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Robots as a Place for Socializing: Influences of Collaborative Robots on Social Dynamics In- and Outside the Production Cells

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Introducing robots in the workplace entails new practices and configurations at the individual, organizational, and social levels. Prior work has focused on how robots may have an immediate effect on individual employees or tasks rather than collectively influencing employees or the organizations they work for gradually over time. By drawing on fourteen in-situ interviews with six collaborative robot (cobot) operators at a Danish manufacturing company, this paper investigates how cobots in the manufacturing context may engage broader interactions beyond the robot-operator interaction. Our focus includes spatial configurations centering around the cobots, social interactions between employees, and information flow through, within, and outside the production cells. Introducing and implementing cobots in the workplace has social dynamics at its core, which we explore in depth. This paper argues that the design of cobots and the environment around them should accommodate the possibility of more complicated social and organizational changes brought about by these robots. Lastly, we discuss research and design implications for the future of workplaces involving robots.

CCS Concepts: • **Human-centered computing → Collaborative and social computing devices**; **Computer supported cooperative work**; *Ethnographic studies.*

Additional Key Words and Phrases: Collaborative robots, Social dynamics, Workers, the Future of work, Workplaces

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1 INTRODUCTION

In an interview [57], Jonathan Grudin, the author of a CSCW seminar paper (1988) titled "Why CSCW Applications Fail," [39] pondered on which of the reasons why CSCW applications and projects fail still hold today. Nuanced activities in organizational and team processes are often overlooked by us, he says. *"The sources of trouble I described back then mostly arose from insufficient understanding of organizational processes and team processes, and I thought we would quickly overcome them... we don't understand the nuanced activities we are hoping to support. So we do still encounter*

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some of the same problems in these new contexts" [57, p.213-214]. In a similar vein, Galegher and Kraut argue in their book on CSCW that the systems' relative failure derives from their insensitivity to "what we know about social interaction in groups and organizations" [37, p.6].

In this work, we present the study that looks at how collaborative robots (cobots) may engage in broader interactions beyond the robot-operator interaction, which highlights the nuanced activities and social interactions around cobots in manufacturing companies. Colgate and Peshkin [84] introduced the concept of cobots in the late 1990s, referring to them as *"a robot for direct physical interaction with a human user, within a shared workspace."* Cobots, as the new type of industrial robot, provide safer working conditions due to the reduction in robot speed and force, leading to the possibility for removal of physical barriers surrounding the robots. As a result, industry has been rapidly embracing cobots in recent years.

HCI researchers have studied collaborative robots [23, 66, 112] or robots for industrial settings [28, 92]. They have focused on either the human-robot interface (e.g., examining how to make the robot's interface accessible [76] and easy to program [35, 112]) or a human's perception of the robots [28, 73, 92] (e.g., how different groups of humans perceive the robots differently). The goal is often to design an effective human-robot interaction so that individual users can adapt the robots smoothly at work. Researchers are beginning to explore the potential broader impacts of robots, such as on the group [59, 74] and on the organizational level [9], rather than on the individual level. Some of this work, for example, has looked at how robots' gaze cues (e.g., [68]), movements (e.g., [104]), expressed emotion (e.g., [29]), and statements (e.g., [54, 81]) shaped people's roles in a group or changed work routines and collaboration patterns [9]. The majority of the work on the influence of robots within groups or on an organization addressed the direct effects of the robots. However, researchers have long informed that robots, like other technologies (e.g., [78]), may have unforeseen but more serious repercussions. For example, despite the widespread belief that social and care robots will be well received by the elderly, some studies show that robots designed for the elderly tend to objectify and infantilize them, eroding their dignity as humans as well as their cognitive abilities [49, 71, 82]. As another example, as Salvini et al [90] point out, service robots, like any other urban object, could be targeted by vandals. This necessitates an examination of the settings in which robots are positioned, as well as the people who share the robots' area, rather than focusing solely on robot users. Given that robots have become increasingly more common in industry than in other places, much work is needed to understand how such robots may engage broader interactions beyond the robot-worker interaction and potentially influence social and organizational dynamics.

In this paper, we investigate how the introduction of cobots has impacted the working environment, inside and outside of the production cell for the production operators. We conducted 14 interviews with six cobot operators in a Danish company. We interviewed each operator between one to three times over the course of three months. All interviews were conducted on-site at the company, typically in-situ in the cobot cell. Grounded in these interviews, our analysis reveals three findings sections: (1) reconfiguration of spatial setup in the production cell and the resulting change in social interaction within the cell, (2) the importance of informal information sharing to address uneven distribution of knowledge among cobot operators, as well as (3) the need for cell-external support both from within and outside of the company.

This paper endeavors to make three contributions: first, we fill an empirical gap by centering our study around social and organizational dynamics brought by robots at the workplace, expanding our understanding of robots' effect beyond the operators-robots interaction. We demonstrate the introduction of cobots facilitating social interactions among operators and other employees around the production cell, although the number of operators per cell is reduced. This effect was hypothesized in a recent study by Smids et al. [103], but without an empirical account. Second, we detail where these social interactions occur, revealing workplace organizational dynamics such as uneven distributions of cobots operation knowledge across shifts, operators' tendency to use cobot knowledge to quantify their roles within and contributions to the company, and the division of workspaces reflecting the relationships among employees. Finally, based on these findings, we discuss design and research implications CSCW researchers can take to further examine the ripple effects [59] of robots at work. We discuss how the new spatial configuration around cobots prompted operators to engage with cobots through a network of social interaction, and what this implies to the current approach to examine human engagement and collaboration with robots. By taking up the concepts of boundary spanning [106] and three relations of boundaries (boundary cooperation, boundary neglect, boundary strain) [8] from organization studies, we elaborate on nuanced differences of social interactions depending on which groups of employees the operators interacted with. We also discuss opportunities for HCI and CSCW researchers to observe how to respond to the malfunction of robots in a workplace, calling for research on how we might capitalize on the failure of robots to foster human engagement and collaboration in an organization.

2 BACKGROUND AND RELATED WORK

This section highlights topics related to the introduction of technology, especially cobots, to industry and existing works related to the impact of robots' presence on social dynamics. We first describe what cobots are and what the Danish cobot industry looks like to provide background for our study.

2.1 Cobots

The term collaborative robot (cobot) is not a new phenomenon, yet the deployment of this specialized type of industrial robot is a more recent development. While multiple types of cobots exist (i.e., for transport or handling of goods), this study purely focuses on 'arm-shaped' cobots (see example in Figure 1b). This type of cobot, while still being an industrial robot, has different characteristics from the classical industrial robot (see example in Figure 1a). The definition given by Peshkin and Colgate in 1996 still holds to this day, namely "[a] cobot is a robot for direct physical interaction with a human user, within a shared workspace." While they visually seem similar, the ability to operate in a 'shared workspace' is made possible due to a decrease in force and speed compared to classical industrial robots. Thereby a potential collision with cobots has less severe consequences. Due to this, direct physical interaction with cobots is possible, as the need for cages around them diminishes. The cheap and flexible nature of cobots in comparison to classical industrial robots makes these more attractive for smaller and medium-sized enterprises (SMEs) and opens up the possibility for gradual implementation. Furthermore, the comparative ease of switching between different modes (e.g., when working on different products) makes interaction with cobots much different from interaction with classical industrial robots. As these factors all contribute to the potential for different and more direct interaction with robots compared to caged classical industrial robots, we believe that it is critical to research cobots in CSCW and HCI.

