Group Effect Aspects in Digitalisation Production Contexts: Articulation Spaces for Emerging Cooperation Challenges

APARECIDO FABIANO PINATTI DE CARVALHO, University of Oslo, Norway
SARAH REICHEL, University of Siegen, Germany
MARCEL MANUEL SANCHEZ MARTIN, University of Siegen, Germany
EVA SONJA ALLEN, University of Siegen, Germany
MARCUS SCHWEITZER, University of Siegen, Germany

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Across the years, production systems have recurrently turned to new digital technologies in the search for enhanced productivity and competitiveness. More recently, a prelude to a Fourth Industrial Revolution has been heard, announcing Industry 4.0 as the future of production and manufacture. It has been claimed that cyber-physical production systems would bring drastic changes in the way that people go about engaging in work. It is therefore sensible to think that the way that cooperation is accomplished within production contexts will be also affected. Based on an in-depth interview study featuring 21 participants from different companies, we go on to discuss which challenges have been emerging from recent digitalisation of production work in regard to the way that workers cooperate in accomplishing their productive activities. Our results suggest that there are associated group effects – e.g., group polarisation, hidden profiles, and exclusion – that pose relevant challenges for cooperation within these settings. In this contribution, we go on to present and discuss these results and to propose articulation spaces, which conceptually bring together aspects of coordination mechanisms and common information spaces, as a potential solution for some of those challenges.

CCS Concepts: • **Human-centred computing** → Human computer interaction (HCI) → Empirical studies in HCI

Additional Key Words and Phrases: Digitalisation; articulation work; coordination; group effect; articulation spaces

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1 INTRODUCTION

The industry sector is currently undergoing radical changes in terms of *digitalisation*. Largely driven by the Industry 4.0 vision, companies have been moving towards new and innovative ways of using

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Author's addresses: A. F. P. de Carvalho, fabiano.pinatti@ifi.uio.no, Design of Information Systems (DESIGN), Section for Digitalisation, Department of Informatics, University of Oslo, Oslo, Norway; S. Reichel, sarah.reichel@uni-siegen.de, M. M. Sanchez Martin, marcel.smartin@student.uni-siegen.de, E. S. Allen, sonjallen@web.de, and M. Schweitzer, marcus.schweitzer@uni-siegen.de, Siegen Institute for Small and Medium-Sized Enterprises (SMI), University of Siegen, Siegen, Germany.

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digital technologies for accomplishing their goals [20]. This vision, as seen in the relevant literature, is mainly underpinned by the widespread deployment and use of cyber-physical (production) systems, which integrate cyber, physical and even biological components over an Internet of Things [49,57,88]. Recent digitalisation can to a large extent be associated with this type of systems.

In essence, digitalisation refers to a *transformative process* leading to new and/or improved practices, spanning important organisational and social changes as well as new forms of interaction between individuals, facilitated by the use of digital technologies. These span both state-of-the-art technologies – such as sensing technology, augmented reality, and machine learning, which very often integrate the abovementioned cyber-physical systems – as well as more traditional and well-established technologies – as for example emails, ERP (Enterprise Resource Planning) systems, among other things. Starting from the replacement of analogue (information) artefacts and procedures for digital ones, new practices are developed, readapted, or even disrupted as workers go on to integrate such digital tools and operations into the socio-technical configurations that they are part of, and appropriate them [20,79].

It can be argued that CSCW has been interested in digitalisation since its very beginning, even if not openly using the term. Investigations of the use and appropriation of digital technologies to support work processes and the new practices facilitated by them have always been the central tenet of the field [86,100]. Among the contexts that CSCW has deeply investigated are control rooms – e.g., [61,93]; hospitals – e.g., [10,103]; offices and call centres – e.g., [70,72]; and software development teams – e.g. [12,97]. Production and manufacture have also been contexts of recurrent interest of CSCW research – e.g. [21,84,98]. Nonetheless, as acknowledged in the recent literature, there are still open questions regarding how the digitalisation of production systems is affecting cooperation in these contexts [20,64]. Understanding these effects, we argue, is essentially important to comprehend how we can better design for those contexts and support people who work together in them.

This article adds to the body of literature addressing these contexts and responds to the abovementioned gap in the literature by addressing the following research questions: *What aspects of cooperative production work have been impacted by ongoing digitalisation of work processes? How can associated negative impacts be possibly mitigated?*

In order to answer our questions, we have carried out an in-depth interview study with 21 participants, distributed across more than 10 companies from the metalwork industry undergoing intensive digitalisation processes. Our investigation brought to the fore aspects of *group effects* – i.e., social forces and norms that impact upon how groups behave [53,82,95] – which can help to explain the impacts of ongoing digitalisation on *cooperation* within production contexts. Our findings suggest that the notion of *articulation spaces* can be useful and instrumental in overcoming some of the challenges that we have identified.

Articulation spaces [12] is a concept that combines aspects of *coordination mechanisms* and *common information spaces*, two well-known CSCW constructs which contribute towards successful cooperation in complex and heterogeneous contexts [12,87,103], as the one addressed in our research. While coordination mechanisms materialise explicit conventions and prescribed procedures in standardised protocols put in practice with the help of specific artefacts [87], common information spaces provide means to put such mechanisms in common, so that actors can communicate, articulate, and adjust their work [7]. Articulation spaces bridge these two constructs, so to support both formal and informal articulation work necessary for successful cooperative initiatives [12]. Put differently, articulation spaces not only support institutionally standardised procedures to coordinate work, mediated by artefacts and technologies devised or approved by

organisations (formal articulation work), but also support more personal and uncontrolled exchanges, through media that have not been pushed by the organisation (informal articulation work) [12,31].

Our contribution *extends* the *knowledge on digitalisation* through the use of *group effects* as a lens to understand changes, challenges and new opportunities emerging from the ongoing digitalisation of production systems. Furthermore, it concentrates on the unique aspects of the metalwork industry. We were particularly interested in the metalwork industry due to its relevance to the economic development of our region and the fact that it has not been widely explored within CSCW [20]. Furthermore, as will become evident through our results, work in this branch is often associated with considerable deadline pressure and a high workload due to cost pressures, which puts articulation work in the spotlight. Although articulation work refers to a type of work that is usually invisible, there are situations where its key role makes it evident [87,92].

As will be noticeable across the paper, some of these situations refers to events concerning additional complexity coming from unpredictable disruptions that require rapid response and communication across distances, as well as fluctuating material quality that requires adjustments. This resembles in much some other complex contexts explored within CSCW, as those referring to air traffic control [52,93] and hospitals [10,83]. Nevertheless, as will become evident through our findings and discussion, there are also differences to be taken into consideration, as the fact that tasks tend to be performed with permanently allocated workers, different from hospital settings where a recurrent problem is to find and assemble highly qualified team members for changing assignments [102]. The lack of expertise is also not as critical as in software development teams, where it can jeopardise the overall success of a given project [28]. Furthermore, in comparison to the domain of air traffic control, which is dominated by a high degree of technical support since many decades, many of them regarding safety critical systems – see e.g., [52,93] – many production contexts, especially the ones referring to small and medium enterprises (SMEs), are not yet strongly equipped with technical means.

Essentially, we have oriented ourselves towards a practice-centred approach to understanding the routinised patterns of action of our participants in the context of their work environment, taking into consideration the social aspects of cooperative work [100]. We have thus placed special emphasis on social, environmental, and organisational aspects surrounding the articulation work that our participants have to engage in – i.e., the work that must be undertaken to make cooperation work – as they go on to accomplish their tasks [12,87,93].

The remainder of this article is organised as follows: in section 2, we go through relevant theoretical and conceptual notions underpinning the findings of our contribution, pointing to relevant related work that we refer to when analytically developing our findings; section 3 introduces our research context and provides some information about our participants and their workplaces; section 4 provides an overview of our methodological approach; section 5 presents the results of our analysis, illustrating them with quotes from the empirical data collected; section 6 goes on to discuss these results in terms of how they advance the status of the art and what they would mean for the design of CSCW technology to support cooperation in production contexts undergoing digitalisation; finally, section 7 lays out our conclusion remarks.

2 RELATED WORK

This section draws attention to articulation and coordination in production systems and highlights the gap in the literature concerning the understanding of related aspects in ongoing production digitalisation contexts. It follows with a short introduction of the subject *group effects* and the

importance to understand them, so to design effective CSCW systems. It is worth pointing out that the section is not meant as a comprehensive review of the literature, given its dimension. Instead, we introduce relevant issues that underpins our findings and discussion sections and highlights our contribution to the CSCW and HCI research community.

