



# Production & Manufacturing Research

An Open Access Journal

ISSN: (Print) 2169-3277 (Online) Journal homepage: <http://www.tandfonline.com/loi/tpmr20>

## Tool use and collaborative work of dock assembly in practice

Rebecca Andreasson, Jessica Lindblom & Peter Thorvald

To cite this article: Rebecca Andreasson, Jessica Lindblom & Peter Thorvald (2017) Tool use and collaborative work of dock assembly in practice, Production & Manufacturing Research, 5:1, 164-190, DOI: [10.1080/21693277.2017.1374890](https://doi.org/10.1080/21693277.2017.1374890)

To link to this article: <http://dx.doi.org/10.1080/21693277.2017.1374890>



© 2017 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 26 Sep 2017.



Submit your article to this journal [↗](#)



View related articles [↗](#)



View Crossmark data [↗](#)

Full Terms & Conditions of access and use can be found at  
<http://www.tandfonline.com/action/journalInformation?journalCode=tpmr20>

## Tool use and collaborative work of dock assembly in practice\*

Rebecca Andreasson<sup>a,b</sup> , Jessica Lindblom<sup>a</sup>  and Peter Thorvald<sup>c</sup> 

<sup>a</sup>School of Informatics, University of Skövde, Skövde, Sweden; <sup>b</sup>Department of Information Technology, Visual Information and Interaction, Uppsala University, Uppsala, Sweden; <sup>c</sup>School of Engineering Sciences, University of Skövde, Skövde, Sweden

### ABSTRACT

In order to deepen the understanding of the intrinsic interactions and interplay between humans, tools, and environment from a systems perspective, research in the wild (RITW) approaches have gained traction during recent decades as they provide a higher ecological validity of findings. This paper presents a RITW study, investigating how assembly, in this case dock assembly of forwarders, was done in practice. As our theoretical foundation, we used the framework of distributed cognition, which is one of the main pillars of RITW. The findings are presented in narrative form, describing and highlighting that the workers achieve an efficient production outcome by being integral parts of the whole production process and doing so through coordination of activities benefitting the shared goal of the distributed socio-technical system.

### ARTICLE HISTORY

Received 31 January 2017  
Accepted 14 August 2017

### KEYWORDS

DCog; dock assembly;  
human factors & ergonomics;  
embodiment; tool use

## 1. Introduction

The research field of human factors and ergonomics (HF&E) essentially deals with the design of artefacts and tools to fit the human body and its cognitive abilities (e.g. Chapanis, 1996). As such, the field has long played an important role when it comes to optimising human performance, explaining why the manufacturing application, particularly human based manufacturing, has been a large driving force in the development of the HF&E research field. While several researchers have called for a more unified view of human cognition in HF&E, a view where the field is not only *described* as a systems discipline but actually *advanced* as such, the attempts made in this direction have not fully managed to abandon the traditional psychologist's view where the individual is the focus of research. One of the main advocates of a systemic view in HF&E, John Wilson, has long argued for humans to be studied and understood within their own context (Wilson, 2000, 2014). He argued that the unit of analysis should be expanded to focus on the interactions between individuals, tools and contexts, i.e. having more in common with anthropology than with

**CONTACT** Jessica Lindblom  [jessica.lindblom@his.se](mailto:jessica.lindblom@his.se)

\*This is a significantly revised and extended version of Andreasson's, Lindblom's and Thorvald's (2017) conference paper Distributed Cognition in Manufacturing: Collaborative Assembly Work, which appeared in *Advances in Manufacturing Technology XXX* [ed] Yee Mey Goh, Keith Case, IOS Press, 2016, pp. 243–248.

© 2017 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

traditional cognitive psychology. In previous work (Lindblom & Thorvald, 2017; Thorvald & Lindblom, 2015), we have argued that the application of HF&E in manufacturing suffers the same shortcomings and thus would greatly benefit from being characterised as a complex socio-technical system where interactions between peers, artefacts, and tools are the proper unit of analysis. In the manufacturing domain, a lot of information is shared among resources and humans, and information delivery at the right time and place is of the utmost importance (Thorvald, 2011), thus adding to the complexity of the socio-technical system. Tools and artefacts are crucial aids in the mediation of many actions and tasks that occur on the shop floor. With this view on manufacturing as a complex socio-technical system, the need to study both cognitive and social activities in practice becomes evident, and also the need for incorporation of external resources that are available to perform their manufacturing tasks.

The ‘research-in-the-wild’ (RITW) approaches were introduced nearly three decades ago when the scholars Jean Lave (1988), Lucy Suchman (1987), and Edwin Hutchins (1995a, 1995b, 2010) started to write about cognition being-in-the-wild (Rogers & Marshall, 2017). In their writings, they criticised the prevailing view of human cognition in the interdisciplinary field of cognitive science. At this time, the classical view of cognition dominated the cognitive theories; cognition was viewed as information-processing in the individual’s head and the construction of rational explanations of human behaviour was in the form of execution of plans (e.g. Rogers, 2012; Rogers & Marshall, 2017). In contrast, the proponents of ‘in-the-wild’ approaches offered another explanation of cognition, stressing that human cognition – when being observed as it unfolds in practice – is distributed and embodied in the social and material sphere and situated in the moment (see e.g. Lindblom, 2015a; Marsh, 2006 for more details of situated, embodied, extended, dynamical, and distributed approaches to cognition). A key concern in RITW studies was to reveal what actually happens in the real world, how do humans act and behave *in situ*, what kind of material and social resources do they use, when, and in what ways? Furthermore, the proponents of ‘in-the-wild’ approaches convincingly argued that cognition should be studied in the wild, going beyond the scope of what is usually possible to observe in a contrived lab study. As pointed out by Rogers and Marshall (2017), *in situ* studies can offer new ways of thinking about how to perform research. When contrasting RITW approaches to more contrived lab studies where researchers try to hypothesise and predict human performance, running *in situ* studies often provides unexpected findings and uncovers insights about human actions in practice beyond the scope and grasp of lab-based settings. In other words, it is argued that RITW uncovers the unexpected rather than confirming hypotheses or aspects already known (Rogers & Marshall, 2017). Rogers and Marshall (2017) point out that this way of conducting research may at first glance be viewed as if it is lacking the rigour associated with the more dominated research paradigm of conducting contrived studies. However, despite the lack of control in RITW studies, they argue that this approach can be the most revealing when it comes to discovering what actually happens in the real world. These studies also provide a greater ecological validity compared with inferring results from contrived lab-based studies. The outcome from RITW studies can be used to inform the rethinking of current cognitive theories or the development of new theories and concepts. It can also provide new insights and understandings of human behaviour in the real world where technology is embedded and used in everyday life (Rogers & Marshall, 2017). Considering this, Rogers and Marshall (2017) stress that RITW studies is becoming more widely accepted as a way of

doing research when studying e.g. human cognition, human–technology interaction, and human–computer interaction. In this way, RITW is complementing but also questioning the validity of the traditional lab-based research paradigm (Rogers & Marshall, 2017). This is consistent with Wilson’s arguments for the future of HF&E research. In fact, Wilson (2000) explained that the increased interest of ergonomists in ethnographical approaches, when the unit of analysis is ‘interactions in the wild’, enhances the argument that field research is fundamental ‘for the core purpose of ergonomics, investigating and improving interactions between people and the world around them’ (p. 563). He argued that this requires integration both within the HF&E discipline and with other disciplines.

Manufacturing as a whole is a very diverse domain and this study is part of a larger research purpose of studying several kinds of manufacturing and various types of assembly processes from a more situated, embodied, and distributed cognition (DCog) perspective. Our previous work has ranged from traditional line assembly, almost of a Tayloristic (Taylor, 1911) kind (Lindblom & Thorvald, 2017; Thorvald & Lindblom, 2015) and interruption management (Kolbeinsson & Lindblom, 2015; Kolbeinsson, Lindblom, & Thorvald, 2017; Kolbeinsson, Thorvald, & Lindblom, 2017), to process oriented monitoring of machines (Andreasson, Lindblom, & Thorvald, 2017). This paper further adds to the body of work through including more complex dock assembly where the longer assembly times and varying work (as opposed to the traditional line assembly) adds to the complexity of the unit of analysis.

This paper aims to characterise and analyse dock assembly of forest machines from a RITW approach. More specifically, the flexible, time consuming, and collaborative dock assembly process is being studied as a complex socio-technical system from a DCog perspective (Hutchins, 1995a, 1995b, 2010), focusing on how the assembly process is accomplished in practice in this particular setting.

## 2. Background: broadening the unit of analysis

This section focuses on how DCog,<sup>1</sup> as put forth by Hutchins (1995a, 1995b), can be, and have been, applied to widen the unit of analysis in a number of domains, specifically human based manufacturing. The section also addresses tool use as well as the concepts of handedness and enacted landscape, describing how tools, in the hands of a proficient user, become a physical extension of the body, which we argue is of major importance in *manual* assembly.