A recent report from ABI Research [105] highlights the current growth of the cobot market, from 475$ million in 2020 to an estimated 8$ billion in 2030. Currently leading cobot innovation and market share is the Danish company (see example robot in Figure 1b). In Denmark, the robot development and robotization of the industry has had an enormous growth—from no Danish robot industry to a revenue of nearly 1$ billion due to robot exports—in the last 15 years [87]. This growth of the global (and Danish) cobot industry led to the establishment of the world's largest robot hub in Denmark, a center to further cobot development.

(a) Classical Industrial Robot (AAB IRB 6620) (b) Collaborative Robot (UR3)

Fig. 1. Examples of a classical industrial AAB robot (payload of 150kg), and the Universal Robot UR3 (payload 3kg).

2.2 Introduction of Cobots in the Workplace

A wide variety of studies have investigated the impact of introducing emerging technologies such as robots and automation in the workplace (e.g., [6, 52, 65]), focusing on various aspects including social interactions [69, 70, 83], safety [64, 67], work organization [42, 113], or the importance of worker involvement and acceptance [48, 63, 65, 88, 103].

With the growing use of cobots in the workplace, it has become more vital to analyze how cobots may improve or disrupt human work experiences [107, 113, 114]. Recent research [65, 103, 113] looked into what dimensions of manufacturing workers' experiences might be changed by working with cobots, as well as how they could better adapt cobots. Welfare et al. [113], for example, identified desired work attributes (e.g., autonomy, human interaction and team dynamics, movement, and exercises) as well as undesired ones (e.g., health issues, long hours, upper-management issues) related to manufacturing tasks. Through interviews with assembly-line workers, they identified how people feel about these attributes based on their work experiences. They found that assembly line workers were particularly concerned that the increased use of automation technologies could reduce or eliminate social interaction with coworkers during the workday. Other scholars examined the impact of workplace robotization on meaningful work from a philosophical standpoint [103]. They show that robots in the workplace could be either a threat or an opportunity, based on the identified five components of meaningful work, such as social relationships, self-development, and autonomy. While Welfare and others [113] classify the introduction of robots as a factor leading to a reduction in social interaction, the study [103] predicted that both scenarios could occur: while the introduction of robots may indeed lead to less social interaction, robots would perform repetitive tasks, freeing up more time for social interactions between colleagues or customers. Building on the previous research, a recent study [97] showed the establishment of social rapport among workers significantly led people to be more willing to work with another human coworker than a robot. To collaborate with another person, their participants reported that they were even willing to forego monetary gain.

In contrast to other studies that have focused on individual assembly-line workers' reactions to cobot introduction, a study by Meissner et al. [65] examined workers' attitudes toward cobots as well as the organizational changes associated with cobot introduction, highlighting the importance of a more comprehensive approach to human-robot collaboration acceptance at work. The study conducted interviews with assembly-line workers (half of whom have cobot experience) in four German manufacturing companies. Their workers indicated the following dimensions of their attitude toward organizational changes brought on by the introduction of cobots: relationship with executives and colleagues, and the implementation process. When it came to the implementation process, in particular, the researchers found the importance of involving workers at eye level and taking their feedback seriously. While communication is essential, it is also crucial to conduct it on equal footing. The findings also showed that the workers expected that the presence of supervisors and/or robot experts would be critical, especially during the first weeks of training, because access to support staff, or the lack thereof, has a direct impact on workers' perceptions of human-robot collaboration. In a similar vein, Charalambous et al. [17] focused on organizational human factors that must be considered in order to help organizations successfully introduce robots, and operator participation in the implementation process was highlighted as a critical part [12, 53]. The degree of worker involvement in the cobot adaption (e.g., [63, 69, 88]) has also been emphasized as it may significantly shape workers' perceptions of cobots [28].

Given that prior research has addressed critical dimensions (individual and organizational) associated with positive perception and adaptation of cobots (e.g., social interactions between employees, resulting organizational changes), we believe it is crucial to dig deeper into them to better understand how introducing and deploying cobots may affect broader interactions between different levels of employees across the organization, and to comprehend workers' experiences of those social and organizational changes.

2.3 Influences of Robots' Presence on Social Dynamics

Prior studies have shown that robots in the workplace can exert influence beyond conventional dyadic interaction with individual workers [2, 3, 9, 33, 92]; they found that robots' mere presence can shape people's behaviors and attitudes as a group toward robots [86, 92], social and interpersonal dynamics within the group [8, 59, 83], new tasks and roles [5, 21, 102, 108], and social norms around the robots [59]. Lee et al. [59] referred to these broader interactions surrounding the robots as "ripple effects". Over four months of field study with Snackbot [59], a snack-dispensing robot, in an office environment, they found that the robot's presence changed employees' snack routines and established new social norms around the robot. Employees who once had snacks alone in their offices began to gather with their coworkers around the Snackbot during their snack time. Also, by interacting with the Snackbot as a group, they learned from coworkers about more effective ways to respond to the Snackbot. Argote et al. [2] showed that robots in the factory could create an opposite effect than that created by Snackbot as the increase in mental demands of workers' new roles (e.g., monitoring the robots) decreased socialization with others.

While some studies on robots in work settings described group and social dynamics (e.g., [72, 83]), the majority focused on the direct effects of robots' behaviors on a group (e.g., changing workers' perceptions of and reactions toward the robots) [16, 73, 98]. For example, in a study by Sauppé and Mutlu [92], the robot operators in the factory began to treat the Baxter robots with whom they worked as closely as coworkers. Studies showed that workers tended to respond to robots differently depending on their workplaces and roles at work. However, the mere presence of robots in a workspace can affect how people behave and interact with others. Several studies have examined this, mostly through experimental studies. According to the study by Dole [31], for example, in the presence of social robots, participants tended to look more often at their medical providers but less warmly toward them. They did not have this tendency when interacting with nonsocial technology (e.g., tablets). Similarly, in scenarios of workplaces using social robots [86], the mere presence of robots around workers facilitated better human performance of easy tasks compared to that when the workers were alone. Barrett et al.'s study [8] at two hospital pharmacies detailed how a dispensing robot inspired new work practices and relationships between different occupational groups (e,g, pharmacists, assistants, and technicians). We seek to dig deeper into the ways in which robots in the workplace may alter human behavior, such as how people in factories communicate and collaborate with one another. To that end, rather than analyzing how people's immediate reactions to and interactions with cobots might change, we examine the more subtle "ripple" effects that these robots will have in the workplace.

The organizational and social impacts introduced by robots have been studied mostly in contexts outside of work such as nursing home [16], autism therapy [94], children's play [100], game playing [29, 81], dancing [50, 51], shopping [55], and museum guidance [75]. For example, some studies on robot use in autism therapy examined how children's social interaction skills could be taught by a robot when the robot mediated interpersonal interactions among a group of children (e.g., [94]). While social robots were purposefully used for such human-robot interaction studies on interpersonal and social dynamics, it has been little explored whether robots without conventional social cues or appearances (e.g., industrial robots with non-anthropomorphic features and movements [54, 66]) also may change how humans socially interact with each other in daily life settings such as workplaces.

To develop robots to support collective employees at the workplace and companies, we must broaden our focus beyond human-robot interaction and investigate how the introduction of robots may trigger subtle and unexpected bearings on human social and organizational behaviors. We elaborate on this intersection throughout this paper.

3 METHOD

The following section describes our approach to data collection, the participants' demographics, unique characteristics of the Danish workplace culture, as well as an overview of our research site – company A. Lastly, this section presents our analytic approach.

