proactive work strategies. Switching back and forth between the here-and-now and the future is a continuous process in operational train traffic, making the challenges of time and space constantly present.

3.3 Summary and synthesis of the empirical settings

As evident from the descriptions above, all four empirical settings have their respective challenges. Although the research presented in this thesis considers these challenges, my ambition is to lift the considered issues to a higher and more overarching level of what characterises work and how work gets done in complex socio-technical systems.

At first sight, the two domains under study appear to be very different. However, both manufacturing and operational train traffic depend on professional teams of workers that are highly trained and skilled. A traffic controller once told me that 'the worst thing you can do is to not act', which suggests that controllers need to act quickly and without hesitation. This has to do with

much of the work being time sensitive and demanding rapid decision-making and problem-solving skills while being continuously oriented to aspects of coordination between workers that may be co-located or distributed. Prior research shows that co-located professionals in highly coordinative settings develop subtle methods and skills for efficiently coordinating information and work (e.g. Heath & Luff, 1992; Mark, 2002); however, these methods do not work as well when the work is asynchronous and distributed (more on this below).

Workers in both domains are frequently challenged by sudden variations in workload and by varying task complexity ranging from routine tasks to unexpected events whose stakes may be high, making safety a constant priority. Their tasks are so demanding that it takes both time and commitment to learn the profession and to develop suitable strategies for handling even the everyday variations. The high demands placed on these workers are not manageable by just anyone, which may explain why most of the workers I met during the research had many years – sometimes decades – of experience. Workers who like the job stay with it for a long time and become highly skilled at it. Some of the tasks are preceded by much training. For example, the train traffic controllers need to pass a number of psychological and cognitive tests before being allowed to enter training in the first place. During active duty, controllers' mistakes are closely reviewed and, depending on their severity, a controller may be removed from operational work, drug tested or sometimes even put back into training. Clearly, both domains require qualified workers – not necessarily in the educational sense, but definitely in regard to their experience in and commitment to the tasks.

Another noteworthy similarity between the two domains is that both involve complex tasks that are extensively supported by different kinds of tools and artefacts. Taken together, the four settings from which my empirical data were collected offer a valuable overview of the spectrum of cognitive artefacts used in complex work domains. At one end of the spectrum, there is the train traffic control room, which contains advanced technological artefacts specifically designed for this control task. At the other end of the spectrum is the small-scale production of forest machines, which involves few technological artefacts but has an abundance of tools and analogue artefacts, and allows for creative workers to design and develop artefacts to meet their own needs.

Yet another similarity between the two domains relates to time and space. All four settings are challenged by aspects of time and space, although their challenges come in somewhat different shapes. In relation to time, the workers in all four settings need to plan for the near future, be proactive and stay one step ahead of the current situation at all times. At any given moment, an event might occur that brings their attention back to the here-and-now; thus, the workers are engaged in a constant circle of proactive and reactive work. When it comes to challenges related to space, the dock assembly setting is less affected in comparison with the other settings, since the workers are co-located

most of the time. However, the workers at the production line for engine components, the train drivers and the train traffic control room workers encounter tasks that require cooperation and coordination among workers distributed along the production line or even – in the case of operational train traffic – across Sweden. In fact, the monitoring of an object of control at a distance is one of the main issues for work in control rooms, since it constrains the workers to tool-mediated seeing (Goodwin & Goodwin, 1996) and makes them reliant on technological artefacts and the (sometimes fragmented) information they present.

In summary, the context for the empirical part of this thesis comprises four work settings that may look dissimilar but share multiple characteristics related to their nature as complex socio-technical systems. The following sections present the research approach used in the appended papers, all of which are aimed at studying the coordinative, social and organisational nature of work practices in order to deepen our understanding of the role of workers in such complex systems.

3.4 Methodological approach: ethnography

Based on the theoretical assumption that work activities are situated in socio-material and cultural practices, this thesis takes ethnography as its methodological approach. Ethnography is a qualitative research methodology used for studying social phenomena, such as people, cultures and activities, and strongly advocates fieldwork involving a combination of observation and participation (Agar, 1996). It arose in the early twentieth century and has roots in the discipline of anthropology, especially the social and cultural branches of anthropology. Ethnographic methods are often credited to Bronislaw Malinowski (1922) and his work on the Trobriand Islands (Dourish & Bell, 2011), but it has been suggested that the tradition of ethnography goes back even further (Agar, 1996). Though this may be, Malinowski has had a great influence on ethnographic research. He was stranded on the Trobriand Islands for approximately 2 years by the outbreak of war. During this time, he lived with the indigenous peoples, learned their language and studied what they were doing. Instead of relying on informants describing the tribe's practices, as was a common research strategy at the time, Malinowski observed the people as they lived their lives and engaged in everyday activities (Button & Sharrock, 2009). He argued that, in order to understand people's activities and ways of doing things, it is necessary to understand their point of view and to grasp '*his* vision of *his* world' (Button & Sharrock, 2009, p. 10, emphasis in original), which has turned into a recurring theme for ethnographic studies.

The emergence of ethnographic investigations that emphasised participation in the members' everyday lives in order to understand their point of view marked a major transition in anthropological practice. This transition changed

the research focus from understanding what members of other culture do to understanding what they experience through their actions (Dourish & Bell, 2011). In the subsequent decades, ethnographic fieldwork became the hallmark of anthropological research; since then it has spread into a number of disciplines, each with its own particular emphases (Button & Sharrock, 2009). In this process, the ethnographic method has also been used to address issues 'closer to home', such as the subcultures and behaviours at specific locations. This development has been an important step towards using ethnographic methods in settings that embed both humans and technologies (Dourish & Bell, 2011). For example, although Suchman (1987) started off in the laboratory, her work has been highly influential in informing the nuances of ethnography for studies of technology use and innovation (Rogers, 2012; Salembier & Wagner, 2021). Unfortunately, when used for these purposes, ethnography has often been followed by expectations of generating requirements for systems development. By reducing ethnography to a data collection method that aims to produce implications for design, we 'fail to capture the value of ethnographic investigations, insights, and knowledge' on how technology is integrated and intertwined into social and cultural spheres (Dourish & Bell, 2011, p. 64).

Ethnography is commonly adopted within DCog (Perry, 2003), which has much to do with DCog's emphasis of cognition as a cultural process. This trend has resulted in an extension of ethnography that goes under the name of 'cognitive ethnography' (Hutchins, 1995a; Hollan et al., 2000). Although cognitive ethnography is rarely specified in the literature, Williams (2006) tries to define the term and identify what distinguishes it from traditional ethnography. He particularly notes that traditional ethnography describes meanings created by a culture, while cognitive ethnography describes *how* such meanings, and knowledge in general, 'determine important outcomes' (p. 838) – that is, how meaning and knowledge is constructed and used. In line with the theoretical construct of DCog, cognitive ethnography focuses on identifying information flow – along with the propagation, representation and transformation of information – in activities and processes, while making use of traditional ethnographic methods to build knowledge of a community of practice. The next section presents details on the research process used in the appended papers.

3.4.1 Data collection: ethnographic fieldwork and interviews

To gain an in-depth understanding of the work practices enacted in the domains of manufacturing and operational train traffic, an ethnographic research approach was considered to be suitable due to the opportunities such an approach offers for unravelling the complexities and intricacies of workplace activities (Ybema et al., 2009). More specifically, the studies follow a methodological approach based on ethnographic fieldwork and interviews, which,

taken in combination, are considered to be suitable data collection techniques for making work practices visible (e.g. Agar, 1996; Hutchins, 1995a; van der Waal, 2009). In fact, ethnography is one of the primary scientific foundations for workplace studies in HCI (Button, 2003) and for this thesis, ethnographic fieldwork has been an invaluable resource for gaining a contextual understanding of the empirical settings.

True to the tradition of ethnography, my interest has been in both the ordinary and the extraordinary work practices under study. Thus, I have paid attention to all work activities, including breakdowns and interruptions of work, as well as ordinary (and seemingly mundane) tasks on uneventful days. The latter are a crucial element in the research presented here. However, there is an important distinction between what something looks like and what may lie beneath it. In this case, it should be noted that it seemed as if nothing happened on certain days. However, within the orderly and routinised flow of events is a whole world of work activities. Or, as Ybema et al. (2009, p. 1) so elegantly express it, 'much of the intriguing "mystery" of organizational life is hidden in the ordinary exchange of ordinary people on an ordinary sort of day.' Spending time in the field and immersing myself in the work practices enabled me to uncover these nuances in ways that would otherwise not have been possible. In this process, I went from being an outsider looking in to a participant in the work setting – a shift described by Moeran (2009) as moving from a participant observer to an observant participant.

A central concern in this thesis is the orientation towards the worker as the expert (c.f. Blandford et al., 2016; Rawls, 2008). Work practices unfold in the interactions between workers, and between workers and technologies or other types of artefacts. This organisation of work is my primary research interest. Therefore, it is essential to view workers as experts and, as a researcher, to take an 'apprentice stance' during the fieldwork (Blandford et al., 2016, p. 36). As experts, the workers understand their work practices and routines, know how work is done, are aware of what kinds of problems they have experienced or are likely to encounter, and understand how problems are detected and dealt with. This perspective is in line with an empirically driven research approach in which the analysis begins with observations of the empirical material rather than with a set of predetermined theoretical assumptions (e.g. Rawls, 2008).

All the appended papers have ethnographic fieldwork in common, mainly in terms of the use of participant observations (c.f. Patton, 2002) and informal interviews. All the data were closely captured using descriptive field notes, with the purpose of creating information-rich data during the observation sessions. This data, along with other types of textual data (e.g. instruction materials, checklists, incident reports etc.), has been essential for examining the work practices under study. Furthermore, the research was conducted as a nonlinear process, iteratively moving back and forth between the phases of planning, collecting data and analysing data. The main reason for this research

design was to ensure that the work settings and the activities therein were captured with rich details. This approach enabled me to continuously add details to the field notes, to make clarifications and to address more nuances of the work practices. The research process started in 2014, with fieldwork at two manufacturing sites: one producing forest machines and the other casting engine components. In 2016–2018, I performed fieldwork in the domain of operational train traffic on several occasions and studied control room work (with a focus on traffic control) and train driving in parallel. During the fall of 2019, I continued the field studies in the control room for train traffic, this time focusing specifically on the work practices conducted by information officers. The complete research process is depicted below as consisting of three phases (Figure 5).

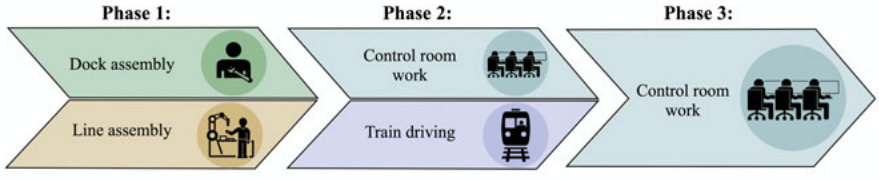

Figure 5: The three phases of ethnographic fieldwork in this research.

The first phase regarded work practices in manufacturing assembly and the research process started with observations at the site for dock assembly of forest machines. On three separate occasions, I observed the same pair of assembly workers while they were assembling a forwarder that was to be used for transporting timber. Out of the four empirical settings, this was the only setting that allowed video recordings and I took this opportunity to capture the work practices in even greater detail. Unfortunately, the environment was loud, which made it difficult to hear voices in the video recording. In addition, the workers continuously moved around the chassis as they were working, and sometimes went to the other end of the building to fetch tools. This resulted in the workers moving in and out of the frame. Altogether, this made the video recordings less useful for analysis than I had first anticipated. However, the material still helped enhance my overall contextual understanding of the work setting.

Ethnographic fieldwork has great value in revealing aspects behind what people say and do not say; however, it also has some limitations. Observing work practices as they unfold in the socio-cultural setting offers an outside perspective of the activities (Suchman, 1995). Therefore, I found it important to gain a deeper understanding of the participants' experiences of conducting their work practices. To achieve this deeper understanding, I conducted what Patton (2002) describes as 'ethnographic interviews', meaning that I posed questions in the form of informal and contextual interviews during the fieldwork sessions. The informal interviews greatly helped me to gain insight into

the workers' perspectives and to better understand the context of the work, which is key in attempting to understand the nuances of work practices (Heath et al., 2010; Leonardi, 2015). For example, the interviews revealed that the workers had constructed some of the tools they used in the assembly process themselves to 'extend their arms', as they put it. To complement the workers' perspective, I also conducted one semi-structured interview with the production manager to grasp a more formal perspective of the organisation and the work they do. This study is reported on in Paper I.

Around the same time as the dock assembly study, I conducted similar observations at the moulding line responsible for the casting of engine components. Prior to the study, the whole research project and all its members took part in an introductory tour of the manufacturing site; this was time well spent, since it provided us with an overall understanding of the formal work structures of the factory. Shortly after, the study was initiated. During the first observation sessions, I familiarised myself with the work practices at the foundry and with the participants in the study, who were a team of five manufacturing workers. For three night shifts in a row, I followed these workers around the foundry, observing what they did and how they did it. Due to the mobile nature of their work, following them included repeatedly climbing the tower where they mix the sand that later becomes the moulds, running along the line every time they were in a hurry, and crawling in the narrow spaces under the cooling chambers, where the moulds were stored, to replace a worn-out driving belt. To gain a deeper understanding of the participants' perspectives and experiences of the work practices they enacted, the instructions they were handed and the challenges they faced, I conducted informal and contextual interviews both during and immediately after making observations. These interviews served as a valuable data source for deepening my understanding of the complex work practices and revealing details that were not identified by observations alone.

Each session of fieldwork enabled a follow-up with questions about what had been observed during the previous shift. As a natural consequence, each occasion involved more detailed questions, some of which were of a managerial nature. This prompted me to interview two of the team leaders working at the foundry. Rather than asking how daily work practices were carried out, these semi-structured interviews focused on the more formal and structured aspects of work. Although these aspects were not central to the study as such, they brought more nuances to the collected data. This study is reported on in Paper II.

In the second phase of research, I entered the domain of operational train traffic. Due to the interrelated nature of work by traffic controllers and train drivers, I conducted fieldwork on both categories of workers during the same period of time. Starting in the fall of 2016 and continuing until the spring of 2018, I continuously visited five out of the eight traffic control centres in Sweden to observe their everyday work and the practices the workers engaged in.