2.1 Articulation and Coordination in Production Contexts

Since its inception, CSCW has placed special focus on how computing systems can support coordination and communication in groups, so to encourage the interaction between group members, strengthen social cohesion and foster knowledge and expertise sharing [1,58]. These systems have often attempted to facilitate coordination of (groups of) people across space and time [68,90], considering that coordination is a fundamental aspect of cooperation.

In a seminal paper, Malone and Crowston [65] thoroughly elaborated on the relevance of coordination theory in supporting the design and development of CSCW systems. Starting from the premise that cooperation is fundamentally organised around division of labour and the management of interdependencies stemming from it [85,86,92], the authors go on to discuss how managing these interdependencies is a defining aspect of coordination [65]. Effective coordination allow cooperative actors to work harmoniously towards the accomplishment of a shared goal or, at least, finding a compromise to accomplish it [85].

Closely related to coordination is the concept of articulation work. Articulation work has been originally defined as a supra-type of work inherent to any kind or initiative involving division of labour [92]. Put differently, articulation work can somehow be seen as the work to make cooperation work – that part of work dedicated to coordinate the working processes through human expression [85,87].

Indeed, cooperative settings are intrinsically related to the organisation and development of social processes [86,94]. Cooperation is inherently associated with dependencies created between cooperative actors, which support each other in accomplishing a shared goal [65,92]. Esbensen and Bjørn [26] introduce a categorisation of these dependencies into four sets of dependencies: *location*, *people*, *collaborative* and *artefactual*. Location dependencies include criteria related to geographical sites as well as workplace design with its conditions for collaboration. People dependencies refer to roles and responsibilities in organisational processes as well as knowledge, what is used for collaboration. Collaborative dependencies, on the other hand, consider situations where multiple people are working together at the same task. Finally, artefactual dependencies arise from technologies that enable collaboration and interaction. To this end, they give the indication, that these four sets of dependencies should not be seen as single entities, but rather they are interrelated to each other.

In the context of production, the importance of articulation work becomes even more evident. Such systems are inherently cooperative and built upon clear division of labour [21,84]. In such settings, articulation work is essential, as it is through it that it is defined who does what, when, and how. It is also through articulation work that co-workers keep updated about the current state of the task at hand. Furthermore, classic industrial contexts are characterised by strong hierarchical dependencies, which determine to a large extent how employees must work with each other, much alike work in other domains like air traffic control and hospital wards. Research in those domains have demonstrated the importance of articulation work and the need for effective mechanisms to allow the flow of information necessary for proper coordination [103]. This importance is further stressed in systems that operates continuously, as is the case of many production companies. In order to keep going, these systems resort to shifts and handovers, which have received considerable attention from CSCW researchers in the past [10,77,78,83]. In time-critical contexts, failing to

effectively convey the necessary information may compromise the accomplishment of the overall task [1,83,103]. In production, this means compromising complete workflows.

It is therefore sensible to think that articulation spaces would be a relevant construct for such contexts. Articulation spaces, as discussed in the literature, gather relevant information for meta- and ad-hoc coordination processes underpinning the decision-making processes as work unfolds [12]. It integrates both coordination mechanisms and common information spaces in a configuration that allows cooperative actors to coordinate their efforts both formally – i.e., according to organisational procedures – and informally – i.e., drawing on personal channels of communication, technologies, and artefacts. This dual nature of coordination work has been observed in many and various CSCW studies addressing issues of articulation work, as for example [11,31,81,97,103]. However, to the best of our knowledge, so far there has been no discussion on how articulation spaces can be useful in production contexts, especially those contexts undergoing digitalisation. This article contributes towards mitigating this gap in the literature.

Articulation spaces, as discussed in Boden et al. [12], has been proposed as a construct to address problems of awareness and coordination resulting from separating between formal and informal aspects of coordination. As widely discussed in the CSCW literature, awareness is an important element for the proper coordination between cooperative actors and successful cooperation [8,9,24,42,44]. Awareness provides a context for activities of individuals working cooperatively, allowing cooperative actors to coordinate among themselves [24,39]. Given the importance, many and various CSCW researchers have applied themselves in findings ways to support different types of awareness – e.g., informal awareness, conversational awareness, and structural awareness [41] – among cooperative actors. Much of this research, as seen in the relevant literature, has focused on visualisation mechanisms. From radar views [45] and network diagrams [6], through (large) interactive displays [9,12,23], to implicit sharing of information [39], CSCW researchers have demonstrated the importance to work on proper awareness mechanisms for effective coordination and, consequentially, successful cooperation. These issues also emerged in our own work, as will be evident in our findings and discussion.

2.2 Group Effects in Cooperative Settings

Contrary to a frequent assumption that group work leads to enhanced productivity, it is not uncommon that people perform less collectively than the sum of their individual performance. Some reasons for this are influences and social forces that impact upon groups and their social norms, triggering or contributing towards certain behaviours. This phenomenon is known and has been extensively discussed in different bodies of literature under the rubric *group effects* [53,99]. Among the effects that help to explain the findings of this contribution are: *group polarisation; hidden profile; social loafing, facilitation, inhibition, and exclusion;* and *free-riding.*

Group polarisation refers to a phenomenon where the group behaviour is more extreme than the behaviour of its separate individuals [89]. Due to the regular exchange of opinions within a group the attitudes of its members solidify, so that groups make decisions that are more extreme than the average of all individual decisions of the group members would be [5,54]. Within CSCW, it is sensible to think that the use of cooperative systems can positively affect technical, environmental, and organisational factors of group work. Here, it is important to consider the interactions of team members from different hierarchical levels and the power relationships involved [85]. Furthermore, leadership roles should be taken into consideration when designing cooperative technology, as these roles have a significant quantitative and qualitative impact on the performance of groups [25]. In computer-mediated communication, this can be triggered by a lack or reduction of social presence, as demonstrated by Sia et al. [89]. In this regard, it should be noted that, in general, de-

individualisation of information increases the risk of negative group effects [58]. Hence, digital information that is provided to groups anonymously and, thereby impersonalised, can potentially reduce social presence and intensify polarisation [33].

Another widely researched group effect is *hidden profile*. It describes the phenomenon concerning the unequal sharing of information among the members of a group [63,91]. In particular, situations of *exclusion* in groups can lead to this phenomenon, especially when individual group members are blocked from sharing information or are not involved in relevant information flows [91]. As shown in the literature, the type of communication technology used can have great impacts upon this [63]. For instance, Goyal et al. [39] argue that understanding the ways in which information sharing improves performance and leads to better outcomes is important for the design of digital tools. Furthermore, since much of the available information within organisations are of a tacit or embodied nature [1,20], important information for decision-making processes may remain hidden. Cyber-physical production systems, it has been claimed, will potentially revolutionise the ways in which knowledge embedded in embodied action can be shared in production contexts [20,49].

Nevertheless, one should remember that technologies should not only be seen as great enablers [18]. At the same token that CSCW systems can have positive impacts on cooperation, their use can also lead to negative outcomes for the socio-technical ensembles that they are part of [100]. Previous research already showed that digitally supported collaboration decelerates processes to develop social norms and relationships in groups [58,68,94]. However, it is still to be found how group effects have been affected by digitalisation processes that many production systems have been undergoing.

A relevant aspect to the expression of the hidden profile effect is group size. In a study about online discussions with distributed knowledge of crowd workers, medium-sized groups with eight members were found to achieve the best results, which was attributed to the balance between information diversity and discussion effort dependent on group size [96]. In addition to that, motivational aspects can also influence group performance [23,53]. For example, *social loafing* can occur when individual performance within a group is not visible and thus lacks individual comparability. This results in individual group members being less motivated to perform to their full potential [62]. This effect on group performance has been also found in CSCW contexts [68]. Particularly, if information is also only available anonymously and thus individual performance is not visible, the risk of social loafing is promoted [58]. Therefore, similar to group polarisation, the design of feedback, which individual group member experienced in digital systems, influences the expression of this effect [95]. Moreover, Leary et al. [74] suggest using blockchain technology to make knowledge and activities of spatially and temporally separated group members transparent so that their individual performances become visible.

Loss of motivation can also be triggered by the phenomenon of *free-riding*. This occurs when group members assume that their individual performance has no influence on the overall outcome of their group [60]. As with social loafing, CSCW studies have demonstrated that the provision of anonymous information can strengthen this effect [58].

