Decision Support Systems in the Context of Cyber-Physical Systems: Influencing Factors and Challenges for the Adoption in Production Scheduling

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Abstract

Cyber-physical systems promise a complete networking of all actors and resources involved in production and thus an improved availability of information. In this context decision support systems enable appropriate processing and presentation of the captured data. In particular, production scheduling could benefit from this, since it is responsible for the short-term planning and control of released orders. Since decision support systems and cyber-physical systems together are not yet widely used in production scheduling, the aim of this research study is to analyse the adoption of these technologies. In order to do so, we conducted a qualitative interview study with experts on production scheduling. Thereby, we identified eleven influencing factors and 22 related challenges, which affect the adoption of decision support systems in production scheduling in the context of cyber-physical systems. We further discuss and assess the identified influencing factors based on the interview study. The results help to explain and improve the adoption of those systems and can serve as a starting point for their development.

Keywords decision support system, production scheduling, cyber-physical systems, industry 4.0, challenges.

1 Introduction

"If you have to reschedule often, such a [decision support] system is worth its weight in gold!" (ExpG)

With this quotation, an expert, whom we talked to during our interview study, underlines the importance of decision support systems in production scheduling. Especially production scheduling, which is responsible for scheduling, executing and monitoring released production jobs, is facing high demands on flexibility due to ever increasing customer demands, for example with regard to customization and delivery times (Schuh, Potente, Thomas, & Hauptvogel, 2014). If furthermore deviations from the initially generated production schedule or disruptions occur (e.g., due to unplanned events like a machine break down), the responsible production management needs to identify and take care of them promptly (Schuh, Potente, Thomas, & Hempel, 2014). The increasing diffusion of cyber-physical systems in companies, which, for example, record real-time data from the shop floor, simplifies monitoring the shop floor as well as the identification of those deviations on the one hand. On the other hand, as a result of a better information basis decisions on possible reactions can improve (Schuh, Potente, Thomas, & Hempel, 2014). Nevertheless, the use of cyber-physical systems itself does not inherently lead to an improvement of the initial situation. On the contrary, the mass of sensor data may lead to an information overload, so that it is hard to identify the concrete problems or to make associated decisions. Therefore, there is a need for decision support systems that provide the decision maker with an overview of the current situation and its problem areas as well as the effects of all possible alternative actions and reactions (Cupek, Ziebinski, Huczala, & Erdogan, 2016). However, as cyber-physical systems and decision support systems that work with real-time data are not yet in use together in most industrial companies, research analysing how the introduction of those systems in production scheduling can be promoted is necessary. Especially since cyber-physical system-based decision support systems in production scheduling are not sufficiently considered in the current state of research yet, there is also a lack of theoretical knowledge in this regard (see section 2.1). Therefore, the aim of our study presented in this paper is to identify factors, which influence the adoption of decision support systems in production scheduling in the context of cyber-physical systems and analyse corresponding challenges. This leads to the following research questions that we intend to answer by presenting results from a qualitative interview study among experts on production scheduling in the industrial sector:

***RQ1**: Which factors influence the adoption of decision support systems in production scheduling in the context of cyber-physical systems?*

***RQ2**: What challenges impede the successful adoption of decision support systems in production scheduling in the context of cyber-physical systems?*

In order to answer these questions, the remainder of this research paper proceeds as follows: In the next sections, we describe the basics and outline related research regarding production scheduling, decision support systems, and cyber-physical systems. In addition, the second section explains the theoretical background. Thereafter, we explain the applied research design. Afterwards, we present the findings of our study by describing the identified influencing factors and the corresponding challenges. Following this, we first discuss and access our findings in the discussion section and then state limitations and future research directions. Finally, we briefly summarize our findings in the conclusion.

2 Background

2.1 Basics and related research

Since both production scheduling and decision support systems (DSS) are well-known and well researched concepts, widely accepted definitions and explanations already exist. Therefore, **production scheduling** is part of the production planning and control (PPC) and describes the creation of a processing sequence for released orders, taking into account the underlying objectives (e.g., adherence to delivery dates or minimization of lead times; Pinedo, 2009; Schneeweiß, 1999). In this respect, a distinction can be made between flow shop problems and job shop problems. In the case of flow shop problems, all orders are processed in an identical machine sequence, whereby it is possible that orders may overtake each other so that the sequence of orders can be changed. With job shop problems, the jobs can pass through the processing stations in different sequences. The processing sequence for job shop problems is either fixed for each individual order, but varies between orders, or there is no predefined processing sequence for individual orders (Pinedo, 2009; Schneeweiß, 1999). Since sequencing therefore is a mathematically complex optimization problem, heuristics based on priority rules (e.g., due date rule, shortest processing time rule, first-in-first-out) are often used to achieve the desired goals (Pinedo, 2009; Schneeweiß, 1999). Furthermore, the fulfillment of the plan is monitored within the production scheduling and, in the event of disruptions or deviations, countermeasures are taken (Schneeweiß, 1999). The countermeasures range from waiting until the cause of the problem is eliminated over repairing the plan (e.g. left or right shift) to a partial or even complete rescheduling (Schneeweiß, 1999; Sabuncuoglu & Goren, 2009; Vieira, Herrmann, & Lin, 2003).

DSS in general can be defined as "computer technology solutions that can be used to support complex decision making and problem solving" (Shim et al., 2002). They focus "on supporting and improving managerial decision making" (Arnott & Pervan, 2005). Therefore, they are primarily used to solve semi-structured or unstructured problems (e.g., decisions between alternative schedules; Gorry & Scott Morton, 1971; Sprague & Carlson, 1982). To support decision makers DSS are interactive systems that utilize models, methods and problem-oriented data to provide and edit required information (Sprague & Carlson, 1982). DSS help to monitor business activities and processes (e.g., by using alerts when metrics fall below predefined thresholds), analyse root causes of problems (e.g., by exploring timely and relevant information), and manage processes as well as people in order to improve and optimize decisions and the performance (Eckerson, 2010). In the context of production scheduling, DSS shall provide the decision makers with an overview of the current situation, alerts and information on deviations, disruptions and their effects, as well as on (re-)planning options and support them in associated decisions. Cyber-physical systems (CPS) offer possibilities of collecting the real-time data from production required for this application of DSS.