In the same period, I had the opportunity to ride along with train drivers as they operated their trains, thus observing their work *in situ* from within the train cab. During all the observational sessions, I closely observed what was done and how tasks were carried out. Meanwhile, I engaged in informal interviews, asking questions and initiating conversations with the workers to gain a deeper understanding of the observed work practices. As the data collection phase progressed, my questions became more specific and specialised. These sessions of ethnographic fieldwork helped me gain a contextual understanding of these two empirical settings.

It should be noted that the co-located nature of control room work aided my fieldwork in such a way that I could observe and listen to all the activity in the room, move between workers and their work stations, and pose questions as I saw fit. For obvious reasons, the same behaviour was not possible in the train cab, which only holds one train driver and his or her work station. Another interesting aspect of this phase of data collection was the contradictions I encountered across the two work settings, which pointed to non-coherences between the work in the control room and the work done by train drivers. Such contradictions or non-coherences are often important in ethnographic fieldwork, since they help to establish 'thick' descriptions and lead to more detailed inquiries (Agar, 1996). In this phase, the questions asked were not just iteratively shaped by my previous sessions of fieldwork in these settings but also coloured by these contradictions, enabling me to 'dig deeper'.

This phase of fieldwork was crucial for gaining basic knowledge and an understanding of the organisation of the work achieved by two of the main categories of workers involved in operational train traffic. This part of my research constituted an orientation phase for me to learn about the domain, its actors, the jargon and the artefacts used. This fieldwork contributed to Paper III, but the insights and learnings derived from this phase of data collection are present in all of my papers relating to the domain of operational train traffic.

In connection with the sessions of ethnographic fieldwork, I also conducted three in-depth interviews, with one traffic controller and one train driver present for each interview. The interviews were approximately 1.5 to 2 hours long, and the topic concerned the relationship and cooperation between the workers and how they divide their responsibilities for the running traffic. As a way to make the discussion more focused and concrete, each pair was given a scenario based on a true incident of a collision with a wild animal that had taken place a couple of weeks earlier. Some of the participants had heard about the incident, but none of them had been actively involved in its handling. However, they had previous experiences of handling similar situations. During the interviews, the participants were encouraged to describe what actions, assessments and knowledge a situation like this would require of them, respectively, and how they would cooperate and coordinate with each other to

handle the incident. Paper IV is heavily based on these pair-wise in-depth interviews, supported by the ethnographic fieldwork conducted in the same research phase.

Phase three of the data collection took place during the fall of 2019. At this time, I conducted fieldwork on four occasions, equally divided between two traffic control centres. The subject of interest was the work practices of the information officers. Although this role had not previously been in focus, the fact that the information officers sit next to the traffic controllers had already given me a basic understanding of what they do, prior to these fieldwork sessions. However, more fieldwork was needed to gain a deeper understanding of the work practices performed by this category of workers.

The research approach was similar to that used in the previous fieldwork sessions, focusing on participant observations and informal interviews in naturalistic settings to help me seize opportunities to learn more about the observed practices. New security regulations affected this phase such that I was no longer allowed to take photographs from inside the control room; as a result, the field notes from these occasions became even more important. Adding this empirical material to the larger data corpus from phase two resulted in Paper V, which has an explicit focus on the work in the control room (i.e. the work by traffic controllers and information officers). During one of the four fieldwork sessions performed in phase three, I observed how an incident with a torn-down electrical wire that caused large delays and cancelled trains was handled through close collaboration between the information officer and traffic controller in charge. The empirical material collected during that particular day is reported on as a case study in Paper VI. For an overview of the empirical work conducted in each of the four work settings, see Figure 6.

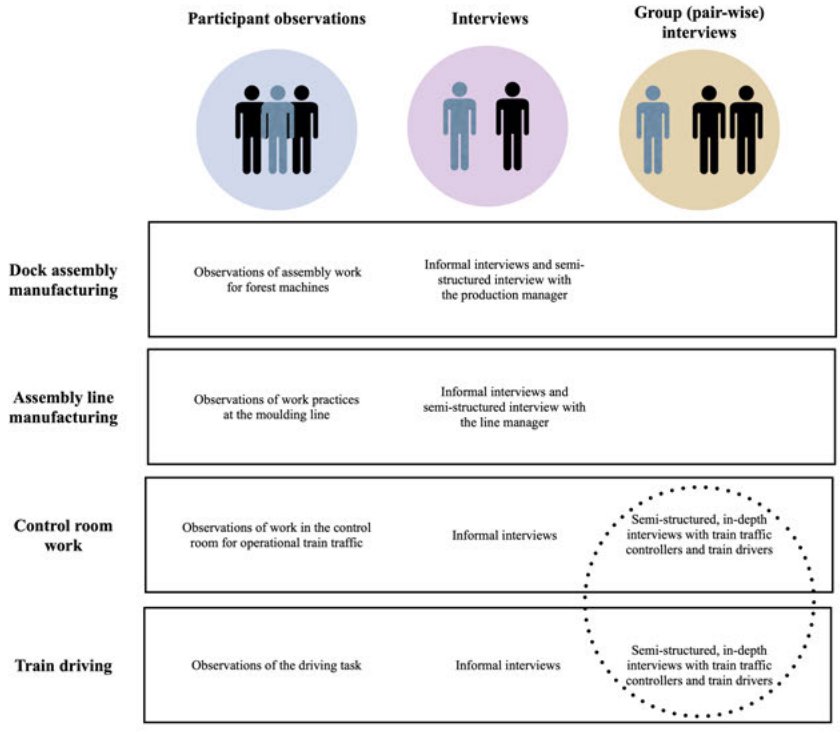

Figure 6: Summary of the empirical work presented for each work setting.

3.4.2 Analysing the data

According to Patton (2002), 'in qualitative inquiry, the researcher is the instrument' (p. 14). In other words, pretending that the researcher is completely objective throughout the research process downplays the individuality of the researcher and the relationship between a researcher and the participant (Blandford et al., 2016). For this reason, qualitative analysis is a product of an 'analytic sensibility' – that is, a skill of reading and interpreting data through a particular theoretical lens – rather than being a product of following a 'recipe' or a set of rules (Braun & Clarke, 2013, p. 201). As the instrument, the qualitative researcher shapes the data that is gathered and produces insights into the meanings of the data in order to notice patterns that link to broader concerns. '[T]he extent of that shaping should be recognised and reported transparently and unapologetically' (Blandford et al., 2016, p. 35). The analytical procedure related to the appended papers had already begun during the fieldwork, and analysis continuously guided the research process, in accordance with the ethnographic tradition. Agar (1996, p. 184) describes this as a funnel approach:

> You begin wide open to whatever you can learn, but within such a broad boundary, you are already bouncing between learning and checking what you have learned. As you begin to focus your interest on certain topics, the funnel narrows. You may focus because of an a priori interest you brought to the field, because of what you learned in the first period of fieldwork, or because of both. But still you are alternating learning with tests of what you have learned.

In line with this perspective, the analysis of my field notes was closely tied to the fieldwork as it was being conducted. Thus, a brief analysis of one fieldwork session would inform the next session. This process aligns with the empirically driven research approach, in which the empirical material drives the analytical process (e.g. Rawls, 2008). The analytical work continued and took on a more systematic form as the fieldwork came to an end, including data transcription of interviews, the selection of episodes from the larger data corpus, and detailed thematic analyses of the empirical material as a whole.

Given that neither DCog nor AT offer a systematic approach for working with collected data, a thematic analysis approach was chosen. There are various formal descriptions of how to systematically identify, analyse and report themes (patterns) across a dataset. Aside from thematic analysis, grounded theory (see e.g. Glaser, 1992) is a popular approach. However, while thematic analysis is a method that is specifically for analysis, grounded theory is rather an approach to qualitative research and is mostly concerned with constructing theory; thus, it is not just a method for analysis (Braun & Clarke, 2013). Nevertheless, both approaches are rather similar in terms of the analysis method, and both strive to organise the analysis – whether around themes (thematic analysis) or key categories (grounded theory).

Although multiple versions of thematic analysis are described in the literature, I have been inspired primarily by the version developed by Braun and Clarke (2006, 2013). These scholars position thematic analysis as somewhere between completely unstructured and highly constrained approaches for analysis, while emphasising flexibility by not prescribing any particular theory, method, epistemology or ontology as the main strength of thematic analysis (Braun & Clarke, 2013). They outline six phases of their analysis method. The first phase involves developing familiarisation with the data by repeatedly reading through notes and interview transcripts, while actively searching for meanings and patterns and creating a deep understanding of the material. The goal is to become intimately familiar with the dataset and with the tiny nuances within it. This phase involves reading the data actively and analytically, and critically going beyond the surface to think about what the data mean. The earlier parts of my analytical work were performed in digital spreadsheets; later on, I engaged with the software ATLAS.ti, which is specifically intended for the analysis of qualitative data. Both ways proved to be useful for organising, systematically coding and making sense of the data.

Next, I assigned initial codes to all the identified ideas, meanings and patterns. In the third phase, the analysis shifted from focusing on codes to a higher level: searching for themes. This involved sorting the codes into themes and mapping out how they relate to each other and how they could be combined to form overarching themes. This stage was done in an old-school way: I usually printed out lists or digital spreadsheets that displayed all the initial coding. Then, using scissors and coloured markers, I shuffled the colour-coded excerpts in order to visualise possible relations between the codes. In the fourth phase, the identified themes were reviewed and refined in an iterative manner to ensure coherence within the theme and in relation to the larger dataset. By moving back and forth between details and the bigger picture, I could ensure that the details were captured correctly, while obtaining a coherent view of the larger perspective. Next, the themes were refined further by evaluating and organising the data excerpts for each theme – for example, by developing subthemes. Much of the analytic process revolved around writing as a tool for deepening my understanding of the collected data and for continuously developing the analysis (c.f. Braun & Clarke, 2013; Wolcott, 2009). In fact, writing is the final phase of thematic analysis: 'You cannot really *do* qualitative analysis without *writing* it … qualitative analysis *is* writing' (Braun & Clarke 2013, pp. 248–249; emphasis in original). I have always considered writing and thinking to go hand in hand; therefore, I used writing as a tool to iterate my themes and to ensure that all the data relating to the chosen themes were considered.

It is not possible to observe everything in the field; just as a video camera must be pointed in the right direction, the researcher must have an appropriate focus to guide the research and the organisation of the complex stimuli experienced in the field (Patton, 2002). The same is true for analysis; therefore, in the appended papers, the theoretical constructs associated with the selected theoretical frameworks were used as 'sensitising concepts' (Patton, 2002, p. 278) and guided the process of analysis. Thus, DCog and AT were filters through which I read and interpreted my data (c.f. Decortis et al., 2000; Halverson, 2002).

Triangulation, in terms of a process in which two or more methods of data collection or sources of data are used, is one way to support and confirm an analysis. In this research, I conducted both participant observations and interviews (informal and, in some cases, semi-structured) in order to capture nuances and obtain a rich understanding of the work practices under study. Much of the workers' knowledge is tacit (Polanyi, 1966), which means that it cannot always be articulated or verbally explained. This creates a discrepancy between what people do and what they say they do – that is, what they are able to articulate – which emphasises the importance of not just relying on interviews but also directly observing the phenomena of interest. It should be emphasised, however, that triangulation is a somewhat problematic concept for qualitative research, since it assumes a single, knowable truth, while most

qualitative research views meaning as fundamentally tied to the context in which it is produced (Braun & Clarke, 2013). Accordingly, triangulation, or crystallisation, as suggested by Tracy (2010), is used in this thesis as a way of strengthening analytical claims and achieving a fuller or richer story (rather than a story that is closer to the 'truth' of the object of study). In line with this perspective, triangulation is understood as a way of capturing multiple 'voices' relating to the topic of study, as it helps 'to open up a more complex, in-depth, but still thoroughly partial, understanding of the issue' (Richardson, 2000, p. 884), rather than being a way of accessing the 'right result' (Silverman, 1993).

3.4.3 Ethical considerations

During all the research phases described above, ethical considerations were made following the general ethical requirements of the Swedish Research Council (2017). This involves informed consent, which was obtained from all the participants; information about the studies, their aim and their purpose was communicated both before and during the data collection in a way that met the information requirements. This included information about the project and its funding, the researchers involved, the study aim, details about the planned data collection and how the data were to be processed, presented, and stored to ensure that the participants would remain anonymous. All participants were also informed of the voluntary nature of their participation and their right to discontinue and withdraw from the study at any time.

In accordance with the confidentiality requirement, no names of participants were used in publications or research presentations, and their faces were not exposed in any images. Most of the photographs used for the publications were made into sketched images to ensure anonymity. In cases where doing so was impossible, such as in Paper I, which was published in a journal that did not permit distorted or edited photographs, the participants gave their consent for the photographs to be used. Furthermore, in accordance with the ethical requirement for data usage, the collected data will be used only for scientific communication, educational purposes and applications for external research funding. They will not be used for commercial purposes of any kind.

From a more personal point of view, I consider ethical considerations to include more than the procedures involved in the collection and analysis of data. As a researcher, I enter professional workspaces to observe the work practices therein, and I need to be aware of how my presence may affect those practices and the workers enacting them. I am not referring to observational factors such as the highly criticised Hawthorne effect (e.g. Carey, 1967), but rather to the importance of meeting the workers with respect for their work, their competencies and their integrity, while upholding the same respect for myself. This is a balancing act – or, as Agar puts it: a 'paradox of professional distance and personal involvement' (Agar, 1996, p. 7). This paradox can be

clearly seen when interviews stray into potentially sensitive areas, such as negative feelings, misuse of or a lack of trust in the technology available in the workplace, or criticism of the actions of colleagues or management. Although it is necessary to be open and aware of biases when approaching a research setting, it may be unethical to remain detached from the setting in such situations (c.f. Blandford et al., 2016). These thoughts are similar to those presented by the British Psychological Society (2018), which highlight respect, competence, responsibility and integrity as the four pillars in a professional code of ethics and conduct. Acting responsibly in my professional role further includes a continuous reflection on the potentially wider impacts of my research on multiple levels, including society, organisations and workers or individuals. Thus, it is necessary for me to reflect on both the positive and negative implications of the situated structures revealed by my research.

