Chapter 14
Human Factors in Production Systems

Motives, Methods and Beyond

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Abstract Information and communication technology (ICT) is getting smaller and faster at a dashing pace and is increasingly pervading production technology. This penetration of ICT within and across production technology enables companies to aggregate and utilize massive amounts of data of production processes, both horizontally (across different products) and vertically (from machine level, over the shop floor, to the supply chain level). Presumably, this yields in Smart Factories with adaptable manufacturing processes that adjust to different goals, such as performance, product quality, or resource efficiency. But the increasing amount of available data also raises considerable challenges: Strategic decisions still depend on humans in the loop who have to perceive and process increasingly complex multi dimensional data sets and to make decisions whose effects are increasingly difficult to forecast. This paper is concerned with the potential of the human factor. Along with three case studies, we demonstrate the potential of human factors in the development of applications for Smart Factories and enterprises in the era of Industry 4.0. The paper concludes with a set of guidelines and methods for the user-centred development of applications for Industry 4.0.

Keywords Human factors · Socio-Technical systems · User diversity · Industry 4.0

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14.1 Motives for Integrating Human Factors in Production Engineering—the Challenge

Production systems are not like they used to be. The 21st century will confront enterprises and manufacturing companies with completely novel generations of technologies, services, and products based on computer technologies (Schuh and Gottschalk 2008; Schuh et al. 2009). In order to meet competition on global markets and to ensure long-term success, the companies need to adapt to shorter delivery times, increasing product variability and high market volatility, by which enterprises are able to sensitively and timely react to continuous and unexpected changes (Wiendahl et al. 2007). One of the major cornerstones to meet these challenges is the implementation of digital information and communication technologies into production systems, processes and technologies, which allow novel developments by combining the physical world and fast data access and data processing via the Internet (Industry 4.0).

Another major cornerstone is to understand the impact of the human factor and to integrate human factors knowledge seamlessly in the technology development cycle, thus moving from traditionally purely technical systems into socio-technical systems.

In the next decades new generations of technology systems and products have to master fundamental societal and technological challenges (Wilkowska and Ziefle 2011). This includes the impact of the greying society, with an increasingly aged work force, but also short technological life cycles triggered by fast changing technological systems and the question in how far diversely skilled workers might learn and adapt to the increasing complexity of systems (Ziefle and Jakobs 2010). Although the crucial potential of usable products that are appropriate for a diverse user group, recognition of the importance of diversity is only slowly influencing mainstream technology development practise. New approaches integrate users as a valuable source for new ideas and innovations (end-user driven innovation cycle) and integrate their knowledge as an integral component into the technical development (Franke and Piller 2004). User communities are a significant source for innovation and provide market insight before launching an innovative product (Fredberg and Piller 2011).

For high-wage countries, which are characterized by competitive production systems and a high pressure to succeed, it is more than high time to integrate human factors knowledge as a natural and expert source of information into the technology development and processing.

We conclude that these challenges can only be addressed if methods from production engineering are “reinvented” and combined with methods from the social sciences. Only a holistic inter- and transdisciplinary methodology will be able to address the changing production processes and changing workforce, in order to strengthen the competitiveness of companies in high-wage countries (Calero Valdez et al. 2012).

14.1.1 The Contribution of the Social Sciences

Traditionally, social science research deals with the understanding of the human factor, i.e. explaining, measuring and predicting human experience, affective states, cognitions, and behaviour. This includes the capturing of emotional states and cognitive abilities in different application contexts, against the background of user diversity and the differences in attitudes within and across individuals. But it covers also developmental changes of humans across the life span as well as the systematic understanding, control and change of human behaviours.

The huge volatility of the human nature and its enormous adaptability to different situations necessitated the development and establishment of standardized human factors' methods and metrics that allow a sound, reliable and valid prediction of the human factor. Hence, on the base of their profound empirical methodology and their sound knowledge base of the human factor, social science can naturally contribute to the understanding of socio-technical systems, as e.g. the current challenges in production technology.

