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Smart Coordination Requires Operators in the Loop

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Abstract. As industrial digitalization progresses and the use and application of digital technology in industrial production increases, it is tempting to view technology as the answer and solution to all the challenges that arise in production. However, does relying solely on the power of digital technological systems do justice to the complexity of today's shop floor? We argue that despite the fact that digital technologies have the capacity to process a considerable amount of data which outperforms human computing abilities, it is crucial to apply a more holistic view and widen the scope of analysis above and beyond the immediate application of digital technologies. Thus, this study aims to explore industrial shop floor practices to increase understanding of the planning and coordination patterns. To get a thorough understanding of how planning and coordination work today and to find new opportunities, a case study approach was adopted. Data was collected in one small and medium-sized manufacturing enterprise through shop floor observations and interviews with six employees during 2022-2023. Further, we applied a coordination framework, including coordination mechanisms, for data analysis. The results show that the three coordination mechanisms Objects and Representations, Roles, and Routines are abundantly present in the case study. Moreover, two additional coordinating mechanisms were identified, Digital Technology and Context, which include a contribution to the earlier coordination framework. We argue to put the challenges that operators face into the limelight, by involving them in the planning and coordination loop.

Keywords. coordination work, industrial digitalization, shop floor, operator

1. Introduction

The area of industrial digitalization is directly connected to the use of digital technology, with a tendency to view digital technology as the answer and solution to all the challenges that arise in production [1]. It's safe to say that digital technology includes ever evolving and increasingly more sophisticated and nuanced technical functions and configurations, which offer uncountable possibilities of how to approach and manage the world around, in this case, production [1]. The international competitive situation of the manufacturing industry is fast-changing and driven by last-minute orders that affect the shop floor activities including the usage of technological solutions, both automated machines and new digital software, hence resulting in increased complexity [2]. Optimizing work

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processes in production is therefore a necessity if a manufacturing company wants to stay in the game and be relevant in the market [3]. New digital technologies and systems such as RFID, and sensor-based systems co-exist with traditional business (ERP) systems and offer many possibilities to survey, collect and analyze production data with a promise to identify the bottlenecks, resolve machine stop time and subsequently optimize production, hence increasing the profit [4]. In other words, digital technology embodies a very concrete and tangible solution to many difficult problems [5]. In industrial production, this complexity of managing the shop floor planning and production is given to the personnel, with operators as key actors [6]. Hence, to handle smart production, a better understanding of the connectivity and coordination between humans, machines, digital systems, and everyday work routines is required [7, 8].

By studying personnels coordination actions and related patterns from an employee perspective this study will improve our understanding of workflow processes and planning. Coordination mechanism theory [8, 9] provides a tool to study complex work and human activities to understand the essentials of complex industrial work on the boundary between Industry 4.0 and Industry 5.0 [10]. Given this, the aim of this study is to explore industrial shop floor complexities and coordination practices for an increased understanding of how coordinating patterns impact production work.

2. Theory

2.1. Industry 4.0 towards Industry 5.0

The term Industry 4.0 was first coined in 2011 in Germany and was described as a ‘new type of industrialization’ [2, 11] that would help Germany to become the leader in manufacturing engineering. Through the development of cyber-physical systems that integrate calculations, communication and physical processes, possibilities were created for completely new digital applications as well as automatic monitoring and control of machines [12]. Today, the advantages of Industry 4.0 are faster delivery times, more efficient and automated processes, higher quality, and customized products [1, 13]. Hence, the importance for industry has primarily been to understand the features and content of technologies and applications of I4.0, to transform industrial production from machine-dominant manufacturing into digital manufacturing, often labeled smart or intelligent manufacturing [14].