3.1 Procedures

To understand how the introduction of cobots affected social and organizational dynamics around operators, we conducted contextual inquiry fieldwork [47, 85]. We recruited companies that recently (within the past three years) adopted cobots through our network, which included a large collaborative robot manufacturing company as well as snowball sampling. Finding company participants was difficult, as we were in the middle of the national lockdown due to COVID-19. After three months of recruitment, we were able to maintain contact with one company, hereafter referred to as company A. Our data collection period was set from February 2021 until May 2021. In this time, at company A, a collaborative cell was built in production in lieu of the existing production pipeline, and operators began working with collaborative robots for the first time. Throughout the implementation process, we visited the company two or three times a week for three months to observe and conduct interviews. The third author had done an internship at company A and thus had already established relationships with some of the operators and other employees. The author's previous experience as an intern at company A provided us with an in-depth understanding of the implementation of cobots from the beginning of our research.

Since company A gradually introduced and implemented cobots one by one, due to administrative issues and a delayed cobot delivery, we decided to conduct multiple (up to three) rounds of interviews. All interviews were conducted on the shop floor or in the cell while the operators were at work. Sometimes we couldn't record all of the interviews and had to rely on our fieldnotes. We also had informal conversations with the operators while visiting the cell regularly for three months and observing their work configuration. These informal conversations and observations provided

ID	Shift	Time in company	Gender	Robot experience	Interviews
O1	Day	14 years	F	Yes	3
O2	Day	5 months	M	No	3
O3	Evening	7 months	M	No	3
O4	Night	4 years	M	Yes	2
O5	Night	13 years	F	Yes	2
O6	Day	2 years	M	No	1
				Total Interviews:	14

Table 1. Participant table summarizing the six participants including the shift they work, time worked within the given company, gender, their prior robot experience, as well as the number of interviews conducted. We conducted a total of 14 interviews.

context for our interview data. Although our observation criteria were open, we focused on the interviewees' perspectives on interacting with cobots and transitioning to new work environments; their confidence when operating cobots (especially over time); and their reactions to technical or relational challenges associated with the cobots. The rounds of observations became more of a continuous series of small interviews. Getting a sense of how people felt in the moment and seeing things that operators might not have talked about in later interviews was especially interesting. As a result of our "fly on the wall" observation [115], we were able to better understand the operators' perspectives and get a clearer picture of the situations they described in later interviews. In the observations, our roles as researchers were conspicuous and our motives were clear: operators and other employees were aware of our data gathering and our goals in gathering the data. This was an important ethical consideration since they could always withdraw their consent for their parts of the data collection. The short, informal conversations in which operators provided us with regular updates on the newest cobot deployments and their impressions of working with the cobots were also included in our data.

3.2 Company Profiles and the Workplace Culture in Denmark

We conducted three months of fieldwork in a Danish company to gain a better understanding of the introduction and use of cobots in the Danish workplace. Here, we present profiles of the company and the Danish work culture.

3.2.1 Company A. A large production company in Denmark with over 2000 employees. To increase competitiveness, and thereby keep producing in Denmark instead of outsourcing to cheaper labor markets, company A started in 2009 to invest heavily in automation using industrial robots. As industrial robots have several downsides compared to collaborative robots (cobots), such as a large footprint, the need for cages, as well as full production stop when something goes wrong, company A decided to invest in cobots. They have now re-structured one of their fully manual production pipelines, containing four employees, to a semi-autonomous cobot cell containing two cobots and three employees. The cobot cell is operated around the clock using three different shifts (day, evening, and night), each with three operators. The company has over 100 industrial robots, including ~10 cobots.

3.2.2 Characteristics of the Danish Workplace. Given that Company A is based in Denmark, it has a few distinguishing features compared to, say, a company based in the United States or East Asia.

The Scandinavian and especially Danish workplace is built around the concept of an egalitarian structure [18, 44, 79]. This was also observed during the interviews, e.g., O6 who stated *"That is the nice thing here in Denmark that you can voice your opinions anytime and you are being heard."* Furthermore, the focus on a decentralized decision-making process, provides individual employees, of all levels, more autonomy about decisions that may affect their jobs [15].

3.3 Operators

We conducted 14 semi-structured interviews with six operators. The semi-structured interviews with each operator lasted between 43 and 94 minutes and were all audio recorded. Given the operators' busy schedules and, at times, the high volume of noises, the interviews had to be brief. As a result, each operator participated in one to three interviews (see Table 1). Although not all operators reported their ages, the operators' self-reported ages were from twenty to sixty-five. They had a wide variety of total duration of employment, ranging from 5 months to 14 years. While half of the workers (O1, O4, O5) have had prior experience with robots (i.e., classical industrial robots), the rest of the operators (O2, O3, O6) had no prior experience with robots or cobots. Our meetings for interviews were arranged by our company contacts, and interviewees voluntarily participated in the study. While we did not pay the operators to participate in the interview, all interviews were conducted within the cobot cell during working hours.

We structured the interview protocol around several topics relating to changes in the company's production processes with the introduction of cobots, including changes in tasks, work routines, social interactions, and workers' involvement in integrating the cobots into the workplace. During the interviews, we also encouraged operators to discuss interests relevant to our protocol. When necessary, we asked further probing questions as well.

3.4 Data Analysis

Drawing from constructivist-grounded theory [19, 20], we collected and analyzed data from our field site (e.g., field notes, pictures, audio/video files) and refined our semi-structured interview questions over time to focus on themes emerging from the data. Following the data collection, we transcribed all interviews. We tried to familiarize ourselves with the data by individually open-coding the first three interview transcripts. Based on initial codes such as "human-human interaction", "changing work environment", and "information flow", we iterated our questions to probe these themes for the remainder of the interviews. As we individually open-coded them again, the codes were expanded to include codes such as "no official training", "relying on others", "spatial configuration", "worker involvement", "different work position." A total of 132 codes were clustered and iterated among our research team through multiple meetings. The relevant photos and videos taken during our company visits were also analyzed at this stage as supplementary data. This resulted in three major themes, which we will report in the following section.

Given our analytic approach [19], we reflect on our individual positionalities which we brought to this study. Two of our research team members were trained as HCI and HRI researchers, and one of them focused particularly on CSCW and design. Given our lack of experience in and knowledge of the manufacturing industry prior to this study, we feared that we might not recognize politically and socially sensitive issues during our research and miss an opportunity to investigate them. Our analysis also similarly could be shaped by our educational backgrounds, which may prevent us from being fully sympathetic with the operators and their blue-collar technical training in lieu of academic educations.

4 FINDINGS

Through the data collection (see Section 3), we observed that the interactions of the cobots and other employees varied depending on the spatial setup, with the setup influencing whether the interactions took place within or outside of the cobot cell. We structure our findings around the spatiality of the interaction, as this kind of organization allowed us to focus on differences and unique aspects of interactions depending on the spatial relationship. In Section 4.1, findings related to work processes and communication within a cell are presented. Then, Section 4.2 moves on to human-human interactions between operators from different shifts, while findings in relation to external communication, including interactions with external supporters and the management, are presented in Section 4.3.

4.1 Within the Production Cell: Rearrangements, Reductions, and Prioritization

In this section we present three related changes within the production cell, these are: the necessity for spatial and procedural changes; the reduction of workers and its impact on social interaction; and the importance of working with the right coworkers. These changes all stem from the transition from manual to cobot-supported operation.

4.1.1 Cobots Necessitate Procedural and Spatial Changes. During the data collection, as described in Section 3, company A described the necessity for a change in working procedure and spatial setup of the production.

