Digital Work Design

The interplay of human and computer in future work practices as an interdisciplinary (grand) challenge

Prof. Dr. Alexander Richter

IT University of Copenhagen

Rued Langgaards Vej 7

DK-2300 Copenhagen S

Denmark

aric@itu.dk

Dr. Peter Heinrich

Zürcher Hochschule für Angewandte Wissenschaften

Stadthausstrasse 14

CH-8401 Winterthur

Switzerland

heip@zhaw.ch

Dr. Alexander Stocker

Virtual Vehicle Research Center

Inffeldgasse 21A

A-8010 Graz

Austria

Alexander.Stocker@v2c2.at

Prof. Dr. Gerhard Schwabe

University of Zurich

Binzmühlestrasse 14

CH-8050 Zürich

Switzerland

schwabe@ifi.uzh.ch

Introduction

More and more academic studies and practitioner reports claim that human work is increasingly disrupted or even determined by information and communication technology (ICT) (Cascio & Montealegre 2016). This will make a considerable share of jobs currently performed by humans susceptible to automation (e.g. Frey et al. 2016, Manyika et al. 2017). These reports often sketch a picture of 'machines taking over' traditional domains like manufacturing, while ICT advances and capabilities seem to decide companies' fate. Consequently, ICT is often put at the core of innovative efforts. While this applies to nearly all areas of workplace design, a recent popular example of increasing technology centricity is 'Industry 4.0', which is often delineated as 'machines talking to computers'.

As objects in the physical environment increasingly house advanced computing and communication capabilities, the resulting composite systems are often referred to as cyber-physical systems (CPSs), as they bridge the digital and physical world (Rajkumar et al. 2010). In other words, CPSs are an integration of computation and physical processes, which is why they serve as an illustrative example in Exhibit 1 and throughout the article. We discuss manufacturing as an application area, because here digital transformation is happening first and fast. We also observe similar transformations in other areas, such as agriculture, logistics, and crafts. The proliferation of ICT in these environments is often termed ubiquitous computing and denotes a shift towards embedded computing that is less perceptible to the end user (Cascio & Montealegre 2016).

Exhibit 1: Case vignette – Manufacturing

Referring to a 4th industrial revolution around the 'informatization' of factories through a mash-up of internet technologies with smart objects (i.e. machines and products, cf. Wortmann & Flüchter 2015), future manufacturing is expected to lead to a paradigm shift towards more flexible production cycles in which products may even control their own production process (Lasi et al. 2014). In the resulting CPS, information from a variety of sources is closely monitored and synchronized between the physical factory floor and the digital space. Using advanced data analytics, networked machines work more efficiently, collaboratively, and resiliently, outperforming humans in many tasks. In this techno-centric vision of a smart factory, ICT implementation creates production flexibility and adaptability, while the individual production worker degrades to a confounder, unnecessary in the control loop.

In a different vision of future manufacturing, achieving flexibility and adaptability in the production system requires a new positioning of production workers. Recently, several innovative companies actively started to rediscover the importance of humans as the most flexible entity in industrial processes like production or maintenance, and they acknowledge the human worker as the central element in smart factories. Humans embody capabilities

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that go far beyond what machines can achieve. At the same time, humans now require better ICT support to exploit their capabilities when it comes to increasingly differentiated work practices.

Recognizing that industrial work is becoming increasingly flexible, the European Commission has called for strategies to achieve new human-centered manufacturing work environments based on safety and worker satisfaction, aiming to enhance the role of humans in manufacturing (European Commission 2013). With their recent call and by funding research projects in the range of more than 100 million Euro, the European Commission underlines the fact that modern ICT should embody capabilities to adapt to the needs and requirements of workers instead of seeking ways to remove humans from the processes.

This article identifies Digital Work Design (DWD) as a research area and a (grand) challenge of business information systems engineering. Building on a thorough understanding of existing human work practices and the subsequent design and implementation of ICT artifacts, DWD reinstates the human worker at the core of information systems development efforts. This requires an integrated, interdisciplinary, participative, and agile approach, which allows identifying, analyzing, and supporting human work practices and their context in a predominantly digital environment.