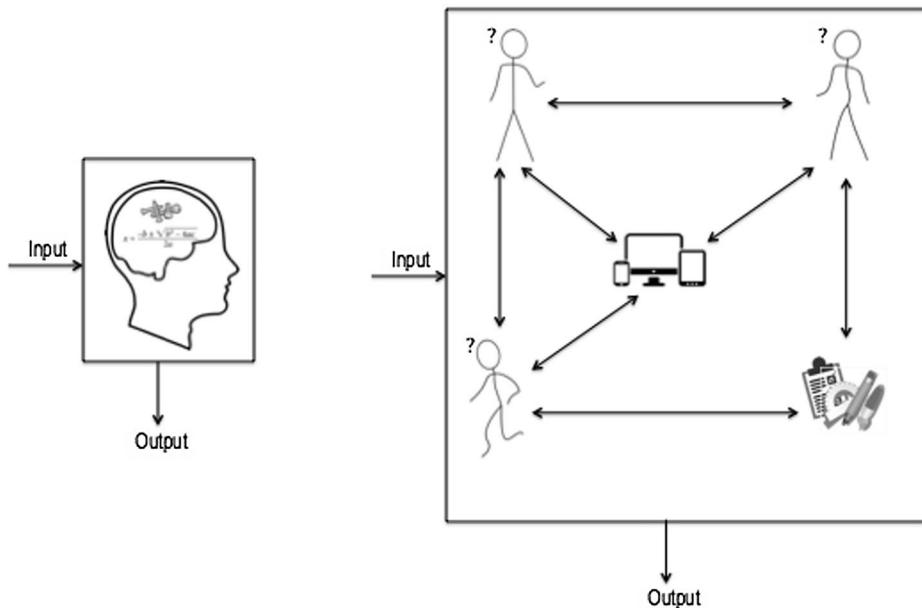
### 2.1. The theoretical framework of DCog

The common and still dominant view in traditional cognitive science is that human cognition is internal to the individual and that humans act on internal representations of the world, i.e. mental representations that represent something else. However, the theoretical framework of DCog, originally presented by Hutchins (1995a, 1995b) extends the unit of analysis of cognition beyond the boundary of the individual organism and proposes that cognition should be studied ‘in the wild’ as it naturally unfolds. From a DCog perspective, human cognition is fundamentally distributed in the socio-technical environment that we inhabit. DCog takes a system perspective and discards the idea that the human mind and environment can be separated. Therefore, cognition should instead be considered as a cultural process, rather than as something contained inside the mind of the individual. That

humans routinely extend and distribute their cognition into the environment can easily be viewed in most settings. For example, a factory worker might use external memory aids to remember the size of the current production batch (Lindblom & Thorvald, 2017) and, in a similar vein, the office worker might use post-it notes to offload memory systems and communicate with colleagues (Kirsh, 2001). Hutchins's own example shows how the ship captain and navigator heavily rely on the crew to fulfil their part in the complex task of running the ship (Hutchins, 1995a). The nature of the distribution of cognitive processes differs very slightly between domains and all of these examples are cases where the cognizers use external tools or peers to extend and mediate their cognition into the environment. This results in: (1) offloading cognitive load and freeing up cognitive capacity for other tasks, and (2) collaborating with peers and tools allows for more effective cognitive processing.

The underlying principle in DCog is that cognition is an emergent phenomenon resulting from the interactions between different entities in the brain, the body, and the social and material environment (Hutchins, 1995a). In other words, the whole is more than the sum of the individual parts. Given that the primary focus of DCog is to characterise the general flow, propagation and transformation of information within a distributed system, DCog provides a holistic view of human cognition and can be considered a reaction to the traditional view of cognition as being internal to the individual's mind (Figure 1).

The DCog framework differs from other cognitive approaches mostly by its commitment to two theoretical principles (Hollan, Hutchins, & Kirsh, 2000). The first principle concerns the boundaries of the unit of analysis for cognition, which is defined by the functional relationship between the different entities of the cognitive system. The second principle



**Figure 1.** To the left, the traditional cognitive science perspective is depicted, suggesting that the unit of analysis is restricted to the individual's mind. From a DCog perspective (to the right), the unit of analysis is distributed across people and artefacts within the cognitive system, and cognitive processes are the result of the relationship between these entities of the system.

concerns the range of processes that is considered to be cognitive in nature. From a DCog perspective, cognitive processes are seen as interaction between internal processes, as well as manipulation of external objects and the propagation of representations across the system's entities. Hollan et al. (2000, p. 176) described that when these principles are applied to the observation of human activity *in situ*, three kinds of distributed cognitive processes become observable:

- Cognitive processes may be distributed across the members of a social group
- Cognitive processes may involve coordination between internal (e.g. decision-making, memory, attention) and external structures (e.g. material artefacts, computer systems and social environment)
- Processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events

A fundamental aspect in DCog is its focus on cognitive artefacts and the way information is propagated and transformed in the socio-technical system. It is therefore common in DCog research to provide detailed analyses of particular tools and artefacts, as *coordination mechanisms* between external and internal structures. In other words, to study material structures like tools, reveal properties about cognitive structures that, with a DCog analysis, become visible 'beyond the skull'. Another important aspect of cognitive artefacts and tools is that they may serve as *mediators* in social interaction. Thus, it is important to recognise how information is transformed when mediated through tools (e.g. Clark, 1997; Hutchins, 1995a, 1995b). The use of strategies such as taking advantage of external structures or tools to coordinate cognitive activity might be considered another and complementary way of explaining intelligent action. These external structures function as a kind of supportive framework or *scaffolding*, i.e. external resources to support and simplify cognitive activity for an individual agent (Clark, 1997; Wood, Bruner, & Ross, 1976). In a broad sense, the human brain and body plus these external factors result in the 'mind', the boundary of which extends further into the world than cognitive science initially assumed. Accordingly, cognition is distributed across the agent, the actual situation and its resources.

For the theoretical framework of DCog, Hutchins (1995a) and Hollan et al. (2000) suggested an extension of ethnography that they call cognitive ethnography, which focuses on describing *how* knowledge is constructed and used, i.e. how cognitive activities are accomplished. Cognitive ethnography is not a specific technique or method for analysis but rather a collection of techniques such as photos, interviews, and observations applied 'in the wild' to determine what things mean to the participants in an activity and to document how those meanings are created (Hollan et al., 2000). As a method of inquiry, cognitive ethnography has key roles to play in HF&E with its aim to reveal how cognitive processes unfold in complex real-world settings.

The primary focus of a DCog analysis is on the general information flow, i.e. how information is propagated and transformed in the distributed cognitive system. Through a properly conducted DCog analysis, it is possible to identify potential problems related to information flow breaks down, or when alternative ways of handling the information flow emerge.

## 2.2. Tool use and handedness

A fundamental aspect in DCog is its focus on cognitive artefacts, and Norman (1991) defined cognitive artefacts to encompass ‘any artificial device designed to maintain, display, or operate upon information in order to serve a representational function’ (p. 17). Hutchins (1995a), for example, illustrated how multiple embodied biological brains combined with tools<sup>2</sup> (sextants, alidades, etc.), and artefacts (maps, charts, etc.) interact and collaborate during human performance. These external resources allow the human users ‘to do the tasks that need to be done while doing the kinds of things people are good at: recognizing patterns, modelling simple dynamics of the world, and manipulating objects in the environment’ (ibid., p. 155). Furthermore, Clark (1999) claimed that

the external environment, actively structured by us, becomes a source of cognition – enhancing ‘wideware’ – external items (devices, media, notations) that scaffold and complement (but usually do not replicate) biological modes of computation and processing, creating extended cognitive systems whose computational profiles are quite different from those of the isolated brain. (Clark, 1999, p. 349)

Various kinds of cognitive artefacts should be considered as a resource in the design of a good working environment, it should complement human abilities, aid those activities for which we are poorly suited cognitively, and enhance and help develop those cognitive skills which we are biologically predisposed to process easily.

Hutchins (1995a) investigated and analysed ship navigation from a DCog perspective, and his fundamental idea to bridge the gap between the inside and the outside world is still valid. Also Gedenryd (1998) viewed the external world as part of cognition, stressing that commonly used sketches, drawings, and other external media function as scaffolds and that they can be explained as serving to *make the world a part of cognition*, emphasising the human need to be *engaged with* the world. Furthermore, Baber, Parekh, and Cengiz (2014) embraced this distributed view on cognition, and referred to the use of ‘workspaces’ when portraying how skilled jewellers lay out their workspace. It should be noted that this particular arrangement is not simply a matter of having certain kinds of tools kept near each other, but the cognitive workspace emerges through the combination of related actions with the available tools. Baber et al. argued that the working environment can be pre-arranged to provide opportunities and anticipations for future actions. This means that the use of tools in the workspace, including deliberately selecting certain tools and materials in preparation of a specific task, picking up and putting down various tools during the performance of the task, and moving tools that are no longer needed further away from the central point of reaching, becomes a *form of distributed cognition* (Baber et al., 2014). In other words, they advocated that rearranging the workspace is not a means to assist thinking, it *is* thinking. The relationship between the available tools and materials used by a jeweller, or a manual assembly worker as in this case, forms a distributed system that not only supports different kinds of actions but also *shapes cognition*. In a similar vein, Kirsh (2013) introduced the term ‘enactive landscape’, which he denoted as the structure that a tool user co-creates with the world when he or she acts in a goal-oriented manner. He argued that when a person uses a tool, their enactive landscape is *reshaped*. Although different tools provide the cognitive artefacts for workers to use, the more skilful the workers are, the larger the enactive landscape they inhabit will be. This is due to the combination of skills, tools, and cognitive artefacts, which together constitute a bigger world of possibilities.