Prior to the cobot introduction, company A was utilizing a pipeline-based approach for manufacturing with four employees along an approximately 60-meter-long, as estimated by O1, production pipeline (see Figure 2). The pipeline was characterized by a linear structure with an input, the disassembled product, and the assembled product as an output. During the process, four assembly workers would each perform a specific task.

As the cobot has limited reach, its optimal utilization required a restructuring of the pipeline to a new spatial setup, focusing on optimal use of the cobot's reachable area. To achieve this, company A restructured the entire process from a linear to a circular process, as illustrated in Figure 3. The spatial shift was organized in four quadrants (Q1-Q4), with the two cobots implemented in Q3 and Q4 as illustrated in Figure 3. By condensing the spatial setup, this allowed each of the two cobots to perform multiple tasks. Specifically, Q3 would (i) unload the disassembled product, (ii) place it on a conveyor belt, and (iii) palletize the completed product at the end of the cycle. The cobot in Q4 would (i) pick up the product from the conveyor belt and (ii) divide the product into three parts, ready for the operator to continue assembly. A third cobot in Q1 is currently planned by company

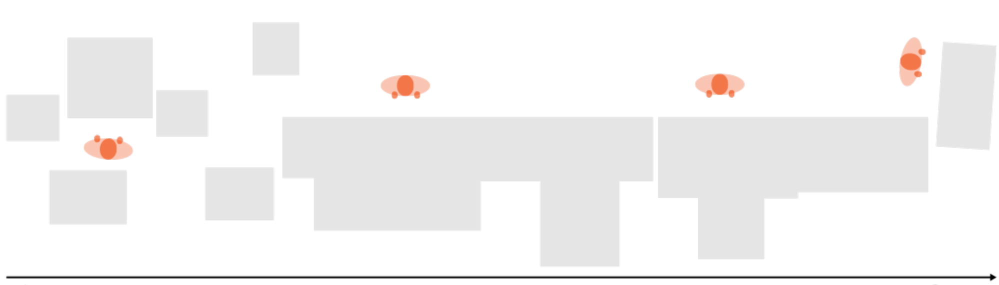

Fig. 2. Production pipeline in company A prior to cobot implementation. Production workers are highlighted in orange (●). Light grey (●) areas highlight machines, carts, storage boxes, and similar.

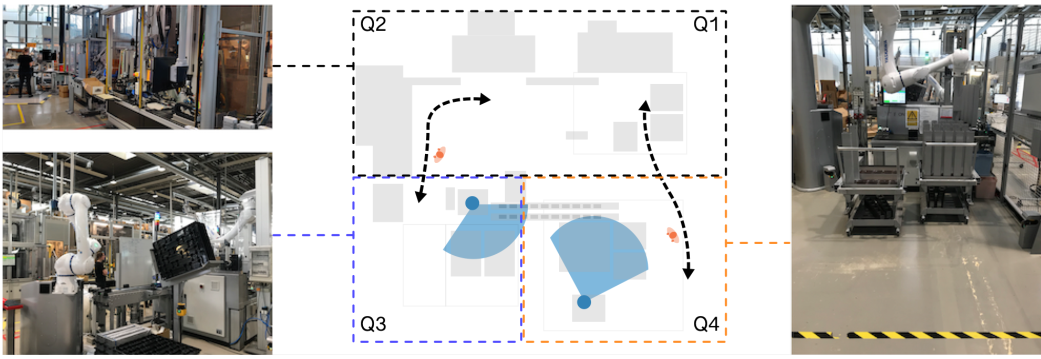

Fig. 3. Company A made significant changes to the work environment due to the introduction of Cobots. Operation starts and ends in quadrant 3 and proceeds counterclockwise. Orange silhouettes (●) highlight the two operators, and the dashed arrows next them represent their respective area of responsibility. Blue circles (●) show the cobot position with a cone illustrating the operating area. Light grey (●) areas highlight machines, carts, storage boxes, and similar.

A. Furthermore, the condensation from production pipeline to production cell reduced physical distance between work processes – allowing the reduction of personnel requirements from four to two (three during the initial period), thereby freeing further human resources for other, high-value, tasks.

4.1.2 A Decrease in the Number of Operators and an Increase in Social Engagement. With the introduction of cobots, and the resulting need for spatial restructuring from a production pipeline to a production cell (see Section 4.1.1), a change in human-human interaction followed. This was particularly relevant in company A, as it reduced the number of human workers from four to three. Even though the number of human workers was reduced, operators expressed an increased sense of social connectedness and interaction with coworkers. This was caused by multiple factors, including the creation of smaller breaks—created by the robot operation—thereby allowing room for small talk. After having worked in the cobot cell for three months on a daily basis, O1 described the increased possibility for social interaction: *"...I can also feel it [increasing interaction among the workers] when we stand in the cell. People talk a lot more together. We talk a lot more together and laugh together. We have a much better togetherness in the robot cell, and I feel that.[...] there is just time for that small talk in between"* (O1).

The increase in human-human interaction—since the number of workers in the cell has been reduced—is strongly related to the cobot-facilitated need of spatial configuration. Even though the pipeline had more workers, the distribution of them (see Figure 2) did not allow for easy communication, apart from the one or two adjacent colleagues. The change towards a cell decreased the maximum distance between workers to just a few meters, thereby making both visual and auditory interaction significantly easier.

Apart from the spatial setup, other cobot-related factors optimized the possibility for social human-human interaction. The continuous operations of the cobots allowed human 'down time' without a full stop of the production, as the cobots would continue operation even though humans would take a break. As the cobots are still relatively new, the effective operation using cobots required workers attention, thereby making the cobots themselves topic for discussion between operators. O3 expressed his appreciation of the increased communication between colleagues: *"I really think you talk more together because there are some things that you need to take a little more* *into account when it comes to robots, so you have to keep your eyes on them [cobots] all the time, and all the time we just talk together"* (O3).

While operators now worked closer together, there was still a clear distinction between areas of responsibility. For example, O3 stated that the division of labor is related to the placement of the new work stations: *"...one person has half [Q1 & Q4 in Figure 3] the cell and the other has the other half [Q2 & Q3]. Right now we are three people [third person helps where needed], so it's a little easier. You can still help each other and just jump in if there is someone who does not have the overview, or we are busy with something else"* (O3). As pointed out in the quote by O3, the ease of 'jumping in' to help other operators allowed for the possibility to troubleshoot collaboratively and interact with each other and the cobots; the operators could easily look over each other's shoulders and intervene in their works, which naturally led to a conversation pertaining to the topic: *"We have a better opportunity now to go in and help each other than we had before [in the pipeline setup] [...] And we have the opportunity to just small talk with each other occasionally. I think we have better communication compared to before, there is no doubt about that. It is the communication and collaboration that has simply gotten better than it was before"* (O1).

4.1.3 The Importance of Whom to Work with. With the decrease in colleagues in the same cobot cell and shift, more importance was placed on the cobot operator's decision as to whom to share the cobot cell with (e.g., O1, O3, O4, O5, O6). Working alongside robots in the cell became a place for our operators to interact with human workers; it is now more important than ever to work with colleagues who share similar work ethics and chemistry. O5 stated the rationale for this explicitly: *"I like to have the same colleagues and stand with the same ones every day. I like that. It just creates something else if you feel good and have fun. I think that is important"*. One operator expressed her desire to work with a specific colleague, whom she had selected as a first preference match. The first pick coworker was placed on a different shift, which prompted her to speak with upper management: *"When I was told that the first one [preferred coworker] I had chosen went on the night shift, I just thought 'this is a challenge for me all of a sudden'. It's [not getting the first choice coworker] not a challenge for him [production cell leader] but it was a challenge for me [...]. Then I had a conversation with him [production cell leader] because now he has removed my partner, 'who do I want' and then I thought about it and then my choice fell on James [new coworker]"* (O1).