4. Summary of Appended Papers

As specified in the introductory chapter, the overall aim of this thesis is to deepen the understanding of the role and relevance of workers in the functioning of complex socio-technical systems. The research questions are as follows:

- What characterises adaptability to work practices in complex socio-technical systems?
- How do workers engage with the complex socio-technical environment in their everyday work practices?

Six papers with high relevance for addressing these research questions are briefly presented below. All of them investigate work as situated practices, and contribute to the aforementioned aim. However, the papers bring different and complementary insights that combine to produce a fuller picture in answer to the research questions. More specifically, the six research papers scrutinise work practices in two complex domains and across four distinct work settings in order to address the research questions posed here, albeit in different ways. I will discuss the research questions further and attempt to provide answers to them in Chapter 5.

This chapter provides an overall summary of the empirical work that is foundational to this thesis. For more details on each study, interested readers can see the individual papers.

4.1 Paper I: Tool use and collaborative work of dock assembly in practice

Andreasson, R., Lindblom, J. & Thorvald, P. (2017). Tool use and collaborative work of dock assembly in practice. *Special Issue in Production and Manufacturing Research*, *5*(1), 164–190. https://doi.org/10.1080/21693277.2017.1374890

Paper I deals with the cooperative and distributed nature of dock assembly in the production of forest machines. Manufacturing as a whole is a diverse domain and, in opposition to the more traditional line assembly represented in Paper II, dock assembly adds complexity to the work process by involving longer assembly times and increased variation in the articles to be assembled.

Manufacturing has been a major driving force in the development of human factors research. However, this paper draws on the argument that a systemic view is called for in such a context, and that the unit of analysis should be expanded to focus on the interactions between individuals, tools and contexts (Wilson, 2000, 2014). Within this particular setting, the object of study is the work practices of two assembly workers assembling a type of forest machine called 'forwarders'. With participant observations, interviews, video recordings and photographs, the study characterises how artefacts and tools are used to support the cognitive strategies aimed at handling the complexity of the assembly task. Using the theoretical perspective of DCog, the paper depicts how the workers' skills, along with the available tools and artefacts, expand the range of opportunities for shaping the assembly activity, which is expanded even more when the workers actively engage in collaborative work.

The key findings in this paper are detailed descriptions of embodied knowledge and craftmanship, emphasising that the knowledge that is required to successfully complete a task of this complexity can only partly be externalised and captured by formal work instructions. Paper I also provides illustrative examples of the distributed nature of cognition as seen in the active creation of cognitive workspaces that provide opportunities and anticipations for future actions, not only supporting but shaping cognition. This is demonstrated in how the workers made use of their unique experiences with building forest machines to create tools and instruction materials that had the sole purpose of meeting a specific need of theirs. One example of such an innovative tool was a long, hand-held tool used for tightening bolts and welded in an angle to enable the workers to more easily reach into the narrow spaces of the forwarder during assembly.

The findings of Paper I offer insights towards the aim of this thesis by exploring the work practices involved in the manual assembly of forest machines. These work practices contain a great deal of craftmanship, which is demonstrated in the innovative ways the workers make use of socio-material resources. The practices include subtle ways to coordinate and distribute the workload, and spoken language – or sometimes a lack of speech that seems to carry its own communicative meaning. Further, the practices display adaptations in the form of new and improved resources that are made to fit the workers' needs and to establish 'lessons learned' and 'best practices' as part of the work practices of tomorrow.

4.2 Paper II: Interruptions in the wild

Andreasson, R., Lindblom, J. & Thorvald, P. (2017). Interruptions in the wild: Portraying the handling of interruptions in manufacturing from a distributed cognition lens. *Cognition, Technology & Work*, *19*(1), 85–108. https://doi.org/0.1007/s10111-016-0399-6

The setting for Paper II is a moulding line for casting engine parts, and the study aim is to investigate how interruptions are handled 'in the wild'. Prior interruption research has mainly been performed in the form of tightly controlled experiments in artificial settings, leaving the understanding of how interruptions are handled in work practices in natural settings as an underexplored research area (e.g. Baethge et al., 2015; Walter et al., 2015; Westbrook, 2014). The production line is highly affected by frequent production stops, which cause interruptions in both the production and the ordinary work process for the team of workers; therefore, the production line was considered to be an interesting case for this inquiry.

The study is based on observations and various types of interviews, and provides an in-depth analysis and narrative descriptions of the work practices at the moulding line, viewed and analysed from a DCog perspective. Although the workers have distinct responsibilities, the study findings reveal that the workers in a team act together and jointly contribute to the whole cognitive system. By doing so, they actively contribute to the efficient handling of production stops and the interruptions they bring. The paper shows how workers within the social organisation of work at the moulding line are constantly exposed to interruptions derived from notification systems and breakdowns of machinery; furthermore, the workers simultaneously – and ironically – create frequent interruptions for their other team members. Although such worker-caused interruptions may be viewed as problematic, they are in fact an important information-sharing practice that functions as a 'glue' allowing the workers to combine their efforts and spread the workload within the distributed system. This can be seen, for example, in how the workers' pay attention to all crosstalk on the communication radio, enabling them to create and maintain a real-time awareness of the current production status and the overall workload for the team as a whole. In the long run, this pattern of communication serves as a coordination mechanism that enables the workers to achieve results within the system that they could not have achieved individually.

The main contributions from this study comprise detailed and ethnographically based descriptions of work practices as they play out in the natural setting of the moulding line, and the identification of four different types of interruptions (process-driven, social, nested and notification-based), three of which have not been previously described in the research literature. Furthermore, adding DCog and the dimension of cognition as socially and culturally inherent to the dominantly laboratory-based interruption research community advances the research agenda to include and learn from natural settings that are prone to interruptions.

Although this paper is still in the manufacturing domain, the highly automated moulding line depicts a socio-technical environment that is quite different from the environment in which forest machines are manually assembled, adding the elements of automation, process monitoring, and the maintenance work of machinery that upholds production. Still, the findings of Paper

II, like those of Paper I, contribute to the aim of this thesis by illustrating the essential role of human workers in establishing and maintaining a functioning system. Paper II adds findings on ways in which the workers share the workload and distribute their knowledge. It also demonstrates how essential this work practice is for upholding production, even though the production line is fully automated, and the role of humans may be misunderstood as restricted or even trivial (c.f. Bainbridge, 1983). Moreover, the findings from Paper II show a large variety of different types of interruptions and breakdowns. These are successfully handled by the workers' use of resources in their social-technical environment in ways that reflect their jointly acquired experiences, which in turn give rise to insightful adaptations and a continuously ongoing development of the work practices.

4.3 Paper III: The coordination between train traffic controllers and train drivers

Andreasson, R., Jansson, A. A. & Lindblom, J. (2019). The coordination between train traffic controllers and train drivers: A distributed cognition perspective on railway. *Cognition, Technology & Work*, *21*(3), 417–443. https://doi.org/10.1007/s10111-018-0513-z

Unlike the previous papers, Paper III is set in the domain of operational train traffic. More specifically, the study takes place within control rooms for train traffic and in train cabs, with the overall aim of creating a deepened understanding of the work practices performed by train traffic controllers and train drivers. Much of the prior research in this field has had one of these two roles in focus, but the interactions and coordination between them are understudied (e.g. Andreasson et al., 2019; Wilson, 2000, 2014). This study makes use of DCog as a conceptual and analytical lens through which the socio-technical system is viewed. Based on observations and interviews, the paper illustrates how cognition is distributed in the established work practices among traffic controllers and train drivers, and reveals how they continuously coordinate with each other to successfully accomplish their respective tasks.

This paper presents an in-depth analysis of the main work practices performed by these two professional roles, with a continual emphasis on the broadened unit of analysis in order to provide insights into coordination mechanisms and knowledge-sharing activities. With this focus, the study provides examples of how socio-material resources are used in resourceful ways to support the workers' task achievements. It also illustrates the central role of coordination between multiple entities, humans and artefacts (both inside and outside the control room and the train cabs). For example, the study illustrates how the traffic controllers talk out loud ('talking to the room'; c.f. Heath &

Luff, 1992) and thereby bring the represented information 'out in the open', which advances their opportunities to coordinate within the room in a seemingly effortless way. Accordingly, the paper displays how the execution of train traffic is a result of the social organisation of work and the distribution of the workload within the functional system, in which both traffic controllers and train drivers play an active part.

The systems perspective applied in this study should in itself be considered a contribution, given that prior research generally demonstrates a much narrower unit of analysis for studies of operational train traffic. The main contribution of Paper III, however, is its illustration of the coordinative nature of work practices and how this coordination creates flexibility and gives rise to opportunities for adaptation during the process of handling complex tasks – which is often successfully achieved, despite challenges such as parallel events and time criticalness. The paper emphasises that socially and culturally developed communities of practice are a product of experience, activity, context and culture. This situated knowledge gives rise to actionable knowledge – a type of knowledge that the workers use to solve real-world problems. In line with this view, we introduce the concept of 'enacted actionable practices', which incorporates both situated and actionable knowledge while simultaneously adding a new dimension: that is, the idea that these types of knowledge only exist when they are enacted in the world.

The domain of train traffic involves socio-technical environments that differ from those seen in manufacturing settings, especially in regard to the advanced technologies used. Hence, Paper III offers complementary insights into the role(s) workers play in the functioning of a system in regard to the adaptations made and the ways in which workers engage with their complex socio-technical environments. With rich descriptions of work practices, including a close analysis of how the workers coordinate themselves both within and across time and space, Paper III illustrates how socio-material resources are at the core of most work activities. This finding is similar to what was found in Papers I and II, even though these three papers report on work practices in distinct socio-technical environments within three separate settings and across two domains.

4.4 Paper IV: ”We're doing this together”

Cort, R. (2020). ”We're doing this together”: An in-depth analysis of the teamwork between train traffic controllers and train drivers. In: A. Holzinger, H. Plácido Silva, M. Helfert, & L. Constantine (eds.). In: *Proceedings of computer-human interaction research and applications (CHIRA)*, 96-103. https://doi.org/10.5220/0010058000960103

Whereas Paper III examined the work practices within the ordinary work conducted by train traffic controllers and train drivers and revealed the importance of successful coordination between them, Paper IV takes a closer look into the relationship between these professional roles and scrutinises how the workers view each other and their opportunities to successfully coordinate and cooperate. The controller-driver relationship exhibits an intimate and dyadic coupling; although the controller and the driver have separate activities and responsibilities, they must work in concert to avoid creating destabilising factors that could impact system functionality and safety (Naweed, 2020).

Much of the research on operational train traffic has tended to focus on one role or the other, with a concomitant neglect of the relationship between the two roles. Observational data of work practices as they unfold in natural settings and informal interviews provide the foundation for the study reported on in Paper IV. Pair-wise interviews with one traffic controller and one train driver were used to build on this foundation and further the understanding of the intricate dynamics at play in this relationship.

This study sets out to reduce the lack of comprehensive human-centred studies that investigate the dynamic in the controller-driver dyad, their relationship and the work they perform together as interdependent entities within the distributed socio-technical system of operational train traffic. The findings reveal strengths in the relationship, as well as the difficulties the traffic controllers and train drivers meet when trying to cope with unexpected events and sometimes multiple – and potentially conflicting – goals. The identified challenges include a lack of transparency between the roles in terms of their different priorities, responsibilities and work situations. Furthermore, the findings reveal that the workers in both roles are unaware of recent changes in the information structure that have consequences for how information is distributed. Train drivers are now being given access to more information and no longer need to rely on paper-based timetables that quickly become obsolete. New technology in the train cab clearly demonstrates how changes in one part of the socio-technical system affect other parts and the ways in which the system functions as a whole.

From a holistic perspective, all of the above challenges create difficulties for managing uncertainties, maintaining efficient communication, identifying how the actions of one person will affect the others and interpreting subtle cues in the interaction between roles. Based on the findings, two critical areas are identified that deserve further attention from both researchers and practitioners to amend the identified challenges and to improve the opportunities for traffic controllers and train drivers to successfully coordinate and cooperate. These critical areas are: (1) taking the informal yet critical processes of teamwork into account when developing future railway technologies; and (2) facilitating teamwork by arranging a learning arena for sharing experiences and knowledge among workers and across the organisations involved in operational train traffic.

While Paper III focuses on work in operational train traffic as it is performed in practice, Paper IV contributes a critical discussion on the workers' prerequisites and challenges for a successful work achievement. It is clearly revealed that the available socio-material resources are an important part of shaping the system and its ability to function smoothly. It is also made visible that insufficient resources and uncertainties regarding what prerequisites the workers have for their actions create challenges that the workers then need to work around in order to fulfil their tasks. Hence, this paper offers insights into the aim and research questions of this thesis by exploring some of the underlying challenges that characterise everyday work in operational train traffic and, by doing so, provides a complementary perspective of such work practices that adds to the fuller picture of how work gets done in the complex system of operational train traffic.

4.5 Paper V: At the centre of coordination for train traffic

Cort, R. & Lindblom, J. (accepted with revisions). At the centre of coordination for train traffic: Activity theory and distributed cognition in times of digitalisation. *Submitted to a scientific journal.*

Paper V addresses the research gap identified by Luff et al. (2018), who call for studies on technology usage in workplaces where workers manage the demands of both co-located and distributed work activities. In line with this call, the paper contributes to the previous research in operational train traffic with an analysis focused of technology use in the work practices and the study is informed by two theoretical approaches: DCog and AT. Both approaches are commonly used in studies of work (in control rooms and elsewhere); however, rarely applied to the same empirical material (see Baumer & Tomlinson, 2011; Decortis et al., 2000; Halverson, 2002; Nardi, 1996). This paper aims to analyse and describe the use of technology in work practices as they unfold in the control room for operational train traffic; thus, the focus of Paper V is on work by traffic controllers and information officers. With a practical application of both DCog and AT to the empirical material on details of everyday work in the control room, the paper emphasises the ongoing digitalisation in complex work settings and the impact such digitalisation has on work practices in the control room. We also address whether – or, to what extent – these theoretical approaches are useful for research in environments that are permeated with modern technologies.