Moreover, social influence on individual behaviour can occur in groups. Here, the presence of others affects the individual's state of arousal and influences his or her performance, which has already been confirmed in many studies in the past, as noted by [13]. Thus, according to the theory of *social inhibition* and *social facilitation*, people perform more complex tasks worse and easier tasks better in the presence of others [101]. Within the CSCW literature, these two phenomena could also be observed in a purely virtual presence of other persons during the execution of given tasks

[69,101]. For instance, Zanbaka et al. [101] could clearly demonstrate the effect of social inhibition in the case of a physical as well as digitally transmitted presence of another person, whereas they found the effect of social facilitation only weakly pronounced in their study. This also confirmed the results of a previous study on these phenomena in virtual presence, in which social inhibition also occurred and social facilitation could not be observed [51]. However, social facilitation could also be founded in the environment of digital applications. For example, in a study with simple online applications, the visualisation of individual group members or the entire group led to an increase in the engagement of individual group members [32].

As evident across this section, group effect is a highly relevant aspect in cooperative settings, which connects with many aspects of the use of CSCW technology. Although many and various CSCW contributions have touched aspects of group effects, none of them, to the best of our knowledge, has used group effects as lenses to understand the impacts of recent digitalisation on cooperative production work and how negative impacts can be mitigated. Our work addresses this gap in the literature, as demonstrated by our findings and discussion.

3 RESEARCH CONTEXT

Our study involved 21 participants distributed across more than 10 German SMEs undergoing digitalisation processes. Similar to what has been previously reported in the literature [71], the workplaces of most employees in our study – except for those working in management positions – are characterised by physical and noise-intensive activities that take place handling a variety of materials at a myriad of machines. There are also many and various sources of danger, such as forklift traffic and overhead cranes [cf. 76]. For this reason, protective clothing – e.g., gloves, often helmets, but also heat protective clothing – is required in most of them. All these measures serve to ensure safety, but hinder the use of small-scale communication systems, such as pens, keyboards, small switches, or head-mounted systems [cf. 71]. In most cases, the individual workplaces we observed are located well apart from each other, which makes direct personal contact costly. In addition to face-to-face exchanges, employees are often involved in asynchronous communication processes about actions and results.

As observable in Table 1, some workplaces are still only equipped with a few digital technologies, such as email. Thus, the use of digital structures is much less widespread than in hospitals [10,83,102], software development [12,97] or air traffic controls [93]. Some others are tied to machine-related systems, such as Programmable Logic Controller (PLC), simple Process Data Acquisition (PDA) or Manufacturing Execution System (MES) (Figure 1a). Nevertheless, only a few employees have access to those systems, through computers placed in the offices (Figure 1b). Furthermore, we have found that the necessary expertise to interact with those systems are often missing both for shop floor workers and even foremen. Access to Enterprise Resource Planning (ERP) is usually widespread, although often only input is possible – no possible configurations. Access to special systems, such as Computer Aided Design (CAD) or Product Life Cycle Management (PLM), is less common and more reserved for management. Instead, non-digital artefacts based on paper are widespread – similar to [20,35] – and the most common means of communication is face-to-face interaction (Figure 1c).



Figure 1. (a) Manufacturing Execution System; (b) Restricted Access; (c) Handover meetings

It is not uncommon for workers to stop work to retrieve more work instructions from a central system near his workstation [30] or to coordinate some activity with colleagues [20]. Event-dependent team formation of experts, on the other hand, tends to be done for coordination purposes and is rare compared to hospitals, where teams for deployment purposes are frequently regrouped [10]. The actual production is usually carried out by permanently assigned workers. Simple work processes are often performed by less qualified workers whose level of expertise tends to be low, unlike in health care [103] or software developers [3,97]. On the other hand, more complex workplaces involving multifaceted tasks usually count with workers with the appropriate level of expertise to operate the required systems [49]. The work content of the participants varied considerably in a daily basis. Said differently, workers are confronted with continuously changing tasks.

These socio-technical configurations bring some cooperation challenges to the fore, especially in terms of the articulation work necessary to coordinate cooperative efforts, as discussed across our Results and Discussion sections.

Table 1. Participants' Table

#	Sex	Sector	Role	YoS	Digital technology available at the workplace
P1	male	metal processing	foreman	3 - 10	ERP (input only), mail
P2	male	metal processing	shop floor worker	> 20	only 1 phone (noise), code scanner
P3	male	metal processing	foreman	11 - 20	ERP (input only), mail
P4	male	metal processing	foreman	> 20	ERP (input only), office, mail
P5	male	metal processing	foreman	3 - 10	PDA, PLC
P6	male	production industry	manager	3 - 10	ERP, MES
P7	male	metal processing	manager	11 - 20	PLC, MES, video conferences
P8	male	mechanical engineering	manager	11 - 20	CAD, programming
P9	male	metal processing	foreman	11 - 20	phone, upcoming: PDA
P10	male	plant engineering	shop floor worker	3 - 10	ERP, MES, PLC
P11	male	automobile industry	foreman	11 - 20	code scanner, digital instructions, partly PDA
P12	male	metal processing	foreman	3 - 10	EPR (enlarged)
P13	male	mechanical engineering	manager	< 3	EPR (enlarged)
P14	male	metal processing	manager	> 20	ERP, MES
P15	female	automobile industry	shop floor worker	3 - 10	sensors (user), Dashboard
P16	male	metal processing	shop floor worker	11 - 20	PDA
P17	male	metal processing	foreman	11 - 20	PLC, CAD, ERP
P18	male	metal processing	foreman	< 3	PLC, PDA, set-up book, set-up cards, ERP (simple)
P19	male	metal processing	foreman	> 20	PLC, PDA, set-up book, set-up cards, ERP (simple)
P20	male	metal processing	supporting services	> 20	PDA, instruction cards
P21	male	metal processing	manager	> 20	CAD, ERP, PLC

YoS: Years of Service; **ERP:** Enterprise Resource Planning system; **PDA:** Process Data Acquisition; **PLC:** Programmable Logic Controller; **MES:** Manufacturing Execution System; **VR:** Virtual Reality; **CAD:** Computer-Aided Design; **PLM:** Product Lifecycle Management system; **CRM:** Customer Relationship Management system

4 METHODOLOGY

Our study focused on understanding how workers have been experiencing the digitalisation of their work and how this has been impacting upon their work practices. It uses a *qualitative approach* and is mainly influenced by a praxeological worldview, focusing on practices and the design of technology to support them [cf. 80]. In summary, we have carried out a *contextual study,* to illuminate our research questions. For the study, we have used *in-depth semi-structured* interviews as our data collection instrument. In-depth interviews are known for their strengths to deeply explore with participants their views and understanding on particular subjects [16]. Originally, observations were also planned. Nevertheless, we had to adjust our research strategy, due to the COVID-19 pandemic situation, which prevented us to get access to the company premises. We have exceptionally managed to visit five companies at the very beginning of the study, when we had the opportunity to register some aspects of the workplace – as illustrated in Figure 1. Nevertheless, we are confident that the insights that we have got from the *in-depth interviews* are invaluable for advancing the state of the art on the subject of our study.

In terms of participant recruitment, we drew on *purposive sampling* [16], which means that participants were included primarily on the basis of criteria concerning our phenomenon of interest. In general, our focus was on participants from production areas in regionally based metalwork companies, due to reasons already discussed above. The related areas of mechanical engineering and the automotive industry were also included, as these are strongly represented in the region. Due to the fact that the workforce in this sector is often biased towards men, the gender distribution within the sample was highly unbalanced, with 19 male and two female participants. We strived to include participants from companies undergoing different degrees of digitalisation in production and who were involved in different hierarchical levels or roles.

Table 1 above provides an overview of our sample. From the 21 participants, 15 work in the metal processing industry, two in mechanical engineering, two in metal assembly/automotive, and two others in related fields. The job profiles were very heterogeneous, e.g., we recruited highly qualified workers in maintenance and workers responsible for rather simple tasks. In terms of their roles in the company, four of them were shop floor workers, 10 were foremen, 6 were managers and one was working in supporting services for plant engineering. Regarding the number of years in the company, two participants were in their respective companies for less than three years, 6 of them had between 3 and 10 years of service, 7 of them had between 11 and 20 years of service and 6 had more than 20 years of service in their respective companies.

Interviews lasted mostly between 45 and 120 minutes (average = 106 minutes) and were audio recorded. The recorded data was transcribed using the *intelligent verbatim method*, where mumbling (e.g., 'hms' and 'ahs'), filler phrases (e.g., 'you know') and stumbles are removed. Subsequently, all transcribed data was subjected to thematic analysis, following Braun and Clarke's [15] approach.