As company A still was in the early stages of cobot implementation—with merely a few months of experience in the production cell illustrated in Figure 3—they where still using three, instead of the planned two, workers per shift. Yet, O1 expresses her prediction, based on some months of experience in the cell, for the future with only two workers: *"It gets different when it [the amount of people in the cell] cuts down to two people. And then it is important that the person you stand with, that you can [work and socially] with that person. [...] We have been allowed to provide some input on who we would like to work with."* Whereas previously every worker had a designated independent role, information, such as new robot errors, is shared between members of the same shift to ensure that everyone has the competencies to deal with the cobots. Despite the fact that the number of workers in the cell has decreased, our operators prefer to work with a single right colleague rather than be surrounded by a large number of human workers who may mingle with them. For O6, the amount of work their cell can accomplish during the workday is also important, and the right teammate can help: *"Four people is really a lot. [...] The fourth person, is really not that huge of a help. But you can ask anyone, three people and cobots is much better than four people and no robots."*

4.2 Interactions between Different Shifts: Information Distribution

This section presents findings that are related to the uneven access of information regarding cobots among different shifts and then details two approaches used by operators to resolve this uneven information distribution, namely, gatherings and meetings for information sharing, as well as informal conversations to strengthen the competencies of operating cobots.

4.2.1 Uneven Distribution of Information across Shifts . We found that the introduction of cobots in the workplace led to new interactions between operators across shifts. These interactions, which occurred either in the production cell or in designated meetings rooms outside of the cell, were initiated to solve the uneven distribution of information about the cobots' operation across shifts. When the first two cobots were installed in the production cell, the operators of the first cell of the day and the evening shifts began working with the cobots. The collaboration was quite slow, as many technical issues demanded resolutions. Within six weeks, the day shift was mostly operating smoothly with the cobots, but the night shift experienced intermittent issues that sometimes were not resolved immediately, as the external cobot integrator was not present during the later working hours (i.e., the evening and night shifts). Cobot operation during night shifts began at that time and then was paused and started again a couple of weeks later. At this point, the cobots were still experiencing intermittent technical issues, and the arrival of a third cobot was postponed indefinitely.

Adopting the cobots at Company A involved many technical challenges that often delayed production schedules, the introduction of additional cobots, or even both. We highlight here two major aspects discovered during the cobot adoption process: first, all operators were asked to start their first day of cobot collaboration without any training or instruction (see also 4.2.3 for more detail). The operators learned how to operate the cobots by running the cobots by themselves. Second, over time, day shift operators naturally accumulated more experience and knowledge about the cobots than the night shift cohort.

During the day shift, external cobot technical support personnel were available around the cobots' cell to observe their operations. As support staff are not employed by the company but outsourced to an external company specializing in the integration of robotic systems, they were not present at the production cell during the night shift. Thus, only day shift operators could rely on expert support from these specialists when needed. For example, O2 told us that *"...the technicians have helped us to learn about the things that I did not really know, as Julie [another person in the same shift] also did not really know them"*.

Operating and working with cobots were new experiences for all operators, regardless of their individual work experience in production. Cooperation among operators of the same shift was of little help in becoming a cobot expert, although the new spatial arrangement of the cobot cell, enabled by the cobot adoption, allowed operators to stand close to and interact more with other operators (see Section 4.1). As support staff availability was greatly limited during the night shift, night shift operators had to reach out to day shift operators for assistance and expertise. O3 from the evening shift describes the information gap resulting from the discrepancy of support availability between the day and evening shifts:

> *"[...] all the professionals who deal with these robots are here during the day, so it is typically only Peter who has been here until 5, 6, maybe 7 PM, and then he drives home and then we are by ourselves. [...] it definitely has an impact if you are on the evening shift, we do not get the same information as those on the day shift. Because they have a greater opportunity to ask if they need to, then they can just ask when those people [external robot supporters] are here from morning to afternoon, so they have all day to ask 'how and what'. We cannot really do that in the same way. And when we need information we talk to the day shift, but of course it is not guaranteed that Laura [from the day shift] can remember everything"* (O3).

Although day shift operators could take full advantage of external staff for technical support during their working hours, they rarely communicated what they had seen and learned to their night shift counterparts.

4.2.2 Resolving Information Inequity. Night shift operators could not avoid relying on other shift operators in the process of acclimation to cobot operation. One evening and one night shift operator (O3, O4 respectively) were temporarily moved to day shifts to obtain access to the external support. While there was no formal cobot operation training, O4 was excited to observe and interact with the day shift operators, allowing him and other night shift workers to become more competent in operating the cobots. O4 said, *"...for sure [I like to continue working with the cobot]. That was actually why I came over to the day shift, to learn it [operating the cobot] and to be able to teach it [to] the night shift. [...] As far as I can understand, we were supposed to have one [night shift operator] on the day shift for a week, so we could be trained [in operating the cobot], and then we teach it [to the other night shift operators]"* (O4).

As there was no formal cobot operation training, information was usually conveyed between shifts by word of mouth without recording or documentation. Even errors were discussed via informal chats during shift changes. For example, O3 told us that occasional cobot mal- functions were addressed in discussions with operators on the day shift and adjustments to the operation of the cobots were made accordingly: *"Yesterday, for example, when we came to work, Laura [from the day shift] told us that the cobot was not really running well, so we had to run it [production] manually."*

As this quotation indicates, cobot errors were not immediately reported to colleagues working the next shift, but only during the shift switch itself, potentially hours later. However, the sharing of knowledge on how to resolve errors via informal discussion between shifts was often insufficient. Night shift operator O5 told us that the knowledge that she could absorb over the shoulders of day shift operators was limited. Addressing complicated situations, such as complex cobot malfunctions, could also not be done through small talk during shift changes: *"[...] now we run with the robots at night, and I am more or less the only one who knows how to run them. Of course I have tried to teach them [other operators] [...]. We have not been taught enough, regarding errors and such things. We came in, for example, today, and there they told us that this robot can not run normally, it has reported an error. There it would have been nice to know what to do about that mistake. It should be able to run, even if the external people are not here anymore"* (O5).

Acknowledging the limitations of the present informal arrangement for information sharing, operators (e.g., O3, O4, and O5) explained their most recent method of conferring: *"[...] now we had a weekly meeting yesterday, [I think] we should have a meeting every other day down in the cell with the people who are dealing with them [the cobots], so that they can tell if there has been some information to pass on and vice versa, if we in the evening experience some things, then we can pass it on to the day team"* (O3). While interactions across the production cells tended to be unilateral (e.g., the evening shift learning from the day shift), meetings conducted outside the cell provided forums in which to share experience and knowledge across shifts.

4.2.3 Strengthening the Knowledge Concentration of a Production Cell through Informal Channels among Operators. Interactions with operators from other shifts in- or outside the production cell enabled operators to learn about the cobots and operate them smoothly during their own shifts. At the same time, sharing information via informal discussions or meetings among shift operators from all three different shifts tended to circulate knowledge of cobots only within the production cell. For example, O3 told us how he was now confident in handling the cobots independently, differentiating him from non-operators outside the cell and other employees in different positions in the company: *"... we have our maintainer [another employee outside the cell] here who does not* *know anything about robots, so it is only us and then the professionals [external robot supporters] who have been on it, who actually know something about it [cobots], and when the outside partner leaves, we're the only ones who know about the cobots, that's cool!!!"* (O3). The concentration of knowledge about the cobots within the production cell gave him a feeling of monopolizing these insights.