As pointed out by Rogers (2012), these successful scaffolds are no longer considered merely cognitive amplifiers or aids, since they have become an integral part of humans' activities through the multiple ways we interact with the environment. This means that the tools and cognitive artefacts that assembly workers use (e.g. torque drivers, wrenches, work instructions etc.) can be combined with several kinds of materials and articles and provide some of the possibilities and constraints for the enactive landscape in the distributed cognitive system. For a skilled assembly worker, the tool seems to become a part of the body, where the experience of manipulating the tool ceases to exist from the attention span and instead the focus is on the object being worked on (Baber et al., 2014). A torque driver can be considered a physical extension of the assembly worker, adapting the action-perceptual couplings to the 'extended hand', and consequently changes the enactive landscape around the tool user.

A major resource here is the human's manual hand, i.e. *handedness* (Drain, 2014). It should be noted that the hand is both an action and perceptual organ, playing a crucial role in understanding the external world. The hand possesses several senses united in one, ranging from tactile (e.g. touch, pressure, heat, cold) and proprioceptive (the position of the hand and fingers) to kinaesthetic (muscle tension) information, contributing to a plastic capacity to infer and manipulate information in the environment (Prinz, 2013). Therefore, the hand is 'the organ of the mind' (Drain, 2014). Results from neurocognitive experiments demonstrate that the hand occupies a unique role in 'determining a participant's ability to detect, discriminate, or pay attention to visual or somatosensory stimuli' (Holmes, 2013, p. 60). Drain (2014) pointed out that handedness has been a neglected and less researched area because its mediating role, which spans the separation of 'internal' and 'external' in theories of mind and cognition. However, recent work shows that handedness not only is used for exploring the world but also creating it. Therefore, handedness is an integral part of human's engagement and experience with the environment through its dexterity (Holmes, 2013). Baber et al. (2014) argued that an integral part of tool use is the ability to both anticipate the outcome of the tool's action and manage the functionality of the tool. These dynamical action-perceptual couplings are of more importance than previously considered, appreciating how a skilled and experienced tool user shapes activity. These actions involve transformation of kinetic energy into tool motion, requiring a sense of how much force is needed to enact the desired motion in the tool to accomplish the desired action on the object (Baber et al., 2014). The focus of these actions is both task and context dependent, and continually changing. In their paper, Baber et al. conducted empirical studies that contrasted and compared experienced and inexperienced silversmiths, and the results revealed that experts use less variability in physical performance and have a better control of energy use during a given task with a given tool. Prior studies have revealed similar results and, for example, experts in making stone or glass beads (so-called knappers) show significantly less inter- and intra-individual variations in their actions than less experienced workers (Roux et al., 1995, in Baber et al., 2014). The expert knappers also used a larger repertoire of joint angle combinations than less skilled knappers (Biryukova & Bril, 2008, in Baber et al., 2014), and they showed a lower variability in kinetic energy compared to intermediates and novices (Bril et al., 2010, in Baber et al., 2014). In other words, experts' tool using actions are conducted in a smoother, more consistent, and more rhythmic manner, resulting in the 'feel' for the tools that experts develop through extended practice of their handedness that is enacted in a distributed cognitive system.

Enaction includes the design of the tools used (as human-made artefacts) that not only reflects the process of performing manual assembly work but also some assumptions about how these tools should be used (Baber et al., 2014). Furthermore, it also involves the process of learning to master the action-perceptual couplings for how the tools should be grasped and manipulated by the hand. Thus separating tools from other material scaffolds in our environment, since their practical use is not only defined by their 'look' and the user's goal, but also by the cultural dimension that either enables or constraints the outcome of using them (Baber et al., 2014). Hence, the use of various tools and artefacts that the assembly workers make use of in their work practice define the broader cognitive socio-technical system, which goes beyond the individual assembly worker.

### **2.3. Pros and Cons of DCog**

Substantial work has been done to apply the DCog perspective in different settings and domains. This includes, among others, ship navigation (Hutchins, 1995a), aviation (Hutchins, 1995b), HCI (e.g. Hollan et al., 2000; Perry, 2003; Rogers & Ellis, 1994), heart surgery teams (Hazlehurst, McMullen, & Gorman, 2007), medical informatics (Hazlehurst, Gorman, & McMullen, 2008), information visualisation (Liu, Nersessian, & Stasko, 2008), nuclear power plant (Mumaw, Roth, Vicente, & Burns, 2000), and technostress in the office (Sellberg & Susi, 2014). However, DCog and its application power as an analytic tool has received some criticism. Two forms of critique that have been posed regard the DCog view of the nature of cognitive phenomena and its utility as an analytic tool (Rogers, 2012). Nardi (1996), for example, criticised the need for extensive fieldwork to reach a proper analysis and subsequent results in a certain setting, and the lack of interlinked concepts that can be used to identify specific aspects from the collected data. In a similar notion, Rogers (2012) as well as Berndt, Furniss, and Blandford (2014) pointed out that a DCog analyst has to be skilled to be able to move between the different levels of analysis necessary to accomplish a proper DCog analysis. Considering these challenges, DCog should not be considered a 'quick and dirty' approach and, consequently, DCog has been used as a base for developing several methods, e.g. the Resources model (Wright, Fields, & Harrison, 2000), DIB method (Galliers, Wilson, & Fone, 2007), CASADEMA (Nilsson, Laere, Susi, & Ziemke, 2012) and DiCoT (Blandford & Furniss, 2005). Although these methods have their foundation in DCog, the methods sometimes oversimplify and omit aspects that are of importance for a detailed DCog analysis (Sellberg & Lindblom, 2014). One of these issues regards the lack of proper notation for changes between representational formats. These changes are highly relevant in DCog since they often occur between humans and cognitive artefacts. Some initial attempts to overcome this gap have been developed in a manufacturing domain and presented by Lindblom and Gündert (2017).

## **3. Research design**

This section presents a workplace study performed at a manufacturing site for assembling forwarders via dock assembly. The study was performed with DCog as its theoretical framework and the data was collected at three separate occasions through cognitive ethnography.

### 3.1. Research setting

The setting for our study was a manufacturing site that assembled so-called forwarders. A forwarder is a forest machine that is used to load timber onto a wagon and transport the timber out of the forest. The forwarders consist of a cab in which the operator is located, a wagon onto which the timber is loaded, and a crane that is used to lift and place the timber onto the wagon. The forwarder is equipped with large wheels and has a capacity to transport up to 18 tonnes of timber and, thus, provides an efficient way to transport large portions of timber (Figure 2). The production at the manufacturing site was done as a type of individual workstation production, i.e. so called dock assembly.

We were provided access to the manufacturing site at three separate occasions and the workplace study was conducted at one of the work stations for assembly of forwarders. The assembly workers were divided into pairs that were always working together, assembling one forwarder at a time. The assembly process started with a welded chassis onto which the workers assembled approximately 3000 articles, working about 200 h combined, in order to finish the forwarder. The forwarders are highly complex to assemble due to a massive amount of components varying from very small and fiddly to handle, to components that are heavy and difficult to handle due to their size and weight. Furthermore, the forwarders are always customised to some extent, which results in constantly varying forwarders due to special requirements and options selected by the customers, further adding to the complexity of assembling the machines.

The main participants in this study were two assembly workers, referred to as participant 1 and 2, cooperating at one of five assembly docks that were active at the manufacturing site. Both participants had extensive experience of working in manufacturing, particularly with the assembly of forwarders and they had for the last four years almost exclusively assembled two different models of forwarders. Accordingly, at the manufacturing site, these assembly workers were considered main responsible for all assembly of those particular models of forwarders.



**Figure 2.** The final product: the forwarder being test-driven for the first time.

### 3.2. Research approach

In line with the RITW approaches, a *workplace study* was the chosen methodological approach with DCog as its theoretical framework. Workplace studies aim at studying, discovering, and describing how people accomplish various tasks in the wild (Luff, Hindmarsh, & Heath, 2000). Furthermore, workplace studies have been described as a prominent method for addressing the interactional organisation of a workplace and the way different tools and technologies are used to support work tasks and collaborations (Heath, Knoblauch, & Luff, 2000). Through observations and analysis of daily work activities and practices, a workplace study is concerned with issues beyond the individual tasks and focuses on entire ‘workscapes’ (Szymanski & Whalen, 2011), thus offering a holistic understanding of work experiences. This type of study entails studying patterns, constructions, and configurations of work practices. But also the social, cultural, and historical environments where the work is performed should be studied, as well as the artefacts that inhabit these sites and are involved in the accomplishment of work. There are a number of theoretical approaches to study practical actions in the workplace, e.g. activity theory (Engestrom, 2000; Luff et al., 2000), situated actions (Suchman, 1987), but the theoretical framework of DCog (Hutchins, 1995a, 1995b, 2010) has been put forward as one of the most pertinent. In fact, Heath et al. (2000, p. 307) described that ‘... distributed cognition [DCog] has provided the vehicle for a body of ethnographic work and an array of findings concerning the ways in which tools and technologies feature in individual and co-operative activity in organizational setting’. They argued that Hutchins (1995a), with his study of ship navigation, has provided some of the most illuminating and influential research regarding workplace studies.