CPS emerged within the concept of industry 4.0 in the last few years and consequently are not well researched yet. They form the technological basis for industry 4.0 and related concepts such as smart factories and the Internet of Things (IoT; Frontoni, Loncarski, Pierdicca, Bernardini, & Sasso, 2018). CPS are embedded systems that integrate physical objects, computation, communication, and networking processes (J. Lee, 2015). "CPS can be illustrated as a physical device, object, equipment that is translated into cyberspace as a virtual model" (J. Lee, 2015). They feature physical components like sensors and actuators to interact with their surroundings as well as networking and processing capabilities to process and communicate information. Therefore, they are able to monitor and control physical processes, usually with feedback loops where physical processes affect computations and vice versa (E. A. Lee, 2008). Figure 1 schematically illustrates the structure of a CPS. With regard to decision support in production scheduling, CPS can, for example, provide a comprehensive real-time data basis on which DSS can present decision makers with an overview of the current situation in production in real-time. This also enables to identify deviations from the initial production schedule promptly as well as to simulate and compare possible reactions to the current situation.

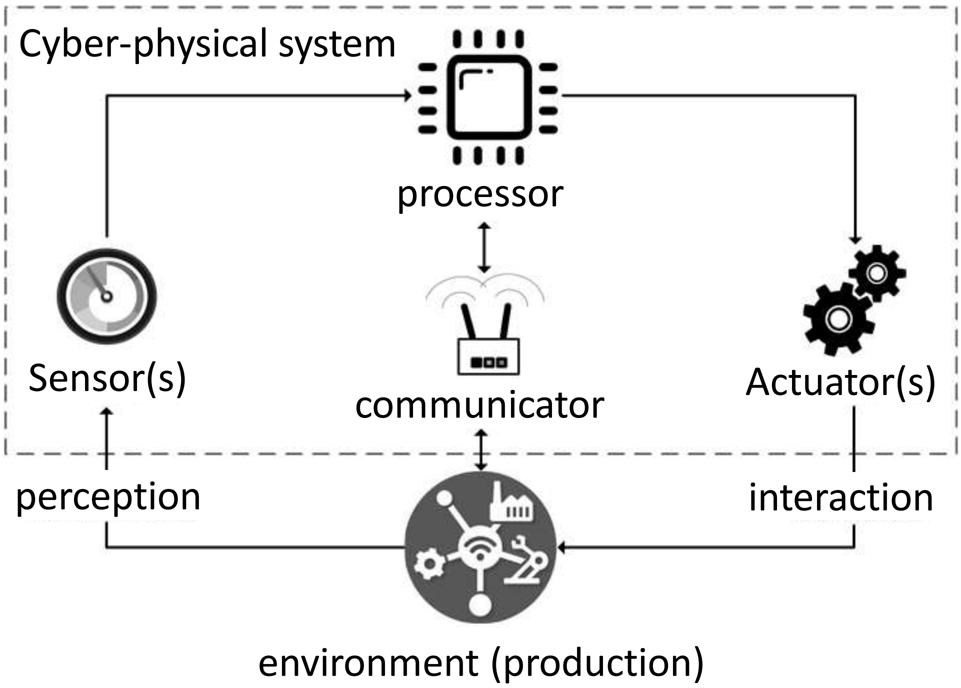

Figure 1: Schematic structure of a CPS

While the topics of production scheduling and DSS themselves are subjects of research for several decades, CPS is a young field of research. In the area of production scheduling, research exists, which considers different disruptions as well as corresponding (re)scheduling strategies and reaction possibilities (Sabuncuoglu & Goren, 2009; Vieira et al., 2003). However, since most of this research originated before the emergence of CPS, it consequently does not take them into account. Although some prior research in the area of production scheduling in the context of CPS exists and already names or addresses some influencing factors and challenges of the use of DSS to support production scheduling, a holistic overview is missing. In most cases, the existing contributions neglect DSS and focus on the changes of production scheduling caused by CPS. The authors primarily deal with the effects for the PPC systems and describe theoretical potentials as well as the technical hurdles that have to be overcome (Krumeich, Jacobi, Werth, & Loos, 2014). Karner, Glawar, Sihn, and Matyas (2019) for example use real-time data to improve production planning based on machine conditions. Jiang, Jin, E, and Li (2018) and Dafflon, Moalla, and Ouzrout (2018) include decision-making of systems in their publications. The former develop a decision model on the basis of which a multi-agent system can dynamically adapt the planning. Dafflon et al. (2018), on the other hand, describe a comparable system that provides the decision-making basis for a self-adaptive production system.

Only a few authors include DSS in their consideration. Those who do so, primarily deal with general challenges for decision support in production planning (Schuh et al., 2013), the necessity of DSS in production planning (Schuh, Potente, Thomas, & Hempel, 2014) or requirements for a prototypical implementation of a DSS (Schuh, Potente, Thomas, & Hauptvogel, 2014). Schuh and Fuß (2015) and Schreiber, Vernickel, Richter, and Reinhart (2019), who each present a DSS in the context of CPS focus on its implementation and neglect the influencing factors for the adoption of the developed systems. Schreiber et al. (2019) further limit their work mainly to maintenance planning. Although some of these studies contain influencing factors or challenges, they do not develop or present them in a structured manner. Moreover, many of the prior contributions only refer to specific industry sectors (Krumeich, Werth, Loos, Schimmelpfennig, & Jacobi, 2014) or cases (Cupek et al., 2016). Thus, it is not possible to make general statements. Therefore, rigorous research that identifies influencing factors and corresponding challenges of the adoption of DSS in production scheduling in the context of CPS is missing.

