

Development of an instrument for the assessment of scenarios of work 4.0 based on socio-technical criteria

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ABSTRACT

The mechanical engineering and related industries are increasingly being dominated by information and communication technology, leading to the development of cyber-physical systems. However, these systems have to be seen from a broader angle, incorporating several other environmental factors such as the organizational structure or human factors. For this reason, the technology cannot be seen as solitary system, but should rather be included in the context of a scenario of work 4.0. These scenarios can help to classify new technologies, their advantages and constraints in order to provide guidance for the digital development of organizations. While several frameworks have been proposed in terms of technological guidance, most of them focus heavily on technology, neglecting their organizational- and human factors. In order to form a uniform understanding of the construct of industry 4.0, we developed an instrument for rating scenarios of work 4.0 on the relevant dimensions ‘technology’, ‘human’ and ‘organization’. This paper describes the chosen relevant criteria including possible constraints we encountered. Future work on this topic will include the creation of profiles of scenarios of work 4.0, further validation of the criteria.

CCS CONCEPTS

• **General and reference** → **Cross-computing tools and techniques** • **Human-centered computing** → **HCI theory, concepts and models**

KEYWORDS

Cyber-physical systems, industry 4.0, scenarios of work 4.0, product engineering, socio-technical criteria of work 4.0

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PETRA '18, June 26–29, 2018, Corfu, Greece

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ACM ISBN 978-1-4503-6390-7/18/06...\$15.00

<https://doi.org/10.1145/3197768.3201566>

ACM Reference format:

This text field is large enough to hold the appropriate release statement assuming it is single-spaced in Linux Libertine 8-point font. Please do not change or modify the size of this text box.

DOI: <https://doi.org/10.1145/3197768.3201566>

1 INTRODUCTION

The mechanical engineering and related industries are increasingly being dominated by information and communication technology [7]. This creates a lot of new possibilities for the design of technical systems and enables the leap from simple

mechatronic to highly automated cyber-physical systems. These cyber-physical systems have had a significant impact on a large variety of processes of the industrial value chain, ranging from individual assistance in manufacturing [54] over organizational process management [47] to large-scale energy systems such as the smart-grid architecture [57]. These cyber-physical systems offer a wide variety of advantages and pave the way for future innovations in product- and process development [18]. However, to fully utilize these advantages it is a necessity to broaden the scope and include a large array of factors that can influence and are influenced by the implementation of a cyber-physical system. In this context, we rather have to speak of scenarios of work 4.0. A scenario is described as a generally understandable and comprehensible description of a possible situation in the future which is based on a complex network of characteristics of influencing factors [29]. The advantages of applying the scenario-based approach on technological development are a deeper understanding of different technologies as well as a clear scope of the factors that are interconnected to its implementation. However, the right choice of technological support and the course of action towards digitized work environments proves to be challenging for a large number of enterprises. Erol Schumacher and Sihni [15] argue that this challenge mostly results from the broad scope of the concept of industry 4.0, its challenges and its opportunities. In addition, a lack of existing roadmaps and clear guidance towards the realization of visions impedes many institutions in taking further steps regarding the digitalization of production [8,9]

To this day, several approaches of guidelines towards industry 4.0 were proposed. Qin, Liu and Grosvenor [39] proposed a framework identifying the achievement criteria of industry 4.0 emphasizing the current research gaps between current manufacturing systems and industry 4.0 such as the real-time communication, predictive maintenance and decision making of manufacturing systems. In another approach Lee, Bagheri and Kao [30] shed light on the system architecture of cyber-physical systems in manufacturing emphasizing the advantages of a 5-layer architecture of cyber-physical systems concerning product quality and system reliability with more intelligent and resilient manufacturing equipment. Several other frameworks for cyber-physical systems in manufacturing have been proposed such as the framework for the implementation of additive manufacturing [32] or a conceptual framework on assistance in human-machine interaction [53].