The chosen research approach was purely qualitative and based on cognitive ethnographical fieldwork as a mean for data collection (Luff et al., 2000). To use this extension of ethnography meant to use several techniques for data collection and to analyse the data with focus on describing *how* knowledge is constructed and used at the workplace, i.e. how the manufacturing workers accomplished their cognitive activities included in their regular work activities. Data was collected at the manufacturing site at three separate occasions by the first two authors. These two authors situated themselves at the working station of the dock assembly to observe the work in practice and to interview the workers. Participant observations, field notes, video recordings, and photographs were the prime sources of data collection. Informal conversations with the participants during and after observations served as a valuable data source enhancing the understanding of the complex domain and revealing issues not identified by the observations alone. In addition, semi-structured interviews were conducted with the production manager as a complement to the collected data and the aspects being observed. In total, there were four hours of video-recorded material and approximately 30 h of observations. Often, video recordings are used extensively in DCog studies (and other RITW studies) to pay close attention to the activities and interactions taking place within the material and social environment (Rogers & Marshall, 2017). In this study, it was difficult to record all activities taking place in the assembly process due to the assembly workers constantly moving around alongside the forwarder they were working on. For this reason, the participant observations were used as a complementary method for data collection and the researchers spent much time in the natural environment of the assembly

of forwarders to achieve an understanding of the activities taking place. Unfortunately, audio recording was not possible at all due to high noise levels in the factory.

During all data collection, the objectives were to characterise how cognition is distributed in established work practices and to reveal how different kinds of scaffolds and tools were used as cognitive strategies developed by the workers in response to handling the complexity of the assembly task.

The data collected from the observations and the informal interviews consisted of quotations and descriptions of what had been observed and said. This data was continuously analysed during the data collection phase and each fieldwork session was followed by transcription of the field notes to make sure that they were understandable. In this way, the preliminary results of the already collected data provided a direction for the following sessions of fieldwork. In cases where the field notes raised ambiguity or uncertainty, the issue was further investigated during the next session at the manufacturing site.

At the end of the data collection phase, all data was analysed once again. This final analysis was done as a sense-making effort to identify consistencies and meanings in the data. This is usually referred to as a thematic analysis and it includes a strategic process of actively working with the data, simplifying and searching for themes and categories (Braun & Clarke, 2006). The focus in the analysis of the collected data was on the illustration of established work practices and on revealing cognitive aspects related to strategies for tool use and scaffolds developed by the workers. These work practices and strategies are a natural response to the handling of the complex assembly tasks and are therefore central features in the assembly workers' creation of their enacted landscape. During the analysis, DCog's theoretical constructs which emphasise the information flow and the coordination of internal and external representations in the socio-technical system were used as a theoretical perspective (cf. Decortis, Noirfalise, & Saudelli, 2000). This was the 'filter' through which the cognitive work processes in the complex socio-technical domain of the assembly of forwarders was interpreted. Therefore, it should be noted that our empirical work was primarily guided by, and possibly constrained by, the DCog perspective that was used in analysing and interpreting what was studied and therefore determined what was considered relevant. The analysis was thus theoretically driven by the DCog perspective and the identified themes that were most related to the aim of the study are described below.

#### 4. Findings

This section presents some episodes that were derived from the data analysis as examples of how cognition is distributed within the sociotechnical system of dock assembly. In accordance with a thematic analysis (Braun & Clarke, 2006), the selected episodes do not represent a chronological order of what was observed at the manufacturing site, but were instead selected as they characterise how the assembly workers cooperate and collaborate to accomplish the assembly process in practice.

Since DCog provides few theoretical constructs, it makes its findings largely descriptive but allows the researchers to reveal how cognitive strategies and tool use unfolds in real-world settings (Halverson, 2002; Rogers, 2012; Williams, 2006). This is the very phenomena we are most interested in explaining and what the following episodes attempt to characterise.

#### **4.1. Creating enactive landscapes in dock assembly: navigating from start to finish without running aground**

The assembly workers constantly needed to navigate through the complex work process of assembling the forwarders, from the welded chassis to the final product, and they performed this journey with the use of different internal and external resources. The workers' internal knowledge was of high importance, but material artefacts and articles used in the assembly practice were also highly relevant, serving as external resources. When visiting the setting, there was an identified lack of a commonly shared and external portrayal of the detailed process of how and in what sequence the various kinds of articles of the forwarders should be properly assembled from the company's perspective. The actual knowledge and skills required to accurately assemble the forwarders from start to finish emerged through the experienced assembly workers' sense making practices in their enacted landscapes. This implied a potential knowledge gap that may result in production losses and diverging quality of the final products, and therefore the production managers had recently re-designed and provided new construction drawings that the workers should use, as part of a major change process that the company was going through. However, since the process of creating these construction drawings was disconnected from the actual workings on the shop floor, the prescribed work process did not match the actual work process adopted by the assembly workers. In essence, the prescribed construction drawings were not sufficient either in terms of having utilised the experience and competence of the workers so as to create an efficient work practice, but also in terms of simply being inaccurate.

In order to accomplish the shared task to finalise a forwarder, the use of several internal and external resources functioned as scaffolds. The assembly workers had developed their own sense making practices of assembling the forwarders and during the study, participant 2 explained that 'the construction drawings are in my head'. When asked to elaborate further, he continued, 'I "feel" when something is right or wrong. I assemble the machine based on my prior knowledge'. Given that actions of manual assembly are acts of knowing, the workers continuously and tacitly evaluated whether a particular assembly action served its purpose or not. Just a few minutes after this statement, participant 1 laughed and said, 'Okay, right now, the construction drawings in my head do not agree with the machine [forwarder]'. He turned to the instructions (see Figure 3) in pursuit of an answer regarding how to assemble the article. Contrary to what is often assumed, the main source of information here was not the provided paper instructions but rather the prior knowledge acquired by the workers over years of practice. While the worker most likely did not have a complete internal representation of every detail of the instructions or construction drawings, we argue that the forwarder in itself functioned as an external scaffold and was its own best representation, also functioning as a coordination mechanism between internal and additional external resources. Thus, from the emergence of external and the internal resources, a complete work instruction emerged.

This argument demonstrated the *interactive* nature of human cognition, portraying how assembling the forwarder is accomplished by combing the manual actions at hand while using the instruction drawings as a mean to still be *engaged with* the world. This means that using external resources during assembly is the very cognitive strategy through which the worker acts to solve the problem at hand. The act of distributing the cognitive processes involved the coordination between internal structures (prior experiences and acquired



**Figure 3.** Participant 1 studies the assembly instructions as central cognitive artefacts used in the assembly work process.

knowledge) and external structures (instruction drawings) and it served several purposes. It included understanding the identified assembly task and what it required of the worker to examine the particular circumstances, what must be done and in which sequence. This involved exploring and testing different approaches to reach a suitable solution for the task. Hence, the emphasis was rather on the *process of assembly* in itself than on the outcome, the final product. This way of acting provided several advantages over mentally pre-planning what to do next. For example, it was revealed that it was better to deal directly with the real world than using mental representations as stand-ins for the world as it offers direct feedback in the form of answers ‘on the fly’.

A related issue, hinted at during this study and clearly recognisable from past studies (Andreasson et al., 2017; Lindblom & Thorvald, 2017), is that not taking into account the workers’ best practice when creating work instructions, leads to low confidence and sometimes even complete disregard in them, thus creating quality hazards when workers create workarounds which are not always appropriate. Consequently, showing the workers that their experience is relevant and allowing them to influence work instruction design, creates larger credibility of the instructions and a more convergent assembly process. Thus, it is important to understand how:

- Workers coordinate different internal and external sources to form a complete picture of the task and how the real world works as its own best representation.
- A lack of understanding of the actual work processes and strategies taken by the workers can lead to insufficient work instructions.

Several examples of cognitive artefacts were used as external resources in the assembly of the forwarders: blueprints, self-made photographs, and what were referred to as 'the old assembly instructions'. These cognitive artefacts displayed different graphical representations of the same machine, which emphasised the relevance of using several, complementing cognitive artefacts as support in the assembly task. The old assembly instructions were the predecessor of the blueprints and both of these external resources presented construction plans of the machine and its parts. The self-made photographs were taken by participant 1 and 2, depicted assembled parts of the machine and were often complemented with representations in textual format (Figure 4). The photographs represented states of the assembly process that the workers earlier had found to be difficult.