2.2 Theoretical Background

The Technology-Organization-Environment Framework (TOE framework; Tornatzky & Fleischer, 1990) is a widely used framework that aids to explain which influencing factors affect the adoption of new technologies, for instance, by classifying them in environmental conditions, organizational characteristics and technological attributes (see Figure 2; Baker, 2012; Doolin & Al Haj Ali, 2008). We use the TOE framework because prior studies like, for example, Angeles (2013) and Doolin and Al Haj Ali (2008) show that this framework is suitable to explain the implementation and adoption of innovations in enterprises in IS research. While the former analyses the use of radio-frequency identification (RFID)-based systems in the industrial sector, Doolin and Al Haj Ali (2008) deal with the adoption of mobile commerce technologies for supply chain activities.

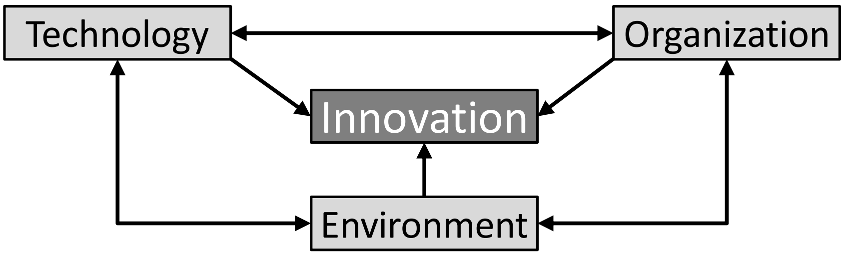

Figure 2: Technology-Organization-Environment Framework (Tornatzky & Fleischer, 1990)

3 Research Design

In order to identify influencing factors (RQ1) and corresponding challenges (RQ2) of the adoption of DSS in production scheduling in the context of CPS, we conducted a qualitative and exploratory interview study among experts on production scheduling in the industrial sector. We conducted an exploratory interview study design because it serves particularly to collect new findings and insights. For this purpose, we followed a three-stepped methodological approach.

First, we selected potential experts from industrial enterprises based on their work experience. We selected experts, which either have experience with the practical application of production scheduling or provide corresponding software solutions. Furthermore, all experts had to have some experience with the concept of CPS. Based on this, we contacted 60 experts in total. Nine of those accepted our interview invitation, which led to an acceptance rate of 15.00 %. Table 1 displays the summarized characteristics of our sample. Although nine interviews represent a small sample size, the participants were specialized in our field of investigation by meeting the above-mentioned requirements. Furthermore, we decided not to conduct further interviews, since the latter interviews did not reveal many new insights and thus showed signs of theoretical saturation (Glaser, 1978).

Expert	Industry	Position	Duration
A	Automotive	IT Planer Logistic Systems	~ 37 min
B	Large electrical appliance	Head of Production Technology	~ 36 min
C	Large electrical appliance	Head of Process Management	~ 36 min
D	Laboratory technology	Production Engineer	~ 37 min
E	Laboratory technology	Production Engineer	~ 37 min
F	Energy and automation technology	Production Engineer	~ 46 min
G	Printing	Head of IT	~ 35 min
H	Automotive	Plant Manager	~ 45 min
I	Software supplier	Technical Distribution	~ 41 min
		Mean Value	~ 39 min

Table 1. Sample characteristics

In the second step, we conducted eight of the interviews via phone and the interview with expert G face-to-face from November 2017 to April 2018. The interviews lasted between 36 and 46 minutes. In order to identify sufficient results regarding our research questions as well as to leave the interviewees enough room for own ideas, we prepared a semi-structured interview guideline that contains open questions about the use of CPS and DSS in production scheduling (see the full interview guideline in Appendix A; Myers, 2013). To allow in-depth analysis of our interviews, we recorded and transcribed all interviews. As the interviews were conducted in German, we translated relevant quotations from German into English by using constant contextual comparison (Suh, Kagan, & Strumpf, 2009).

Third, we coded and analysed the transcripts by using open and selective coding as well as the structured content analysis approach (Mayring, 2014). Therefore, we constantly double-checked and discussed the coding during the analysis to minimize subjective influences, assigned the codes to the core topics of our study (influencing factors and challenges) and classified them according to the dimensions of the TOE framework (see Section 2.2).

4 Findings

In this section, we present our findings regarding the influencing factors and the resulting challenges of the adoption of DSS in production scheduling in the context of CPS. We subdivide our results according to the three categories of the TOE framework. Figure 3 shows an overview of our results including the relative number of interviewees naming the respective factor.

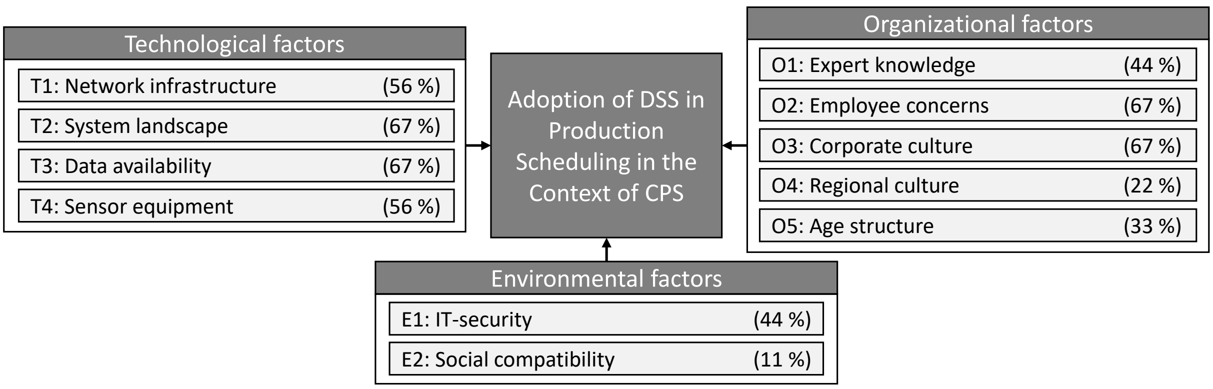

Figure 3: Influencing factors of the adoption of DSS in production scheduling in the context of CPS