Data analysis started immediately after the transcription of the first interviews. Overall, more than 6,200 text excerpts have been coded with one or more of the 65 codes that have been elaborated during the analysis. All authors were part of the data analysis team and participated in the elaboration of the initial code schema. Interviews were then distributed between the members of the data analysis team. Each analyst started their analysis assignments by familiarising themselves with their transcripts, i.e., reading, re-reading and memoing – *first phase* of Braun and Clarke's approach. Effective coding of a transcript – *second phase* – only took place after the analysist felt familiar with it. As they were coding, analysists not only watched for excerpts concerning the *apriori codes* [38] generated from the interview guide, but further developed the code schema using a bottom-up approach, as they engaged with the data and identified new relevant codes. The transit

between bottom-up and top-down coding approaches is expected and accepted in thematic analysis. This facilitates the coding process insofar the apriori codes can be easily identified, but still leaves room for the data to speak and relevant issues to be identified [15,38]. Examples of *empirical codes* identified during the analysis are *weak digital support; restrict use of digital solutions;* and *hierarchical aspects of digitalisation.* It is worth to point out that it was during the coding phase that we started noticing the potential of using group effects as lenses to explain the phenomena that have been captured during our data collection phase. As a result, some of the generated codes were associated with particular group effects that we knew from the literature.

From time to time, analysis coordination meetings have been carried out to discuss new codes generated and align the code schemas. After the meetings, analysts went through the interviews they have coded so far and checked if any of the codes generated by other colleagues would also be present in their interviews. Once the coding was completed, the members of the analysis team have engaged in searching for themes that could answer our research questions, and defining and reviewing them – *phases 3, 4* and *5* in Braun and Clarke's approach [15]. The phases happened collaboratively in data analysis workshops among the members of the analysis team.

Three themes have been elaborated out of the analysis sessions: (1) *organisational barriers towards digitalisation of coordinative practices;* (2) *the sociality of articulation work;* (3) *transparency over hidden profiles and related effects.* We go on to introduce and elaborate on each of these themes in the next section – *phase 6* of the analysis approach used.

It is worth pointing out that, as for any qualitative study, the results presented are not generalisable, although they are potentially transferrable to other contexts, which share some characteristics of the original one. This is a well-acknowledged and accepted limitation of qualitative approaches [16]. Nevertheless, we have been careful to address *trustworthiness* and *authenticity* in our results, by drawing on a systematic data analysis approach, and illustrating our findings with empirical evidence representing the voices of our participants. These are quality criteria of qualitative research, as discussed in [40]. It is also worth pointing out that this research has observed rigorous ethical principles, as for example, obtaining informed consent from participants, assuring them confidentiality, offering them opportunity to check transcripts, giving them the opportunity to ask for removing any data that they were not comfortable with, and complying with the European General Data Protection Regulation (GDPR) 2016/679 [29].

5 RESULTS

As we progressed with our analysis, we have found that, despite the considerable efforts that production companies have been employing towards digitalisation, there are still organisational barriers associated with assorted group effects, which prevent or make it difficult to fully develop. Furthermore, our findings brought to the fore issues concerning the sociality of articulation work, which adds another layer of complexity and, sometimes, resistance against digitally mediated articulation work. Last but not least, our findings highlight the potential of digitally mediated articulation work for transparent and successful coordination. We elaborate on each of those issues across this section.

5.1 Organisational Barriers towards Digitalisation of Coordinative Practices

Production in steel processing manufacture is characterised by a large number of innovative systems, most of which are programmable logic controlled [49], less can be found in terms of digital support to cooperative work, especially in terms of its coordination through articulation work. Some information and communication technology have indeed been introduced – e.g., emails – however,

our findings suggest that there is a lack of organisational support for digitally mediated coordination. Access to digital systems is usually constrained to higher management levels, meaning that workers in the shop floor usually do not have access to digital information:

> … not everybody is allowed to have access to this [email] system. So, there are two, three [people who can access it], so the foreman, supervisor and maybe the deputy who usually work closely with the system. The normal workers usually don't have access to such digital information. (Quote 1, P1)

This means that a large portion of the staff is excluded from the information flow and receives only verbal and filtered information from the direct supervisor. P1 goes on to justify the exclusion of staff due to their difficulties to learn some of the systems in place, as for example, SAP (Systems, Applications and Products in data processing) systems. According to him, *"…colleagues are not allowed to use this SAP system […], because it wasn't really easy to learn."* (Quote 2, P1). This is confirmed by P8, who points out that a digital system only makes a positive contribution if it is used by someone who can handle it. According to him, *"…the system is only as good as the person who sits in front of it and maintains it."* (Quote 3, P8)

In both cases above, supervisors are aware that problems can arise when untrained employees use a digital system, and they seem to prefer to exclude these employees, instead of investing in upskilling them, or looking for alternatives with better usability. Amongst the reasons given for not investing in training employees to deal with such systems is the time pressure that would prevent the company to provide the necessary training, which is tightly coupled with issues of productivity and revenue. However, the collected data suggests that this is only a disguise for existing rigid structures, which clashes with the potential of digitalisation.

As a result, access to digital resources turn out to be a source of inequality and to reinforce hierarchical structures common in production and manufacture. At the same token, articulation work happens in different levels and in chain, with very few people having access to the higher-level management actors:

> The management has one or two people from whom they get information, whether it is correct or not of course doesn't matter to them at that moment. […] Because of the work atmosphere, of course, people often keep a low profile, i.e., just clock in with their timecards early in the morning, do their work and clock out again at lunchtime, and keep out of matters decided by the management. (Quote 4, P5)

This kind of management communication *excludes* individual employees from the information flows. The resulting limited ability to articulate between relevant actors can in turn lead to coordination problems, as these actors ultimately do not share all relevant information, creating a *hidden profile* situation that reduces the quality of necessary decisions [91]. In addition, the exclusion and associated perceived expendability of an individual causes them to lose motivation, as they assume their opinion is of less relevance to work outcomes. Such an experience is described in the group effect literature under the term *free-riding* [60]. These effects companies should actually want to avoid, as it is well known that poor management communication affects the performance of a team [25].

Typically, companies try to determine, at least to some extent, how coordination among their employees happens and which sort of articulation work is involved. This is mainly done to protect relevant information from competitors, or to comply with certain legislation, such as that governing the workload of their employees. However, the introduction of the appropriation of digital technology may challenge this and even foster flexible work practices at the shop floor, as those already seen in among knowledge workers, as for example, using mobile devices to coordinate and accomplish work in different locations [19]:

> But it's all so much easier these days when we message each other on WhatsApp. [...] At one moment we are working and short time after you don't know: "Okay, are we working now or aren't we working now?" (Quote 5, P1)

The quote above indicates that employees compensate the shortcomings of organised support by using digital pathways with private devices. They use software familiar to them from their private lives to coordinate within their group and transfer its application to company processes. In particular, weak operational support from a digitally mediated coordination in organisations may lead groups to devise practical digital solutions. Put differently, if the organisation does not provide ways for them to feel connected enough, they do it through self-organisation. They would even disregard company rules against using private devices to avoid ***exclusion*** and be able to communicate with colleagues. Even language barriers that are not addressed by the company are overcome using unauthorised applications: *"Google, Google Translator. We don't have another possibility at all, and we do that despite the ban on mobile devices. [...] But we have no other choice at all."* (Quote 6, P5).

Thus, employees arbitrarily broaden their opportunities for articulation work by using private devices of communication. This pragmatism has a stronger effect regarding this context than organisational regulations [4]. Furthermore, it can be seen that by using private devices against the norms, workers distance themselves from the company's guideline and do not take its arguments seriously. This leads to employees sticking to their ways and ignoring possible dangers or other possible courses of action.

Nevertheless, the circumvention of company rules is sometimes encouraged by group leaders, as they are not willing to give up the advantages of digitally mediated articulation work, as for example, overcoming distances [75]. For example, a foreman in maintenance usually gets in touch with the employees under his responsibility contacting them in their private phone numbers. This speeds up the contact with people distributed across the company, as suggested in the quote below:

> Normally I should not allow [the use of smartphones] or strictly forbid it. [...] Sometimes I call the employees myself on their phones. When we are on site somewhere, we occasionally take pictures and send them [...]. That would definitely be a very big plus if something like that was introduced as a standard. (Quote 7, P9)

Here it becomes clear how strongly the employee wants a formal digital communication option to be emplaced. Despite of that, organisational barriers at the coordination level inhibit it. In summary, employees are widely moving towards implementing the infrastructures they need on their own responsibility, as officially granted structures no longer meet their demands.

On the other hand, it should be noted that private devices can also lead to overcompensation of operational gaps in coordination work, which in turn can promote group effects such as the ones referred to above.