The findings reveal the coordinative nature of work within the control room, which arises from how traffic controllers and information officers are attuned to each other, continuously sharing information out in the open while

having ‘ears like an antenna’ and making use of each other’s skills and knowledge to handle dynamic work tasks. This study contributes to the systems perspective of operational train traffic by introducing the role of information officers, who have not previously been focused on in this type of research. We also reveal that the limitations posed by artefacts that are central to the work practices result in challenges in relation to how traffic controllers and information officers are physically situated far away from the situations they aim to solve. These challenges relate to issues of time and space, and we found that neither DCog nor AT provide the theoretical constructs needed to properly capture such challenges. As a contribution to both the frameworks used and to the time/space matrix (c.f. Baecker et al., 1995) commonly discussed in CSCW, we introduce the concept of a ‘sense of place’ as a new dimension that is essential for understanding the challenges such workers continuously cope with concerning time and space. By including meaning and relationship beyond the mere spatial position of a place, we hope that this concept can support future research endeavours to deepen the understanding of how control room workers adapt to and cope with spatio-temporally complex challenges.

Paper V presents deepened insights into the work practices in operational train traffic and provides views on both the work practices and the interdependencies between workers and between workers and artefacts that complement Papers III and IV. This paper provides illustrations of the intertwined weave between internal and external resources, displaying the nuances of how the workload is distributed within the socio-technical system and supported by the use of socio-material resources in ways that represent the workers’ acquired experiences over a horizon of learning.

4.6 Paper VI: Managing complexity at the railway

Cort, R. & Lindblom, J. (under review). Managing complexity at the railway: Sensing the breakdown. *Submitted to a scientific journal.*

Paper VI reports on how an unexpected infrastructure breakdown and its consequences on the traffic flow are handled by the train traffic controller and information officer responsible. The event was due to a torn-down electrical overhead wire, and the nature of the incident was such that the traffic was temporarily stopped, and the trains were either cancelled or rerouted around the site of the incident. The consequences of an event like this for travellers and for the overall flow of train traffic can be major, making the event time sensitive. In contrast to most reports on accidents and incidents, which are normally conducted in retrospect, this study reports from inside the control room for operational train traffic as the handling of the incident unfolds in real time. Even though the situation is both unexpected and critical in terms of its

potential consequences, the conduct illustrated in the paper is, to some extent, part of everyday work practices within the socio-technical environment of operational train traffic. Thus, this situation demonstrates that the workers have acquired experiences and skill that enable them to handle the circumstances of the unexpected situation at hand. In line with Paper V, this study continues to explore the 'sense of place' concept and its applicability to this situation, in which the workers engage in activities aimed at grasping the incident and its severity before they can attend to handling the incident and its effects.

This paper continues to contribute to a deepened understanding of the work practices of information officers, who comprise a category of workers that are gravely understudied within this domain (thus complementing Paper V). Furthermore, the findings highlight how the coordination and collaboration between the workers are not self-evident, but are rather an accomplishment that requires effort and interaction. Practices that enable the workers to be constantly attentive to the activities of others are an essential part of what makes the work in the control room successful. They also contribute to a knowledge-sharing that facilitates the workers in maintaining safe and timely train traffic and supports them in the development of a sense of place. The reported case study demonstrates how reaching through time and space (mediated by technology) is facilitated by a sense of place, which is acquired by the workers and is part of the learning and development processes involved in the way they work in the control room. With a sense of place providing a deeper understanding of and meaning to the place of the incident, the control room workers can carry out meaningful actions from afar.

Paper VI complements the abovementioned papers from the domain of operational train traffic in its much narrower focus on the handling of one specific incident. With this focus, the study demonstrates in more detail how the workers use the socio-material environment and its available resources to continuously negotiate the boundaries of the socio-technical system, and how continuous adaptations are part of this endeavour to reach through time and space.

5. Discussion and Conclusions

This chapter presents a synthesis of the overall findings of the foundational research papers and highlights how they contribute to the aim and research questions (Section 5.1). These empirical findings are further discussed from the overall perspective of the thesis in Section 5.2, followed by reflections on the theoretical approach (Section 5.3) and a discussion on the trustworthiness of this research (Section 5.4). In Section 5.5, the main contributions are summarised, and a discussion on some of the implications they may bring to research and practice is provided. The thesis ends with the identification of relevant issues to pursue in future research (Section 5.6); finally, the main conclusions are summarised and highlighted (Section 5.7).

5.1 Synthesis of the empirical findings

The introductory chapter stated the overall aim of this thesis: *to deepen the understanding of the role and relevance of workers in the functioning of complex socio-technical systems*. The research questions will be explicitly addressed below.

The appended papers illustrate how work gets done in complex work domains and place emphasis on the workers and the role(s) they play in the system and for the continuous development of successful work practices. Accordingly, Papers I–VI contribute to the aim of the thesis but do so by providing insights from different work settings and across two separate domains. Moreover, they provide close and detailed analyses of work practices from the perspective of a number of different professional roles, and thereby explore various work constellations and their use of the available socio-material resources. Accordingly, all the papers highlight issues related to the aim and research questions in different ways. Each contributes with its own nuances, perspectives and examples of human adaptability and of the many resourceful ways of using socio-material resources to skilfully keep the system functioning despite continuous exposure to unexpected events. Some of the illuminating examples derived from the research papers are highlighted below to illustrate their contribution to the overall quest of this thesis.

R.Q. 1: What characterises adaptability to work practices in complex socio-technical systems?

Looking at the appended papers, it is clear that adaptation to work practices (of various kinds and for various purposes) takes place continuously across all four studied work settings. Paper III illustrates how a train driver receives notice of malfunctioning infrastructure that is resulting in a temporarily lowered speed limit within an upcoming rail segment. This news causes the driver to consciously adapt his driving behaviour by speeding up the train and exceeding the speed limit before approaching the affected segment of rail[10]. This adaptation enables him to get ahead of the timetable, which buys him enough time to pass the segment of rail with malfunctioning infrastructure at a significantly lowered speed yet still arrive on time at the next stop. What is especially noteworthy in this example is that the circumstances giving rise to the adaptation are out of the driver's control and are thus not something he is expected or required to 'solve' or adapt to in any way. Paper II exemplifies something similar when the workers decide to organise the order of activities and the division of labour within the team differently than the way these are described in the formal work instructions. Here, I refer to the way in which the maintenance workers deviate from the prescribed ways of handling a production stop: the instructions state that they should (a) call in to report the problem and (b) attend to the problem and perform the necessary repair work. By organising these activities differently, the workers are able to directly attend to the repair work and get the production up and running faster than if they followed the prescribed work instructions. In many ways, this adaptation is an improvement of the overall work process and one that benefits the production at large. However, it is not a necessary adaptation to be made, nor is it required by the demands of the environment.

Both of these examples portray adaptations as being more than a response to environmental circumstances. Hence, my research points to a human agency in which adaptations are internally driven by the human rather than by the demands of the environment. In the dock assembly setting, the workers make adaptations to their work practices by creating new tools and upgraded material resources in order to improve the quality of the assembled forest machines – even though this is not the responsibility of the individual worker, nor is it something the management asks of them (Paper I). The workers adapt their work practices in ways that make them the sole creators of those practices. Doing so enables them to achieve control over their work situation and contributes to the development of work practices in which their 'best practices' are carefully stored and maintained. These illustrations point to the role

[10] The train drivers refer to this as '*köra på pipet*', a phrase that does not translate well to English but means something like 'driving on the beep'. This term means that when a train exceeds the speed limit, the inbuilt automatic train protection system makes a loud beeping sound to warn the driver about the speed violation. This beeping continues for as long as the driver exceeds the speed limit.

of adaptations as a way of realising an individual's personal need for autonomy and as a display of competence that makes use of acquired experiences to fulfil the needs of perceived meaningfulness at work.

R.Q. 2. How do workers engage with the complex socio-technical environment in their everyday work practices?

This thesis began with the overarching claim that cognition emerges in the interaction between humans and their environments, meaning that the two mutually inform and shape each other and cannot be separated or studied in isolation. The appended papers offer numerous demonstrations of this claim and illustrate how the intertwining of workers with their socio-technical environment unfolds in the work practices in everyday work. Paper I examines tool use and collaborative work and illustrates how workers use tools and material artefacts that not only allow them to manually assemble forest machines (which is arguably their main task), but also inform how they coordinate their activities. For example the workers' activities, and the coordination between them, are not only dependent on talk or visible conduct, but also heavily rely on the sounds made from the use of various tools and equipment during the assembly process.

Regarding the use of more advanced technological artefacts, Papers II, III, V and VI demonstrate, for example, how control room workers (both in operational train traffic and in the smaller control room within the foundry for engine production) make sense of the world outside through rather obscure representations on a digital interface. Accordingly, it can be concluded that tools and artefacts are arranged and used in ways that inform coordinative behaviours and are central to the performance of the highly specialised activities the workers engage in.

Furthermore, Papers III, V and VI report on observations from within the control rooms of operational train traffic and illustrate how the workers are attentive to the conduct of others, which enables them to initiate cooperation in a timely and situationally relevant way. Within the control room, information and knowledge are shared in effective and seemingly effortless ways as the workers continuously engage socially with their surrounding environment by 'talking to the room', making eye contact with others and using body orientations and gestures (along with the use of various material artefacts) as important resources to accomplish work activities. These interactional aspects are intertwined with the observed work practices. Moreover, these papers make visible how physical proximity enables and supports cooperation, while a decentralised organisational arrangement requires new forms of coordination and cooperation. In the case of operational train traffic, such new forms of coordination mostly involve controller-driver communication in which the subtle interactional practices observed within the control room are no longer

viable; instead the communication requires the use of communication resources (the telephone) that are specifically aimed at enabling such interactions.

The above findings provide examples of how workers engage with their socio-technical environment in ways that utilise that environment as a reservoir of resources, which enables successful strategies for coordination and cooperation to evolve. These examples illuminate ways in which the environment simultaneously supports and creates specialised work practices and how they are conducted.

5.2 The workers' role in a complex socio-technical system

At the forefront of the empirical findings presented, two particular aspects stand out: (1) adaptations as internally driven; and (2) the fact that workers make use of the socio-material resources in their environment while simultaneously partaking in the creation of those resources and of the system at large. Taken together, these aspects showcase the role and relevance of the worker as related to human agency and present the worker as a driving force in a process of constant development that enables the system to function on an everyday basis despite large variations and unexpected events.

These findings have both theoretical and practical implications. Theoretically, they display the necessity of extending the scope of research in complex, safety-critical systems with methods and approaches that focus more clearly on human values and on workers as part of a messy world in which the social, physical, physiological and technological pose both limitations and opportunities. These findings also reveal that the methods and approaches need to include conceptual aspects that capture the human as an active driving force of development. From a practical standpoint, the findings presented here means that we should leave behind the view of human agents as passive factors in socio-technical systems who await instructions on how to act. Workers are an invaluable asset in the processes that make complex socio-technical systems function.

Adaptations to work practices in safety-critical domains are commonly described as a response to demands in the environment (e.g. Cook et al., 2000; Koopman & Hoffman, 2003; Woods & Dekker, 2000), conveying a perception of the worker as a passive factor in a system of fragmented components (c.f. Bannon, 1991). In contrast, my findings point to adaptations as being internally driven by human values and motivations. Such adaptations draw on the workers' experience and skill acquisition and demonstrate the role and relevance of the worker as a meaning-making actor – not only participating

in, but also actively contributing to the system and its functioning. In the everyday work practices in complex socio-technical systems, the role of the worker is expressed by continuous adaptations to how the work gets done and by resourceful – and sometimes even innovative – ways to make use of the available socio-material resources. Essential to this display of agency is how the workers constantly drive a process of change and development with the aim of improving their work practices in ways that reflect the workers' acquired skills and the 'know-how' that enables the system to successfully handle all types of events. Although it is common to credit technological artefacts with possessing human-like qualities such as intelligence and intentions, such artefacts can only manage previously known contingencies, which leaves the most difficult problems arising from abnormal system behaviour or breakdowns for the worker to handle. Accordingly, in the technology-intensive environments studied in this thesis, the role of the workers is to bring the uniquely human capabilities that are associated with human will and the ability to choose and assess suitable criteria and objectives for decisions based on judgements, negotiations and values learned from the experience of life. When dealing with uncertainty, drawing conclusions based on experience and applying these to new situations, the human brings something that is qualitatively different in terms of adaptations and resourceful usage of the socio-material environment, compared with the response an artefact can produce.

From the findings of this thesis, it can be concluded that the workers in the complex socio-technical systems of manufacturing and operational train traffic strive to enact autonomy and competence in their everyday work practices. The ways in which they engage in the creation and development of work practices and their socio-material environment display an intrinsic motivation, which has previously been described as important in the realisation of an individual's personal potential and perceived meaningfulness at work (e.g. Ryan & Deci, 2001). The perspective of the worker as an actor with values and motivations supports a recent movement in the HCI community that calls for a value-oriented direction and research on engagement and well-being at work – especially in relation to interaction with technology (Bhutkar et al., 2019; Mekler & Hornbæk, 2019; Palanque et al., 2019). This thesis contributes to this direction and points not only to the importance of supporting workers in expressing their skill and competence in their interactions with technology, but also to how and in what ways this competence can be expressed in work practices in general. Furthermore, and beyond the benefits for the workers at the centre of the system, I suggest that this view of the human and the contribution her agency brings to work in settings that are permeated by technology can serve as a means of supporting the system's safety (c.f. Grundgeiger et al., 2021; Savioja et al., 2014). Contributing to workers' feelings of autonomy and competence and giving them space and opportunity to bring their inherently human skills to the workscape makes the system better suited for dealing with

varying conditions and unexpected events, which contributes to establishing and upholding system safety (Hollnagel et al., 2015; Leveson, 2020).

5.3 Theoretical reflections

During the whole research process, I have been guided and directed by theoretical frameworks, which have offered a filter through which to study the phenomena of interest. They have also helped me make sense of, and create meaning out of, the observed situations and the collected data (c.f. Decortis et al., 2000; Nardi, 1996). As has been previously mentioned, the theoretical frameworks of DCog and AT were used in this research. They illuminated the work practices observed in manufacturing and operational train traffic in different ways and thereby allowed me to explain a larger range of processes involved in how work gets done in these domains. As Leonardi (2015, p. 260) puts it, using alternate theoretical perspectives 'can help to generate new findings and surface new solutions to old problems'.