4.1 Technological Factors

Based on our study, we identified four technological factors. Technological factors encompass characteristics of technologies, which are already in use as well as those, which are not yet present in enterprises (Baker, 2012). The first of which is the network infrastructure (T1), which was mentioned by 56 % of the surveyed experts. In this respect, the experts first cited the need for the existence of Wi-Fi coverage ($T_{C1.1}$). A sufficient network connection is a prerequisite for connecting sensors. Although the experts described that the implementation of factory-wide network coverage is technically no longer a limit today, it does pose further challenges (see e.g., E1: IT-security). Furthermore, the experts describe that it is currently not yet possible to simply integrate machines or sensors into the network infrastructure according to the plug and produce principle ($T_{C1.2}$). Table 2 shows exemplary statements on this factor and the associated challenges.

T1: Network infrastructure	
"As long as we have a network connection […], we can do that." (ExpA) "In the long run interfaces need to be created, which simply minimize the effort, so that in the best case plug and play is available for the most different solutions." (ExpI)	
Challenges:	**$T_{C1.1}$**: Existence of area-wide Wi-Fi coverage **$T_{C1.2}$**: Integration of new nodes in the infrastructure

Table 2. Technological influencing factor (1/4)

In addition to the network infrastructure, 67 % of the experts also mentioned the system landscape (T2) as a critical factor. They describe the current situation in companies as a historically grown collection of information systems that communicate with each other via proprietary interfaces. According to the interviewees, joint databases or integrated data processing are rarely to be found. Consequently, the provision of interfaces to the systems ($T_{C2.1}$) as well as a consistent database ($T_{C2.2}$) are central challenges for the adoption of a DSS in production scheduling. Furthermore, the experts described that the connection of further systems is associated with considerable effort, which is why the connection of the DSS to the existing system landscape ($T_{C2.3}$) is also a challenge. Table 3 displays the challenges of the influencing factor system landscape with exemplary quotations.

T2: System landscape	
"Because I always experience in this whole discussion that a world is described, which we do not see from the practical point of view at all yet. We do still have no interfaces, still have no databases, which can do the whole evaluation. In principle, this is not yet available. And that's what makes it so difficult for us." (ExpC) "The interplay of certain databases or systems […] is a big challenge in Industry 4.0, to let such systems talk to each other or to exchange the right data." (ExpE) "Second, how is the signal processed? The signal must again intervene somewhere in the next system. Every company not only has an ERP software package, but also a few others that are connected via interfaces. And that, of course, results in a huge effort for the installation." (ExpH)	
Challenges:	**$T_{C2.1}$**: Providing interfaces **$T_{C2.2}$**: Providing a consistent database **$T_{C2.3}$**: Connecting the DSS to the existing system landscape

Table 3. Technological influencing factor (2/4)

Furthermore, 67 % of the interviewees indicated that data availability is another technological factor, which needs to be considered. The experts referred to master data (e.g., machine or process master data) that is currently not managed, known or even available ($T_{C3.1}$). This challenge poses a major problem for the development and introduction of a DSS, since accurate mapping and simulation of production is not possible without the corresponding master data. Another challenge is the availability of machine or sensor data and measured values ($T_{C3.2}$). Although the experts stated that standard industrial machines nowadays have sensors, these are either uninterpretable on their own or can only be accessed to a limited extent by the company, as the manufacturer primarily uses the data for its own evaluations. Table 4 depicts exemplary quotations for data availability and the resulting challenges.

T3: Data availability	
"If I want to point out such possibilities, then I must know the complete basics, the complete master data first. I honestly couldn't say whether we know this master data at all at the moment." (ExpA) "If the people do not know where the data is or what data is available at all, which you would find out in most cases, I think, then the project is doomed to failure. And that is […] a big obstacle to spreading it to the masses." (ExpG) "Of course, every reasonable machine you buy today, no matter for what, i.e. for the industrial sector, for industrial production, will be equipped with sensors, will be equipped with control computers […]. The manufacturers of such machines are more and more interested in it because they have recognized the potential to access the data of their own machines, even if they are at the customer's site. […] But that does not mean that the data is in the company, and that's where I see the big problem." (ExpG)	
Challenges:	**$T_{C3.1}$**: Availability of master data **$T_{C3.2}$**: Availability of machine/sensor data

Table 4. Technological influencing factor (3/4)

As mentioned above, the possibility of collecting real-time data depends on the sensor equipment of the machines. Since the service life of machines in industrial practice can be several decades, sensor equipment is not inevitably available in industrial enterprises. This leads to the influencing factor of existing sensor equipment (T4), which 56 % of the experts mentioned. The experts addressed both technical and financial hurdles when retrofitting old machines ($T_{C4.1}$). They furthermore addressed the problem that the sensors and their measured values are by no means standardized ($T_{C4.2}$). This can lead to incompatibilities between new machines equipped with sensors and retrofitted machines as well as between different new machines. Table 5 shows these challenges together with exemplary quotations on the factor of sensor equipment.