Knowledge about the cobots was either learned from other shift operators or acquired independently in a more tacit and experiential manner. Operators found that they became adept at cobot operation through experiencing a variety of errors and malfunctions: *"We also just have to learn how the robots run, how it orients itself in the given situation, and you first learn that along the way. Not all errors are the same. The errors are handled differently, and [resolving] some errors take longer because you just have to find out what the error is. Have we had it before? What was it I did last time? That is why it is important that they [the company] give us time for that"* (O1).

During the interview, the operator (O1) had difficulties articulating how to run the cobots. She confessed that when new operators or interns joined the production cell, she let them learn by doing, just as she had learned cobot operation through trial and error: *"Let go now, [we] just give them [new operators] a try here. We also just have to learn for ourselves how they work. We are also new to it. Just as you are new when we assemble manually, so you are also new to the robot - we have no one to train us other than that [short intro they received]."* She described how acquiring cobot operation skills required more hands-on practice than theory, in contrast to operating traditional industrial robots. She highlighted her feelings about learning through commanding, touching, and observing the cobots.

> *"..[if] you ask it [the cobot] to stop, then it stops. If you you start it then it starts, and then you can stop it again and it stops. It could be that a robot course would be beneficial, but not when it comes to collaborative robots like those here. Yes, it may well help in the long run. But right now? No I will not [take a robot course]. I do not want to because I want to stand and play with it and see what it does. All that theory, it is not always that theory and practice are connected. I would rather stand and use it with my hands than I would sit on a screen and watch it. I would rather stand with it [the cobot] as we do now. But, the thing about having it [the cobot] in my hands and learning by doing it is what I feel best about."*

Such hands-on knowledge was perceived as insight rather than specific skills or techniques. O3 told us that *"I do not know if I have the full competencies, but I just want to say that I have at least some kind of good insight into it [the cobots]. Already at the moment I think."*

4.3 Interactions Outside the Cell: Relationships with Non-Operators and the Management

This section presents findings on interactions with both internal and external personnel outside the cobot cell, including interactions, and lack thereof, with external supporters and the management.

4.3.1 Learning from RoboBuddy. As described in Section 4.2, most cobot training was based on a hands-on approach without formal instruction. While this approach was sufficiently effective to acquire knowledge for most situations, some errors required support from expert technicians. As the two cobots used in each cobot cell at that time were different models and had different tasks, the steps required for error solving were not directly transferable. These differences could lead to frustration and confusion on the workers' side, as they would feel helpless in regard to resolving a given issue. To handle such situations company A had external supporters, here called RoboBuddy, stationed on site during its regular business hours. O3 described a situation in which an external support staff fixed an issue, and then left the company's premises for the day. Then the issue would often occur again, leaving the workers helpless during a breakdown.

> *"...you had run into one [error] first and got it [cobot one] ready, then you might have had a little more knowledge, i.e., for the next [cobot two]. So if there was an error, one could fix them faster [using experience from cobot one]. Yes, you can at least on the packing robot - every time RoboBuddy [external supporter] thinks he has fixed it [cobot one] and that it is okay. Then it does not take long before he drives home, and then it's crazy again [breakdown occurs]. Yes, then I could well imagine that when you drive two robots at the same time, so quickly get confused or stare blindly at it."*

Especially during the day shift, these types of problems that exceeded operators' current know-how could be solved in direct collaboration with the external technicians (RoboBuddy), *"I thought that was really nice, because if there is something they have not seen before then we [worker and RoboBuddy] can talk about it and find a common solution. Or if there's something I do not quite understand then I can just go to James [worker of RoboBuddy], he's good at helping get it going again. So it has been really nice that he is there"* (O2). As this vital access to external experts was limited to the primary working hours (i.e., the day shift), only the day shift operators had consistent access to this expertise. To make sure that the evening and night shifts also acquired the necessary knowledge, the operators and company A used multiple different strategies. Among other strategies, the informal information exchange between operators (as described in Section 4.2) was an effective measure. Yet, this only worked as a remedy to deliver information between operators and not from experts to, for example, night shifts operators. Another approach was the temporary exchange of operators from different shifts to provide the other shifts direct access to the external support. This measure was particularly important, as the availability of external support was only temporal in the introductory phase of the cobot implementation. Therefore, acquiring independent error-resolving expertise was also a matter of timeliness.

> *"I think it's a little weird that RoboBuddy is not here that often. When one can say that it's their project [they are responsible for integration]. If you can put it that way, they delivered the robots. So it's kind of weird that they are not here, and it's really only Susan [employee of company A] who is here. And it's not even her job. So it works very well when Susan is here"* (O3).

The introduction of cobots as a new technology and the cobot knowledge that the operators acquired acted as points of interest for their colleagues in other positions that were not connected to cobot operation in the company, sparking communication across positions. O2 expressed satisfaction with regard to the cobots being a conversation starter between him and his colleagues: *"I think it's fine, the people [non cobot related coworkers] come and ask for it now. They are interested in it so one can have a little chat with everyone around."* Having conversations with operators and external cobot integrators around the cobots allowed their coworkers to learn about the company's new technology, the uncaged industrial robots.

4.3.2 Relationships between Operators and Office Workers Reflecting Perceptions of Two Separate Workspaces. As illustrated in the previous section, the areas surrounding production cells became places where office workers congregated to talk with the cobot operators and watch the cobots in action. While this setup afforded operators opportunities to socialize with cell-external colleagues, the increasing social interactions also revealed how operators mentally configured the company's workplaces differently by separating the production cells from the desk offices. Specifically, operators' descriptions of these two workplaces often indicated their perceptions of the spatial arrangements of office spaces and production cells (e.g., O1, O3). Although the office space was located on the same floor and just a few meters away from the production cell (as illustrated in Figure 4, in which the green-colored office space floor is clearly identifiable) behind a glass wall with several passable junctions, indicative phrases like "going up" or "they come down to us" were nevertheless heard during the interviews. The desk office space feels inaccessible to operators, demonstrating their perceived distance from the office workers. We found that their perceptions of the spatial arrangements of the two workspaces implicitly show the relationship between the cell-external staff (e.g., office workers and project supervisors) and the cobot operators. Our operators described how their communication with office workers had been problematic and posed an obstacle to an efficient information exchange between themselves and their management.

Fig. 4. View from the cobot cell toward office workers and managers, separated only through a floor-to-ceiling glass wall with multiple openings. The office area is indicated with a light green floor. All employee faces have been anonymized.

For example, O1 stated that she felt dissatisfied with the expectation of one-directional information delivery between the cobot cell operators and their cell area supervisors. O1 expressed that she would appreciate a supervisor's occasional visit to her production cell to show his interest in the cobots (e.g., asking "How does it perform?" or "What problems have arisen?"), instead of it being incumbent upon operators to constantly "go up" to the desk office to update their supervisors on the status of the cobot implementation.

> *"He [the cell area supervisor] is not present as much as I think he should be. He comes down and says 'good morning', and then we see no more of him. [...] I think that my supervisor should be a little more visible when it [the cobot] is as new as it is, that he comes down and just shows a little interest in it rather than just being indifferent. Excuse the expression, but that's how I feel. [...] But they [project supervisors] should try to come down here. Come down and show some interest in it, instead of us having to pull everything out and bringing it to the table. That's not fair. It's just as fair that they come down and look at it. 'How does it run? Is it running well enough? How do you feel about this and all that stuff?' These games [the forth and back between all involved parties], we miss that"* (O1).