As companies started to embrace and relate to Industry 4.0, along came Industry 5.0 [15] which puts human needs and a sustainable environment at the center of progress and development, with the focus to sustain a resilient planet. As a counterpart to the technology-driven Industry 4.0 era [16], Industry 5.0 is a human-centric and value-driven initiative in which humans and machines are expected to work in a symbiotic relationship. As a result, industry workers will develop new roles as a shift of value from considering workers as “cost” to “investment” [17]. Hence, in the industrial production context, human needs are put at the core, and we ask what the technology can do for us, rather than asking what we can do with the new technology [10]. Viewing industrial work and technological implementation tighter than before represents a new type of collaboration, that kind where a human does not only give command and receive a clear answer but one that is rather similar to an ongoing dialogue. The aspect of communication is especially visible when it comes to big data but also automation, where humans and machines are in constant interaction. As machines get connected into one system that includes many different single items, it creates an ecosystem on its own. A very complex one with chain reactions and downtimes, where the role of a human being seems to have changed. One way to see it is that technology has become so powerful that it affects all around it including what a human being does in a work context.

2.2. Coordination mechanism theory

A traditional theory of coordination is explaining coordination in terms of managing dependencies between activities and routines [18]. An example of that is when several activities require the same resources, that is, there is a dependency between activities and this dependency needs to be managed in order to make the activities work. An implicit belief in this theory is that the dependencies as well as processes to deal with them can be identified and sorted out in a neat framework [19]. However, today organizations operate in a volatile environment with unpredictable demands which pushes organizations to be flexible and adaptable [20, 21]. In this kind of context, it becomes difficult to specify routines to the last detail and other less formal ways of coordination are needed [19]. Coordination is therefore by many researchers no longer seen as a constant formal structure that can be managed exclusively through administrative means, such as task assignment or schedules, but rather as an emergent effort of practitioners to accomplish a task in a joint manner, often through means of sharing knowledge [21, 22].

In line with the latter view on coordination, Okhuysen and Bechky [8] present five coordination mechanisms that describe emergent actions that coordinate work. These five coordination mechanisms have been applied as a useful theoretical lens for this study. The main focus is to identify the mechanisms that produce coordination actions based on workplace conditions and statements from the personnel. The five mechanisms are: plans and rules, objects and representations, roles, routines, and proximity. In the following we will explain what each mechanism entails.

Plans and rules. The main point with plans is to explain to the involved parties what needs to be done, and with rules, it is to explain how it needs to be done. Plans and rules can be pertinent to a specific department or to the entire organization. They also fulfill the following functions: to match organizational resources to the tasks, to spur negotiations between different parties and thus make the underlying misalignments visible.

Objects and representations. Objects and representations are used as a common referent to share information. They visualize activities, which makes it possible to align them as well as make the progress of these activities visible.

Roles. The relationships between roles show who does what. This creates a certain hierarchy of responsibilities where some people assume the role of following up on progress and keeping other people accountable for their work.

Routines. Routines are tightly connected to making the task completion visible, that is, it is about knowing what steps need to be taken to accomplish something. They can be written but also unwritten and are governed both by rules and customs. Understanding the routines of the other group, guides how to perform their own work.

Proximity. Proximity refers to people's physical proximity at work. When people share the same location, they can easily see how activities progress and adjust accordingly. In case co-location is not possible, the possibility to direct updates is replaced with updates by other communication means.

3. Methodology

3.1. Case description and Data collection

A case study design lends itself well to exploring a certain phenomenon in detail and in its context [23]. More precisely, a qualitative case study was used to explore one small and medium-sized manufacturing enterprise (SME) in Sweden with approx. 50 employees. The company is a manufacturer of pressure die-casting tools and located in a rural area and specializes in single-piece production. The main operations on the shop floor are machining (CNC), assembling and CAD/CAM systems. The study includes employees from both the shop floor and the construction department. Data for this study was collected during 2022-2023 through 18 observations and six interviews with company employees, see Table 1.

Table 1. Data overview

Role	Nr of participants	Duration
Team leader	2	Interview 90 min
Production planner	1	Interview 70 min
CAM technician	1	Interview 50 min
CAD Design Engineer	1	Interview 50 min
Sales Manager	1	Interview 30 min
Operators, assemblers, production planner, CAD design engineers	18	Observations 20 hrs
Sum	6	Interviews 290 min (approx. 5h)
	18	Observations 20 hrs

In 2022 two observation sessions were held. During these sessions, one of the authors met representatives from each department in the company, that is, operators, assemblers, CAD design engineers, production planner. During the observations, the observer took notes and had an ongoing dialogue with the participants. The aim of the observations was to get an overall understanding of what each employee's work consists of, how it is carried out, and how different steps in production are interconnected. After the observation was done, the observer made a comprehensive description of what was discussed as well as what happened in the situation of the observation.