T4: Sensor equipment	
"In our investment strategy, we […] have old machines and new machines in combination. The fact that you can buy new machines means you have to retrofit old machines. Then there is the question, how do the sensors interact? How do you get the transfer to the platform?" (ExpC) "Especially with older machines, the retrofitting, I imagine difficult." (ExpF)	
Challenges:	**$T_{C4.1}$**: Ensuring that old machines can be retrofitted **$T_{C4.2}$**: Ensuring the compatibility of different sensor data

Table 5. Technological influencing factor (4/4)

4.2 Organizational Factors

With regard to the organizational aspects, we identified five factors relating to the structure of the respective companies and the associated organizational aspects (Baker, 2012). 44 % of the interviewees named expert knowledge (O1) as the fundamental prerequisite for adopting CPS in production scheduling. Accordingly, the employees must have the competences and abilities to retrofit the equipment with production resources (e.g., equipping with sensors and actuators; $O_{C1.1}$) and to connect the resulting CPS to the IT infrastructure ($O_{C1.2}$). The employees of the companies themselves do not have sufficient expertise, but the external acquisition of knowledge is also problematic, since on the one hand, the providers of the corresponding resources tend to strive for the sale of new devices and on the other hand, those devices often only offer proprietary interfaces. Table 6 provides an exemplary quotation for this influencing factor and its corresponding challenges.

O1: Expert knowledge	
"Everyone talks about it and thinks it is all great, but by saying, "I'd like to have such a system", all these topics start. You have to retrofit the available systems, where you stick sensors on engines for example, which then report themselves. We actually have to say, we are not set up in respect of qualification of our employees and to create the framework conditions in the IT." (ExpC)	
Challenges:	**$O_{C1.1}$**: Low expertise in technical upgrading and retrofitting of machines **$O_{C1.2}$**: Low expertise about the connection to the system landscape

Table 6. Organizational influencing factor (1/5)

Furthermore, 67 % of the respondents mentioned employee concerns (O2) as an additional influencing factor that might limit the acceptance of the introduced system and thus also its use. On the one hand, they stated that employees could not use the DSS because they are afraid not to understand it, do not want to learn it or do not trust it ($O_{C2.1}$). The latter is also a possible reason for employees doing double work ($O_{C2.2}$), as they still use the original problem-solving paths in addition to the new system. Furthermore, employees fear that the progressing automation will make them increasingly less important for the company and that they will lose their jobs as a result of rationalization measures ($O_{C2.3}$). This could, for example, influence the employees in their work or also result in rejecting the system. Table 7 presents quotations on this influencing factor with the resulting challenges.

O2: Employee concerns	
"You have to know that it's always a critical point. That is very individual, very employee-related. [...] One is afraid of losing his job, the next one is afraid, he could not understand it, the next one simply does not want to learn something new again, because he retires in three years and the other one does not trust in the system and then perhaps makes duplicate work because of the new system, which he is supposed to use, instructed by the management, but he also does everything on paper, because he has no trust in the IT, so there are manifold reasons." (ExpG) "Especially when it comes to decision support, it is slowly changing into the system takes the decision away from you and at some point the worker may feel superfluous and the fear of losing the job is always present." (ExpE)	
Challenges:	**$O_{C2.1}$**: Non-use of the solution **$O_{C2.2}$**: Double work for employees who do not trust the DSS **$O_{C2.3}$**: Fear of losing their job

Table 7. Organizational influencing factor (2/5)

A further organizational factor we identified based on the study is the existing corporate culture (O3). In this respect, both the support of the management ($O_{C3.1}$) and the departments themselves ($O_{C3.2}$) are important factors for the realization of a DSS in the production scheduling. With regard to the management support, it is necessary, on the one hand, that the management is open to innovative technologies and, on the other hand, that it can be convinced of the potential benefits of the technology despite any high investment costs. With regard to the department support, it is important to convince the employees of the active use of the solution and minimize their concerns (see O2). In addition, some of the experts stated that enterprises introduce new technologies in the production environment quite conservatively ($O_{C3.3}$), since they only expect small benefits of the technologies, which do not outweigh the investment costs. Table 8 shows exemplary quotes for the influencing factor corporate culture and the corresponding challenges.

O3: Corporate culture	
"If I can get a production control system for 8 million Euro, which shows me whether my punch at the end of my line is full or I just go there and see that there are three boxes on top of it. We keep things a bit simpler. We are not that IT crazy. […] That is just how we work. That's why it's hard for us to imagine things like that to be real beneficial." (ExpB) "The best system will not work if people do not cooperate." (ExpD)	
Challenges:	**$O_{C3.1}$**: Lack of management support **$O_{C3.2}$**: Lack of support from departments **$O_{C3.3}$**: Conservative attitude in industrial enterprises

Table 8. Organizational influencing factor (3/5)

Two of the experts mentioned regional culture (O4) as another influencing factor. They indicated that there are factors, both national and international that can inhibit the acceptance of DSS ($O_{C4.1}$). On the one hand, there is a different understanding of responsibility and self-initiative in different countries. Thus, in some cases employees only follow direct instructions from the superior. This could also lead to rejecting the use of a DSS, as it merely provides the basis for making a decision. Furthermore, especially employees in economically underdeveloped regions seem to reject innovative solutions like DSS, as they are afraid of rationalization measures (see O2 employee concerns). Table 9 depicts exemplary quotations for this challenge.

O4: Regional culture	
"I notice, now that I am here in Mexico, the way of working, the understanding of how one works, is quite different from what it is in Germany. We have a lot of personal responsibility and think, a skilled worker has the courage to make his own decisions. In Mexico, someone decides at the top and passes on the order downwards. E.g. the executive organ, the worker on the shop floor, or even a skilled worker, simply does not make decisions, either because he does not dare, or because he simply is not used to it. [...] It's a different way of working from ours and you have to take that into account when you talk about whether or not there can be such a thing." (ExpA) "Especially here in the region, we are relatively weak in terms of structure and of course I always have to ask the question when creating something new […] what is the goal? Is the goal rationalizing in order to be even more effective […] in terms of costs?" (ExpG)	
Challenges:	**$O_{C4.1}$**: Regional differences in acceptance

Table 9. Organizational influencing factor (4/5)

The last organizational factor we identified in the study is the age structure (O5). 33 % of the experts cited this factor and described younger employees as more open to new technologies that would accept and use a DSS faster, while older employees are less willing to accept new technologies ($O_{C5.1}$). Accordingly, the effort required to convince older employees to use a new system is higher than for younger employees ($O_{C5.2}$). The experts stated, however, that it is of central relevance to also convince older employees of the benefits of the solutions. Table 10 shows the described challenges and exemplary quotations for them.