Especially the self-made photographs were useful cognitive artefacts and frequently used as external memory aids regarding the assembling procedure of specific parts of the forwarder. Internal representations are difficult to externalise and verbalise, however, the use of photographs was an attempt to externalise fragments of the participant's internal knowledge and cognitive strategies regarding details of the assembly practices. In doing this, the workers enabled the external representations to be available to other assembly workers and distributed socially over time and place. This clearly demonstrated that information is flowing back and forth between the assembly workers internal representations and the external textual and graphical representations in the socio-technical system. An important insight here is the coordination of cognitive processes between the external structures (the different representation formats) and the internal structures (the memory process), in which the knowledge of how to mount the forwarder emerged.

In addition, participant 2 expressed that he and his colleagues were assembling each machine based on 'feeling' or in more scientific terms, situated, and embodied knowledge (Dreyfus, 1992). In fact, when asked about different assembly operations, the participants often attempted to clarify their actions with explanations such as 'I just know it, I feel it'. This



**Figure 4.** The image on the left displays one of the self-made assembly photographs, which also has been complemented with symbolic instructions in the shape of article numbers and the quantity of each article needed. The image on the right shows how participant 2 has placed the photographs nearby while he is working.

phenomenon was also explained by Polanyi (1966, p. 4) with the words: ‘we can know more than we can tell’. Polanyi (1966) referred to this as tacit knowledge. One frequent example that was central in this study relates to the internal representations regarding how tight a bolt should be. This is an example of internal, situated and embodied knowledge that is difficult to externalise in any other way than through the practice of the assembly workers, which is what Gallagher (2005) referred to as embodied practice. The internal knowledge emphasised that the act of assembling is a craftsmanship and the assembly workers ‘know how’ is often internally represented and difficult to verbalise (craftsmanship has previously been discussed, e.g. by Keller & Keller, 1996). To know when a bolt is properly tightened requires utilisation of tactile-kinaesthetic couplings in the form of internally embodied representations. Accordingly, the internal representations are externalised through the practice of the assembly worker (for more details about embodied aspects of cognition, cf. e.g. Gallagher, 2005; Lindblom, 2015a, 2015b). This emphasises the great importance of tactile-kinaesthetic and sensory-motor coordination in time-locked activities such as tightening the bolt, i.e. a bodily experience of the harmonisation of movement and sensation that is hard to verbalise. Consider the following two bullets:

- The knowledge required to perform tasks of some complexity, can only partly be captured by work instructions.
- Embodied knowledge is central to successful task completion but very difficult to externalise and verbalise. Thus, very difficult to include in work instructions but still a type of knowledge that needs to be accounted for in the work process.

If, through the reported observations and arguments, we can agree on the above bullets as premises, then it is easily argued that to develop the craftsmanship of assembly, following work instructions is necessary but by no means sufficient for effective work. Thus, there is a need to acknowledge the role and relevance of first-hand experience of the various skills of manual assembly.

To summarise, the process of creating and developing own cognitive artefacts to rearranging the workspace does not assist thinking, it *is* thinking. The relationship between the available tools and several different knowledge sources used by the assembly workers forms a distributed system that not only supports different kinds of actions but also *shapes cognition*. This also changed the view that the sense making process of assembly should be predetermined or engineered. Instead, the ‘planning’ should be considered as an ongoing outcome from an emergent process that crystallises via the developed interactions between assembly workers’ internal resources and available external resources, e.g. tools, and artefacts being used in this particular ‘enactive landscape’ (Kirsh, 2013). Kirsh argued that when a person used a tool, their enactive landscape was *reshaped*; and the more skilful the person is, as portrayed by the assembly workers in this setting, the larger enactive landscape they will inhabit, because prior knowledge and skills combined with external resources constitute a bigger world of possibilities. From our perspective, this kind of flexible, complex and coordinated process of dock assembly, can be considered intricate examples of enactive landscapes, providing a demanding navigation throughout the many possibilities of mounting huge amounts of articles into a finalised forwarder.

## 4.2. Gloves as mediating tools in the enactive landscape

The assembly workers used different kinds of external resources as scaffolds to maintain the complex task of assembling the forwarders. One example of this could be seen twice every day when a bell rang and announced that it was either time for lunch break or the end of the workday. Every time the bell rang, participant 1 took off his gloves and placed them on top of the tool and materials he was using at the time of the bell sound (see Figure 5). After lunch break, as well as every morning, when participant 1 returned to his workstation, he usually stood still for a couple of seconds just looking at the gloves and their placement in relation to the forwarder being built and other material artefacts placed in the near surroundings. After this, he reached for the gloves, put them on and continued the work task where he had left it. When asked about this procedure he explained, 'It is just like using a bookmark in a book, the gloves show me where I should continue working'.

While the gloves appeared to be the 'bookmark' of choice for the worker, in cases where collaboration with his colleague required him to leave his workplace while still wearing his gloves, other 'bookmarks' were used in terms of placement of tools etc. However, these were less prominent. The gloves served as an external resource and when coordinated with internal resources (the workers' knowledge about the assembly process), they enabled the worker to map the placement of the gloves to a specific step in the work process. Interestingly, when the gloves were on the participant's hands, they held no special meaning but as soon as he explicitly placed them in the physical work setting, he turned the gloves into information bearers, functioning as a mediating and coordinating mechanism to support the navigation through the work process, serving to *make the external world a part of cognition*. This is another example of creating an enacted landscape, where the placement of the gloves for a



**Figure 5.** When interrupted in the work process, participant 1 used his gloves as an external memory aid and a mediating tool to remind himself of where to continue after the break.

non-professional onlooker may seem arbitrary but it demonstrates assembly as a cognitive process that provides the worker with reason and motives for the ways in which he acts.

Participant 1's gloves functioned as an external memory aid to represent the status of his individual work process, supporting processes distributed across time, presenting the progress and results of earlier performed assembly tasks, which in turn could change the nature of later tasks. Accordingly, this is also an example of what Baber et al. (2014) referred to as the use of 'cognitive workspaces', portraying how skilled practitioners create and lay out their workspace. As previously mentioned, arrangements like this is not simply a matter of having certain tools in a particular arrangement, but an example of how the cognitive workspace emerges through the combination of certain actions conducted with the available tools. Baber et al. (2014) argued that the material environment could be pre-arranged to provide opportunities and anticipations for future actions. This means that the use of tools in the workspace becomes a form of DCog; including actions such as deliberately selecting certain tools and materials in preparation of a specific task, picking up and putting down various tools during the performance of the task, and moving tools that are no longer needed further away from the central point of reaching (Baber et al., 2014). Similar findings were reported in Lindblom and Thorvald (2017), where workers in traditional assembly placed articles for assembly in sequence to help keep track of production status. The relationship between the available tools and materials used by an assembly worker forms a distributed system that not only supports different kinds of actions but also *shapes* cognition. Thus, it is important to recognise that:

- To ease their own work situation, workers rearrange their environment so that objects can serve as cognitive scaffolds and be included in the distributed cognitive system.
- The work environment can be pre-arranged to provide opportunities for cognitive offloading onto the environment.

In a similar vein, Kirsh (2013) argued that when a skilled individual uses a tool, the enactive landscape is *reshaped*. An additional example to further characterise this process is the design and use of self-made tools. It was revealed that the assembly workers had created and frequently used self-made tools, specialised for supporting certain steps in the assembly process where they had experienced that the prescribed tools did not provide enough support for the task. For example, sometimes during the assembly process, the workers were required to reach into narrow spaces of the forwarder, which hindered the worker's ability to move their bodies and use their physical strength optimally. They were also forced to work with the tools in difficult angles, which put a lot of strain on the worker's wrists and made it difficult to properly tighten the bolts. These issues had influenced the functionality of the self-made tools, which were welded in an angle to ease the workers access to the narrow spaces of the forwarder. Kirsh (2013) described that being skilled in a certain area informs the human on how to look at the world. He exemplified this with an example of a cook who is trained in using a blade and how to skilfully wield a spatula, and sees the 'cooking world' differently than someone who is new to cooking. Similarly, the assembly workers were skilful when it came to assembling the forwarders and their competence enabled them to look at the separate articles that together formed a forwarder in a different way than most people. Their assembly skills informed them on how to look at for example a bundle of hoses and fuel lines or a pile of different bolts and nuts, attending to different features of the items and seeing possibilities that were invisible to the more naïve

workers. The tools and artefacts used in the process of assembling the forwarder can be viewed as material scaffolds, which no longer were considered as cognitive amplifiers or aids, because they had become an integral part of humans' activities through the multiple ways we interact with the environment (Rogers, 2012). For the skilled assembly workers, the tool seemed to become part of the body, where the experience of manipulating the tool ceases to exist from the attention span and instead the focus is on the object being worked on, e.g. tightening a bolt. The tool can be considered a physical extension of the worker, adapting the action-perceptual couplings to the 'extended hand'.