In 2023 six interviews were held with the employees. The respondents were chosen through a dialogue between one researcher and the sales manager at the company. The choice was to focus on interviewing the representatives from each department who have the role of leader or in other ways have an overall responsibility over a certain task, for example planning the production. During the interviews the aim was to get an understanding of the whole operation flow. The interviews lasted between 30 and 70 minutes and were conducted onsite except for one interview that was held online. The interviews were open and explorative targeting the respondent-initiated stories of coordinated work [24]. Respondents describe their regular day at work, what they do when things do not go as planned, what shared tasks different departments need to solve, how communication happens and what are the main challenges at work. The interviews were recorded and later verbatim transcribed [25].

3.2. Data analysis

In total six interviews were recorded, transcribed, and a content analysis was done in the qualitative analysis tool Nvivo 14 and by using Excel [26, 27]. The transcripts were read through and coded with descriptive codes by the first author in NVivo 14. Then the co-authors collaboratively discussed these codes and in a joint effort made sense of how the respondents verbalize their work procedures with a focus on coordination activities. The sub-categories and categories were created in Excel. During this laborious work it became apparent that some parts of the interviews concerned other areas than coordination and these parts were excluded from the analysis.

After forming the categories, a further analysis was done with the help of the five coordination mechanisms identified by [8]. This allowed us to identify how each coordination mechanism is embodied in the company. For example, a category *'The screen partly fulfills coordination function'* was identified as a coordination mechanism Objects and representations. Table 2 presents the examples of each coordination mechanism that were identified through data analysis.

Table 2. Data analysis overview of five coordination mechanisms [8], combined with related descriptions and two new additional coordination mechanisms

Coordination mechanism	Examples and description
Objects and representations	Project planning Excel, a digital screen, weekly plan in paper, tool information document, deviation list, delivery protocol
Roles	Team leaders, production planner, design engineers, operators, assembly personnel
Routines	Daily departmental meetings, daily enterprise meetings, hand overs
Plans and rules	Project planning Excel
Proximity	Daily meetings for the leaders
Digital technology	ERP system, CNC programming, Teams
Context	Disruptions beyond enterprise control and disruptions within enterprise control

4. Results

In order to interpret the results of the analysis in terms of what coordination challenges the company experiences, the five coordination mechanisms identified by Okhuysen and Bechky [8] were used as a theoretical lens. During the analysis of the data collection, we found that respondents repeatedly made statements concerning digitalization in production, hence industrial digitalization. As an overall result we identified and suggest two additional mechanisms, i.e., *digital technology* and *context*. In the following, each coordination mechanism is described by various analyzed examples, followed by significant representative quotes from the respondents.

4.1. Objects and Representations

This mechanism includes various objects and representations, see Table 2, that in various ways have a coordinating function to support planning and follow up of the production. In the following excerpts it is illustrated what objects and representations the various departments use and how they are represented.

The engineering department has a shared excel matrix where each project has a clear timeline with progression and deadlines indicated with colors. All the design engineers have access to it and use it daily. It is also accessible to the CEO of the company who has overall responsibility for Sales. However, this object (the matrix) is not available for shop floor personnel: *'Yes, we built it for our own sake, so we can be one step ahead and see when a need for something comes up, so we can have some extra time then. […] It is our group using it.'* (Respondent 1)

The machining department on the other hand, has a digital screen where each CNC machine is visualized together with the workload for each of them. When a machine is double or triple booked, it blinks red on the screen and the production planner needs to do adjustments: *'When it happens that two jobs are scheduled to be done simultaneously in the same machine, that's not gonna work. If it's more than two, well then it blinks red.'* (Respondent 4). The screen also shows the whole operation flow, that is, where a certain piece will go after, for example drilling.