5.2 The Sociality of Articulation Work

Past and current CSCW research has demonstrated how face-to-face interactions can be very important for the success of cooperative work – see e.g., [75] and works that follow. The findings from our study echo findings from this broad literature, in particular those concerning conflict management. In trying to understand the cooperation challenges faced by workers of production systems undergoing digitalisation, we have yet again stumbled in such issue. Participants suggested that meeting in person can be instrumental for resolving conflicts, especially in cases of disagreements with superiors. Even in situations where, in principle, employees could easily coordinate with colleagues through email or messenger services, they seemed to prefer to go and talk directly if the issue is sensitive:

> [...] because I would rather say that to the person's face, and I would also like to have an answer directly [...] I am such a person. I will wait, come in the morning, no matter if I wait an hour, I will still clarify it face-to-face. (Quote 8, P3)

Indeed, many participants suggested that they would take additional time to come and meet in person in such situations, instead of responding to emails or use other digital media. Our findings suggest that this is mainly related to motivational issues [17], the time required to resolve such issues via a poorly mediated interaction, the associated stress and the reduced level of social presence, which can be very important in setting out a quarrel. In face-to-face interactions, there are no technically induced pauses for thought, as there would be when coordinating via emails or messenger services; it is hence understandable that workers would feel that possible misunderstanding can be solved more quickly in this way.

Nevertheless, also in accordance with more recent CSCW studies, our findings suggest that the resistance against digitally mediated coordination and associated articulation work reduces as the social presence allowed by the used media increases [64,66,75]. For instance, videoconference systems have been considered more acceptable than just text-based systems, as they allow for capturing nonverbal cues which can be useful to grasp the intentions of the interlocutor [48,75]. P6 says that he *"... always emphasise[s] that a video conference is more effective because you can also follow the facial expressions and gestures."* (Quote 9, P6). However, P6 still has concerns with possible misunderstandings because *"[...] it is not so easy to conduct everything through a digital system"* (Quote 10, P6). Furthermore, the technology, at least the one which is more easily accessible in the workplace, is still not there. Our participants expressed many reservations about digital conversations because gestures and facial expressions of the interlocutors are only partially captured by a camera:

> A face-to-face conversation might detect a bit more authority than a digital conversation, which you conduct about a certain thing, definitely. Because mimics and gestures, I think, also come across well with digital media, but you also see, for example, when you only use your mobile or [...], the hands don't come across so well or the body [...] (Quote 11, P13)

Obviously, essential content is only partially transmitted, which may affect the perception of the situation considerably [75]. This two-dimensional perspective coming from mediated interaction seems to convey less expressiveness and to result in a lower effect of authority, as identified in previous CSCW studies in other contexts – e.g., [36]. Furthermore, participants were critical towards digitally mediated articulation and coordination, as they feel that interlocutors can hide real emotions. Put it differently, they mostly distrust mediated articulation and coordination [32] because:

> You're not as honest because the digital system doesn't allow you to sit oppose each other, to look into each other's eyes. (Quote 12, P7)

Looking from the angle of group effects, it is possible to argue that Quote 12 suggest that a low level of social presence doesn't foster *social facilitation*. On the other hand, there are also (face-to-face) situations in which employees perceive too much authority: "*There are also colleagues who are then understandably quieter and who do not dare to [say anything] next to the superiors*" (Quote 13). These employees feel *socially inhibited* by the authority of their superiors, so they feel uncomfortable in a situation with a high *social presence,* and they contribute less.

Closely related to the observed presence effects is the emergence of *hidden profile* situations. A high social presence can, on the one hand, lead to withholding information, thus leading to a hidden profile situation in Quote 13. On the other hand, low social presence can lead to a loss of honesty, which in turn reinforces a hidden profile (Quote 12). However, it should also be noted that reduced

transmission of non-verbal communication can also protect marginalised users, as has been found in other contexts [66].

Related to this, the results show that the relationships between the group members also have a strong influence on the effect of social presence [78,79]. The following quote refers to production situations in which only a few activities are coordinated by digital technologies and articulation based on papers and verbal instructions is used for instruction. Essential and especially controversial aspects are often clarified directly in person, which has as a consequence: *"[...] Because of this thing [issue], just with the set-up, we get into each other' business so often lately."* (Quote 14, P19).

In addition to Quote 14, Quote 15 expresses that as a result of the disturbed relationship between P19 and his supervisor, the latter chooses indirect communication channels via subordinate employees in order to no longer have to give P19 direct instructions:

> [The superior] prefers to say that to [colleagues] this way because he doesn't get any objection. But I had to realise, people say something [irrelevant] about certain topics. But I think that's the way it is here. [...] And before I lie to someone or tell them what they want to hear, I'd rather keep my mouth shut. (Quote 15, P19)

In an environment characterised by a partially digital structure, but also by verbal, non-standard communication channels, these channels contribute to suppressing social problems but not to solving them. However, this does not solve the problem of different views but only covers it up temporarily. As a result, P19 also no longer talks about all issues and only does his job by the book. P19 therefore feels excluded by the supervisor's behaviour and no longer actively participates in discussions. This leads to a hidden profile effect because not all information and ideas, e.g., for improving the set-up, are exchanged on both sides.

However, it is not only the avoidance of opposing opinions that causes employees to hold back, but also the fear of negative professional consequences: *"Should I say my opinion or shouldn't I do that [...] if I say that, that can also go wrong [...]"* (Quote 16, P2).

The employee's perceived fear leads to the avoidance of conspicuous behaviour and thus to the withholding of ideas in uncertain situations and causes social inhibition of P2. This manifests itself in a hidden profile resulting from P2's unwillingness to speak up to decision-makers.

Thus, P19 and P2 show that negative relationships between colleagues lead to a downward spiral, starting with social inhibition or exclusion and leading to hidden profile situations. Extended chains of command, fear and an intensification of conflicts further reinforce the effect. The reason for this situation, we argue, is the strong negatively loaded personal relationship of the persons who cannot resort to a standardised and e.g., digitally supported articulation work to coordinate. In such situations, digitalisation is manifested in new practices concerning communication at a distance, which means that the personal component is no longer as strong, and the cycle may be broken.

Not only emotional aspects, but also the leadership behaviour of superiors has an impact on the production information flow, as P3 suggests:

> Of course, [the working atmosphere and motivation] depends on the supervisor because all information is given to the employees by the supervisor, all data, news must be passed on by the supervisor. (Quote 17, P3)

The quote above suggests that this handling of information at higher hierarchical levels can have a significant impact on the information flow. Nevertheless, although supervisors have a high level of responsibility, some of the articulation to staff also bypasses them via a digital system. P4 suggest that problems can arise from this by stressing that groups with limited information do not understand decisions made by superiors. At the same time, it becomes clear that the supervisor who speaks up here has the strength of character to defuse the problem through personal, further articulation:

> [...] because employees see some, many things quite differently, because they have less information flow, they see everything quite differently. I used to see it that way too, I always thought: "why is he doing it that way now", although we have a completely different information influence, that's why we think that way too. That's why I tell people a lot of the information I get, so they can understand it better. (Quote 18, P4)

To summarise, it is sensible to say that supervisors have to find a compromise between formal and standardised, digitally mediated articulation work and face-to-face articulation work. Employees may otherwise feel socially inhibited due to the poor working climate, which prevents them from participating in discussions and decisions. Quote 18 already indicates that employees can also derive completely their own models of thinking from this and that a hidden profile group effect develops combined with a polarisation [59]. On the other hand, Quote 18 can also be taken as a way out, which is for supervisors to explain standardised articulation face-to-face. This helps to avoid measures to be rejected due to personal reservations. In this sense, suitably supporting digital systems may help to improve understanding of workers' coordination needs and to increase trust – similar results are shown by [74].

However, comparable situations can lead to a loss of motivation, as P5 reports in Quote 4.19 Since P5 not only withholds his opinion and engages in hidden profile, but also speaks of general restraint, a *free-riding* effect emerges. This also corresponds with the obvious resignation of P5: *"And basically everyone has to live with the idea that [the managers] already know what they are doing."* (Quote 20, P5). It underlines the typical thinking of free-riders that they cannot influence events with their activities anyway. Specially if hierarchy is taken into consideration, as evident in the quote above. Findings from our study suggest that generally participants do not feel comfortable to contest decisions from higher management levels and resign.

5.3 Transparency over Hidden Profiles and Related Effects

Production systems are often characterised by coordination activities between many actors [20]. The findings presented across this section suggest that enhancing transparency in terms of decisions taken or agreements made is key to prevent that hidden profiles and other related effects emerge. In particular, bridging temporal distance should happen without additional effort to reduce hidden profiles. This, as we will see, is particularly favoured by digitally supported articulation. It will also become evident that transparency can have an impact on employees' psychological safety.