In line with O1's remark, we found that operators had come to resent supervisors' indifference to the production cell during the process of cobot integration. Although the operators were integral to the integration process, they lost their sense of initiative as they became disappointed with the lack of communication with their supervisors. O6 described a sense of taking too much responsibility for the cobots that were still very new to them also, entirely without any guidance from their supervisors: *"It would have been nice if management people would have gotten out here to the cell which they, at least at the night shift, never do. When we implement a whole new machine, maybe once or twice they will come by, but after that we are completely on our own."*

Operators also confirmed that having a project leader who cared strongly about the operators and the process would have been more motivational for working in the new work environment with cobots. O1 said, *"That is so great that you have someone responsible to go to if there is something. [...] If you have one that is just sitting in their chair with crossed arms the motivation would not be the same at all."* She highlighted her disappointment about supervisors visiting the production cell only once and asking seemingly random questions only. The lack of attention led her to hope that the supervisors would pay more attention to the production cell and maintain better communication with operators: *"They [supervisors] should not just come and say 'Why did not you perform with green numbers?' That equipment is only just six weeks old, so is quite clear [that we are not yet experts at operating the cobots]. ... I get mad when they come down and ask why we do not perform with green numbers."*

The desire of operators for increased supervisor engagement in the cell and the operators' work has grown due to the cobots' novelty. Prior to introducing the cobots, work processes were very familiar and did not require the same amount of engagement from the supervisors. However, the introduction of the new technology and the accompanying challenges led to uncertainties and problems in the daily operation that, while being solved by RoboBuddy, should still have been of interest to the cell supervisors. The supervisors' low engagement may be related to an (over)reliance on the external support staff, e.g., RoboBuddy, to address problems that might arise in the operation of the cobots. Quotes like O1's in the preceding previous paragraph show that the operators did not need cell supervisors to be in the cell to address concrete issues—RoboBuddy would attend them instead—but simply needed supervisors who would show appreciation for and interest in the operators, checking in with them regarding the new work environment with the cobots and any associated challenges.

5 DISCUSSION

We have shown how the introduction of cobots affects the industrial workplace on the individual, organizational, and social levels. We found that the introduction of cobots alters the way operators interact with one another and the workplaces in which cobots are used. Furthermore, we present findings on the interaction outside the cell to facilitate knowledge sharing and effective interaction with the cobots. In this section, we discuss our findings in relation to the role of spatiality in the structuring social interactions, boundary relations around cobots, and design opportunities from robot malfunctions and recovery.

5.1 Spatial Configuration around Cobots

As recent literature highlighted (e.g. [103, 113]), the introduction of automation such as cobots might lead to a change in social interactions among coworkers. The interview study with assembly-line workers [113], for example, investigated positive and negative effects on workers with increased robotic automation in a manufacturing facility, revealed that an increase in robotic automation could lead to negative perceptions of robot, due to their potential for reduction in human interaction and movement. Smids et al. [103] also hypothesized that the introduction of robots can have a negative impact on workers' social interactions if it leads to the layoff of human workers. They also predicted that if the robot eliminated monotonous tasks, the time available for social interactions would increase. In this paper, we were able to provide empirical results for the positive hypothesis, namely the increase in social interaction following the adoption of the cobot. As we presented in Section 4, this aligns with our observations: cobots reduced the number of workers in manufacturing, but they actually increased the amount of time spent interacting with one another.

As we highlighted, the introduction of cobots leads to a rearrangement in spatial configuration from pipeline to circular production cell. Similarly, the study by Pelikan et al. [83] showed that the change of spatial configuration caused by the robot resulted in a decrease in social awareness and interaction. The researchers investigated the impact of surgical robots (Da Vinci robot) on team configurations compared to non-robotic surgical teams. They found that the introduction of the Da Vinci robot switched the main interactions from surgeon-patient relation to robot-patient relation. The physical distance between the surgeon and the patient increased as the surgeon sat further away from the control interface. This spatial rearrangement also increases cognitive distance between team members because not everyone has access to the same sensory information, such as someone receiving information via screens while others do so via joysticks. This necessitates the development of new modes of communication, such as a combination of explicit verbal and nonverbal interactions [5, 33]. Contrasting with [83], our findings show that robot introduction does not always have to result in a decrease in social interaction. In the industrial cases shown in this paper, the introduction of the cobots reshaped the production pipeline to a circular pattern instead of a long pipeline, thereby bringing operators closer together, resulting in better opportunities for social interaction. Our operators reported increased human-human interaction while simultaneously reducing the number of operators in the cell. In the case of the hospital setting [83], the spatial rearrangement that accompanied the introduction of the Da Vinci robot leads to an increase in distance between surgeon team members [33], thereby decreasing social closeness between team members.

As was highlighted in our study and others [68, 83], the spatial configuration of humans toward robots (e.g., either standing too far from or close to them, or moving off to the side when interacting in close proximity) has been a subliminal metric by which to gauge people's engagement with and enthusiasm for interacting with robots overall [13, 101, 110, 111]. Michalowski et al. [68], for example, examined the measurement and prediction of different levels of social engagement between robots and humans based on the relative spatial positioning and movement of interaction participants. When the human participants were in close proximity to the robot, the researchers categorized it as a more intimate level of interaction between the robots and the group and then measured the corresponding amount of human engagement.

According to Sabanovic et al., the organization of situated action develops "from the interaction between actors and between actors and their social and physical environments" [89]. The concept of "organization of situated action" has been demonstrated in several studies of socially situated robotics (e.g., social robots for older adults). Kidd et al.'s study on social robots for older adults [56], for example, found that different actors, including non-robot users [95], should receive more focus. They showed how the presence of caregivers or experimenters affects social interaction with robots, despite the fact that caregivers or other actors are frequently left out of researchers' analyses of older individuals or children's robot engagement. The researchers found that when experimenters or caregivers were more willing to participate in the interaction, social contact increased as people started to discuss the robot as a common subject. Based on this discovery, we might want to shift our attention away from a single person or system and toward how various actors collaborate to complete various tasks. In terms of human engagement, the organization of situated action assesses it in conjunction with users, other actors, and situated environments, taking into account a "network" of users' social connections. Such coordination and interaction rely on a set of skills and practices that enable different people to understand what they are doing and, as a result, produce acceptable task results. Heath and Luff [43] refer to this as "social organization."

Through mingling with other employees, our operators sought tips and advice on how to operate cobots, for example, by having informal chats with other operators and reaching out to technicians. These social interactions revealed how cobot operators engaged with cobots through their social organization, such as learning more about how to operate robots and developing skills to control a larger portion of a robot's capabilities. Individual physical distance from robots, as well as time spent around robots and watching for cues, were not indicators of our operators' engagement with cobots. Their social interactions with other coworkers revealed the extent of their engagement. Given that the organization of situated activity has received minimal attention in studies of industrial robots (e.g., Baxter), we believe that studying the organization of situated action would be useful to investigate ways in which robots have ripple effects. With that, designing human-robot interaction in the workplace could go beyond "user-centered" technology adoption and acceptance [24, 91].