Writing this thesis and looking back on my research process, I can conclude that Hutchins and DCog have had a large influence on how I approach a new study topic. This influence can also be seen in the way I report my findings, which are usually structured around a narratively described selection of episodes – similarly to how Hutchins reported on the navigational work in his seminal book *Cognition in the Wild* (1995a). With that said, DCog offers a limited conceptual apparatus and does not explicitly provide the analyst with any guidelines or checklists to support the extensive fieldwork that is required or to sort out the often large amount of data (c.f. Halverson, 2002; Rogers, 2012). These limitations have been addressed by a number of scholars in attempts to provide a more structured account of how to apply the DCog framework to research (e.g. Blandford & Furniss, 2006; Galliers et al., 2007; Wright et al., 2000). Clearly, DCog offers high flexibility, however, in my experience, it not only makes adjustments to the framework possible, but also requires certain adjustments to be made. Regardless of the context, all the DCog analyses I have engaged in left me with the feeling that my observations contained more than what the framework allowed me to express. This feeling has caused me to make my own adjustments in the form of the inclusion of theoretical constructs that I consider to be compatible with DCog and its core assumptions. These assumptions, I believe, concern the bounds of cognition and the processes that are considered to be cognitive in nature. To recap, Hutchins takes the socio-technical system as the unit of analysis, as it has observable properties and makes inferences about internal processes within an individual's head unnecessary. In addition to being socially distributed and embodied, Hutchins consider cognition and culture to be inseparable, since the history of artefacts and social practices shapes cognitive processes and how they are distributed in the socio-material environment. Hutchins' positioning in

these questions clearly separates him – and DCog – from traditional cognitive science, although he has been criticised for not fully taking the leap but instead hiding within 'a redundant cognitive vocabulary' (Button, 2008, p. 89). In my view, expansion of the cognitive system brings fundamentally different definitions and meanings to the cognitive vocabulary. Moreover, since Hutchins almost exclusively discusses computation in the extended system (in contrast to computation in the mind of the individual), I view this concept as a metaphor that is not literarily applicable to how cognition should be viewed within the DCog framework.

I have experienced DCog to be highly usable for studying the socio-technical system and for understanding how the different parts of the system contribute to making it function. However, after some time with my studies on operational train traffic, I felt that I had achieved such an understanding of the system and that I instead wanted to zoom in on the human entities in the functional system. This desire made me turn to the literature and to the theoretical perspectives that often adjoin discussions on DCog – namely, situated action (SA) (Suchman, 1987) and AT. While SA emphasises interactions, and especially their social side, it tends to only implicitly consider the role of artefact-mediated human behaviour (Susi, 2006), which I had already identified as a large part of the work practices in operational train traffic at this point in time. Therefore, I considered AT to be the more appropriate choice, as its focus on human agency and drive fit very well into my research in general. In fact, AT emphases the importance of human motive and consciousness, and therefore highlights human agency and the human as a driving force for development in a way that DCog does not. The theoretical language in DCog does not privilege the human over other components of the functional system. This has given rise to criticism against DCog, accusing it of viewing 'people and things as conceptually equivalent' and leading to the idea that 'artifacts are cognizing entities' (Nardi, 1996, p. 43). Although artefacts can propagate and transform representations of information, they can do so without 'knowing' anything; therefore, I argue that this is a misinterpretation derived from statements such as 'propagation of knowledge between different individuals and artifacts' (Flor & Hutchins, 1991, p. 37). Such a propagation between nodes in a functional system does not automatically mean that people and things should be considered to be conceptually equal. However, the fact remains that DCog does not explicitly give the human the central role in the socio-technical system, and DCog's conceptual language and commitment to the system, rather than to the human actor, introduces the risk of 'losing' the human within the system. This limitation is also perceivable in how DCog only implicitly considers the history of the socio-technical system, even though work practices arguably should be seen as the result of workers' acquired experiences. AT strongly highlights the history and development of the system, making the activity system more encompassing than the notion of a socio-technical system, which DCog defines as its unit of analysis.

This thesis takes the human actor as its starting point and highlights workers' essential role in making complex systems function and driving the development of the system, based on their intention towards what they want to accomplish within the system. Accordingly, it is relevant to apply a framework that supports and highlights this perspective. This is where AT comes in. In AT, humans are viewed as actively and constantly recreating their environment through their activities. This creates a cycle of constant development driven by the human agent (Engeström, 2015). This agency is clearly illustrated in my studies of work practices in manufacturing and operational train traffic, so I felt that AT was the next natural step in my research. As a first attempt, Paper V presents an analysis in which both DCog and AT are applied to the same empirical material, highlighting their main characteristics, similarities and differences when used in a work setting undergoing a process of digitalisation. This can be seen as an initial step towards exploring whether – or, to what extent – these theoretical approaches are useful for studies of work in times of increased digitalisation. This is an intriguing inquiry; however, it is too large to be thoroughly explored in one research paper. Thus, its investigation remains as a challenge for future research.

No theoretical perspective or framework is complete, and I found that most of the settings for my research were characterised by challenges related to time and space that neither DCog nor AT could properly describe or explain. Both approaches were developed prior to the digital era that is today's reality, and more research is needed on how they should be further developed to align with the HCI research agenda in relation to modern workplaces and the advanced technologies therein (e.g. since these technologies make the propagation of information more difficult to observe and analyse; for a related discussion, see e.g. Karanasios et al., 2021). One such attempt on my part was to introduce the concept of a 'sense of place' to my research, although this endeavour is still in its infancy (see Papers V and VI). The 'sense of place' concept is originally found in the field of human geography and its studies of the relations in and across space and place. I believe that this concept is of interest as a way to complement the rather renowned time/space matrix that conceptualises CSCW as either synchronous or asynchronous and as co-located or remote (see e.g. Baecker et al., 1995). The missing dimension in this matrix refers to a challenge for workers in operational train traffic: the need for information relating to 'place'. There is an experiential account in the definition of place – an 'experienced space', as expressed by Ciolfi (2004) – that cannot be represented in technical systems. However, in terms of the control room, the experienced workers seem to have developed a sense of place for locations outside of their physical setting that are pivotal in their successful work achievements. To conceptually explore this concept and its application to complex work domains, the questions of how workers develop and maintain a sense of place, and in what potential ways this process can be supported by system design, are challenges for future research to address.

I hope that it has become evident that my research is grounded in the theoretical tradition of situated, embodied and distributed cognition, in which DCog and AT are two well-substantiated frameworks. My background in cognitive science and my personal interest in these frameworks have affected not only how I conduct my research, but also the values and beliefs with which I perceive the world. Therefore, it might be surprising that both Papers IV and VI lack a deliberately expressed theoretical lens. Although I believe there is great strength in having a theoretical framework to help filter and focus on the rich stimuli associated with the messiness of natural settings (c.f. Decortis et al., 2000), a predetermined theoretical approach can also bring constraints derived from its attributes. Depending on those attributes, reality will map to theoretical constructs in different ways – either well or poorly, depending on what a theory is predisposed to do and what the researcher wants the theory to do (see Halverson, 2002). Although Papers IV and VI lack an explicitly presented theoretical lens, they should not be understood as being atheoretical or lacking all connection to theory. This has to do with the foundational principles and assumptions of the researcher, which make it impossible to be objective and to lack any theoretical influence. My principles and basic assumptions (see Section 1.3) are firmly based in the embodied, situated and distributed views on human cognition, which affect how I scope, manage and make sense of the work practices under study. This is true for all my papers, even though their theoretical depth and commitment vary and they present distinct framings and rhetoric.

5.4 Trustworthiness of the findings

Throughout the research process, I have aimed to enter the research settings without preconceptions regarding where the inquiry will take me. I have been guided by openness, a genuine interest and respect for the workers who share their time and knowledge. Given the nature of qualitative research and the fact that the researcher is the instrument, it is also important to try to learn about – and be aware of – my own personal, cultural and professional biases and assumptions. In addition to continuous reflection on this, I feel that the prolonged engagement with my empirical settings have helped me maintain a healthy distance from the participants and the social and cultural organisation they are part of by providing time in between sessions of data collection. All in all, I believe that my research closely aligns with how my participants think, feel and learn in their everyday work, and thus demonstrates high ecological validity (c.f. Braun & Clarke, 2013).

In regard to the trustworthiness and quality of this research, I will focus on the four criteria for establishing a trustworthy qualitative study suggested by Guba (1981) and Lincoln and Guba (1985), and review these in relation to my work. The criteria to be considered are: (1) credibility, (2) transferability, (3)

dependability and (4) confirmability. These are analogous to the conventional quality criteria of internal and external validity, reliability and objectivity used within quantitative research, which are inappropriate for qualitative research (Braun & Clarke, 2013; Janesick, 2000; Lincoln & Guba, 1985; Patton, 2002).

Credibility is concerned with the credibility of the findings and the interpretations made (Lincoln & Guba, 1985). To increase credibility, I used different data collection techniques, which made it possible to capture a richer and more nuanced image of the phenomena under study. All semi-structured interviews were concluded by me summarising the interview, my interpretations and conclusions, which enabled the participants to provide feedback and to correct any misunderstandings. Interpretations were continuously discussed and corrected during observational sessions as well, as a way of feeding my research process and making sure that my understanding of the work practices continued to deepen (see Section 3.4.1). This was especially prominent in the operational train traffic research, for which a prolonged engagement was possible. These are all activities that, according to Lincoln and Guba (1985), increase the credibility of the research findings.

Transferability concerns the extent to which the findings can be transferred to, or have applicability in, other contexts or settings. To enhance transferability and make it possible to determine the degree of similarity between two contexts, the researcher is responsible for providing sufficient descriptions of the phenomenon under study to make transferability judgements possible (Lincoln & Guba, 1985). In my research, I have sought to provide detailed descriptions of all the empirical cases, including information about the organisations, participants and employed data collection techniques. These descriptions enable readers to reflect on whether the results are transferable to other domains.

Dependability is equivalent to reliability and is thus concerned with the stability, consistency and predictability of the research findings over time, which assumes the existence of an unchanging truth. This idea contradicts the very nature of qualitative research, where reliability is seen as one part of a larger set of factors associated with observed changes (Lincoln & Guba, 1985). Guba (1981) suggests that dependability can be enhanced by, for example, overlapping methods and an inquiry audit. As mentioned above, overlapping techniques for collecting data were used in all of the appended papers, and I have addressed the dependability criterion by repeatedly presenting my research results to both peer-reviewed journals and conferences, thereby enabling external 'auditors' to review and verify my research process and findings. The KAJT research programme contributed to my second and third research phases as a valuable network consisting of both researchers and practitioners knowledgeable in operational aspects of Swedish train traffic. In this network, my research process and findings were exposed to additional reviews on a more regular basis than what is offered by the peer-review system. Furthermore, the empirical processes within the three research phases have been

closely reported with rich descriptions in order to enable readers to assess for themselves the extent to which an appropriate research practice has been followed (Shenton, 2004).

Confirmability refers to the quality of the data and how it is reported, and is thus concerned with establishing that the findings are clearly derived from the data and are not products of the researcher's imagination (Lincoln & Guba, 1985). To enhance the confirmability of my research, I have made sure to audio-record interviews when possible and to keep all of my written field notes, including write-ups, summaries, ideas and hunches. In addition, the analysis process through which the findings and conclusions were made has been closely documented so that the data and the constructions of themes and relationships can be re-examined. Moreover, each study is presented with a detailed methodological description so that the reader can decide if, and to what extent, the data and its constructs can be accepted. These strategies largely overlap with Halpern's (1983, in Lincoln & Guba, 1985) idea of creating an audit trail for establishing confirmability.

5.5 Contributions and implications

Throughout this thesis, I have attempted to contribute to a deepened understanding of how work gets done in complex socio-technical systems in general, and what role(s) workers play in the functioning of such systems in particular. As a means to that end, I have presented and integrated concepts and theoretical perspectives and conducted empirical studies with the aim of informing this overall purpose. It is my hope that the contributions and implications discussed below will broaden and provide input to some of the theoretical, conceptual and practical issues in studying work and how workers contribute to its execution and success.

The main contribution of this thesis is its 'thick' descriptions of how work gets done in practice in complex and highly demanding work environments. By providing a detailed picture of situated work practices from within such environments, my research contributes to a deepened understanding of the role of workers, with emphasis on their adaptations and various ways of using cognitive resources. It also demonstrates how this ultimately human contribution is expressed in everyday work practices. Accordingly, this thesis contributes to a deeper understanding of human behaviour in professional contexts. In my ethnographic descriptions of work, informal knowledge and work practices are made explicit, demonstrating their continuous development based on workers' acquired experiences and skill. In turn, this result contributes to how workers are viewed and valued as an intricate actor in the system. Ultimately, I hope that my research contributes also to how workers value themselves, their knowledge and their essential role in the functioning of the system at large.

Other contributions of this thesis include:

- An explanation for a novel account of adaptations, pointing to the active role of the workers in work practices and to their agency in such actions. This provides a perspective of the worker that has often been missing in prior research within manufacturing and operational train traffic as complex, high-risk work domains (c.f. Norros, 2018; Savioja et al., 2014; Wilson, 2000, 2014). Furthermore, this perspective of adaptations as an inherently human behaviour based on values and motivations advances discussions on how workers contribute to the functioning of socio-technical systems and enables the development of current and future studies of work. It can also serve as a means of supporting research on system safety.
- A theoretical overview of studies of work from a historical perspective, with roots in research by prominent scientists such as Rasmussen, Vicente, Klein and Suchman. More generally, this overview considers research directions that emphasised the relevance of contextualising work and studying it as it unfolds in its natural environment, thereby contributing to moving the then-current research out of the laboratory.
- A contribution in the rich – yet incomplete – picture of two of the most prominent post-cognitivist theoretical approaches for studies of work: DCog and AT. This contribution includes empirical applications of these frameworks in safety-critical domains where they have yet to gain traction and discussions and investigations into the frameworks' applicability to studies of work shaped by today's advanced technologies. The conceptual additions made to DCog in particular further add to this theoretical contribution.
- Advanced the toolbox for manufacturing and operational train traffic research, by theoretically and empirically demonstrating the applicability and usefulness of the modern perspectives on cognition to these domains.
- Illuminating analyses of true work practices that can serve as a backdrop for technology development (c.f. Bannon, 2000). Accordingly, by highlighting how workers contribute their uniquely human capabilities to the successful achievement of work practices, this thesis advances the discussion on how to design a well-functioning and mutually beneficial relationship between humans and technology.