Yet, a large portion of the current frameworks regarding industry 4.0 rely a lot on a technological approach such as the implementation of a new technology in a manufacturing environment while aspects such as the change of the organizational structures or the impact of new scenarios of work 4.0 on human factors are rarely taken into account [15]. Processes and structures as well as the activities, tasks and competencies of employees must be adapted to the new requirements as well [2,5]. Decision makers become increasingly aware that the scope of the changes exceeds the technical perspective. Although organizational and social aspects have been identified as central levers for the

successful digitalization of working environments, there is uncertainty on how the scenarios can be implemented sustainably. [17,24]. Manufacturing strategy researchers, with rare exceptions, have continued to make their own way, drawing little from the closely related fields of business strategy economics and organization behavior [1] human factors such as technology acceptance [49] or intrinsic motivation [28]. Furthermore, the currently existing frameworks often address very specific issues in the implementation of cyber-physical systems without giving a broader overview of the resulting possibilities and constraints for the organizations. An application of the former mentioned frameworks often requires a deep analysis of the current (manufacturing)-system, a process which can be time- and resource-intensive. Furthermore, organizations often do not have a clear overview about the actual benefits of implementing new technologies and processes without having to conduct additional measurements. Especially for small and medium sized enterprises, this poses a significant constraint on taking further steps towards industry 4.0.

In this paper, we want to establish on the existing research and bridge the gap between theoretical frameworks and the need of organizations for clear guidance in technology implementation by developing an instrument of identifying scenarios of work 4.0 in regard to the three core dimensions TECHNOLOGY, HUMAN and ORGANIZATION as proposed by Gausemeier [18]. To achieve this goal, the core criteria for each dimension have to be assessed for each of the three dimensions. This assessment and rating of the criteria will aid towards the goal of creating a profile of each scenario of work 4.0, giving organizations an easily-accessible means of finding the technologies that fit their needs.

2 BACKGROUND

As mentioned earlier, the implementation of new technologies should be addressed far beyond the technological perspective. Orlikowski [36] emphasizes the way technological change is constrained by organizational structures and, at the same time, shows that technologies can induce gradual structural change. Several frameworks underwent the challenge to incorporate additional aspects to the further mentioned technological focus. For example, Drazin [12] aimed to develop a decision-making framework which included the entire process of product innovation, ranging from the development to the implementation of new technologies. In this framework, he identified three different levels which influence the decision of a firm's technology adoption: The technological context, the organizational context and the environmental context, leading to the proposition of the Technology-Organization-Environment Framework. Researchers have furthermore suggested that not only should the technological, organizational, and environmental contexts be considered, but also that task characteristics and individual factors should be included in successful technology implementation [38]. Digital change influences employees to a large degree, as they work more and more in an increasingly

digitized and automated, therefore increasingly complex environment. For example, Lorenzi [31] reviewed and classified key factors associated with IT implementation and user acceptance according to level of influence. This included factors such as organizational structure, organization type, user satisfaction and participation. Even though this approach goes in line with the factors proposed in our current work, the focus of the factors mainly relies on the technology acceptance of the users, which mostly corresponds to the human dimension of our work, leaving the advantages and disadvantages in term of organization and technology out. Concerning this, the goal of research of Computer Supported Cooperative Work (CSCW) information systems is to improve the performance of people cooperating in organizations through the use of information technology [20]. This interdisciplinary research field looks at Human-Computer-Human Interaction, the organizational structure of the users of a collaborative system, as well as the relationships that take place among them [37]. Lastly, work led by Sun and Zhang [49] incorporated all three dimensions human, technology and organization in the development of a framework on moderating factors in user technology acceptance. However, while this research entails the influencing factors on technology acceptance and therefore successful technology implementation, it does not mention the outcomes of new technologies on these dimensions, a factor which we consider as important in the understanding of scenarios and the subsequent technological guidance of organizations.

3 PROPOSED SOLUTION

In the following chapter, our current work concerning the relevant criteria for scenarios of work 4.0 will be discussed in detail. In a first step of achieving this goal, the different **criteria** for the dimensions have been chosen based on thorough literature reviews and expert interviews. In a second step, we aimed to provide a means of quantification or categorization, ideally based on existing questionnaires that addressed the same or similar issues. For this reason, each criterion was given one or more *factors*, which cover the core aspects of the issue and help in developing a form of assessment. The current accumulation of criteria that is presented in this paper has been iteratively worked out and underwent several feedback loops. However, we consider these criteria to be a first approach to achieve our goal, while further development and possible issues of the criteria will be further addressed in the discussion of this paper. An overview of the worked out criteria and the corresponding factors for all three dimensions can be found in table 1.