DWD aims to facilitate current and future work practices of employees through digital technologies. After identifying DWD's roots in long-standing traditions of workplace studies, we elaborate its key characteristics. Next, we demonstrate through examples how DWD can be applied in manufacturing – from the initial data collection up to the iterative solution development cycle and possible outcomes. To conclude, we mention key points where DWD stands out from other approaches and present an outlook on the future in the form of research questions.

The roots and key characteristics of Digital Work Design

Workplace design has a long-standing tradition in ergonomics (Luczak 2013) and human-oriented computer science (Floyd 1989). Based on Northern European ethics of social partnership, workplace study designs have been refined for many years, for example by using ethnographic approaches (e.g. Randall et al. 2007) and having developed a vast array of human-centered design methodologies (e.g. Rosson & Carrol 2002).

In the last years, the nature of work has significantly changed. While traditional workplace design targeted physical environments augmented by ICT, today's work environment has become predominantly digital, with some remaining physical parts. At the same time, smart software environments have replaced traditional human capabilities to make sense of the physical work environment and to execute mainly routine tasks.

A digital work environment simultaneously demands and enhances different human capabilities, such as the ability to flexibly respond to unforeseen events, learn continuously, or solve novel problems collaboratively (Brynjolfsson & McAfee 2014). If one accepts this change in the nature of work, researchers and practitioners need new approaches to analyze and (re)design work practices. This requires a basic understanding of the traditional field of work design (Humphrey et al. 2007, Parker et al. 2001, Wall et al. 1990).

As Figure 1 shows, traditional work design touches on motivational (e.g. autonomy and task variety), social (e.g. interdependence), and contextual (e.g. ergonomics) work design characteristics. It enables organizations to leverage the envisaged opportunities in terms of different outcomes: behavioral (e.g. performance), attitudinal (e.g. job satisfaction) or well-being (e.g. stress).
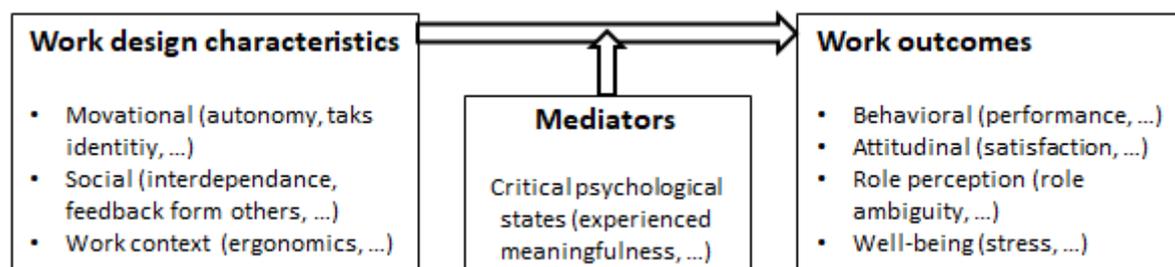

Figure 1: Work design characteristics and work outcomes (based on Humphrey et al. 2007)

Supporting employees through ICT in their daily work environment can be understood as a wicked problem. Wicked problems are defined as problems where there is no 'correct' solution, but where a (possibly infinite) number of 'good' and 'bad' solutions exist, defined by the value they create (Schoder et al. 2014). Designing successful digital solutions can therefore not be done in a linear way. Many existing large-scale systems fail to support the solution of wicked problems. It has been argued for years that those attempts are based on an oversimplified understanding of the nature of human work. It has been proposed that software should be designed in close interaction with the workers it is aimed for, starting with exploring their work practices and then developing appropriate solutions (e.g. Mumford 2003). Therefore, DWD makes the individual the focus of ICT development efforts. It is characterized by a number of distinct features, as illustrated in Exhibit 2.

Exhibit 2: Key characteristics of Digital Work Design and a definition

• **Practice-centeredness**: The primary design objective is to improve and transform existing human work practices by providing them with information technologies that fulfil their needs. A rich and holistic understanding of work practices and needs of the individual actors is therefore inevitable. Practices always include an array of material resources (Nicolini 2012). All this necessitates a close interaction with those actors when analyzing how they work and when evaluating developed prototypes.