All four empirical settings studied here display varying workloads, rapid decision-making and continuous problem-solving as characteristic features of everyday work. It is my intention and hope that this research does justice to the complexity of the social settings in which this work gets done, as well as providing insights into the efforts made by the workers who make the system function on a daily basis. I hope this research will not only contribute to the growing body of literature on work as it naturally unfolds, but also have im-

plications that allow workers to see and value their own experiences and professional knowledge, and to understand that they are at the core of these systems and the reason why the systems function in the first place.

This thesis contributes to the body of literature that establishes DCog in complex work domains. By repeatedly using the framework and applying it to different work settings, I have gained valuable experiences and insights that I hope can be of use to the larger research community interested in understanding work practices as distributed in a socio-material and cultural setting. A great deal of effort remains to be done before we can claim to understand work through these premises, and I imagine that some of it will involve developing the conceptual aspects associated with DCog and/or reforming the framework into an adapted and more detailed structure. Identifying the framework's insufficiency for addressing aspects of embodiment and adding theoretical constructs to its conceptual apparatus was one way for me to further develop DCog and increase its applicability in the context of HCI research (see also Lindblom, 2015b). My initial attempt to empirically compare the application of DCog with AT was another. As functional systems become more complex and as advanced technologies change the balance between what is out in the open and what is non-observable, DCog might need to be adapted accordingly (see Section 5.6 for more on this). I hope that my use of, and these reflections on, the theoretical frameworks of DCog and AT can promote a discussion on how and for what purpose these frameworks are really used.

Although I argue that the task of describing and understanding work is an achievement in its own right, and that there is no need to present 'implications for design' (c.f. Plowman et al., 1995), I hope that this research will have indirect implications for system design. I especially hope to influence the common view on the human aspects of human-technology interactions in complex work domains. By addressing how work gets done in practice, I believe we can shed light on fundamental issues regarding how technological artefacts serve human cognition in the complex work domains that are in focus here. Such insights may make it possible to increase our ability to both improve existing artefacts and design new ones that are better in the sense that they can enable a more beneficial human-technology relationship. Moreover, this research highlights positive variation in technology use, and I hope that my 'thick' descriptions of work practices can demonstrate that variability is not always something we should strive to restrict. In my view, the deepened understanding this thesis provides of the worker's role and contribution to the socio-technical system can be used as inspiration and as a driving force for design activities; in the long run, it can help to ensure that the design solutions of the future allow for such a positive variability.

5.6 Limitations and future research

The type of research presented in this thesis is rather explorative and, in order to facilitate such an exploration, it could be valuable to record and analyse video-based material. However, video recordings were not allowed in most of the settings of the appended papers (with the study presented in Paper I being the only exception). In the later phases of the research process, taking photographs or recording audio was also forbidden, due to security regulations. This lack of audio-visual material is a limitation of my research, especially in regard to understanding the chronological order of how certain situations or events unfolded and in relation to the depth and level of detail in the analysis. Video-based data would enable an even closer and more detailed analysis of the actions and interaction (e.g. gestures, gazes and facial expressions) that are relevant to the work practices under study. However, video has its limitations as well (e.g. it is highly dependent on the positioning and functioning of the camera equipment and, as in other types of data collection, the challenge of capturing the 'right' things still remains), and not being allowed to record video forced me to develop my note-taking skills to make the field notes as detailed and accurate as possible. Whether or not this was enough to capture the nuances of the work that was observed is an interesting discussion, but unsolicited reports made by both the participants and researchers with experience from these domains suggest that this was indeed the case. With that said, if the opportunity presents itself, I would like to complement my research with video-based studies to achieve a lower level of granularity in the analysis. The possibility of such a study is, however, out of my control, as it is decided by the security regulations for each work domain.

Like most research, this thesis leaves a number of questions unexplored and in need of further research. One important extension of the research presented here would be to further explore the role of the body in order to account for the inherently embodied nature of learning, knowledge and practice. Although both DCog and AT belong to the embodied, situated and distributed 'family' of theories of cognition, neither possess a theoretical language that commits to understanding embodied practices (e.g. Lindblom, 2015b). In fact, Hutchins has acknowledged that DCog has 'remained oddly disembodied' and that 'the cognitive processes described in *Cognition in the Wild*, and in other treatments of distributed cognition, are presented without reference to the role of the body in thinking' (Hutchins, 2006, p. 1). Nevertheless, I have included aspects of embodiment in my research to some extent, especially in Paper I, which addresses craftsmanship as embodied knowledge of the manufacturing workers. Further studies are needed to account for embodiment as something that is lived and experienced in the work practices in complex systems, and to provide a deepened understanding of the role embodiment plays in the relation between knowledge and practice. In relation to this, I hope to continue to explore the 'sense of place' concept as a complementary perspective on how to

view the challenges involved in work where the object of control is out of sight. In such settings, the worker's embodiment anchors him or her to the world in the here-and-now; yet it still seems to be important to develop and maintain a sense of place for the outside, which can only be mediated by technology. In a sense, the system is continuously stretched out to encompass the many places experienced by the worker through media, and I believe that Relph's (1976) discussion of 'insideness' and 'outsideness' offers a compelling idea for how to explore this further.

Another avenue of future research relates to the constant development of advanced technologies, which creates continuous change in how tasks are allocated between the worker and the technologies supporting or enabling work in these complex domains. This development is, for example, seen in the ongoing digitalisation of the time-distance graph as a key artefact in the control room for operational train traffic, as well as in the current trend of increased automation and data exchange in the manufacturing domain (Industrie 4.0). Hollan et al. (2000) describe DCog 'as a new foundation for human-computer interaction'; however, when Hutchins (1995a) studied the navigational work conducted onboard a U.S. Navy ship almost 30 years ago, most of the work was observable and 'out in the open'. Today, rapid technological development has made certain parts of the cognitive system 'hidden' inside technological artefacts – a development that is especially true for automated systems that produce decisions and predictions whose basis is rarely known by the worker. In a sense, technologies are climbing the hierarchy of the workplace, changing how work is done, and sometimes even relieving the human from certain tasks altogether. For some time now, research has picked low-hanging fruit in relation to the interactions between humans and technology/automation and how to design a beneficial relationship between the two (c.f. Bainbridge, 1983). As this relationship continues to become more complex, these questions pose research challenges that are more relevant now than ever, including questions on how and to what extent DCog and similar approaches are applicable in modern HCI research. This is an ongoing discussion in the AT community (Engeström & Sannino, 2021; Karanasios et al., 2021); however, to the best of my knowledge, this topic has not been discussed to similar lengths in relation to DCog.

5.7 Concluding remarks

It is my hope that I have managed to make it clear that there is much more to the concept of 'work' than what first meets the eye. With an empirical foundation in complex, high-risk socio-technical systems, this thesis set out to study work practices with the primary aim of deepening the understanding of the role and relevance of human workers in the functioning of such systems.

This aim allows for a discussion on the future of human-technology interactions in general, while specifically contributing to the development of current and future research in complex, safety-critical domains.

With ethnographic studies that were informed by DCog and AT, two theoretical frameworks belonging to the embodied, situated and distributed perspectives on cognition, this thesis examined what constitutes true work practices when they naturally unfold in complex socio-technical systems. It is argued that detailed analyses of true work practices are needed to uncover the acquired experiences, skills and 'know-how' that enable practice. This thesis has highlighted the creation of internally driven adaptations to work practices as a typically human attribute that illustrates human agency in situations where the worker makes use of acquired experiences and skills to fulfil her need for perceived meaningfulness at work. Furthermore, it is demonstrated how workers actively engage with their socio-technical environment in resourceful ways that utilise that environment as a reservoir of resources, simultaneously supporting and creating the way the specialised work practices are carried out.

The main contribution is the rich descriptions of situated work practices in domains that place high demands on their workers due to safety-critical environments and time-sensitive tasks that call for rapid decision-making and problem-solving. Accomplishing activities under these conditions requires skill and the competent use of acquired experiences. The thesis illustrated how this is expressed in the ways in which the workers continuously adapt their work practices and use socio-material resources in the process. Through this conduct, human workers become a driving force within the system, actively creating and recreating their environment in their endeavours to continuously adapt and improve the work practices they enact. By illustrating the role and relevance of the worker in the functioning of complex systems, this thesis also contributes to a deeper understanding of human behaviour in professional contexts – which in turn contributes to how workers are viewed and valued and how they view and value themselves.

Disentangling the intricate nature and complexity of the ordinary work in modern, technology-permeated workplaces is a research endeavour that does not stop here. In this time of rapid technological development, work as we know it is constantly changing and developing. Thus, questions regarding what role the human plays versus technology and how to create a mutually beneficial relationship between the two are a recurrent and important topic.

Bibliography

Agar, M. H. (1996). *The professional stranger: An informal introduction to ethnography*. San Diego, California: Academic Press, Inc.

Andersson, A. W., Jansson, A., Sandblad, B. & Tschirner, S. (2014). Recognizing complexity: Visualization for skilled professionals in complex work situations. In: A. Ebert, G. C. van der Veer, G. Domik, N. D. Gershon & I. Scheler (eds.). *Building bridges: HCI, visualization, and non-formal modeling*. Berlin, Heidelberg: Springer Berlin Heidelberg, 47–66.

Andreasson, R., Jansson, A. A. & Lindblom, J. (2019). Past and future challenges for railway research and the role of a systems perspective. In: S. Bagnara, R. Tartaglia, S. Albolino, T. Alexander & Y. Fujita (eds.). *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018): Volume VII: Ergonomics in design, design for all, activity theories for work analysis and design, affective design*. Cham: Springer, 1737–1746.

Baecker, R. M, Grudin, J., Buxton, W. A. S. & Greenberg, S. (1995). *Readings in human-computer interaction: toward the year 2000*. 2nd edition. Morgan Kaufmann Publishers.

Baethge, A., Rigotti, T. & Roe, R. A. (2015). Just more of the same, or different? An integrative theoretical framework for the study of cumulative interruptions at work. *European Journal of Work and Organizational Psychology, 24*(2), 308–323. https://doi.org/10.1080/1359432X.2014.897943

Bainbridge, L. (1983). Ironies of automation. In: G. Johannsen & J. E. Rijnsdorp (eds.). *Analysis, design and evaluation of man–machine systems.* Pergamon, 129–135. https://doi.org/10.1016/C2013-0-06057-4

Bannon, L. J. (1991). From human factors to human actors: the role of psychology and human–computer interaction studies in system design. In: J. Greenbaum & M. Kyng (eds.). *Design at work: cooperative design of computer systems*. Hillsdale: Lawrence Erlbaum Associates, 25–44.

Bannon, L. J. (2000). Situating workplace studies within the human-computer interaction field. In: P. Luff, J. Hindmarsh & C. Heath (eds.). *Workplace studies - Recovering work practice and informing system design*. Cambridge: Cambridge University Press, 230-241.

Bannon, L. J. (2011). "20 years a-growing": revisiting from human factors to human actors. In: H. Isomäki & S. Pekkola (eds.). *Reframing humans in information systems development*. London: Springer, 181–188.

Bardram, J. & Doryab, A. (2011). Activity analysis: Applying activity theory to analyze complex work in hospitals. In: *Proceedings of the 2011 ACM conference on computer supported cooperative work, CSCW '11*. ACM Press, 455–464.

Barsalou, L. W., Niedenthal, P. M., Barbey, A. K. & Ruppert, J. A. (2003). Social embodiment. *Psychology of Learning and Motivation, 27*(43), 43–92.

Barthelmess, P. & Anderson, K. M. (2002). A view of software development environments based on activity theory. *Computer Supported Cooperative Work (CSCW), 11*, 13–37. https://doi.org/10.1023/A:1015299228170

Baumer, E. P. & B. Tomlinson (2011). Comparing activity theory with distributed cognition for video analysis: beyond" kicking the tires". In: *Proceedings of the SIGCHI conference on human factors in computing systems*, 133–142.

Baxter, G. & Sommerville I. (2011). Socio-technical systems: From design methods to systems engineering. *Interacting with Computers, 23*(1), 4–17. https://doi.org/10.1016/j.intcom.2010.07.003

Benders, J., Hoeken, P., Batenburg, R. & Schouteten, R. (2006). First organise, then automate: A modern socio-technical view on ERP systems and teamworking. *New Technology Work and Employment, 21*(3), 242-251.

Bertelsen, O. W. & Bødker, S. (2003). Activity theory. In: J. M. Carroll (ed.). *HCI models, theories and frameworks: Toward a multidisciplinary science*. San Francisco: Morgan Kaufmann Publishers Inc, 291–324.

Bhutkar, G., Roto, V., Clemmensen, T., Barricelli, B. R., Abdelnour-Nocera, J., Meschtscherjakov, A., Lopes, A. G., Campos, P. & Gonçalves, F. (2019). User experiences and wellbeing at work. In: D. Lamas, F. Loizides, L. Nacke, H. Petrie, M. Winckler & P. Zaphiris (eds.). *Human-Computer Interaction - INTERACT 2019: Proceedings of the 17th IFIP TC 13 international conference, part IV*. Springer. Lecture Notes in Computer Science Vol. 11749, 754–758. https://doi.org/10.1007/978-3-030-29390-1_75

Blandford, A. & Furniss, D. (2006). DiCoT: A methodology for applying distributed cognition to the design of teamworking systems. In: S.W. Gilroy & M. D. Harrison (eds). *12th International workshop on design, specification and verification of interactive systems*. Springer-Verlag Berlin, 26–38.

Blandford, A., Furniss, D. & Makri, S. (2016). *Qualitative HCI research: Going behind the scenes*. Morgan & Claypool Publishers.

Bostrom, R. P. & Heinan, J. S. (1977). MIS problems and failures: A socio-technical perspective. Part I: The causes. *MIS Quarterly, 1*(4), 17–32.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology 3*(2), 77–101.

Braun, V. & Clarke V. (2013). *Successful qualitative research: A practical guide for beginners*. SAGE Publications Ltd.