Classification and rating of the technological dimension

Concerning the technology used in a scenario of digital work, one of the most important and validated concepts proves to be the criterion of **technological maturity** [43]. The classification of the technology into one of the four categories (*introduction, growth, maturity and decline*) enables a simple, but effective means

for organizations in having a first and clear definition of the technology in the corresponding scenario.

Another criterion, that goes in line with the technological maturity is the criterion of **compatibility** of the technology, indicating its ability to share any type of information across any technology component throughout the organization [14]. Compatibility has been identified as a key part in successful technology implementation [3,8,46]. Concerning the rating of the criterion, no valid and applicable rating scale indicating the compatibility of a technology has been found. In this case, we chose to rather rate the technological possibilities of different forms of compatibility of the technology in the given scenario. This led to the development of the following factors: *Interoperability with mobile devices, interoperability with stationary devices, personal-based services, situational services, time-based services, location-based services* as well as the *possibility of using the technology with different platforms* such as tablets, computers or handheld devices.

While the compatibility has been identified a key factor in the communication and integration of the technology with other technical devices and systems, the communication between the machine and its human operator is not included in this category. Therefore, the **means of (human) interaction** with the technology are an additional factor in technology implementation, especially given that most organizations aim to implement a technology which fits best to their employee's needs [50]. Concerning the rating of the different means of interaction, similar to the criterion of compatibility, no applicable means of assessing the whole construct have been found in literature. Again, we chose to assess the different means of interaction, which can be used in the scenario, leading to the following factors: *Interaction with information tags (e.g. RFID), interaction through visual codes, direct tactile interaction, direct textual interaction, acoustic interaction* as well as *gesture recognition*.

Another important factor concerning the successful implementation of new technology is the **flexibility** of the system. Research shows, that flexibility of IT systems has been identified as a necessity for (rapid) changes in a business environment and the effective implementation of new technologies [9]. Concerning the quantification of flexibility, Duncan [14] identified three measurable key factors: The *compatibility*, the *connectivity*, including the ability of the technology to communicate with other components in and outside of the organization and the *modularity*, the ability of the technology and its components to be reconfigured. While the compatibility has already been classified as a single dimension in the scenario assessment, the latter two factors were included in the questionnaire to assess the criterion of flexibility.

While the former criteria can be seen as advantages resulting from the implementation of new technology, several possible constraints were identified, which may had a hindering impact in technology implementation. Primarily, the **complexity** of a technology can be seen as a key factor in technology implementation and diffusion. Research led by Schmidt emphasizes, that low technological complexity may be positively related to successful technology implementation [46]. Concerning

the assessment of technology complexity, it has been proven difficult to apply a quantitative means of measurement to this concept, given that for the broad range of currently used technology and IT-systems, a single definition of the system's complexity has not yet been established [4]. In an attempt to grasp the concept of complexity, we identified the three factors (*inter*)connectivity of the components [12], *degree of understanding and active participation* [41] and *specialization of the technology* [12] as the factors for the assessment of complexity in our questionnaire.

Another important criterion, which influences the implementation and diffusion of new technology, has shown to be the monetary effort of technology implementation. Concerning the cost of a technology, we can distinguish between the one-time initial **invest** in the technology, the **effort of implementation** in terms of personnel as well as the **cost of maintenance** of the technology. While the initial invest was easily quantifiable, since every technology comes with a more or less clearly defined price, the effort of implementation was more difficult to grasp. Given that for each organization, the amount of available personnel, the cost of personnel as well as the competences can differ, no clear monetary value can be given as a quantifiable means for this criterion. However, we adapted a scale used in research by Gruber and colleagues [21] who distinguished the effort of technology implementation in four different stages (*no need for additional tools, need for simple installation and additional tools, need for implementing new (complex) system components, need for a restructuring of the system*) giving us the possibility to rate this construct. For the costs of maintenance of a technology, we chose not to assess a monetary value, since the cost of workers, equipment and infrastructure may differ between companies, countries and industrial sectors. Instead, we tried to assess the effort of maintenance which is needed concerning the factors *overhead of the organization, system maintenance, upgrades, system management and employee training*