• **Contextualization**: Analyzed work practices and identified needs are context-specific (Feldman and Orlikowski 2011). Instead of defining generic requirements to envisaged solutions with lists of system functions, it is necessary to understand and describe how relevant stakeholders act in the current situation, and how the envisaged digital solution can be used in a specific (organizational, physical, and social) context to improve the situation.

• **Design for flexibility**: Human workers have individual, diverging, and continuously changing needs. Therefore, it is necessary to design usable, useful, and malleable digital solutions (Richter & Riemer 2013) that can be adopted easily and flexibly, according to their specific needs.

• **Agility & participation**: Integrating workers into the digital solution design process urges digital technology designers to first and quickly come up with lightweight solution approaches to ensure a "common understanding" for the next design steps. 'Cooperative prototyping' (Bødker & Grønbæk 1991) enables worker feedback in all design steps, from the earliest mock-ups to demonstrator, validator, and pilot. While users do not have to participate in all aspects of a design project, it is important to allow them to contribute to creating choices (Bratteteig & Wagner 2016).

• **Interdisciplinarity**: Designing digital technology for a group of people implies background knowledge about how humans behave as individuals (psychology) and in a group (sociology), as a basis to develop software (computer science) and implement it in an organizational work context (information systems, organizational science) (Wagner et al 2010). Boundary objects are often used to facilitate communication with stakeholders, stemming from various disciplines (Bergman et al. 2007).

In summary, we define Digital Work Design as an agile, participative, and interdisciplinary process of designing flexible workplaces by putting human work practices and their context in the center when investigating the potential of digital technologies.

Applying Digital Work Design

As highlighted before, DWD necessitates a deep understanding of work practices, embedded in the organizational contexts, and thereafter defining requirements for sociotechnical solutions that allow work to be more autonomous and varying, and enabling workers to learn

and connect with one another. Figure 2 shows a DWD process in a manufacturing context, from the initial data collection to the iterative solution development cycle.
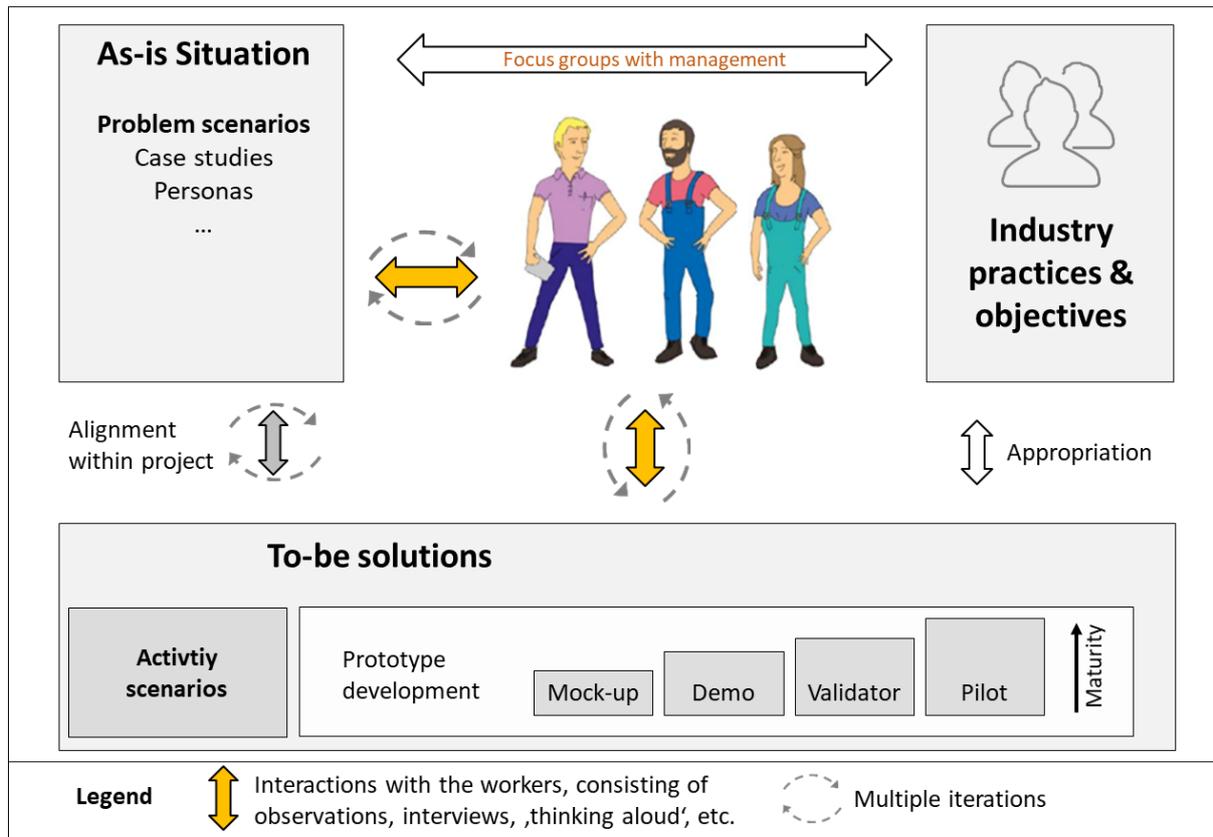