Button, G. (2003). Studies of work in human-computer interaction. In: J. M. Carroll (ed.). *HCI models, theories and frameworks: Toward a multidisciplinary science*. San Francisco: Morgan Kaufmann Publishers Inc, 357–381.

Button, G. (2008). Against 'distributed cognition'. *Theory, Culture & Society, 25*(2), 87–104. https://doi.org/10.1177/0263276407086792

Button, G. & Sharrock, W. (2009). *Studies of work and the workplace in HCI: Concepts and techniques*. Morgan & Claypool Publishers.

Bødker, S. (1991). *Through the interface - a human activity approach to user interface design*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Carey, A. (1967). The Hawthorne studies: A radical criticism. *American Sociological Review, 32*(3), 403–416. https://doi.org/10.2307/2091087

Castañer, X. & Oliveira, N. (2020). Collaboration, coordination, and cooperation among organizations: Establishing the distinctive meanings of these terms through a systematic literature review. *Journal of Management, 46*(6), 965–1001. https://doi.org/10.1177/0149206320901565

Chryssolouris, G., Mavrikios, D., Papakostas, N., Mourtzis, D., Michalos, G. & Georgoulias, K. (2009). Digital manufacturing: history, perspectives, and outlook. *Proceedings of the institution of mechanical engineers, Part B: Journal of engineering manufacture, 223*(5), 451–462.

Ciolfi, L. (2004). *Situating "place" in interaction design: enhancing the user experience in interactive environments*. Ph.D. thesis. University of Limerick: Ireland.
Clark, A. (1997). *Being there – putting brain, body and world together again*. MA: MIT Press Cambridge.
Clark, A. (2005). Beyond the flesh: some lessons from a mole cricket. *Artificial life, 11*(1–2), 233–244.
Clegg, C. W. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*(5), 463–477. https://doi.org/10.1016/S0003-6870(00)00009-0
Clemmensen, T., Kaptelinin, V. & Nardi, B. (2016). Making HCI theory work: an analysis of the use of activity theory in HCI research. *Behaviour and Information Technology, 35*, 608–627. https://doi.org/10.1080/0144929X.2016.1175507
Cole, M. & Engeström, Y. (1993). A cultural-historical approach to distributed cognition. In: G. Salomon (ed.). *Distributed cognitions: Psychological and educational considerations*. Cambridge University Press, 1–46.
Collins, P., Shukla S. & Redmiles, D. (2002). Activity theory and system design: A view from the trenches. *Computer Supported Cooperative Work (CSCW), 11*(1–2), 55–80. https://doi.org/10.1023/A:1015219918601
Cook, R. I., Render, M. & Woods, D. D. (2000). Gaps in the continuity of care and progress on patient safety. *BMJ (Clinical Research Ed.), 320*(7237), 791–794.
Decortis, F., Noirfalise, S. & Saudelli, B. (2000). Activity theory, cognitive ergonomics and distributed cognition: three views of a transport company. *International Journal of Human-Computer Studies, 53*(1), 5–33.
Dekker, S. (2004). *Ten questions about human error: A new view of human factors and system safety*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
Doherty, N. F. (2014). The role of socio-technical principles in leveraging meaningful benefits from IT investments. *Applied Ergonomics, 45*(2), 181–187. https://doi.org/10.1016/j.apergo.2012.11.012
Dourish, P. (2001). *Where the action is*. Cambridge, MA: MIT Press.
Dourish, P. (2006). Implications for design. In: *Proceedings of the SIGCHI conference on human factors in computing systems*. New York, NY: ACM Press, 541–550.
Dourish, P. & Bell, G. (2011). *Divining a digital future: mess and mythology in ubiquitous computing*. MIT Press.
Dourish, P. & Button, G. (1998). On "technomethodology": Foundational relationships between ethnomethodology and system design. *Human-Computer Interaction, 13*(4), 395–432.
Dreyfus, H. L. (1972). *What computers can't do: The limits of artificial intelligence*. 1st edition. Cambridge, MA: MIT Press.
Eason, K. D. (1982). The process of introducing information technology. *Behaviour & Information Technology, 1*(2), 197–213.
van Eijnatten, F. M. (1997). Development in socio-technical systems design (STSD). In: P. J. D. Drenth, H. Thierry & C. J. de Wolff (eds.). *Handbook of work and organizational psychology.* 4th edition. Sussex, UK: Lawrence, 61–88.
Engeström, Y. (2015). *Learning by expanding. An activity-theoretical approach to developmental research*. 2nd edition. New York: Cambridge University Press.
Engeström, Y. & Sannino, A. (2021). From mediated actions to heterogenous coalitions: four generations of activity-theoretical studies of work and learning. *Mind, Culture, and Activity, 28*(1), 4–23. https://doi.org/10.1080/10749039.2020.1806328

Erlandsson, M. & Jansson, A. (2013). Verbal report and domain-specific knowledge: a comparison between collegial and retrospective verbalisation. *Cognition, Technology & Work, 15*, 239–254. https://doi.org/10.1007/s10111-012-0223-x

Fitzpatrick, G. & Ellingsen, G. (2013). A review of 25 years of CSCW research in healthcare: Contributions, challenges and future agendas. *Computer Supported Cooperative Work (CSCW), 22*, 609–665. https://doi.org/10.1007/s10606-012-9168-0

Flor, N. V. & Hutchins, E. (1991). Analyzing distributed cognition in software teams: A case study of team programming during perfective software maintenance. *Empirical Studies of Programmers: Fourth Workshop*, 36–64.

Fortune, J. & Peters, G. (2005). *Information systems – Achieving success by avoiding failure*. New York: John Wiley & Sons, Ltd.

Gallagher, S. (2006). *How the body shapes the mind*. Oxford: Oxford University Press.

Galliers, J., Wilson, S. & Fone, J. (2007). A method for determining information flow breakdown in clinical systems. *International Journal of Medical Informatics, 76*, 113–121. https://doi.org/10.1016/j.ijmedinf.2006.05.015

Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Heights: Prentice-Hall.

Glaser, B. G. (1992). *Basic of Grounded theory analysis*. Sociology Pr.

Goodwin, C. (1994). Professional vision. *American Anthropologist 96*, 606–633.

Goodwin, C. & Goodwin, M. H. (1996). Seeing as situated activity. In: Y. Engeström & D. Middleton (eds.). *Cognition and communication at work*. Cambridge: Cambridge University Press, 61–95.

Graham, S. & Thrift, N. J. (2007). Out of order: Understanding repair and maintenance. *Theory, Culture & Society, 24*(3), 1–25.

Grudin, J. (2017). *From tool to partner: The evolution of human-computer interaction*. Morgan & Claypool Publishers.

Grundgeiger, T., Hurtienne, J. & Happel, O. (2021). Why and how to approach user experience in safety-critical domains: the example of health care. *Human Factors*, 1–12. https://doi.org/0018720819887575

Grundgeiger, T., Sanderson, P., MacDougall, H. G. & Venkatesh, B. (2010). Interruption management in the intensive care unit: Predicting resumption times and assessing distributed support. *Journal of Experimental Psychology: Applied, 16*(4), 317–334. https://doi.org/10.1037/a0021912

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Technology Research and Development, 29*, 75–91.

Halverson, C. A. (2002). Activity theory and distributed cognition: or what does CSCW need to do with theories? *Computer Supported Cooperative Work (CSCW), 11*(1), 243–267. https://doi.org/10.1023/A:10152 98005381

Hazlehurst, B., McMullen, C. K. & Gorman, P. N. (2007). Distributed cognition in the heart room: how situation awareness arises from coordinated communications during cardiac surgery. *Journal of biomedical informatics, 40*(5), 539–551. https://doi.org/10.1016/j.jbi.2007.02.001

Heath, C., Hindmarsh, J. & Luff, P. (2010). *Video in qualitative research: Analyzing social interaction in everyday life*. London, UK: SAGE.

Heath, C., Knoblauch, H. & Luff, P. (2000). Technology and social interaction: the emergence of workplace studies. *British Journal of Sociology, 51*(2), 299–320.

Heath, C. & Luff, P. (1992). Collaboration and control: crisis management and multimedia technology in London underground line control rooms. *Computer Supported Cooperative Work (CSCW), 1*(1–2), 69–94. https://doi.org/10.1007/BF00752451

Hollan, J., Hutchins, E. & Kirsh, D. (2000). Distributed cognition: toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction 7*(2), 174–196. https://doi.org/10.1145/353485.353487

Hollnagel, E. (2012a). Coping with complexity: past, present and future. *Cognition, Technology & Work, 14*(3), 199–205. https://doi.org/10.1007/s10111-011-0202-7.

Hollnagel, E. (2012b). Resilience engineering and the systemic view of safety at work: Why work-as-done is not the same as work-as-imagined. *In Bericht zum 58. Kongress der Gesellschaft für Arbeitswissenschaft vom, 22*. Dortmund: GfA-Press, 19-24.

Hollnagel, E. (2014). *Safety-I and Safety-II - the past and future of safety management*. Farnham, UK: Ashgate Publishing Limited.

Hollnagel, E., Wears, R. L. & Braithwaite, J. (2015). *From Safety- I to Safety-II: A white paper*. The Resilient Health Care Net: University of Southern Denmark, University of Florida, USA, and Macquarie University, Australia.

Hutchins, E. (1995a). *Cognition in the wild*. Cambridge: MIT Press.

Hutchins, E. (1995b). How a cockpit remembers its speeds. *Cognitive Science, 19*(3), 265–288.

Hutchins, E. (2006). Imagining the cognitive life of things. In workshop on: *The cognitive life of things: Recasting the boundaries of mind*. The McDonald Institute for Archaeological Research, Cambridge. Available online: http://liris.cnrs.fr/enaction/docs/documents2006/ImaginingCogLifeThings.pdf [Accessed 9 August 2021].

Hutchins, E. (2008). The role of cultural practices in the emergence of modern human intelligence. *Philosophical Transactions of the Royal Society B, 363*, 2011–2019. https://doi.org/10.1098/rstb.2008.0003

Janesick, V. (2000). The choreography of qualitative research design. In: N. K. Denzin, & Y. S. Lincoln (eds.) *Handbook of qualitative research*. 2nd edition. Thousand Oaks, CAL: Sage, 379–399.

Jansson, A. & Axelsson, A. (2017). Knowledge elicitation in naturalistic decision making: Collegial verbalisation with "conspective protocols". In: *Proceedings of the 13th bi-annual conference on naturalistic decision making (NDM)*, 87–93.

Jansson, A., Erlandsson, M. & Axelsson, A. (2015). Collegial verbalisation – the value of an independent observer: an ecological approach. *Theoretical Issues in Ergonomics Science, 16*(5), 474–494, https://doi.org/10.1080/1463922X.2015.1027322

Kaptelinin, V. (2013). Activity Theory. In: M. Soegaard & R. F. Dam (eds.). *The encyclopedia of human-computer interaction.* 2nd edition. The interaction design foundation: Aarhus, Denmark. Available online: https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/activity-theory [Accessed 27 April 2021].

Kaptelinin, V. & Nardi, B. A. (2006). *Acting with technology: Activity theory and interaction design*. Cambridge, MA: MIT Press.

Kaptelinin, V. & Nardi, B. A. (2012). *Activity theory in HCI: Fundamentals and reflections*. Morgan & Claypool Publishers.

Kaptelinin, V., Nardi, B. A. & Macaulay, C. (1999). Methods and tools: The activity checklist: A tool for representing the "space" of context. *Interactions, 6*(4), 27–39. https://doi.org/10.1145/306412.306431
Karanasios, S., Nardi, B., Spinuzzi, C. & Malaurent, J. (2021). Moving forward with activity theory in a digital world. *Mind, Culture, and Activity*, 1–20. https://doi.org/10.1080/10749039.2021.1914662
Klein, G. A. (1998). *Sources of power: How people make decisions*. MIT Press.
Klein, G. A., Calderwood, R. & Clinton-Cirocco, A. (1986). Rapid decision making on the fire ground. In: *Proceedings of the human factors society annual meeting, 30*(69), 576–580.
Koopman, P. & Hoffman, R. R. (2003). Work-arounds, make-work and kludges. *IEEE Intelligent Systems*, *18*(6), 70–75. https://doi.org/10.1109/MIS.2003.1249172
Korpelainen, E. & Kira, M. (2013). Systems approach for analysing problems in IT system adoption at work. *Behaviour and Information Technology, 32*(3), 247–262. https://doi.org/10.1080/0144929X.2011.624638
Kuutti, K. (1996). Activity theory as a potential framework for human-computer interaction research. In: B. A. Nardi (ed). *Context and consciousness*. Cambridge, MA: MIT Press, 17–44.
Kuutti, K. & Bannon, L. J. (2014). The turn to practice in HCI: Towards a research agenda. In: *Proceedings of the SIGCHI conference on human factors in computing systems*, 3543–3552. https://doi.org/10.1145/2556288.2557111
Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge University Press.
Lee, J. D., Wickens, C. D., Liu, Y. & Boyle, L. N. (2017). *Designing for people: An introduction to human factors engineering*. Charleston, SC: CreateSpace.
Leonardi, P. M. (2012). Materiality, sociomateriality, and socio-technical systems: What do these terms mean? How are they related? Do we need them? In: P. M. Leonardi, B. A. Nardi & J. Kallinikos (eds.). *Materiality and organizing: Social interaction in a technological world*. Oxford: Oxford University Press, 25–48.
Leonardi, P. M. (2015). Studying work practices in organizations: Theoretical considerations and empirical guidelines. *Annals of the International Communication Association, 39*(1), 235–273, https://doi.org/10.1080/23808985.2015.11679177
Leontiev, A. N. (1978). *Activity, consciousness, and personality*. Prentice-Hall: Englewood Cliffs, NJ, USA.
Leveson, N. (2020). *Safety-III: A systems approach to safety and resilience*. Aeronautics and Astronautics Dept., MIT Engineering systems lab. Available online: http://sunnyday.mit.edu/safety-3.pdf [Accessed 17 October 2021]
Leveson, N., Dulac, N., Marais, K. & Carroll, J. (2009). Moving beyond normal accidents and high reliability organizations: A systems approach to safety in complex systems. *Organization Studies, 30*(2–3), 227–249.
Lincoln, Y. S. & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage.
Lindblom, J. (2015a). *Embodied social cognition*. Springer, Cham.
Lindblom, J. (2015b) Introduction to a non-classical view of meaning-making and human cognition: Meaning-making as a socially distributed and embodied practice. In: A. Scarinzi (ed.). *Aesthetics and the embodied mind: Beyond art theory and the Cartesian mind-body dichotomy*. Dordrecht: Springer Science, 3–19.
Lindsay, P. H. & Norman, D.A. (1972). *Human information processing: an introduction to psychology.* New York: Academic Press.
Luff, P., Heath, C., Patel, M., vom Lehn, D. & Highfield, A. (2018). Creating interdependencies: Managing incidents in large organisational environments. *Human*