Lastly, two major criteria were identified concerning the safety aspects of a new technology. In this case the distinction between two types of safety were made: On the one hand, we wanted to assess the **safety** of a technology. This is defined as the protection of the environment and the user from an object. In terms of technologies this includes occupational safety, ESD protection and the labelling of potentially hazardous elements [23]. As for the rating of the criterion, it has been proven difficult to give a single uniform rating of the safety of the scenario. Instead, we adapted a classification used by Saleh [45] who identified three main factors of safety (*training of employees, supervision of the work environment and implementation of security technologies*) which could be used in our questionnaire. The last factor, the **security** of the technology, goes in line with the safety of the system. However, while the safety concentrates more on the physical workspace, safety addresses the protection of an information technology from its environment with a focus on cybersecurity, privacy and data security. Several methods of quantitative measurement of IT security have been found in the literature[11]. Nevertheless, these measurements often require a deep and narrow understanding of the technology at hand as well

as rather complex methods,, making them unsuitable for being used in our questionnaire. Instead, we chose to use the factors *training of employees, supervision of the work environment and implementation of security technologies* by Saleh [45] and adapt them to the criterion of security.

Classification and rating of the human dimension

Concerning the classification of criteria for the human factors, one of the main premises of our work has been the fact that with the implementation of new technologies, the characteristics of work have fundamentally changed over the last years [6]. Given that the tasks at hand in the scenarios of work 4.0 have changed, there has been a shift in the **prioritization of the abilities** which are required to successfully complete these tasks [10]. For a classification of the required skills in the scenario to be analyzed, we focused on research by Fleishman and Quaintance [16], who argued that specified tasks can be characterized by special requirement profiles. Although the categories were not initially designed concerning digitized work environments we see the categorization fitting for giving an overview about the nature of the task(s) in the scenario at hand. Following Fleishman and Quaintance, five categories of abilities were used for rating the scenario: *cognitive, psychomotoric, physical, sensory and social/interpersonal abilities* [52].

A criterion which goes in line with a shift in the prioritization of the abilities is that new work often requires additional **qualification of employees** in order to carry out the tasks in a scenario, a factor which has been identified as a critical requirement for the successful implementation of technology [42]. Given that the use of a new technology might require a specific skill set or certain competencies, this criterion is important for organizations since it allows an estimation of the effort that a new technology might bring in terms of workforce development. As for the rating, we have chosen to rate the qualification by the *amount of effort* that is needed to qualify personnel for the given scenario. In addition, for each scenario, the *form of the qualification* such as single-day training or workshops over multiple days were specified. Besides the requirements of the employees, a factor that is crucial for a successful implementation of new technologies is the way the work is designed. Research has found that work design can have a significant impact on individual factors such as autonomy and cognitive ability [33] or organizational factors of work such as group feedback [28]. To assess the requirements, efforts, uses and constraints of work design, the work-design questionnaire (WDQ) [34] has been found to be a valid means of rating the scenarios. However, given the scope of our work, we did alter the dimensions of the questionnaire to fit our needs given the following two reasons. Firstly, using the entire scope of the WDQ would surpass our aim to develop an easily accessible tool for rating scenarios of work 4.0. Secondly, the rating system of the WDQ is highly subjective, given that it was designed for employees to assess their own work environment. Since our aim is the development of an objective rating scale, some of the items were altered.

One of most important work criteria has found to be the **scope of action** or **autonomy** of the work, a criterion which has been linked to the acceptance of technological innovations in organizations [49]. In terms of rating the scope of action of a work environment, we have chosen to adapt the three factors *work scheduling* which includes the freedom of individual time management, *decision making* and *work methods* which includes freedom in the choice of how to obtain work results. The second criterion, which has been adapted from the WDQ is the **possibility of social interaction**. Given that factors such as social support in work are a critical factors of well-being [56] and can help in overcoming work overload [51], the assessment of the work environment should not neglect this. For the rating, the factors *social interaction at the workplace*, *interaction with external parties*, *interdependent work tasks* as well as *task independence* have been adapted from the social characteristics of the WDQ.