Figure 2: Application of DWD in a manufacturing context

To capture and understand the as-is situation, a number of qualitative and quantitative data collection methods can be used. Qualitative methods include observations, focus groups, thinking aloud, and interviews. Quantitative methods include mining processes and surveys. To embed the identified requirements in a rich context, it is necessary to describe the actors (e.g. in form of personas (Pruitt and Grudin 2003, Nielsen 2012)) and how they currently perform their work. The latter is done by highlighting critical issues in their daily activities that yield improvement potential (in problem scenarios), and suggest how the workers could be supported with sociotechnical solutions (in activity scenarios) in a narrative style. It is crucial that these narrative descriptions of present and future environments are co-designed with the stakeholders involved to facilitate acceptance of the intended solution and take care of stakeholder expectations from the launch of the project (Bødker et al. 2009). Solution design and implementation have to be highly iterative and supported by a number of prototypical implementations with a rising degree of maturity. These design activities do not solely focus on technical artifacts. In addition, processes, methodologies, and general concepts can be subject to design activities.

Digital Work Designers must understand how and why things work before they can provide a digital solution to support work practices. The core challenge of DWD can therefore be broken up into two questions:

(1) How can we understand current work practices to turn them into digitally empowered work practices of the future? (As-is situation)

(2) How can we transform this in-depth information into digital artifacts that support and transform envisaged work practices in the best possible way? (To-be solutions)

Referring to our earlier example of DWD in a manufacturing context, it is essential to study daily worker routines that have evolved over time in a production environment due to continuously changing requirements (e.g. smaller lot sizes, mass customization, open innovation, changing work cultures, or changing production models). These work practices often oppose top-down specified production processes, and studying these processes creates a deeper understanding of individual needs.

DWD contributes to a better understanding of technologies-in-practice, that is, the ways in which people adopt information and communication technology in their particular context (Orlikowski 2000). Applying this holistic approach helps to identify requirements for the development of new adaptive human-centered automation approaches and prepares their implementation in organizations in terms of cultural change. At the same time, the problem scenarios function as reminders of positive aspects in the current situation in terms of motivational (e.g. autonomy and task variety) and social (e.g. interdependence) work design characteristics (Humphrey et al. 2007, Parker et al. 2001) that should not be changed by the digital transformation.

Exhibit 3: Case vignette – Manufacturing (continued)

The problem scenario in Figure 3 displays a situation that happens millions of times a day in companies worldwide: A tool setter, Hans, documents important occurrences at the end of the shift in the handwritten shift book. Hans also has to complete a shift handover sheet on which he documents key issues concerning the personnel, material, machines, and further planning. Both processes are redundant, as almost the same information is being documented. Hans does not consider his notes in the shift book as important. He often keeps them short and in busy times he even forgets to document incidents that occurred some hours before. The shift book is a simple paper notebook, which means he cannot attach additional information, such as documents or photos, although these could be useful to document defective parts. That can be a problem if he wants to look up similar incidents a few weeks later. The chance of finding a well-documented incident and learning from it is relatively low.