It should be noted that a major resource here is the worker's manual hand, i.e. *handedness*, where the hand contributed to a plastic capacity to infer and manipulate tools and objects in the environment, thus, playing a crucial role in understanding the external world (Drain, 2014). This demonstrated the mediating role of handedness, spanning 'internal' and 'external' resources of distributed cognitive processes, where handedness was not only used for exploring the world but also enacting it. When tightening a bolt, an integral part is the ability to both anticipate the outcome of the tool's action and manage the functionality of the tool. These dynamical action-perceptual couplings revealed how a skilled and experienced assembly worker shaped the tool use activity, which involved transformation of kinetic energy into tool motion, requiring a sense of how much force needed to enact the desired motion in the tool to accomplish the desired action on the bolt. The focus of these actions is both task- and context-dependent, and continually changing, thus resulting in the 'feel' for the tools that skilled assembly workers develop through extended sense making practice of their handedness.

Accordingly, the self-made tools demonstrated the acquired skills of the assembly workers and the fact that they saw possibilities on how to improve and ease the assembly process that others were unable to recognise. Thus, the easiest solution was to create the tools themselves and actively *redesign* and *reshape* their enactive landscape, characterising the cognitive distribution between the workers and their materials and tools used while mounting the forwarder.

The use of self-made tools indicate that cognition does not only include what we traditionally might consider as mental tasks such as planning and making decisions, but that it also covers the physical and the embodied aspects through the cognizer's action-perception couplings. The real time, dynamical coordination of the 'internal' and the 'embodied' thereby becomes impossible to exclude from the idea of how the mind works.

### **4.3. Cooperative and collaborative assembly work**

Besides the use of different kinds of external resources as scaffolds, the assembly workers were also part of a social organisation that permitted them to combine their efforts during their work process. The cognitive processes were *distributed across time, space* and the *members of the group* during the coordination of their individual, but also cooperative and collaborative work activities. In order to achieve this joint result, different coordination mechanisms at the dock assembly were needed that had the capacity to handle the propagation of representational states through the system. The assembly of the forwarders was thus the result of cooperative efforts of two assembly workers working in a social organisation that enabled them to combine their efforts in such a way that the result was the outcome of the team rather than from individual activities. Even though the assembly workers most

of the time were engaged in separate assembly tasks, however on the same forwarder, they were constantly working towards the same goal and the assembly work was thus inherently cooperative and sometimes also collaborative. Despite actively working on separate assembly tasks, i.e. cooperative work, the participants showed great awareness about each other and they were constantly aware of the other person's activities and how the work proceeded.

As long as the assembly progressed the way it was expected to, the participants rarely communicated verbally. The workers' internal knowledge about the assembly process made it possible for them to adjust their individual work progress to the progress of the colleague without explicitly communicating about this coordination of activities. In fact, it seemed that oral silence was a form of communication in its own way, providing information that the situation was under control. This is consistent with the argument provided by Hollan et al. (2000), suggesting that silence can provide important information. When asked about verbal communication, participant 2 smiled and said that they do not need to talk to each other, 'I hear him over there', he pointed to the other side of the machine, and continued 'I know what that sound means, it means that he is working on the hydraulics'. This means that the sound functioned as a *coordination mechanism* for their sense making process where the way the assembly process proceeded functioned as a coordination mechanism between the two workers, represented 'out in the open' and, thus, without the need to be internally represented.

The participants were coordinated in their performance of the assembly activities and participant 2 explained that 'we usually start at one end each. After a while, we meet in the middle. It is as simple as that'. Occasionally the workers asked each other for assistance,



**Figure 6.** Though work is mostly carried out individually, assembly work is inherently cooperative, and occasionally they also actively collaborate.

leading up to the participants switching from cooperative work to being engaged in collaborative work (see Figure 6). One example demonstrating this was when participant 1 was assembling the electrical parts in the front of the chassis, while participant 2 was assembling the diesel tank, working at the other end of the machine. Suddenly, participant 1 uttered, 'I think I will need your help with this.' Once the silence had been broken, participant 2 immediately interrupted his ongoing assembly task, placed the wrench he was using on a nearby tool wagon, and walked over to participant 1. During the minutes to come, the participants were engaged in a collaborative work process, as opposed to the cooperative work they normally performed. The interaction unfolded naturally and the communication about the specific assembly operation was once again wordless while the two participants were trying to mount two separate parts of the forwarder together.

Suddenly, the assembly workers scattered, and participant 2 resumed to his prior work task. Clearly, the specific part of the assembly task that needed assistance was completed. Their seamless integration of work activities demonstrated the coordination of work where the performance of different operations in the end of the work process leads to a joint result. The different tools and cognitive artefacts used in dock assembly of the forwarders provided means for the assembly workers to use, but it was when the workers' skills were combined with these materials and tools that the enactive landscape grew larger and provided a bigger world of possibilities.

The complexity of assembling the forwarder and the large amount of operations that are accomplished by the assembly workers via their use of different tools and cognitive artefacts serves as an illustrative example of the cooperative and collaborative distributed nature of cognition where continually rearranging the workspace *is* thinking, and not only a way to assist thinking. In the collaborative work described here, it is argued that:

- Cooperative work entails a coexistence of the workers while still maintaining independence in the individual tasks performed. Through sharing a common goal, cooperative work allows adaptiveness and responsiveness to the overall work process and collaboration, which in turn allows for effective interplay between the two.
- Collaborative assembly work is characterised as the whole being greater than the sum of individual efforts. This means that in the process of collaboration, the workers together can accomplish more than both could have achieved separately.

Considering the examples above, it is clear that the workers were effortlessly shifting between cooperation and collaboration without losing track of the overarching, shared goal, i.e. to finish the forwarder. By doing this, they were constantly learning from each other and, even when engaged in separate tasks (cooperation), they know how the colleague's work process was proceeding by actively working in the context, learning the sounds of success as well as the sounds of mistakes or errors being made. Their attentiveness to the information presented in the surroundings supports the development of their own skill and competence. By observing each other work, the tacit knowledge is put into the open where the strategies used can be observed, practiced, and enacted by the colleagues. This is the cornerstone of apprenticeship where a novice learns a certain skill from observing an experienced master performing that skill (Keller & Keller, 1996). Allowing the workers to learn from each other enables the spreading of knowledge and is especially beneficial for training new employees. The workers in focus in this paper are both well experienced when it comes to assembly but they bring different perspectives and can therefore both

act as apprentice and master in different situations (e.g. informal learning), changing roles depending on the specific situation at hand and the desired skill it demands.

## 5. Discussion and conclusions

By studying the process of dock assembly of forest machines from a RITW approach, we have characterised aspects of coordination and tool use that are central for the accomplishment of the assembly process in practice. It is clearly shown that the workers enable a safe and efficient production outcome through coordination of activities that benefits the shared goal and that the craftsmanship and the assembly workers' embodied experiences are of high relevance for successful assembly work. The systems perspective of DCog, and the naturalistic approach of RITW, provides a framework that allowed us to study how the assembly workers act in their everyday work life to accomplish a successful assembly process of forwarders from a systems perspective. This does not only provide a high ecological validity but it also enabled us to theorise about cognition in the world and the complex relationship between the assembly workers, their tools and the environment of dock assembly in that particular system (Rogers & Marshall, 2017).

This study was limited to one organisational setting and one pair of assembly workers, studied during approximately 30 h during a total of three occasions. Due to the high noise level at the shop floor, it was not possible to collect audio recording and the main sources of data were therefore photographs, video recordings, and field notes from the observations. We are fully aware of the limitations in the data collection, and we do not wish to generalise from this sample to the population of manufacturing workers. However, it is relevant to acknowledge that the DCog perspective, with the unit of analysis being the whole socio-technical system, brings a valuable approach to naturalistic inquiries. Rogers and Marshall (2017) mention that research *in situ* often need this pragmatic approach to the collection and analysis of data. This way of working enables the researchers to explore and document even unanticipated phenomena that can only be revealed in RITW studies (Rogers & Marshall, 2017). In this study, qualitative and ethnographic methods were used to investigate and characterise how the assembly process is accomplished in practice in the often restricted environments of dock assembly.

It can be argued that employment of DCog in manufacturing settings can increase the understanding of the work practices as they are performed 'in the wild' within this complex socio-technical domain. DCog, with its theoretical focus on the system level, can help with the identification of information flow and various kinds of representation formats being used to support the work process. The various representational formats include graphical, numerical, and written representations, but also 'embodied representations' such as the embodied interactions and experiences of our senses. This emphasises the tacit knowledge that is part of the craftsmanship associated with being a skilled worker in manufacturing, which becomes visible when observing work practices 'in the wild'. It will also help in identifying the workers' 'best practices' and 'lessons learned' that are developed to ease their work process. This in turn can be used to inform design and redesign of new products such as various tools and cognitive artefacts.