Among other issues that must be coordinated in modern production structures, order quantities frequently take centre stage, because precise coordination of order quantities avoid unnecessary stocks and unplanned time pressure:

> P19: Then I go 10 minutes later and say, "You're doing 125 [pieces] of it", that we're on the safe side. Even then it's not enough because there's always tight planning.
> I: That is, you simply increase the number of units.
> P19: Yes.
> I: [...] Is there a feedback loop to material management?
> P19: Yes. The people [...] enter the piece numbers in the evening via the barcode and then everything is reported back to the system. (Quote 21, P19)

However, the articulation work needed to coordinate this can sometimes be challenging, especially when there are relationship difficulties between the cooperative actors. In the quote above, P19 decided to take responsibility and diverge from decisions that he judges incorrect, because he believes to act better than the responsible planners. This, we believe, is partially because his difficult relationship with his supervisor (see Quote 14).

Via informal coordination channels, P19 implements his own planning ideas without consulting his superior, which have an impact on upstream and downstream processes (e.g., provision of

materials). Crucial here is a hidden profile situation where P19 does not fully know the context on the basis of which his superior plans. Although immediate feedback on the rescheduling would actually be necessary, the information is only passed on automatically in the evening, so that planning errors can occur in the meantime [68].

The consequence resulting of such situations and the misuse of capacities becomes clear by P18, who expresses: *"[...] if there is not enough information then instead of 200 parts, 300 parts are bent and we lack the time afterwards somewhere ..."* (Quote 22, P18). The cause here is again a lack of information that would be relevant for correct decisions. The *hidden profile* stemming from the fact that a single person is withholding information [91], we argue, could be avoided by introducing some sort of formal and standard digital media. Similar problem structures, which emphasise the spread of poor communication in other processes such as vacation planning, shows P12: *"If he has vacation, we don't know when he has vacation. Suddenly he's not there ..."* (Quote 23, P12). In this way, P12 describes how information that would be necessary for correct vacation planning is withheld and he is excluded from the information flow.

These findings suggest that employees resort to self-regulated informal coordination when there is no formal coordination mechanisms in place – much alike to what has been observed by [12]. As seen in the situations described, this leads to suboptimal and uncoordinated plans as reported in Quote 22 above.

Furthermore, our findings suggest that untraceable decisions and information channels represent a frequent problem. The consequences of non-transparent coordination lead to exclusion of employees, as suggested in Quote 24 below, resonating with issuers reported in [91]. There, it becomes particularly clear that *group polarisation* also occurs away from the installed information channels. It manifests itself in the fact that a group forms its own isolated ideas about the situation. The person in charge, however, ensures transparency through digital technologies thus exposing the coordination problem to the employees. This mitigates the polarisation, as the following quote suggests:

> Groups are formed when you tell someone "I can't give you a holiday". Because there are employees who want to have spontaneous leave. They say, "from tomorrow I need holidays for a week". Then I say no, because there are already people missing due to illness or holidays. […] If the employee comes again and again saying, "I need leave from tomorrow", and I then say "no" more and more, then of course they feel excluded. And when people feel excluded, they pass it on in the coffee breaks, [they will go and say] "It is like that, he won't give me any leave". Then the other people say "yes, he did it to me too". […] But I always solve it by opening […] a software programme for planning holidays. I open it and call the employee and say, "come and see if it's possible" […] (Quote 24, P11)

These findings suggest that polarisation can be avoided if exclusions are resolved through transparency and decisions are traceable to all employees involved. In this case, the foreman solves his problem by drawing on the holiday planning software, which show how many employees are currently on holidays or sick. This way he can provide evidence to employees that at the moment no other employee can take holidays, because of shortage of workers. The special importance of supervisors in shaping the operational coordination (as seen in Quote 17) is again emphasised.

Similar to errors due to information deficits in production departments, errors can also occur in the coordination of work across shift changes, as previous literature have found in other contexts [77,78,83]. Here, unfinished orders are handed over to colleagues, while employees often do not want to stay longer after the end of their shift but leave to go home. Typically, information about material problems, patients or the condition of machines and tools must be handed over in a narrow time window.

In the cases described, common information spaces can be particularly relevant to avoid exclusion emerges during the exchange of information in shift changeover [103]. In this situation, the question arises as to how far employees build up trust here and how they would like to see work handed over.

One possible way out of it, our analysis suggests, is to maintain an electronic shift book via software applications or mobile apps. This ensures that information is better passed between shifts because it is stored in a way that is accessible to everyone, which has been proven effective in handover situations [78,83]. Therefore, the information is well documented and retrievable even after the end of the shift:

> We have all this paperwork gone. We type everything in by hand and transfer it like this and then we also send the file to him again by email so that he also has it with him. [...] It is a bit better because you can always check what was there. [...] And that's how it is, it's there, he didn't tell me verbally, it's there, I have it in black and white. 'YOU gave me the instruction here'. (Quote 25, P3)

Here, it can be expected that the records of a digital shift book will also allow employees to prove their work is correct and thus contribute to their psychological safety. In this respect, a digitally simplified coordination mechanism to support articulation work, involving the digital shift book and the procedures concerning its use, may make it possible to improve the low level of participation [2]. Also, a hidden profile situation can be prevented by a digital shift book, as the common database makes the information accessible to all interested people [63]. The documentation also makes it easier to remind shift supervisors of their commitments if they fail to meet them.

In addition, under time pressure, unfinished processes and problems have to be handed over to colleagues during shift changes. This requires trust in the colleagues because any errors also apply to the employee from the previous shift. Newly established digitally supported practices can potentially relieve workers of such a burden, as they can more easily document the handover of information. In this way, the employee no longer has to carry the responsibility alone, but can share it with colleagues from the other shifts [78]. This means that social facilitation can be fostered through such a *coordination mechanism*. At the same time, this can be problematic as the documentation may reveal shortcomings of the workers [75] for which they could be held accountable, as P10 reports:

> I find it rather freeing. I was able to tell my following maintenance technician what I had already done. He was informed. I could get rid of the comment. Restricting, it is just, if you have not done anything, I say, nothing, if you cannot cope with the task, then it is restrictive, because all the others can read it and then, yes, you come to the compulsion to write something. (Quote 26, P10)

The corresponding concerns of the employee indicate that the shift book will force him to also disclose information about poor work results. Indeed, there are trade-offs when investing on mechanisms to workspace awareness [43]. In this case, however, the possibility is opened up to identify and reduce free riding. It can be noted that the use of digital communication technologies in particular can help to share knowledge and expertise [20,49], which can contribute towards dissolving *hidden profiles*, so that coordination can be simplified [34]. It should be noted, however, that his or her support must also very accurately capture the context of a problem situation and, if necessary, should be given in real presence [37].

For this reason, and to relieve the pressure of having to speak out publicly, the digital tools for coordination and the articulation work involved should also be restricted to a specific circle of employees related to the content of the respective topic (as in Quote 1, Quote 2 and Quote 3). Nevertheless, digital systems fulfil the task of enabling a large number of participants to coordinate at the same time, but also to create a temporal and spatial bridging with which the work results can be documented [14]. As pointed out in [28], team knowledge is of essential relevance for

coordination, especially in situations involving distance collaboration. As noted in previous literature, improved awareness can prevent the development of hidden profiles, and promote a sense of social presence and social cohesion [58]. In this context, our analysis suggests that data transparency can increase a sense of competition between shifts and workers, as P11 pits it with the words *"You have competition. There is often pressure to perform between shifts. […] And if an employee worked less that day, then I have to account for that. […]"* (Quote 27, P11). This competitive situation is accompanied by comparability, which can rather lead to social inhibition in complex tasks. With easier tasks, on the other hand, social facilitation can occur, leading to enhance productivity. In this respect, depending on the complexity of the task, care must be taken to establish an appropriate level of competition.

Beyond that, data transparency and potentially increased competition help to prevent social loafing by making performance and results visible within and between groups [58].By analogy with Quote 27 the feedback should be adapted to the situation in which the transparency is made available to a defined group of users [95]. Quote 26However, if the influence of individual performance becomes less transparent, this can also lead to a reduced awareness by employees of their own contribution to the group result, which in addition can increase the risk of social loafing and free-riding [60]. Therefore, special attention should be given to the design of feedback in such digital systems meant to mediate articulation work [95].