The activity scenario shows how the tool setter and his colleague document important occurrences in a digital shift book. The solution does not only contain manually entered information, but also information that the system generated during task execution, for example maintenance work or retooling. The shift handover sheet is integrated in such a way that it does not have to be completed separately.

A major advantage of the solution is that all the entries, notes, and the status of completed tasks are done in parallel with the task processing during the shift. The tool setter no longer needs extra time at the end of a task or shift to complete documents. Additionally, it allows him to link the documents and the photos, providing a coherent view that includes all activities and incidents at a particular machine. Aggregated information is stored centrally and the team leader can access the data at any time. This makes troubleshooting and problem analysis far easier and more efficient.

Figure 3 illustrates the potential outcome of the DWD process through a concrete example in the manufacturing context that was explained above. It shows how specific human work practices can be supported digitally.
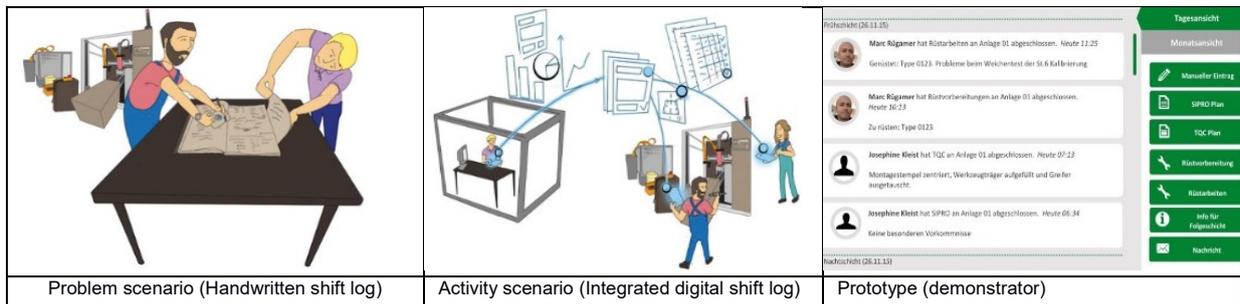

| Problem scenario (Handwritten shift log) | Activity scenario (Integrated digital shift log) | Prototype (demonstrator) |

Figure 3: Case vignette – Outcome of the DWD process (scenarios and prototype)

Conclusion and research agenda

Whereas DWD has its roots in long-standing traditions of workplace studies, it can be understood as a research area that goes beyond traditional approaches. Table 1 shows the differences.

Dimensions	Traditional Work Design	Digital Work Design
Target	Designing the physical environment augmented with ICT	Transforming work practices enabled by ICT
Object of study	Automation of top-down defined business processes for	Understanding practices and providing ICT that supports

	efficiency	flexibility
Role of human	Operating tools and machines	Orchestrating tools and machines
Human capabilities	Coordinating and efficient handling of tasks	Creativity, problem solving, learning
Role of ICT	Replacing strenuous human work (machine-centric)	Augmenting human capabilities (human-centric)
ICT capabilities	Production system	Cyber-physical production system

Table 1: Traditional Work Design vs. Digital Work Design

DWD offers ample research opportunities in the fields of organizational change, technology appropriation, and using these new design artifacts. Research is needed about a) the process of studying and designing tools and digital work environments, b) how appropriate digital support for workers can be introduced, and c) the context in which DWD is happening.

a) Studying and designing tools

- How can we support human-to-human collaboration in a dirty and noisy environment?
- How can humans and robots collaborate in an effective and safe way?
- Which are meta design principles and design patterns for digital work practices?

b) Introducing digital support

- How can new forms of work be implemented digitally in a participatory way?
- How can workers be qualified in the workplace for changing and challenging tasks?
- How can we assure that workers understand the benefits of the proposed solutions? How can these be evaluated?
- Which boundary objects are suited to facilitate the interdisciplinary discussion about future work with various stakeholders?

c) Context of DWD

- What characterizes an organization that has good institutional frame conditions for digital work design?
- What is the role of DWD when it comes to introducing robotic process automation in order to reduce repetitive, routine tasks through software-based automatisms in domains like the service industry (Willcocks et al. 2017)?

Answering these questions is key for a successful transformation of organizations to meet tomorrow's demands.

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