O5: Age structure	
"I believe that in the future, younger generations will be more likely to accept such an approach, so that a system will evaluate something like this, perhaps also show connections that people do not even notice in the first place. Our management is, on average, 40 years old, or even older. They made decisions for themselves all their lives, from the gut, according to their feelings and experience, and I find it difficult to say to those people that a system will do that now." (ExpA) "You often start with a team of young, dynamic people. You should better not start off with those who are already at war with IT." (ExpG)	
Challenges:	**O$_{C5.1}$**: Lower interest in new technologies on the part of older employees **O$_{C5.2}$**: More convincing effort required for older employees to use the system

Table 10. Organizational influencing factor (5/5)

4.3 Environmental Factors

The category of environmental factors includes conditions that originate outside the company like guidelines and laws or attacks initiated by externals (Tornatzky & Fleischer, 1990). In this category, we identified two factors and, based on these, we derived two challenges. 44 % of the interviewees regard IT security (E1) as the central factor in this category. By integrating various nodes (e.g., machines, work pieces or products) into the corporate network, the number of potentially vulnerable connections rises sharply. Therefore, the security measures in question for securing the network are considered essential (E$_{C1.1}$). The data and information as well as their transmission need protection as well as the individual nodes in the network (e.g., machines). Although the influencing factor of IT security could also be categorized as a technological factor, we understand it as an external factor in accordance with the definition given above, since security threats are mostly caused by external attacks. Table 11 presents the influencing factor of IT security and associated quotations.

E1: IT security	
"When machines in production are connected to the Internet, the issue of safety inevitably has a very high priority." (ExpI) "If we get a lot of signals now and process them, how do we make our system open, but still closed enough to fend off attacks. At the moment, we cannot have machines going into our networks." (ExpC)	
Challenges:	**E$_{C1.1}$**: Security measures to protect against IT attacks

Table 11. Environmental influencing factor (1/2)

One of the experts sees a further environmental factor in the social compatibility (E2) of the new solutions. The increasing automation of production and its planning and control potentially offers the possibility of reducing the number of employees in production (E$_{C2.1}$). When introducing a DSS, enterprises must therefore consider social responsibility and rather use the DSS to increase the flexibility and efficiency of the company. Table 12 shows an exemplary quotation on this influencing factor.

E2: Social responsibility	
"Are we technically capable of building a system that can make all the decisions? I would almost say technically yes. The question is do we want that at all? [...] We could build systems, which then decide for themselves. [...] So you have not an ethically, but a social responsibility." (ExpG)	
Challenges:	$E_{C2.1}$: Automation enables rationalization

Table 12. Environmental influencing factor (2/2)

5 Discussion

The findings we presented in this paper imply that four technological, five organizational and two environmental factors influence the adoption of DSS in production scheduling in the context of CPS. Altogether, we identified eleven influencing factors and derived 22 corresponding challenges. Although in general all these factors are relevant for the adoption of a DSS in production scheduling, it emerged from the discussions with the experts that a differentiated consideration of the challenges is necessary.

With regard to the **technological factors**, the challenges are to be assessed as uncritical as considering them at an early stage can help to overcome them. The challenges associated with the network infrastructure (T1), such as the existence of comprehensive Wi-Fi coverage ($T_{C1.1}$), are currently still existing problems in companies, but can already be solved technically, for example by setting up additional access points. In this regards, expert F gave the following assessment, "It is not rocket science to get this. Of course, it depends on the size of halls, but when I think about universities, there is Wi-Fi in every room. We also have power and cable lines everywhere in production and adding a few LAN cables with routers should not be the bottleneck of the problem." (ExpF) The challenges regarding the system landscape (T2) are also described as solvable, although this is not easily possible for a single company. In this regard, progressive standardization is particularly relevant, especially with regard to interfaces, which could also contribute to mastering the $T_{C1.2}$ challenge. The experts described the solutions in this area as feasible, but machine manufacturers, for example, delay the solution process. Expert I stated in this context, "The problem with machine manufacturers is that many have somehow come up with their own protocols. There are often associations for industries that have joined […], but the current market is of course very difficult for a software manufacturer, because there is an incredible variability. Every machine manufacturer is doing his own thing." (ExpI) The influencing factor of data availability (T3) and the associated challenges are not critical for companies as well. To target the corresponding challenges, it is necessary to maintain the existing master data ($T_{C3.1}$), which does not encounter any technical obstacles apart from the resulting maintenance effort. Ensuring the availability of machine and sensor data ($T_{C3.2}$) can be considered in combination with the influence factor sensor equipment (T4). Although machines nowadays generally have the sensor equipment to record the machine data, and retrofitting existing machines is technically feasible ($T_{C4.1}$), the collected data differs in terms of both quantity and quality ($T_{C4.2}$), which leads to additional data maintenance or standardization efforts. Expert I summarizes this as follows, "There are approaches for retrofitting old machines. They are designed to make it relatively easy to connect them to the existing system and to install them in order to extract certain data from the machine […]. Nevertheless, the variety of data in the old machines is still relatively limited. You can read out the controller, but that is of course not enough to make an overall equipment effectiveness analysis." (ExpI)