The assembly department does not have a digital screen and instead uses a simple plan laid out on paper by their team leader. The team leader does the planning once a week and they go through the weekly planning together: *'No, we have something similar, but it's not a digital screen but I'm doing the planning for the coming week and we go through it with the team.'* (Respondent 6)

The company has documents and digital tools to follow up on the workflow. However, 'build it and they will come' approach is not enough and certain organizational arrangements need to be in place to make it work.

4.2. Roles

The company in the study is a medium-sized enterprise with a rather flat hierarchy structure. This also means that often the roles are not mutually exclusive, and the areas of responsibility entwine. More specifically, all employees besides the operators and assemblers have multiple roles and responsibilities. For example, the responsibilities of the company CEO stretch over managing customers and sales relations, discussing technical details with design engineers, participating in weekly production planning, stepping in as a temporary leader in assembly department as well as occasionally being a team leader for design engineers.

The right hand of the CEO is responsible for sales relationships with several customers, making certain purchases, but also for improvement processes, documentation, work environment, standards to name a few.

Even designers have at least double roles: they are both designing a tool and acting as project leaders: *'Someone from design engineers is also a project leader. The project leader is always one among us, design engineers.'* (Respondent 1)

The same goes for team leaders, they are both operators and team leaders: *'So these are two new roles that did not exist before. We have had team leaders, but they only worked with leading the work. They did not work at the machines at the same time.'* (Respondent 5)

The groups with a more delimited area of responsibility are operators and assemblers. Their responsibility consists mainly of carrying out assigned jobs. It could be said that due to the fact that many positions encapsulate several roles, the asymmetry between responsibilities and authority is not always clear.

4.3. Routines

A very important routine for the entire company is short daily status meetings. There are three types of daily meetings. Firstly, each department holds their own status meeting with department employees. Secondly, right after this, the personnel in charge of each department meet up for an internal daily company meeting, including representatives from economics. This is followed by a third short production catch-up meeting with only the leaders responsible for the production. The daily meetings are very much appreciated through out the company: *'You get an overview over the whole factory. Before it was only about the department, now we have an overview over all departments, all the way from the CEO to assembly line, so to speak.'* (Respondent 6)

Besides the daily meetings, the company also has a three-step handover routine to ensure a smooth production flow. The first step includes a handover from Sales to the design engineering department that usually happens friction free, no issues have been reported during this step. The second step is a handover to the production department. The difficulty here has been that sometimes the operators discover too late that a planned machining process is not technically executable: *'How the hell are we gonna produce it? – No, but that is an example of... when an operator discovers [an issue]. And if he did that in an earlier stage, that is, before the piece is fixated in the CNC machine, then it's really no problem.'* (Respondent 4). For this reason, the design engineering department has initiated a closer dialogue with the production department resulting in a more floating handover. It means that design engineers check-in with the CAM technician who in his turn checks-in with specific operators before the handover actually takes place.

The third and last handover includes an inspection of the product before shipping as well as a review of deviations encountered during the project. An unexpected error or a miss that resurfaces at this point might aggravate the set deadline and is therefore treated with the highest priority. This might demand adjustments that interrupt the original workflow, such as emergency replanning.

To summarize, the existing routines are designed for a problem-free transfer of information from one group to another. However, issues do arise which opens for changing coordinating routines to better correspond the actual practice on the shopfloor.

4.4. Plans and rules

An important part of steering production is through adhering to international standards. The company is following strict rules and regulations to ensure production quality and is subjected to repetitive independent revisions.

In the context of everyday planning, the following two tools have been witnessed in the interview data. One is the shared Excel file mentioned earlier in Objects and Representations. It contains an overview of each ongoing project including deadlines for external deliveries, deadlines for internal handovers and can also be described as plans. The file illustrates how the work progresses for each design engineer and it has indicators of the workload at the engineering department. It also has a color sensitive notification function built in the file: *'So we have built an Excel matrix, so that we… Well, we add all the projects, and who is responsible. We also have deadlines; they indicate when the production department needs the drawings to be ready. I add these dates manually. And the file warns me, the date turns yellow. So, we use this Excel matrix every day.'* (Respondent 1)