5.2 Boundary Spanning and Relations around Cobots

We have articulated how social interactions and dynamics inside and outside the cell emerged with the introduction of cobots. Operators learned by reaching out to other operators, external employees, and supervisors in and outside the cell. Like these operators, when the members of an organization relate their practices to an external area to develop knowledge-based competency, the activity is called *boundary-spanning* [106], which has been widely adopted in CSCW research (e.g., [1, 10, 30, 40, 45, 93]). While our operators created social interactions, they also conducted boundary-spanning by reaching out to external technicians for their know-how. Existing work on boundaries in organization studies (e.g., [36, 61, 62, 106]) emphasized that different professions often used boundaries to draw distinctions between themselves and others, create status inequalities, and cooperate with or even blindside other groups in their practices. Our study also found that the operators began to distinguish themselves from other employees who performed fewer or non-cobot-related tasks in the company as they got to learn more and accumulate knowledge about operating cobots. Researchers in organization studies (e.g., [11, 46, 116]) highlighted that boundaries are relational: they sometimes expand or lessen depending on specific contexts and actors. To articulate the characteristics of boundaries, Barrett and colleagues [8] classified three different kinds of boundary relations – *boundary cooperation*, *boundary neglect*, and *boundary strain*, all identified and detailed in our study.

Boundary cooperation describes developing interdependent and collaborative relations while adopting and using new technologies in an organization. Relations among the cobot operators and those between the operators and external technicians exemplify the cooperation boundary. Operators convened informal meetings to share knowledge gained during their assigned work shift. The technicians have also served as a group for the operators to closely collaborate with and learn technical knowledge from. *Boundary neglect* describes a phenomenon formed by a lack of attentiveness, interests, and plans for certain groups' use of new technology. We observed this boundary between operators and supervisors. From the operators' perspective, supervisors seemed insufficient in their confirmation of the cobots' optimal progress or their concern in operating the cobots as often as they should, while the operators asked other operators and external partners for information and advice. Lastly, the *boundary strain* is characterized by a particular group's increasing unilateral control over knowledge or technology implementation. In the case of our study, the boundary strain often came up in two cases: (1) technicians only remedied specific and limited cobot malfunctions without pursuing issues further or sharing more of their technical acumen to maintain their exclusive technical job authority (and therefore) job security, and (2) operators tended to use cobot knowledge to quantify their roles within and contributions to the company.

Introducing new technologies into a workplace often reorganizes work [7, 14]. By detailing the social interactions and dynamics that the different groups of employees [33, 34, 72] created to improve their work practices, we show how they worked out the unevenly distributed knowledge of cobots across the companies. Through the adoption of cobots, the operators and other groups of employees appeared to restructure various critical boundaries (cooperation, neglect, and strain). As CSCW researchers, this raises the question of how to facilitate cooperation while impeding neglect and strain imposed by the subtle influences of cobots in the workplace. While previous work has emphasized how robots can mediate social and group dynamics by changing people's attitudes and behaviors in a group (e.g.,[16, 28, 73]), our findings focus on **how robots become an occasion for social interaction rather than play a direct role in the dynamics among people**.

HCI and CSCW researchers are dedicated to examining not only design implications but also unexpected organizational and societal consequences of emerging technologies [5, 95, 97]. These various boundaries, we believe, provide an opportunity and thereby assign an implicit obligation for CSCW researchers to pursue ecological approaches to introduce new technologies to their work.This could include investigating how emerging technologies become boundaries, how they are perceived and adopted by different employees, and how various types of boundaries are developed or weakened. To facilitate boundary cooperation, cobot design should conspicuously address advantages [39] conferred to operators and companies for operators to work more independently in developing their hands-on skills. Integrating educational technologies and programs into the cobot controllers could be one way to do so. We may also have to reframe our perspectives on collaborative robots, from industrial robots to workplace technologies, which help us pass the bounds of the roles of cobots as technologies [23]. From this perspective, we could also alter our design approach: for example, how we integrate systems to mediate communication between operators and supervisors [27]? How could cobots be used as a computer-mediated collaborative tool to establish "boundary cooperation" between different groups of employees in a company [43]?

5.3 Malfunction of Cobots as a New Opportunity

As we presented in our findings, malfunctioning cobots often led our operators to seek help from others both inside and outside the cobot cell and initiate social interactions with varying groups of employees in the company. While robot errors and breakdowns seemingly are unavoidable, most studies in HCI and HRI have seen the malfunctioning robots as problems to be solved and focused on how to resolve the malfunctions promptly, for example, by examining what recovery strategies would work better [4], how the failure of robots could be prevented [96], how novice users could deal with the unexpected breakdown of robots [99], and even what recovery strategies robots should take to give users positive impressions (e.g., politeness, competence, and trust) [58]. Lessel et al. [60] also investigate how the malfunction information could be documented and shared across the manufacturing company. They identify six primary problems, including lack of documentation where it is needed (in the production cell) or lack of a non-verbal trail of how to address a given error. To address these problems, they developed a web application that operators and other employees could use to report errors or malfunctions through verbal input or written text and share them with the relevant employees. However, while the error reports from this application might guide operators to find the errors and fix the robots from downtime by themselves, it can also result in demotivating operators to reach out to other employees and talk, which may lead to the isolation of workers in terms of social interaction. Given that our findings highlight the positive yet unintended consequences of cobot malfunction, we, as CSCW researchers would need to think about how we might cope with designing robots in manufacturing settings. As many CSCW works have taught us, efficiency and productivity are not always our ultimate goals in our design [22, 25, 26, 32, 41, 77, 109]. Our roles would be focusing on how we could creatively embrace two conflicting events – malfunctions and social interactions in our design. For example, we may have to design technologies as a mediating tool for operators. The mediating tool could be a place where operators can still get together but work toward reducing overall robots' malfunctions.

5.4 Limitations

We conducted a longitudinal interview study with six cobot operators in a large Danish company. Since the organization is based in Denmark, and work-related factors like wages, job security, and job satisfaction might differ significantly between countries, these findings may not be applicable to other work cultures or countries [38]. Furthermore, the predominantly positive sentiment towards cobots that we observed might be related to the fact that the company still was in growth and did not need to terminate employment with any employees. Even though several employees acknowledge that cobots remove part of their work or even believe they eventually will replace employees, their sentiment remains positive. Therefore, we believe that the choice of company, namely a company in growth, has had a potential impact on the overwhelmingly positive experiences with cobots. Furthermore, given that we conducted the study during a period of transition, when employees were still learning to use the cobots and adjusting to new work situations, this could have an effect on the majority of our key findings, such as information flows and the need for knowledge exchange. It would be interesting to explore how long the novelty effect of cobots will last and how the end of novelty may result in different interaction dynamics (both for individual workers and organizations). A longitudinal study would be required to investigate these. Moreover, the findings presented here in relation to social and organizational dynamics inside and outside the cobot cell cannot be compared to the ones prior to the introduction of cobots. Since we joined the companies during (or soon after) the transition to cobot cells, we didn't have a chance to find out about such dynamics throughout the company prior to the introduction of cobots. Lastly, while we did not consider any gender-related topics in this paper, the common problem of gender balance of participants in HCI studies [80] could be considered a limitation, as we only have two female operators.

6 CONCLUSION

This work details social and organizational dynamics that the introduction of cobots made as a ripple effect. Through an analysis of fourteen interviews with six cobot operators, findings from this field study showed three notable changes that were in and around the production cell: (1) the cobot introduction necessitated a reconfiguration of the spatial setup in the production cell, which resulted in a change in social interaction among workers within the cell, (2) the uneven distribution of access to knowledge emphasized the importance of informal information sharing to distribute knowledge among cobot operators of different shifts, as well as (3) the reliance on cell external support both from within and outside of the company. Together these findings demonstrate what unexpected impacts of cobot introduction in an organization can look like from the operator's point of view, providing implications for research on workers' engagement with robots, identifying social interactions among different groups, and taking malfunctions of robots as an opportunity. Each of these findings broadens our understanding of what gradual changes cobots might bring about on social and organizational levels. This paper contributes to HCI and CSCW communities by offering design and research implications for the future of workplaces involving robots.

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