With respect to the **organizational factors**, the interviewees regard the challenges derived from the influencing factors expert knowledge (O1) and age structure (O5) as uncritical, since, on the one hand, the increasing research and dissemination of CPS and DSS is expected to lead to an increasing number of experts. On the other hand, with regard to the age structure, they assume that in future an increasing number of younger employees with a high affinity for technology will lead to a shift in the age structure of the workforce, which will enable enterprises to meet the challenge of the age structure in mid to long term. In contrast, the factors of corporate culture (O3) and regional culture (O4) must be regarded as critical. A conservative attitude on the part of company management towards new technologies ($O_{C3.3}$), for example, represents a hurdle that is difficult to overcome when introducing CPS and DSS into production scheduling. To overcome this challenge, possibilities must be created to quantify the benefits of the solutions. However, even then there is no guarantee that the solution will be introduced and accepted in the company. Expert G summarizes this challenge as follows, "If it is not understood by the management, who in the end make the decisions, what we are introducing, what we are spending money on, then an IT specialist as such will always fail." (ExpG) Furthermore, the experts stated that employee concerns (O2) are similarly problematic. Here, too, protracted measures are necessary to reduce employees' concerns or to convince them of the solution. Employees must be involved as early as possible in the planning and implementation processes (e.g., in workshops) in order to create acceptance of the DSS. However, it cannot be guaranteed that employees will also use the application ($O_{C2.1}$) or not do additional double work ($O_{C2.2}$) when implementing such measures, as the employees differ in their concerns.

With regard to the **environmental factors**, the experts stated that enterprises could overcome corresponding challenges if they consider them at an early stage in the planning process. In order to ensure adequate IT security (E1), appropriate security measures ($E_{C1.1}$) must be included as early as possible. In particular, the integration of CPS and the associated networking of production resources leads to further risks for IT security. Security precautions must therefore be taken when designing and implementing a DSS as well as for the individual production resources and their production. The social compatibility (E2) of the solution can also be achieved by making it credibly clear to the users of the DSS that the system is not intended to rationalize, but rather to relieve and support the users. Expert G stated the following in this regard, "Create free capacities in order to support the good people with new tasks, maybe even just create a little space to look a little to the left and right. That is actually the first goal, knowing it is a small degree to a certain point where the system can be used to rationalize." (ExpG)

In summary, our study shows that the organizational influencing factors represent the greatest challenges for the introduction and deployment of a CPS-based DSS in production scheduling. The environmental and technological factors, however, are less critical or uncritical if they are taken into account at an early stage. These results imply that for the successful adoption of DSS in production scheduling in the context of CPS not only technical factors are decisive, but also that the companies as well as all actors and stakeholders have to be considered. Figure 4 shows an overview of the results of the discussion and assessment of the influencing factors.

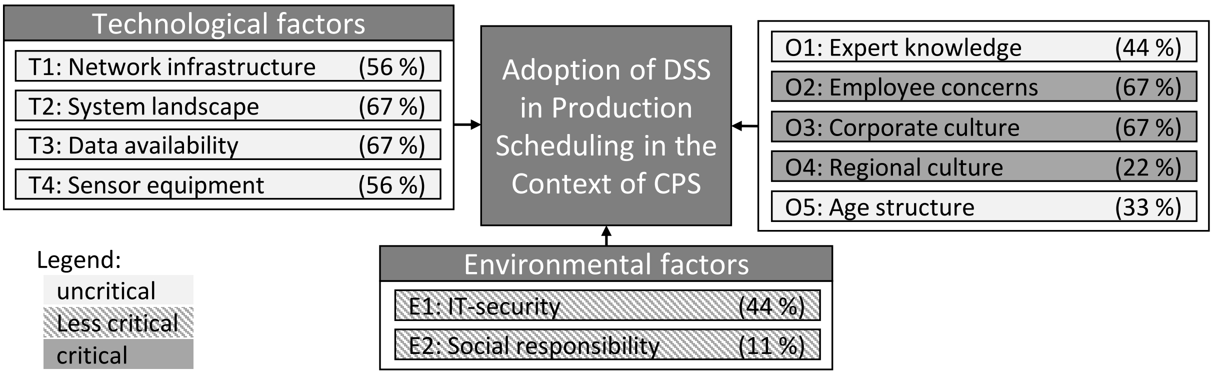

Figure 4: Assessment of the identified Influencing factors of the adoption of DSS in production scheduling in the context of CPS

6 Limitations and Future Research Directions

As with any similar qualitative interview studies, we are aware that there exist several potential limitations. First, our interview study is based on a relatively small sample size. Even though we were trying to reach theoretical saturation, we cannot assure that our results are complete. Second, the results of an interview study are dependent on the selection of interviewees. Although we carefully selected a broad variety of experts from industrial enterprises as well as software suppliers, there might be additional experts that would supply further results. Related thereto, although some of our experts were working abroad (e.g. in Mexico), we only interviewed German experts. Thus, our results feature a limited generalizability. Hence, further research should investigate whether they can confirm our results in other countries. Third, as the analysis of interviews is always subjective, different researchers might come to different results interpreting our data. However, in order to minimize subjective influences, we used, for instance, structured content analyses and double-checked our codes and results. In order to address these limitations and further investigate our findings, we are currently developing a prototypical DSS to support production scheduling in the context of CPS. Thereby, we want, on the one hand, to verify whether the identified and presented results occur in practice and to generate further insights on, for example, design science research knowledge like functional requirements or generalizable design principles and potential effects on the other hand (Freier & Schumann, 2020; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007).

7 Conclusion

The goal of this research paper was to analyse the adoption of DSS in production scheduling in the context of CPS by identifying influencing factors (**RQ1**). We further investigated which related challenges (**RQ2**) result from those factors. Therefore, we conducted an empirical interview study among nine domain experts. Based on the results of this study, we identified eleven influencing factors and 22 related challenges and classified them in three context categories according to the TOE framework (technological, organizational and environmental). Although all factors are relevant, it emerged from discussing the results that especially organizational factors are critical, as short-term measures are not sufficient to meet them.