Another tool is the company's ERP system which serves various to production and resources related areas, such as scheduling all jobs for the machining department, visualizing the overall production planning, it also provides a clocking in function for operators and assembly workers and have order handling and personnel managing functions. The ERP system is an indispensable aid in everyday production planning: *'It is much simpler and more comprehensible since we moved to Monitor. The change is enormous, not only for me but also for the economy department and the management. It's a whole different world to work in, compared to the system we had before.'* (Respondent 4)

When it comes to describing how certain tasks need to be carried out, two documents are of importance. Machining instructions from the CAM technician is one of them. The other one is a tool information document from the design engineers. It contains tips and remarks that help the assemblers during the assemblage of the tool.

In other words, the leaders' main focus lies within documents and systems that describe what and when needs to be done. Whereas shopfloor personnel involvement in the planning is manifested through their input on the CAM instructions. As in the case with routines, a stronger participation from the side of operators and assemblers could contribute to a smooth workflow.

4.5. Proximity

The layout of the company allows for proximity within a department but to a various degree. The design team is sitting in their own office, the operators work in two different halls and the assembly employees work in a separate hall. To join employees from other departments everyone needs to cross some passages. The team leaders, however, participate in the joint company meetings where representatives from each department are present, this creates a temporary opportunity for cross-sectional proximity: *The next meeting is at 8 am. We are here then, with representatives from each department. We have one design engineer, the management, the CAM technician, he is responsible for some deliveries and such. People from the economy department also are present. Team leaders for production and assembly are also here. And we have a short resumé, shortly about what has happened out there in the production, and what has happened here in.* (Respondent 4)

The operators and assembly line workers do not have this type of scheduled cross-sectional gatherings which also puts into question whether they get the information about the progress in other departments to the same extent as the team leaders: *'We don't really meet that much. Or, well I meet many people, but the rest of the assembly down here do not really have that many meetings with other colleagues.' (Respondent 6)*

Team leaders have scheduled occasions to be in proximity with employees from other departments while shopfloor employees need to do that on own initiative.

4.6. Industrial digital technology and context

Apart from the five categories of Okhuysen and Bechky [8] we also identified two additional types of coordinating forces. One is digital technology, and the other is context.

Industrial digital technology. One example of how digital technology changed routines is when drawings were replaced with 3D models. Having a digital 3D model made it possible to reuse it and have it as a reference that is easy to pick up. This led to standardization of CAM instructions, an important aid in shopfloor personnel everyday work: *'We got digitalized around seven, eight years ago, we took away paper drawings so to speak. [...] In relation to that we also started a standard with CAM instructions and such.'* (Respondent 2)

Another instance where technology is very prevailing is the situation of *CNC programming.* According to the respondents this type of programming is getting more and more advanced and complex: *'Especially when it comes to 5-axis machines. It's really tricky… It's more and more difficult, and then you get upgrades, and you can do more, and you need to think in new ways… So it is getting more and more complex to sit and do CNC programming.'* (Respondent 5)

It takes time and skills to do a CNC programming for a piece with complex surface, and when the piece is new, it is only possible to do the programming one step at a time. That is, operators cannot do an entire program for the next piece in advance, but they are doing that as they go about the job: *'You can't really… It's difficult to get too much ahead of yourself, 'cause if you make an error and you've written the program, and then you need to go back. It's not very easy to go back and do it over. You might need to delete everything you've done and start over. So you don't really dare to go too much ahead.'* (Respondent 5)

Sometimes it means that the machine stands still because the operator needs to first check how the previous programming step was executed before continuing further.

The coordinating power of technology is also recognized in communication between operators and the design department. In the company they have *Teams* installed on their computers which gives access to Team chat. That is an effective communication tool, however only those who are more computer savvy choose to use it. This means that information and knowledge is siloed within those individuals who use Teams as communication tool.