The next criterion that has been chosen for the assessment is the **holistic nature of the task**. This includes the degree to which the job can be seen as a whole with identifiable results [48]. Understanding the holistic nature of the task has found to increase the attractiveness of a job [22], classifying this criterion as an important indicator of a scenario of digital work. The rating included the factors *influence of the work on other employees*, *holistic of the work* and *automatic performance feedback*. Lastly, the criterion of **work diversity** has been identified for the development of the questionnaire. The work diversity include the possibilities of using a range of skills, knowledge and competences that can be brought in during work to obtain the employees goals [51]. The factors which were included in the questionnaire, include the *task variety*, *task complexity*, *the amount of information processing*, *creativity*, *the variety of skills* as well as *the variety of tools* that are needed to complete the task.

Classification and rating of the organizational dimension

In addition to the evaluation based on technical and human criteria, the dimension of organization is essential for the assessment of scenarios of work 4.0. Significant for this dimension is the general categorization of the scenario in regard to its position in the development process leading to the criterion of **product development process**. Classification into *Strategic Product Planning*, *Product Development*, *Service Development* and *production system development* defines the area of responsibility for the scenario [18].

For companies, the criterion **promotion of innovation** can be decisive for the introduction of a scenario of work 4.0. In order to assess the benefits for the promotion of innovation, the scenario is analyzed in terms of the factors *product orientation* and *customer orientation* [40]. Furthermore, the **reduction of time-to-market** of a scenario can lead to an adaption of a new scenario, given that this reduction can prove beneficial in terms of costs and product development time. For the assessment of this categories, we have adapted the factors influence on *process control*, reduction of time-to-market through *process optimization*, *infrastructural changes* as well as the strengthening of *interdisciplinary collaboration* [25]. Work 4.0 aims to counteract the complexity and

interdisciplinary of cyber-physical systems in order to reduce the time-to-market. Therefore, the promotion of innovation and reduction of time-to-market have to be considered as a decision-making criteria.

Labor cost estimates play a central role in project management [58]. The success or failure of project work such as operational activities of a scenario of work 4.0 is decisively dependent on it. Factors to estimate the criterion **labor expenditures** are *the number of different and complexity of activities for execution*, *number of participants*, *training period* and *necessity of distributed persons*. Besides labor expenditures to execute scenarios of work 4.0 there is a **need for competences and expert knowledge**. This criterion is required for both technological implementation and execution. The results of a Competence Development Study 2016 divides the competencies that are crucial for companies to implement Industry 4.0 into three areas: *Technology and data oriented* (e.g. IT security, Artificial Intelligence, data scientist), *process-/customer-oriented* (e.g. process management, systems engineering specialist, eCommerce) and *infrastructure-/organization-oriented* (e.g. network/database administration, protection of privacy, dealing with specific IT systems) [26].

An indicator for assessing the complexity of organizational implementation is the **Influence on process organization**. To grasp the concept of influence, we identified the three factors *adjacent/related factors processes*, *organizational units and customers or suppliers*. The **degree of collaboration** describes the distribution of decision-making powers within an enterprise or its subunits. This can influence the company's policy and strategy and is therefore important from an organizational point of view. Weaver classifies this in cooperation, coordination and collaboration [55]. For the evaluation, we used a qualitative appraisal of the *axle's organizational structure* and *mutual management*. Similar to the degree of collaboration can the **degree of delimitation of work** influence the operational organization by dissolution of 'traditional' structures. Factors are *decentralization* [27] *working time flexibility* and *project flexibility* [25]. A high degree of delimitation leads to a flattening of hierarchies. Lastly, **agility** is becoming more and more important for product development in order to meet the rapidly changing requirements of the customer and the system context. For the assessment of scenarios of work 4.0 the influence on agility is therefore significant. For this criterion the factors *customer orientation*, *participation and transparency as well as decentralization and breaking up the dominical thinking* have been chosen as measurable indicators for agile projects [35].