Last but not least, the resulting competition situation can create an additional incentive and can help to avoid social loafing as well as free-riding [60,62]. To prevent that transparency will not lead to social inhibition on the part of employees, the psychological safety needs of co-workers should be considered when designing such digital tools. When errors arise, documentation can help steer a discussion to a factual level, making group polarisation more difficult. However, the temporal distance remains crucial for trust between the participants [56].

6 DISCUSSION

The findings presented across section 5 demonstrate how *group effects* are considerably present in production contexts undergoing digitalisation and how they impact upon coordination, and consequentially cooperation, in those contexts. In the following, we further elaborate on the aspects introduced across section 5 and outline how articulation spaces can be useful to mitigate some of those effects.

6.1 Group Effects and Coordination Challenges in Digitalisation Production Systems

As seen in section 5, a series of group effects frequently occur in production contexts, some of them leading to other group effects. Digitalisation, according to our analysis, can on the one hand augment some of these effects, but on the other hand, can contribute towards reducing some others.

As seen above, workers are at risk of being excluded from relevant articulation work and social inhibition may arise as the result of low transparency about the informed circle. In some cases, the experience and skills of the employees play a role in the extent to which they are integrated. This raises the question of the extent to which these characteristics lead to polarisation among the employees. Our findings also show that employees within informed circles are subject to compartmentalisation, which manifests itself in the form of polarisation. If we take a step back, so to look at the bigger picture, relationships as the one illustrated in Figure 2 can be noticed.

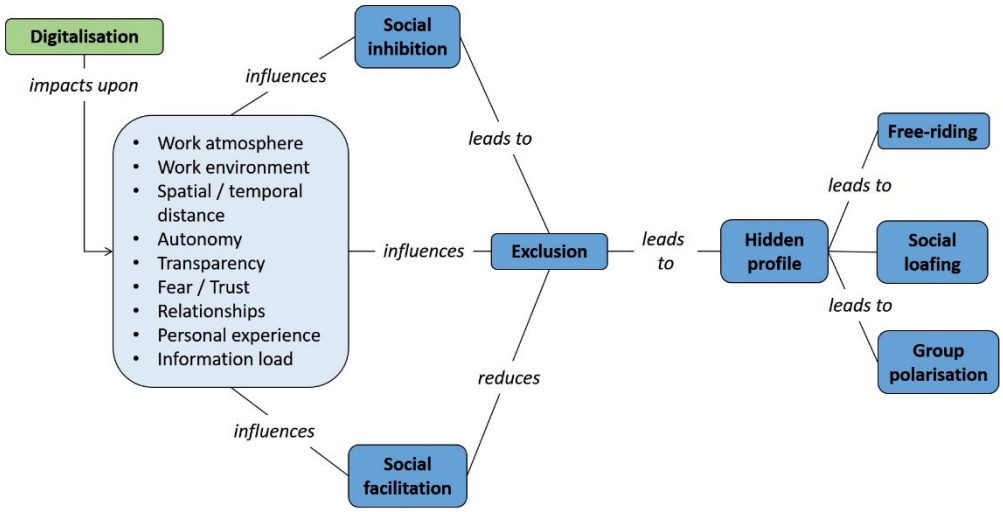

Figure 2. Identified relationships between digitalisation and group effects

These findings have direct implications for CSCW as a field, insofar they suggest that designing for cooperative actors working in production contexts undergoing digitalisation have to take into consideration many nuances of the personal, social, and organisational elements of the socio-technical configurations in question. Group effects, as we have demonstrated across section 5, can help understand those nuances and provide invaluable insights. As visible, there are many competing issues which should be individually analysed and addressed creatively. For instance, it is widely accepted that not every worker should be involved in all coordination and articulation work going on in the shop floor and other organisational levels. Nevertheless, as seen across section 5.3, it is ultimately important to introduce mechanisms to monitor restrictions and make them transparent, in order to avoid undesirable group effects.

Our findings also suggest that there is a danger of polarisation to emerge in a group of disadvantaged employees, as they try to avoid exclusion by using private tools. In order to stimulate proper cooperation, employees, we argue, should be given the opportunity to decide, at least within limits and in a self-determined manner on the use of tools for coordination and articulation work. Especially when the individual workplaces are located at a distance from each other, digital support, e.g. through a common information space [11,81,103], can potentially help. Furthermore, it is noticeable that in these cases a communication tool is also needed. These tools, our analysis demonstrates, should consider the worker's personal preferences in terms of coordination and articulation work, and also cover the private sphere.

Another aspect that we, as CSCW professionals should take into consideration concerns the sociality of the articulation work, which sometimes is taken for granted. As shown in section 5.2, a high level of social presence through face-to-face contact or at least video transmission is sometimes an explicit demand. This is due to the possibility of a spontaneous reactions of the interlocutors, whereby a quick adaptation to changing situations with minimal training efforts is achieved, amongst other things. These findings are aligned with results of Esbensen and Bjørn [26], who observed that standardising artefactual dependencies is more difficult than standardising organisational practices. Furthermore, issues of honesty and authority also matter, as suggested by Maréchal and colleagues [67].

In terms of the desired heightened social presence, it is clear that this cannot be achieved for all areas, nor would it be strictly beneficial, as found in studies reporting on lower quality of a medical diagnosis [27]. On the contrary, our analysis suggests that designing to allow co-workers to make themselves socially present at different intensities as they go on to engage in articulation work would be a better solution. Particularly with the issue of authority, digitally mediated articulation work could support leaders to follow up the developments regarding a particular task, without imprinting a sense of control. Consequentially, this can help prevent social inhibition and, ultimately, the development of hidden profiles, which can result from a sense of intimidation coming out of exerting authority [22].

Leadership also needs to be supported in a way to prevent the rise of undesirable group effects. It is true that in production contexts, as in any other contexts, the presence of a leader is instrumental to move things forward. Nevertheless, our findings suggest that there are situations when this presence can lead to social inhibition and, consequentially, to hidden profiles and polarisation (see also Figure 2 above). From this, one could argue that a mediated transfer of leadership presence can foster motivation and to increase trust. However, one should not forget that mediated interactions can lead to problems in communication, which may be a source of misinterpretations [75] and, again, lead to polarisation.

In regard to coordination, as shown across section 5.3, limited communication can hinder it and favour hidden profiles. Tenorio and Bjørn [97], for instance, recommend using informal chats instead of emails for communication to reduce the risk of sub-group dynamics causing disruptions. Our analysis suggests that personal divergences are a relevant issue behind coordination failures and indicates that a transparent and, above all, common database can contribute towards mitigating these divergences. Quote 24 underlines this issue, contextualise it within holiday planning and shift changes. Furthermore, through our analysis it became clear that the shared database represents documentation for evidence purposes and contributes to personal safety. This would represent a move from social inhibition towards social facilitation, by means of which articulation work may be reduced. However, it is necessary to find a compromise between privacy and common understanding [47].

Last but not least, there is the issue of competition, also addressed in section 5.3. Our findings suggest that, when competition among employees is properly managed, it can lead to increased performance and stimulate exchange of information. A reduction in social loafing and free-riding can also be expected in such situations. At the same time, if not carefully handled, it can result in rivalry and jeopardise cooperation among co-workers.

6.2 Conceptual Aspects of an Articulation Space for Production Contexts

As discussed above, our analysis suggests that employees are constantly looking for ways to stay up to date with all necessary articulation work necessary to coordinate cooperative efforts in the production. Our findings also demonstrate the relevance of taking into consideration formal as well as informal coordination media, for successful cooperation. Our analysis supports the argument that, independent of how well one plan, when it comes to work, situated actions are most likely to arise [93]. This has consequences to how we should design to support the articulation work necessary for proper coordination among cooperative actors [87,93].

Boden and colleagues [12] introduced the concept of articulation spaces as an instrument to bridge between formal and informal coordination among employees. We argue that this concept, which has been initially proposed in the domain of software development, can and should be appropriated for complex domains, as production and manufacturing. We have identified a series of elements that articulation spaces for production contexts undergoing digitalisation should have,

which are illustrated in Figure 3. The articulation space represented in that figure is composed of two channels. The first channel is shared by employees E1, E2 and E3 and facilitates transparent access to filtered information. Channel 2, on the other hand, is shared by employees E3 and E4. For illustrative purposes, Management Engineering Services (MES) and Process Data Acquisition (PDA) systems compose the technological infrastructure of channel 1. As seen in Table 1, these devices are usually integral part of production contexts undergoing digitalisation. The technological infrastructure of Channel 2 includes Enterprise Resource Planning (ERP) and Computer-Aided Design (CAD) systems and collaborative software systems. While MES, PDA, ERP and CADs support coordination at a formal level – as for example, assigning tasks to particular workers, fixing deadlines, etc. – collaborative software systems should be prepared to support both formal and informal coordination – as for example, asking a colleague to cover for a shift at a short notice because something awful unexpectedly happen that would prevent the worker to go to work. In particular, implicit sharing, as discussed in the literature, can come in handy in such contexts, by providing serendipitous way to keep informed about relevant aspects [39].