Context. Context could be described as a sum of circumstances that the work is being carried out at. In this company the working context is strongly governed by all kinds of unpredictable changes in the production planning and hence also production flow: *'It happens at least a couple of times a week. I set up a weekly schedule on Thursdays. Next week they come and say, and maybe the schedule changes a couple of times every week, it does. It's because of a machine breakdown in the production department, or an emergency job from the foundry because they broke something, or somebody is on sick leave.'* (Respondent 6)

Other reasons that disrupt the planned workflow can be changes from the customer, last-minute orders, emergency repairs, but also personnel on sick leave, machine breakdown. To add, uneven order flow, though also seen as a necessity, can result in varying workload and work intensity, leaving no time to work with internal improvements: *'But that's the branch we live in. The big companies wait until the last minute before placing an order. And then they place a very large order, and we have to accept it.'* (Respondent 6)

The examples above show that most of the changes are beyond the company's control and happen unexpectedly. Order intake, though to a high degree dependent on the volatile market, could potentially be regulated by managerial means.

5. Discussion

The study aimed to explore industrial shop floor work practices to understand planning and coordinating patterns of industrial production. The model of coordination mechanism by Okhuysen and Bechky [8] showed that this company has a developed set of objects and representations to organize a smooth production flow. To make them fulfill their function, however, a tighter cross-sectional collaboration is needed especially between the shop floor personnel and the design engineer and the assembly personnel [20].

When it comes to roles the analysis has shown that operator and assembly personnel roles have been stable whereas the roles of the team leaders and development engineers have expanded. But as the roles become more complex and responsibilities intertwine, it is not always clear who has the authority to take decisions. More clarity and balance in the areas of responsibility and authority for team leaders and development engineers could contribute to faster and more smooth coordination. This has to do with who is having the control, both within the professional role and informally in everyday practice [22].

The company has well-structured routines for daily department meetings, however cross-sectional communication and information sharing is firsthand available for the personnel in leading positions (top management, development engineers and team leaders) but not for shop floor personnel. By more strongly involving shop floor personnel in, for example, handover meetings, there is potential to prevent unexpected error and emergency measures later. Establishing cross-sectional meeting routines for the shop floor personnel would allow them to share their knowledge and information, for example to develop their understanding of CNC programming in the machining department.

Plans and rules, constitute a part of the overarching structure of the company, they serve the common goal of the company, therefore finding ways to use it might be a powerful aid. As interview data showed, the overall planning in this company is visualized through the Excel matrix that design engineers own. Such documentation, visualized for other roles and departments, would increase the possibilities to make sharper plans and rules to follow, and hence increase the overall planning process [7].

Finally, the proximity mechanism, which stands for sharing the same physical location at work, is available through cross-sectional meetings for the personnel in the leading positions, however not for the shop floor personnel. It might be difficult to change the physical layout of the factory. Establishing new routines with cross-sectional meetings for shopfloor personnel can, however, improve the situation.

The suggested mechanism of industrial digital technology showed that the possibility to adopt and use Industry 4.0 technologies such as digital screen, advanced CNC programming, Teams chat is very much bound to personal knowledge of these technologies [3]. Those who are more technology savvy get access to information and knowledge and those who are less technology savvy are bound to either rely on previous knowledge or on information from others. This also means that the knowledge in the company runs a risk of remaining siloed and fragmented.

All the above is embedded in the enterprise *context* that we recognize as one more coordination mechanism. In the case of this company, the challenge is to balance out disruption that is beyond enterprise control and disruption that is within enterprise control.

6. Conclusions

We have found examples of the five coordination mechanisms in the study case. Analysis showed that the mechanisms are interdependent and need to be addressed as a whole. In addition, this article suggest two additional mechanism *Digital technology* and *Context* to be added to the theory, and as new contribution. The company has many good tools such as documents, plans and digital objects which are coordination tools with a potential to plan and overlook the production. However, to make them fulfill their goals, the routines that would facilitate a proper usage of these tools need to be in place. Moreover, data showed signs of emerging routines, such as ad-hoc meetings between operators and design engineers. A clearer authority within leading roles could make this transition smoother and perhaps even accelerate the process. The two newly identified mechanisms put in the limelight the importance of knowledge among all the personnel as well as the importance of understanding the context that the company is embedded in. Some contextual areas are beyond management control, while others could potentially be regulated.

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