We argue that the RITW approaches can provide HF&E practitioners and the research field as such with novel ideas about how tasks are done. In line with the RITW approaches, the importance of understanding the ways humans are structurally coupled, i.e. *embodied*,

to the social and material environment has been stressed in further writings in the fields of cognitive science and in human–computer interaction (HCI) (Rogers & Marshall, 2017). It has been pointed out by several researchers that the physical body has a fundamental role and relevance for our interactions with the social and material world (e.g. Clark, 1997; Gallagher, 2005; Kolbeinsson & Lindblom, 2015; Lakoff & Johnson, 1999; Lindblom, 2015a, 2015b). Consequently, the way we embody and interact with the external resources in our environment affects and changes the ways we perceive, act and think, offering a ‘philosophy in the flesh’ (Lakoff & Johnson, 1999). Hence, we do not just think with our brains but through our bodily interactions and there are times when we actually ‘think’ with and through our hands and with accompanying tools, as demonstrated in the handedness of the enactive landscapes portrayed in this paper.

Kirsh (2013), among others, points out that ‘the theory of embodied cognition offers us new ways to think about bodies, mind, and technology. Designing interactivity will never be the same’ (p. 3:1). Therefore, the inclusion of embodied cognition within the RITW approaches can provide both practitioners and theorists with new ideas about how the interaction is shaped in human behaviour as well as offer new implications for better design solutions and technology interventions (Rogers & Marshall, 2017). Embodied cognition has also been stressed in ergonomics (Bagnara & Pozzi, 2015; Marras & Hancock, 2014) and we agree that the embodied cognition approach offers complementary perspectives to the area of physical ergonomics to also include cognitive aspects of embodied and sense making actions that may offer significant insights and contributions to the fields of HF&E. Generally speaking, in the past, physical ergonomics had to worry about fitting technology to the functionality of human bodies, but today’s technology must also fit humans from an embodied cognition perspective. Bagnara and Pozzi (2015) pointed out that ergonomics has been rather sparse to integrate the methods used to examine cognitive aspects with the methods used to investigate physical interaction. As a consequence, the relationship between the cognitive and physical aspects has often been oversimplified. However, Bagnara and Pozzi (2015, p. e129) stated that ‘It is our opinion that the embodied cognition approach might help in overcoming the dichotomy between physical and cognitive ergonomics’. They argued that when ergonomics is more adapted to the embodied cognition approach, this would have implications also for design and not only for analysis of complex systems. As demonstrated in the episodes in this paper, the act of creating and shaping enacted landscapes may provide some initial steps in this direction, since the RITW approaches does not offer the split into physical ergonomics and cognitive ergonomics.

To clarify the issue of the role and relevance of the theoretical contributions of DCog (and other RITW approaches) in manufacturing engineering and HF&E, this section offers some implications. Theories provide significant insights that may improve the analysis and design of a complex socio-technical system, which can be considered the most important criterion for any theory used in this context. This does not mean that the value of any theory is whether it provides ‘an objective representation of reality’. In practice, this means that a useful theory can shape an object of study, highlighting relevant issues, probing certain questions, providing a classification scheme that frames significant insights about the domain it is applied to. From this pragmatic RITW perspective, theories are more like different lenses that bring some objects into sharper contrast, while others fade out of our focus of attention.

In order to analyse and design usable complex socio-technical systems we need a foundation in theory that span both human and technology, rather than only using checklists or off the shelf methods. Many engineers and designers are not interested in theories; they rather want a method, technique, or process that can be followed step-by-step to a satisfying design solution or evaluation of a system. However, we are skeptical whether these approaches can be successfully and credibly applied unless the professionals using them are familiar with the underlying theoretical foundations (see Flach & Voorhorst, 2016).

Despite the large amount of research on human cognitive behaviour, there is still a knowledge gap about every day human experiences and how people use ‘common sense’ to successfully ‘muddle through life’. We argue that using RITW approaches in the study of human actions in practice may narrow this knowledge gap. This is especially of importance in manufacturing where the adoption of frameworks such as Industrie 4.0 have been created to support the conception of the smart factories of the future (e.g. Bundesministerium für Wirtschaft und Energie, 2016; Hermann, Pentek, & Otto, 2015). This development leads to the use and increase of sensors, adaptive technologies, and various information and communications technology (ICT) systems that support the use of continuously updated information on the shop floor for managers and assembly workers.

As pointed out by Flach and Voorhorst (2016), technology is not disconnected from what we do, but rather, it is a fundamental part of human life. Much of current workspaces force the workers to bend their bodies into an unnatural shape of interaction and we therefore address the need for theories that reduce this common friction between human and technology. In order to accomplish the workspaces of tomorrow in manufacturing, or other domains studied by ergonomics, there is a need for a greater understanding of the always-existing link between human and technology that is required to be spread throughout the HF&E community.

Many issues may be addressed in the future of assembly work and manufacturing. Adopting the RITW approaches in HF&E creates new opportunities for posing questions regarding what matters in manufacturing as well as when analysing and designing the smart factories of the future. It is widely acknowledged that the technological advances in assembly work result in an increase of the amount of available data and ICT at the shop floor, which adds to the cognitive complexity and cognitive demands of the assembly workers. However, we argue that if the RITW approaches are adopted in the HF&E toolbox, there is a vast potential to decrease the workers’ cognitive load while at the same time increase performance. We emphasise the need for creating mutual relationships between humans and technology, thus designing for the emergence of ‘cognitive workspaces’ in manufacturing, realising the factories of the future where manual assembly still matters in an innovative work environment.

Allowing the boundaries of what constitutes cognition to expand into the environment offers a new toolset for identifying both potential problems as well as opportunities for improvement of human based assembly work. We do not argue for a decisive single theoretical perspective but rather for a complementary one that considers the intricacies of human–human and human–technology interaction. We admit that the RITW approaches may not be sufficient but we do claim that the understanding of cognitive work cannot be complete if they are omitted. Thus, the ultimate goal of design of workspaces should be to engage humans more effectively in their work practice in order facilitate better muddling

at work, i.e. enacting and designing cognitive landscapes, increasing humans' motivations in wanting the socio-technical system to work accurately in practice.

## Notes

1. When abbreviated as DCog, we refer to Hutchins's theoretical framework of distributed cognition (Hutchins, 1995a, 1995b, 2010), while when written, we will refer to the general phenomena of cognition being distributed. The concepts and arguments put forth in this paper are mainly true to Hutchins's original work and omit approaches that deviate significantly from his original focus on the cognitive system (see Lindblom & Thorvald, 2017 for more details on different views on cognitive systems).
2. In this article, we do not explicitly distinguish between tools and artefacts, but see the work by Susi (2006) regarding different characterisations of tools and artefacts.

## Acknowledgements

We are grateful to the participants in this study for the time and expertise they shared with us. We also wish to thank Christine Olsson for the help with the illustrations, whose publication has been consented by the participants.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Rebecca Andreasson  <http://orcid.org/0000-0003-0159-9628>

Jessica Lindblom  <http://orcid.org/0000-0003-0946-7531>

Peter Thorvald  <http://orcid.org/0000-0002-8369-5471>

## References

- 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. doi:10.1007/s10111-016-0399-6
- Baber, C., Parekh, M., & Cengiz, T. G. (2014). Tool use as distributed cognition: How tools help, hinder and define manual skill. *Frontiers in Psychology*, 5, 1–13. doi:10.3389/fpsyg.2014.00116
- Bagnara, S., & Pozzi, S. (2015). Embodied cognition and ergonomics. *Journal of Ergonomics*, 5, e129. doi:10.4172/2165-7556.1000e129
- Berndt, E., Furniss, D., & Blandford, A. (2014). Learning contextual inquiry and distributed cognition: A case study on technology use in anaesthesia. *Cognition, Technology & Work*, 17(3), 1–19. doi:10.1007/s10111-014-0314-y
- Blandford, A., & Furniss, D. (2005). DiCoT: A methodology for applying distributed cognition to the design of team working systems. *Proceedings of Design, Specification, and Verification of Interactive Systems* (pp. 26–38), 12th International Workshop, DSVIS 2005, Newcastle upon Tyne, UK, July 13–15, 2005. doi:10.1007/11752707\_3
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3, 77–101. doi:10.1191/1478088706qp063oa
- Bundesministerium für Wirtschaft und Energie. (2016). *Was Ist Industrie 4.0?* Retrieved December 20, 2016, from <http://www.plattform-i40.de/I40/Navigation/DE/Industrie40/WasIndustrie40/was-ist-industrie-40.html>