Computer Interaction Journal, 33(5–6), 544–584. https://doi.org/10.1080/07370024.2017.1412830
Luff, P., Hindmarsh, J. & Heath, C. (2000). Introduction. In: P. Luff, J. Hindmarsh, & C. Heath (eds.). *Workplace studies – Recovering work practice and informing systems design*. Cambridge, MA: Cambridge University Press, 1–28.
Malinowski, B. (1922). *Argonauts of the western pacific*. New York: E. P. Dutton and Co. Inc.
Mark, G. (2002). Extreme collaboration. *Communications of the ACM*, *45*(6), 89–93. https://doi.org/10.1145/508448.508453
Mekler, E. D. & Hornbæk, K. (2019). A framework for the experience of meaning in human-computer interaction. In: *Proceedings of the 2019 CHI conference on human factors in computing systems*, 1–15.
Moeran, B. (2009). From participant observation to observant participation. In: S. Ybema, D. Yanow, H. Wels & F. H. Kamsteeg (eds.). *Organizational ethnography: Studying the complexity of everyday life*. Sage Publications, 139–155.
Mumaw, R. J., Roth, E. M., Vicente, K. J. & Burns, C. M. (2000). There is more to monitoring a nuclear power plant than meets the eye. *Human Factors, 42*(1), 36–55. https://doi.org/10.1518/0018720007 79656651
Naghiyev, A., Sharples, S., Carey, M., Coplestone, A. & Ryan, B. (2014). ERTMS train driving-incab vs. outside: an explorative eye-tracking field study. In: *Contemporary ergonomics and human factors 2014, Proceedings of the international conference on ergonomics & human factors 2014*. CRC Press, 343–350.
Nardi, B. A. (1996). Studying context: a comparison of activity theory, situation action models, and distributed cognition. In: Nardi B. A. (ed.) *Context and consciousness: activity theory and human-computer interaction*. Cambridge: MIT Press, 35–52.
Naweed, A., (2020). Getting mixed signals: Connotations of teamwork as performance shaping factors in network controller and rail driver relationship dynamics. *Applied Ergonomics, 82,* 102976. https://doi.org/10.1016/j.apergo.2019.102976
Neisser, U. (2014). *Cognitive psychology: Classic edition*. New York, NY: Psychology Press.
Newell, A. & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice and Hall.
Norman, D. (1980). Twelve issues for cognitive science. *Cognitive science, 4*, 1–32.
Norros, L. (2014). Developing human factors/ergonomics as a design discipline. *Applied Ergonomics, 45*(1), 61–71. https://doi.org/10.1016/j.apergo.2013.04.024
Norros, L. (2018). Understanding acting in complex environments: Building a synergy of cultural-historical activity theory, Peirce, and ecofunctionalism. *Mind, Culture, and Activity, 25*(1), 68–85. https://doi.org/10.1080/10749039.2017.1350714
Orlikowski, W. J. (1992). The duality of technology: Rethinking the concept of technology in organizations. *Organization Science, 3*(3), 398–427.
Orlikowski, W. J. (2007). Sociomaterial practices: Exploring technology at work. *Organization Studies, 28*(9), 1435–1448.
Palanque, P., Campos, P. F., Abdelnour-Nocera, J., Clemmensen, T. & Roto, V. (2019). User Experience in an automated world. In: D. Lamas, F. Loizides, L. Nacke, H. Petrie, M. Winckler & P. Zaphiris (eds.). *Human-computer interaction - INTERACT 2019: Proceedings of the 17th IFIP TC 13 international conference, Part IV*. Springer. Lecture Notes in Computer Science Vol. 11749, 706–710. https://doi.org/10.1007/978-3-030- 29390-1_67

Patton, M. Q. (2002). *Qualitative research and evaluation methods.* 3rd edition. London: Sage Publications Inc.
Perrow, C. (2011). *Normal accidents: Living with high risk technologies*. Princeton University press.
Perry, M. (2003). Distributed cognition. In: J. M. Carroll (ed.). *HCI models, theories and frameworks: Toward a multidisciplinary science*. San Francisco: Morgan Kaufmann Publishers Inc, 193–225.
Plowman, L., Rogers, Y. & Ramage, M. (1995). What are workplace studies for?. In: *Proceedings of the fourth European conference on computer-supported cooperative work (ECSCW'95)*. Dordrecht: Springer, 309–324.
Polanyi, M. (1966). *The tacit dimension*. Chicago, IL: The University of Chicago Press.
Poli, R. (2013). A note on the difference between complicated and complex social systems. *Cadmus, 2*(1), 142–147.
Rasmussen, J. (1974). *The human data processor as a system component: Bits and pieces of a model.* (Report No. Risø -M-1722). Roskilde, Denmark: Danish Atomic Energy Commission.
Rasmussen, J. & Jensen, A. (1974). Mental procedures in real-life tasks: a case study of electronic trouble shooting. *Ergonomics, 17*(3), 293–307.
Rawls, A. W. (2008). Harold Garfinkel, ethnomethodology and workplace studies. *Organization studies, 29*(5), 701–732. https://doi.org/10.1177/0170840608088768.
Read, G. J. M., Salmon, P. M. & Lenné, M. G. (2012). From work analysis to work design: A review of cognitive work analysis design applications. In: *Proceedings of the human factors and ergonomics society annual meeting, 56*(1), 368–372. https://doi.org/ 10.1177/1071181312561084
Reason, J. (2008). *The human contribution - Unsafe acts, accidents and heroic recoveries*. Farnham, England: Ashgate Publishing, Ltd.
Relph, E. (1976). *Place and placelessness*. London: Pion.
Richardson, L. (2000). Writing: a method of inquiry. In: N. K. Denzin & Y. S. Lincoln (eds.). *Handbook of qualitative research.* 2nd edition. Thousand Oaks, CA: Sage, 923–948.
Rogers, Y. (1997). *A brief introduction to distributed cognition*. Available online: http://www.id-book.com/fourthedition/downloads/chapter%208%20dcog-brief-intro.pdf [Accessed 23 April 2021]
Rogers, Y. (2008). 57 varieties of activity theory. *Interacting with Computers, 20*(2), 247-250. https://doi.org/10.1016/j.intcom.2007.07.004
Rogers, Y. (2012). *HCI theory: classical, modern, and contemporary*. San Rafael: Morgan & Claypool Publishers.
Rogers, Y. & Marshall, P. (2017). *Research in the wild*. San Rafael: Morgan & Claypool Publishers.
Rooksby, J. (2013). Wild in the laboratory: A discussion of Plans and situated actions. *ACM Transactions of Computer-Human Interaction (TOCHI), 20*(3), 1–17. https://doi.org/10.1145/2491500.2491507
Roth, E. M., Malsch, N. & Multer, J. (2001). *Understanding how train dispatchers manage and control trains: results of a cognitive task analysis*. (DOT/FRA/ORD-01/02). US Department of Transportation, Federal Railroad Administration, Office of Research and Development.
Ryan, R. M. & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual Review of Psychology, 52*, 141–166.
Sacks, H. (1992). *Lectures on Conversation* (Vols. I–II). Oxford, UK: Blackwell.

Salembier, P. & Wagner, I. (2021). Studies of work 'in the wild': The field study tradition in work practice research. *Computer Supported Cooperative Work (CSCW), 30*, 169–188. https://doi.org/10.1007/s10606-021-09396-2
Savioja, P., Liinasuo, M. & Koskinen, H. (2014). User experience: does it matter in complex systems? *Cognition, Technology and Work, 16*(4), 429–449.
Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information, 22*, 63–75.
Silverman, D. (1993). *Interpreting qualitative data: Methods for analysing talk, text and interaction*. London: Sage.
Simon, H. A. (1996). *The sciences of the artificial*. MIT Press.
Stephanidis, C., Salvendy, G., Antona, M., Chen, J. Y., Dong, J., Duffy, V. G., ... & Guo, Y. (2019). Seven HCI grand challenges. *International Journal of Human–Computer Interaction, 35*(14), 1229–1269. https://doi.org/10.1080/10447318.2019.1619259
Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge: Cambridge University Press.
Suchman, L. (1995). Making work visible. *Communications of the ACM, 38*(9), 56–64.
Suchman, L., (1997). Centers of coordination: A case and some themes. In: L. Resnick, R. Säljö, C. Pontecorvo & B. Burge (eds.). *Discourse, tools, and reasoning: Essays on situated cognition*. Berlin: Springer-Verlag, 41–62
Susi, T. (2006). *The puzzle of social activity – the significance of tools in cognition and cooperation*. Ph.D. thesis. Linköping University: Linköping, Sweden.
Swedish Research Council (2017). *Good research practice*. Stockholm, SE: Vetenskapsrådet.
Szymanski, M. H. & Whalen, J. (2011). Work practice analysis at Xerox. In: M. H. Szymanski & J. Whalen (eds.). *Making work visible*. Cambridge: Cambridge University Press, 1–17.
The British Psychological Society (2018). *Code of ethics and conduct*. Available online: https://www.bps.org.uk/sites/www.bps.org.uk/files/Policy/Policy%20-%20Files/BPS%20Code%20of%20Ethics%20and%20Conduct%20%28Updated%20July%202018%29.pdf [Accessed 12 April 2021]
Tracy, S. J. (2010). Qualitative quality: Eight "big-tent" criteria for excellent qualitative research. *Qualitative Inquiry, 16*(10), 837–851.
Trafikverket (2021). *Järnkoll – fakta om den svenska järnvägen*. Available online: https://www.trafikverket.se/resa-och-trafik/jarnvag/jarnkoll--fakta-om-den-svenska-jarnvagen/ [Accessed 4 May 2021]
Trist, E. L. (1981). *The evolution of socio-technical systems*. 2nd edition. Toronto: Ontario Quality of Working Life Centre.
Trist, E. L. & Bamforth, K. W. (1951). Some social and psychological consequences of the longwall method of coal-getting: an examination of the psychological situation and defences of a work group in relation to the social structure and technological content of the work system. *Human Relations, 4*(1), 3–38. https://doi.org/10.1177/001872675100400101
Vernon, D. (2014). *Artificial cognitive systems*. Cambridge, MA: MIT Press.
Vicente, K. J. (1999). *Cognitive work analysis: toward safe, productive, and healthy computer-based work*. Mahwah, N.J.: Lawrence Erlbaum Associates.
Vicente, K. J. (2006). *The human factor: Revolutionizing the way people live with technology*. New York, Routledge.
van der Waal, K. (2009). Getting going: Organizing ethnographic fieldwork. In: S. Ybema, D. Yanow, H. Wels & F. H. Kamsteeg (eds.). *Organizational ethnography: Studying the complexity of everyday life*. Sage Publications, 24–39.

Walter, S. R., Dunsmuir, W. T. & Westbrook, J. I. (2015). Studying interruptions and multitasking in situ: the untapped potential of quantitative observational studies. *International Journal of Human-Computer Studies, 79*, 118–125. https://doi.org/10.1016/j.ijhcs.2015.01.008

Waterson, P., Le Coze, J-C. & Andersen, H. B., (2017). Recurring themes in the legacy of Jens Rasmussen. *Applied Ergonomics 59*, 471–482. https://doi.org/10.1016/j.apergo.2016.10.002

Westbrook, J. I. (2014). Interruptions and multi-tasking: moving the research agenda in new directions. *BMJ quality & safety, 23*(11), 877–879. https://doi.org/10.1136/bmjqs-2014-003372

Wiener, N. (1948). *Cybernetics: or control and communication in the animal and the machine*. Cambridge, MA: MIT Press.

Willems, T. (2018). *'Monsters' and 'mess' on the railways: Coping with complexity in infrastructure breakdowns*. Ph.D. thesis. Vrije Universiteit: Amsterdam, the Netherlands.

Williams, K., Haslam, C. & Williams, J. (1992). Ford versus 'Fordism': The beginning of mass production?. *Work, Employment and Society, 6*(4), 517–555.

Williams, R. F. (2006). Using cognitive ethnography to study instruction. In: S. A. Barab, K. E. Hay & D. T. Hickey (eds.). In: *Proceedings of the 7th international conference of the learning sciences, 2*. Mahwah: Lawrence Erlbaum Associates, 838–844.

Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics, 31*, 557–567.

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics, 45*, 5–13.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Wolcott, H. (2009). *Writing up qualitative research*. 2nd edition. California: Sage Publications Inc.

Woods, D. D. & Branlat, M. (2010). Hollnagel's test: being 'in control' of highly interdependent multi-layered networked systems. *Cognition, Technology & Work, 12*(2), 95–101.

Woods, D. D. & Dekker, S. (2000). Anticipating the effects of technological change: A new era of dynamics for human factors. *Theoretical Issues in Ergonomic Science, 1*(3), 272–282.

Woods, D. D., Dekker, S., Cook, R. I., Johannesen, L. & Sarter, N. B. (2010). *Behind human error.* 2nd edition. Aldershot, UK: Ashgate Publishing Limited.

Wright, P. C., Fields, R. E. & Harrison, M. D. (2000). Analysing human-computer interaction as distributed cognition: The resources model. *Human-Computer Interaction, 15*(1), 1–41. https://doi.org/10.1207/S15327051HCI1501_01

Ybema, S., Yanow, D., Wels, H. & Kamsteeg, F. H. (2009). Studying everyday organizational life. In: S. Ybema, D. Yanow, H. Wels & F. H. Kamsteeg (eds.). *Organizational ethnography: Studying the complexity of everyday life*. Sage Publications, 24–39.

Zsambok, C. E. (1997). Naturalistic decision making: Where are we now? In: C. E Zsambok & G. Klein (eds.). *Naturalistic decision making*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

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