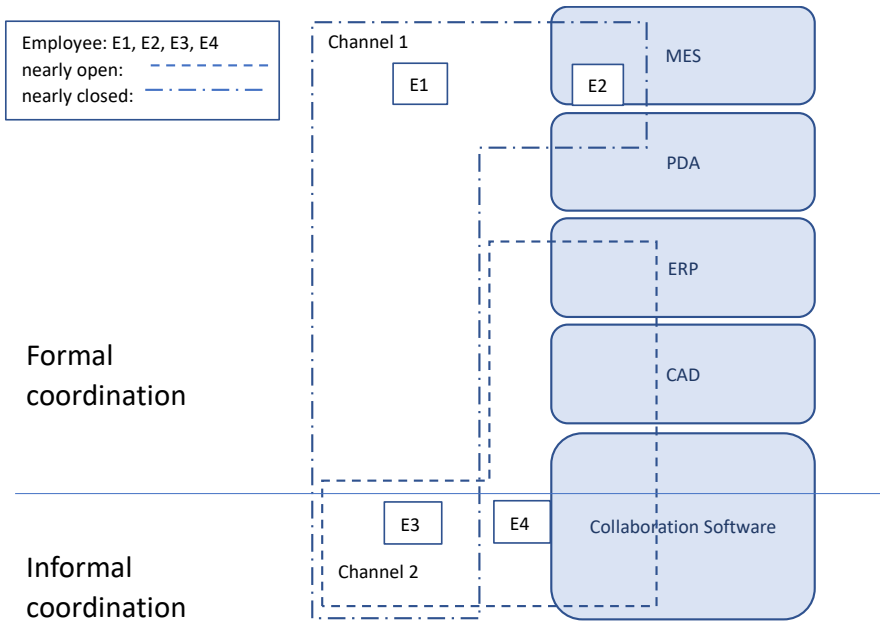

Figure 3. Articulation Space Outline for Production Systems

In summary, the envisioned articulation space would have a common database allowing co-workers to coordinate their cooperative efforts, by making transparent which open tasks, the status of ongoing tasks, and the work assignments in place. It would be subdivided into channels according to topics also linked to different membership rights. Depending on the importance of the topic, corresponding channels could be made active for different lengths of time and facilitate the necessary articulation work. This is a very important aspect, as employees do not want or cannot handle too much information; this can ultimately impact negatively on their attention and spill over productivity. Therefore, the coordination mechanisms of articulation spaces for production contexts as the one that we have investigated should provide context-dependent information and avoid information overload, in line with discussions found in the literature – see e.g., [23].

In particular, the working conditions in production must be considered individually [55]. Accordingly, articulation work must be supported by easy-to-use media that can be handled as workers are engaged in actual work [10]. This has also been noted in the medical domain, as reported in [103]. Being able to accomplish secondary work, as articulation work or knowledge transfer, as one is actually engaged in primary work has been shown to be a recurrent demand in production contexts [20].

Moreover, as demonstrated across section 5, privacy is a relevant aspect to take into consideration for the design of such articulation spaces, as it contributes towards creating an atmosphere of trust and avoid polarisation [89]. Bringing together formal and informal forms of coordination will add a further layer of complexity on the issues of privacy. This should be carefully considered and seriously addressed in designing articulation spaces for such contexts, in other to protect employees – and also employer – from legal complications. This makes up for a relevant topic, which deserves a dedicated paper.

Furthermore, these articulation spaces should have the ability to filter and aggregate data [12]. In industrial environments, this feature is needed to ensure partial transparency to the outside, without compromising privacy. This can be made to a larger of shorter extent, as represented by the dotted line of the articulation channels in Figure 3. Conversely, aggregation and filtering of data must not exceed a certain level, so to avoid polarisation in such channels. To a certain extent, polarisation can be (partially) seen as the result of too little information. Our findings have shown that transparency can counteract this effect, and this can be achieved by using versatile accessible digital systems. In particular, the use of visual information can have a greater impact than the use of its textual counterpart [89]. However, it is elementary to maintain the common data basis in order to maintain the transparency required on an up-to-date basis and to ensure trust in the system.

With such a configuration, the articulation space can potentially contribute towards achieving a balance between social facilitation and social inhibition. Social inhibition, our analysis suggest, is often associated with the emergence of hidden profiles. Hidden profiles, which can also be attributed to struggles regarding power imbalance, can be further promoted if the awareness mechanisms of the referred articulation space are not carefully designed [43]. In particular, as demonstrated in our analysis, a strong separation between managers and shop floor workers can lead to hidden profiles. Articulation spaces, as the one that we outline, can also counteract triggers of hidden profiles by making the activities of a channel graspable to the outside world with the appropriate level of transparency. Sufficient transparency of a channel must be ensured so that the members of a group keep an appropriate level of social presence [50]. As demonstrated in our analysis, imprinting social presence in different degrees during articulation work in production contexts is considerably relevant. The degree of social presence can be controlled through digitally mediated articulation work, which can include videos and other less rich media as audio and textual messages [46]. Protocols can be formalised in coordination mechanisms [87] and chat technology can foster informal communication [97]. However, too much choice of media does not seem appropriate, as there is a risk of presenting employees with a selection problem [37]. Furthermore, previous studies have already demonstrated that rich media may have a negative impact in work performance [23], so extra care is necessary.

Nevertheless, such media must also facilitate a transition from the digital to physical world and help employees connect face-to-face when they so require. The purpose of this measure is to create an atmosphere in which personal differences are reduced and a more open discussion atmosphere can be created, which according the theory of social comparison [73], is an important aspect for harmonious social interaction. The ‘act of working together harmoniously’ is the common-sense

definition of coordination [65 p. 358]. Even when considerable conflicts exist among cooperative workers, succeeding in managing dependencies harmoniously has been shown to be key for successful cooperation [17,65,85].

7 CONCLUSION

Understanding the impacts of digitalisation on cooperative production work is timely and relevant, taking account of the drastic changes that we have been observing in companies around the world. Our study has investigated how workers from the metalworking industry have been experiencing ongoing digitalisation in their workplaces and how it has been impacting upon the ways that they cooperate among themselves. Our two leading research questions were: *What aspects of cooperative production work have been impacted by ongoing digitalisation of work processes? How can associated negative impacts be possibly mitigated?*

In searching for answers to our first research question, we have found that coordination and the associated articulation work have been considerably impacted upon by the introduction and appropriation of digital technologies at the shop floor. In addition to that, our findings suggest that *group effects,* a construct from social psychology that has been recurrently mentioned in the CSCW literature can help us to shed some light on such impacts and provide insights for the design of infrastructures to support production work happening within those contexts. As discussed across section 6.1 and 6.2, using this construct as lenses to understand the impacts of ongoing digitalisation in cooperative production work provide invaluable insights for the design of new and innovative socio-technical solutions for these contexts.

In regard to answering our second research question, our analysis suggested that taking account of formal and informal forms of coordination is very important to come up with solutions that can effectively support cooperation among production workers. We hence saw the opportunity of appropriating the concept of *articulation spaces* in software development projects introduced by Boden and colleagues [12] to production contexts undergoing digitalisation. Articulation spaces, as has been demonstrated in [12], can provide ways to bridge between the formal and informal forms of coordination and support successful coordination and decision-making. Starting from this and following the premises of practice-centred computing, which poses that we have to carefully understand user contexts and practices to design for them, we have progressed to outline how an articulation space could potentially look like for contexts similar to the one we have addressed.

Naturally, the articulation space that we have outlined it is not prescriptive: it is only an example of a potential solution for the context that we have addressed and should be further developed and tested in future work. A potential future research direction is, therefore, to investigate and uncover how workers would appropriate such articulation spaces. Some possible aspects to be investigated are the impacts of having such articulation spaces installed on distributed computers, the effects of allowing fully autonomous or centrally controlled groups, and the extent to what addition media could led to further cognitive demands. Another interesting aspect to be investigated is the extent to what emerging systems can be associated with current trends in digitalisation and what advantages and disadvantages they would offer in cooperative work process. Furthermore, there is still a long way to better understand the extent to what articulation spaces as the one we outline would effectively support in mitigating negative aspects stemming from digitalisation, such as the ones that we have observed. All of this demands further studies with a deeper analysis of the issues.

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