Table 1. Overview of the different criteria and the corresponding factors for the dimensions technology, human and organization

Criterion	Factors
Technological maturity	Category of Technological maturity (introduction, growth, maturity, decline)
Compatibility	Mobile interoperability Stationary interoperability Personalized services Situational services Time-based services Location-based services Platform independence
Means of (human) interaction	Information tags, Visual codes, Direct tactile interaction, Direct textual interaction, Acoustic interaction Gesture recognition
Flexibility	Compatibility Connectivity Modularity
Complexity	(Inter)connectivity of the components Degree of understanding and active participation Specialization of the technology
Invest	Price (€)
Effort of implementation	Implementation effort
Cost of maintenance	Overhead System maintenance Upgrades System management Employee training
Safety	Training of employees, Supervision of the work environment, Implementation of security technologies
Security	Training of employees, Supervision of the work environment, Implementation of security technologies
Prioritization of abilities	Cognitive Psychomotoric Physical Sensory Social/interpersonal
Qualification of employees	Amount of effort Form of qualification
Autonomy/scope of action	Work scheduling Decision making Work methods
(Possibility) of social interaction	Social interaction at the Workplace, Interaction with external parties,

Dimension Technology

Dimension Human

	Interdependent work tasks, Task independence
Holistic nature of the task	Influence of the work others, Holistic of the work, Automatic performance feedback
Work diversity	Task variety, Task complexity Amount of information processing, Creativity, Variety of skills Variety of tools
Product development process	Stage of the product development process (strategic product planning, product development, service development, production system development)
Promotion of innovation	Product orientation Customer orientation
Reduction of time-to-market	Process control Process optimization Infrastructural changes Interdisciplinary collaboration
Labor expenditures	Number of different activities Complexity of activities Number of participants Training period Necessity of distributed persons
Need for competences/expert knowledge	Technology/Data-oriented, Process-/customer-oriented Infrastructure-/organization-oriented
Influence on process organization	Adjacent/related factors processes, Organizational units, Customers/suppliers
Degree of collaboration	Organizational structure Mutual Management
Degree of delimitation of work	Decentralization, Working time flexibility Project flexibility
Agility	Customer orientation, Participation transparency Decentralization

Dimension Organisation

4 CONCLUSIONS AND FUTURE RESEARCH

We have seen that, with the rise of information and communication technology in the industry, highly automated cyber-physical systems will have an increasing importance in the development and implementation of new technologies. However, given the complexity of technological systems nowadays and its interdependence with environmental factors such as the organizational structure and socio-psychological aspects of work

lead to adapting a more scenario-based approach incorporating the formerly mentioned dimensions. Nevertheless, these scenarios prove to be difficult to assess and rate with current, mostly technology-oriented, frameworks of industry 4.0. Our approach takes up the growing understanding that a socio-technical perspective is needed. While these scenarios permit organizations a deeper understanding of a technology, the right choice of technology has still been proven difficult. By creating an instrument for rating these scenarios on the dimensions technology, human and organization, we made a first step towards a uniform definition of scenarios to provide a common understanding of the rather complex construct of industry 4.0.

The next steps of our work will concentrate on applying the developed instrument on relevant scenarios of work 4.0 with the aim to create scenario profiles which will serve as a guidance for the choice of technology implementation. In addition, the process of applying the instrument to current scenarios will serve as an effective mechanism of validation of the questionnaire and will aid in the iterative development of categories and rating factors. For further validation, we aim to gather feedback from a broader range of people including employees of project partners as well as experts from other backgrounds.

The rating of relevant scenarios will enable a clear and uniform presentation of scenario profiles including a scenario description as well as a visual representation of the formerly mentioned criteria. Future work will aim to provide these profiles with additional information such as process diagrams of the tasks being carried out and technology fact sheets, giving a deeper understanding of the technology being used in the scenario. Furthermore, we aim to conduct laboratory studies with regards to the ergonomics, usability and technology acceptance of certain technologies. The results of these studies may prove to be a useful addition to the scenario profiles in order to obtain more information about the technology at hand.

ACKNOWLEDGMENTS

This work as a part of the project “Instrumentarium zur Gestaltung individualisierter virtueller Produktentstehungsprozesse in der Industrie 4.0 – IviPep” is funded by the German Federal Ministry of Education and Research (BMBF) and the European Social Fund (ESF) under the registration identification 01FI16133. The financial project organization is directed by the Karlsruher Institute of technology (KIT). The contents of this publication are the sole responsibility of the authors and do not necessarily reflect the views of additional project partners and/or the funding committee.

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