The results of our research can contribute to both, research and practice: Our study expands the existing knowledge base by contributing to the understanding of using DSS in production scheduling in the context of CPS. Thus, the results may help to improve the adoption of CPS-based DSS in enterprises as they enable to explain and predict challenges on the one hand. On the other hand, they can serve as a starting point for further studies (e.g., regarding the overcoming of challenges) as well as for the development of DSS for practical use in a CPS-based production scheduling.

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Appendix A: Interview Guideline

1 Conversation opening

Welcome and introduction

- Welcoming the interview participants and thanking them for their willingness to participate
- Brief introduction of the interviewer
- Asking the interviewee(s) for a brief introduction

Introduction to the research project

- Presentation of the contents and objectives of the research project
- Creating a common understanding and short explanation of the terms decision support systems, cyber-physical systems and production scheduling

Clarification of formalities

- Privacy statement and permission to record the interview
- Interview procedure

2 Areas of application and previous use of cyber-physical systems and decision support systems

[Introduction:] The central research interest relates to the use of decision support systems in production scheduling. In particular, the focus is on changes caused by and the interplay with cyber-physical systems. The following questions, however, should not be strictly limited to production scheduling. Interesting in this context are also the further phases of production planning and control, which may overlap or be interdependent with the process planning.

Questions regarding the use of decision support systems in production scheduling in the context of cyber-physical systems

- **Are cyber-physical systems already in use or being tested in your company? (e.g., in the context of research or development projects)**

  If yes: (collect on a case-by-case basis)
  - **How are cyber-physical systems used in your company so far?**
    [Possible detailed questions - depending on the course of the conversation: p. 2]
  - What effects does the use of cyber-physical systems have on the (activities of) production scheduling?
    [If the interviewee does not come up with his or her own ideas, the interviewer names exemplary challenges and has them assessed by the interviewee]
  - What do the cyber-physical systems have to do to support the production scheduling?
    [What data do they need to collect? What does the data need to look like?]
    [More detailed questions - depending on the course of the conversation: p. 2]

  If no:
  - Is the introduction of cyber-physical systems in your company planned for the future?

    If yes:
    - How should and will the use be structured in the future?
    - *[Possible detailed questions - depending on the course of the conversation: p. 2]*

    If no:
    - Has a deployment within your company already been discussed?
    - What are the reasons for not introducing it so far?

1

Questions regarding the previous or planned use of decision support systems in production scheduling

- **Are decision support systems already in use or being tested in your company's production scheduling? (for example in the context of research or development projects)**

  if yes: (collect on a case-by-case basis)
  - **How are decision support systems used in your workflow planning so far?**
    [Possible detailed questions - depending on the course of the conversation]
  - Which processes, tasks or areas of activity are supported by the decision support systems in process planning? Who is the user group?
  - What are the objectives?
  - Why did you decide to use decision support systems in your company's production scheduling? From which initiative were the decision support systems introduced (top-down / strategically planned vs. bottom-up)?
  - Which information about the execution or the results of the production scheduling can be viewed by whom? How is this information presented (e.g., Gant-Charts)?
  - What are the benefits for your company?
  - What effects does the deployment have on the supported processes (e.g., with regard to sequences, interfaces, actors)?
  - What obstacles or limits did you encounter when introducing decision support systems?
  - What obstacles or limits did you encounter when using the decision support systems?
  - Which other influencing factors or conditions had to be taken into account during the introduction/use of the applications?
  - How are these applications technically implemented?
  - Which requirements does a decision support system have to meet in order to support the production scheduling?

  if no:
  - **Is the introduction of decision support systems in your company's production scheduling planned for the future?**

    if yes:
    - **How is the use designed?**
    - *[Possible detailed questions - depending on the course of the conversation]*

    if no:
    - Has a deployment within your company already been discussed?
    - What are the reasons for not introducing decision support systems so far?

Questions regarding other (not yet tested or used) areas of application

- **Can you imagine (further) areas of application in which the use of decision support systems in production scheduling / production planning and -control in your company or industry would make sense?**
  [If the interviewee does not come up with his or her own ideas, the interviewer names exemplary deployment scenarios and has them evaluated by the interviewee].
  [Possible detailed questions - depending on the course of the conversation: p. 2]

2

3 Suitability of the technology for corporate use

[Introduction:] After we have just talked about possible applications scenarios, I would like to talk about the suitability of decision support systems in production scheduling in the context of cyber-physical systems.

- **What challenges and problems do you see <u>currently</u> and <u>in the future</u> (e.g., in the context of CPS) when using decision support systems in production scheduling?** *[If the interviewee does not come up with his or her own ideas, the interviewer names exemplary deployment scenarios and has them evaluated by the interviewee].*
- **How can the challenges and problems mentioned before be met from your point of view?** *[Address previously mentioned challenges and problems].*
- **What <u>new</u> possibilities arise from the use of decision support systems in production scheduling in the context of cyber-physical systems?** *[If the interviewee does not come up with his or her own ideas, the interviewer names exemplary deployment scenarios and has them evaluated by the interviewee].*

4 Discussion

[Introduction:] At the end of the interview I would like to ask for your personal opinion on decision support systems and cyber-physical systems.

- **Would you personally be willing to use decision support systems (in the production scheduling)?**
  - If yes: Why?
  - If no: Why not?
- **How would you evaluate decision support systems compared to fully automated production planning and control? Do decision support systems offer benefits?**
- **How would you evaluate the use of cyber-physical systems in production scheduling? Do cyber-physical systems offer benefits (for production scheduling / for decision support systems)?**

5 Conclusion of the conversation

Concluding remarks

- **Finally, is there anything else you would like to address?** *[End audio recording afterwards]*
- Are you still interested in the research area of decision support systems in production scheduling and research results? If so, we would be happy to contact you again as part of further research.

Acknowledgment and farewell

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