- Chapanis, A. (1996). *Human factors in systems engineering*. New York, NY: Wiley.
- Clark, A. (1997). *Being there: Putting brain, body, and world together again*. Cambridge, MA: MIT Press.
- Clark, A. (1999). Where brain, body and world collide. *Cognitive Systems Research*, 1, 5–17. doi:10.1016/S1389-0417(99)00002-9
- 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, 5–33. doi:10.1006/ijhc.2000.0378
- Drain, C. (2014). The hand and cognition ... and intersubjectivity, agency, culture, and more. *AVANT: Journal of Philosophical-Interdisciplinary Vanguard*, 2, 279–291. doi: 10.12849/50202014.0109.0013
- Dreyfus, H. L. (1992). *What computers still can't do: A critique of artificial reason*. Cambridge, MA: MIT Press.
- Engestrom, Y. (2000). Activity theory as a framework for analyzing and redesigning work. *Ergonomics*, 43, 960–974. doi:10.1080/001401300409143
- Flach, J. M., & Voorhorst, F. (2016). *What matters? Putting common sense to work*. Dayton, OH: Wright State University Libraries.
- Gallagher, S. (2005). *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, S113–S121. doi:10.1016/j.ijmedinf.2006.05.015
- Gedenryd, H. (1998). *How designers work: Making sense of authentic cognitive activities* (Lund University Cognitive Science, Vol. 75). Lund: Lund University.
- Halverson, C. A. (2002). Activity theory and distributed cognition: Or what does CSCW need to do with theories? *Computer Supported Cooperative Work (CSCW)*, 11, 243–267. doi:10.1023/A:1015298005381
- Hazlehurst, B., Gorman, P. N., & McMullen, C. K. (2008). Distributed cognition: An alternative model of cognition for medical informatics. *International Journal of Medical Informatics*, 77, 226–234. doi:10.1016/j.ijmedinf.2007.04.008
- 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, 539–551. doi:10.1016/j.jbi.2007.02.001
- Heath, C., Knoblauch, H., & Luff, P. (2000). Technology and social interaction: The emergence of 'workplace studies'. *British Journal of Sociology*, 51, 299–320. doi:10.1080/00071310050030190
- Hermann, M., Pentek, T., & Otto, B. (2015). *Design principles for industrie 4.0 scenarios: A literature review* (Working Paper No. 01/2015). St. Gallen: Technische Universität Dortmund, Fakultät Maschinenbau, Business Engineering Institute St. Gallen.
- 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, 174–196. doi:10.1145/353485.353487
- Holmes, N. P. (2013). Hand-centered space, hand-centered attention, and the control of movement. In Z. Radman (Ed.), *The hand, an organ of the mind: What the manual tells the mental* (pp. 57–76). Cambridge, MA: MIT Press.
- Hutchins, E. (1995a). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Hutchins, E. (1995b). How a cockpit remembers its speeds. *Cognitive Science*, 19, 265–288. doi:10.1016/0364-0213(95)90020-9
- Hutchins, E. (2010). Enaction, imagination, and insight. In J. Stewart, O. Gapenne, & E. A. Di Paolo (Eds.), *Enaction* (pp. 425–450). Cambridge, MA: MIT Press.
- Keller, C. M., & Keller, J. D. (1996). *Cognition and tool use: The blacksmith at work*. Cambridge: Cambridge University Press.
- Kirsh, D. (2001). The context of work. *Human-Computer Interaction*, 16, 305–322. doi:10.1207/S15327051HCI16234\_12
- Kirsh, D. (2013). Embodied cognition and the magical future of interaction design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 20(1), Article No. 3. doi:10.1145/2442106.2442109

- Kolbeinsson, A., & Lindblom, J. (2015). Mind the body: How embodied cognition matters in manufacturing. *Procedia Manufacturing*, 3, 5184–5191. doi:10.1016/j.promfg.2015.07.576
- Kolbeinsson, A., Lindblom, J., & Thorvald, P. (2017). Missing mediated interruptions in manual assembly: Critical aspects of breakpoint selection. *Applied Ergonomics*, 61, 90–101. doi:10.1016/j.apergo.2017.01.010
- Kolbeinsson, A., Thorvald, P., & Lindblom, J. (2017). Coordinating the interruption of assembly workers in manufacturing. *Applied Ergonomics*, 58, 361–371. doi:10.1007/s10111-016-0399-6
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenges to Western thought*. New York, NY: Basic Books.
- Lave, J. (1988). *Cognition in practice*. Cambridge: Cambridge University Press.
- Lindblom, J. (2015a). *Embodied social cognition*. Cognitive systems monographs (COSMOS). Berlin: Springer International Publishing Switzerland.
- Lindblom, J. (2015b). 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* (pp. 3–19). Dordrecht: Springer.
- Lindblom, J., & Gündert, J. (2017). Managing mediated interruptions in manufacturing: Selected strategies used for coping with cognitive load. In: K. S. Hale, & K. M. Stanney (Eds.), *Advances in neuroergonomics and cognitive engineering* (pp. 389–403). Cham: Springer International Publishing.
- Lindblom, J., & Thorvald, P. (2017). Manufacturing in the wild – Viewing human-based assembly through the lens of distributed cognition. *Production & Manufacturing Research*, 5, 57–80. doi:10.1080/21693277.2017.1322540
- Liu, Z., Nersessian, N. J., & Stasko, J. T. (2008). Distributed cognition as a theoretical framework for information visualization. *IEEE Transactions on Visualization and Computer Graphics*, 14, 1173–1180. doi:10.1109/TVCG.2008.121
- Luff, P., Hindmarsh, J., & Heath, C. (2000). *Workplace studies*. Cambridge: Cambridge University Press.
- Marras, W. S., & Hancock, P. A. (2014). Putting mind and body back together: A human-systems approach to the integration of the physical and cognitive dimensions of task design and operations. *Applied Ergonomics*, 45, 55–60. doi:10.1016/j.apergo.2013.03.025
- Marsh, L. (2006). Dewey: The first ghost-buster? *Trends in Cognitive Sciences*, 10, 242–243. doi:10.1016/j.tics.2006.04.004
- 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: The Journal of the Human Factors and Ergonomics Society*, 42, 36–55. doi:10.1518/001872000779656651
- Nardi, B. A. (1996). Studying context: A comparison of activity theory, situation action models, and distributed cognition. In B. A. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction* (pp. 35–52). Cambridge, MA: MIT Press.
- Nilsson, M., Laere, J., Susi, T., & Ziemke, T. (2012). Information fusion in practice: A distributed cognition perspective on the active role of users. *Information Fusion*, 13, 60–78. doi:10.1016/j.inffus.2011.01.005
- Norman, D. A. (1991). Cognitive artifacts. In J. M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface* (pp. 17–38). Cambridge, MA: Cambridge University Press.
- Perry, M. (2003). Distributed cognition. In J. M. Carroll (Ed.), *HCI models, theories, and frameworks* (pp. 193–223). San Francisco, CA: Morgan Kaufmann.
- Polanyi, M. (1966). *The tacit dimension*. London: Routledge and Kegan Paul.
- Prinz, J. J. (2013). Foreword: Hand manifesto. In Z. Radman (Ed.), *The hand, an organ of the mind: What the manual tells the mental* (pp. ix–xvii). Cambridge, MA: MIT Press.
- Rogers, Y. (2012). *HCI theory: Classical, modern, and contemporary*. San Rafael, CA: Morgan & Claypool.
- Rogers, Y., & Ellis, J. (1994). Distributed cognition: An alternative framework for analysing and explaining collaborative working. *Journal of Information Technology*, 9, 119–128. doi:10.1057/jit.1994.12
- Rogers, Y., & Marshall, P. (2017). *Research in the wild*. San Rafael, CA: Morgan & Claypool.
- Sellberg, C., & Lindblom, J. (2014). Comparing methods for workplace studies: A theoretical and empirical analysis. *Cognition, Technology & Work*, 16, 467–486. doi:10.1007/s10111-014-0273-3

- Sellberg, C., & Susi, T. (2014). Technostress in the office: A distributed cognition perspective on human–technology interaction. *Cognition, Technology & Work*, 16, 187–201. doi:10.1007/s10111-013-0256-9
- Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge: Cambridge University Press.
- Susi, T. (2006). *The puzzle of social activity – The significance of tools in cognition and cooperation* (Doctoral dissertation). University of Linköping, Linköping, Sweden.
- Szymanski, M. H., & Whalen, J. (2011). Work practice analysis at Xerox. In M. H. Szymanski, & J. Whalen (Eds.), *Making work visible* (pp. 1–17). Cambridge: Cambridge University Press.
- Taylor, F. W. (1911). *The principles of scientific management*. New York, NY: Harper & Brothers.
- Thorvald, P. (2011). *Presenting Information in Manual Assembly* (Doctoral dissertation). Loughborough University, Loughborough, UK.
- Thorvald, P., & Lindblom, J. (2015). Distributed cognition at work – A systemic perspective on human based manufacturing. In L. Newnes, A. Nassehi, & V. Dhokia (Eds.), *Proceedings of ICMR 2015* (pp. 195–200). Bath, UK: University of Bath.
- Williams, R. F. (2006). Using cognitive ethnography to study instruction. In S. A. Barab, K. E. Hay, & D. T. Hickey (Eds.), *Proceedings of the 7th International Conference of the Learning Sciences* (Vol. 2, pp. 838–844). Mahwah, NJ: Lawrence Erlbaum Associates.
- Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics*, 31, 557–567. doi:10.1016/S0003-6870(00)00034-X
- Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics*, 45, 5–13. doi:10.1016/j.apergo.2013.03.021
- Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17, 89–100. doi:10.1111/j.1469-7610.1976.tb00381.x
- Wright, P. C., Fields, R. E., & Harrison, M. D. (2000). Analyzing human–computer interaction as distributed cognition: The resources model. *Human-Computer Interaction*, 15(1), 1–41. doi:10.1207/S15327051HCI1501\_01