Basically, social science knowledge can contribute to different challenges:

- *Dealing with Complexity* Understanding human cognition and decision making in production systems
- *Meeting Requirements of User Diversity* Understanding the impact of the demographic change and diversely skilled workers
- *Handling of Heterogeneous Teams* Understanding the interaction and communication of impacts by interdisciplinary working environments and team culture
- *Measuring Technology Acceptance* Understanding the benefits and caveats of the interaction and communication of humans with technology (from (hybrid) systems to interfaces)
- *Dealing with Usability and User Experience* Understanding the impact of respecting human cognitions, emotions, expectations and values in the development of technology
- *Providing Experimental and Empirical Metrics* Understanding novel contexts and potential settings (from prototypes to real settings) by applying testing scenarios that allow evaluating the quality of measures and settings.

With regard to work environment and design of production systems, usability and user experience research has been shown to exploit a huge benefit for diverse application setting within industrial environments. In many domains (perceived) usability is an established criterion for the quality of a product and is increasingly a deal breaker for the buying intention for consumer electronics. However, usability is not yet widely acknowledged for professional applications in production engineering (Myers et al. 1996; Ziefle and Jakobs 2010) and many interfaces suffer from complicated screen layouts (Arning and Ziefle 2009; Ziefle 2010a), not understandable labels and buttons, undistinguishable and unclear icons (Pappachan and Ziefle 2008), and steep learning curves. Interfaces that somehow work for specific user groups, but fail for the increasingly changing and increasingly diverse labour force (Wilkowska and Ziefle 2011; Calero Valdez et al. 2013).

The reason for investing in usability is simple: Good soft- and hardware usability is the reason for a higher quality of the achievements and increased productivity of the workers (Arning and Ziefle 2007; Ziefle 2010b). Also, good interfaces reduce the time and costs for training and support and increases the users' work satisfaction, loyalty and commitment (Arning and Ziefle 2010). Furthermore, if usability is considered from early on in the design process and not an added on top in the final stages of the development, it can dramatically decrease the development time and costs (Nielsen 1993; Holzinger 2005). Hence, establishing usability as a core criterion for professional applications can increase the return of investment (ROI) and decrease the total costs of ownership (TCO) dramatically.

14.2 Methods for Understanding and Quantifying Human Factors—the Potential

The following section presents a bouquet of measures that can be applied in various stages of the development process and how efficient, effective and usable systems can be realized for a changing and increasingly diverse user population.

ISO/EN 4291/11 defines *effectiveness, efficiency*, *and user-satisfaction* as the three central criterions for the usability of interactive products. Although this norm provides essential usability criteria, it neither presents methods for realizing systems with high usability, nor does it provide off-the-shelf measures to quantify the usability of systems. So how can user-friendly systems be realized?

The foundations for designing usable systems for people can be found in the early dawn of graphical user interfaces: In 1985—just a year after Apple introduced Macintosh—Gould and Lewis proposed three key principles for building usable software (Gould and Lewis 1985): *Early focus on the users tasks*, *empirical measurement of the product usage* and *iterative design*. Many stakeholders are involved in the specification and development of new software systems: Software engineers, user interface designers, and software architects on one side, as well as domain experts and managers who are responsible for the introduction of the new software. Of course, the end users also belong in the circle of stakeholders, but often enough they are neglected or consulted only in the latest stages of the development.

Early focus on the users tasks The decision to invest in new software often comes from the managers of a company or external consultants. As they are not the actual users this often leads to miss defined or insufficiently defined task descriptions. Hence, users must be included in the earliest stages of the design of a system, their tasks must be well understood and the users' wishes, abilities and motives must be captured and well understood by the design team.

Empirical measurement of the product usage To ensure that the developed system supports the tasks users want or have to perform the execution of prototypic

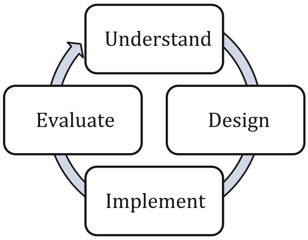

Fig. 14.1 Schematic presentation of an iterative development process as proposed by Gould and Lewis (1985)

tasks by actual users must be observed. These task executions can be quantified (e.g. by measuring task completion, accuracy) and will identify the critical parts of the software that do not support users in their work and need to be revised.

Iterative design It is not sufficient to attest a certain level of usability at certain point in time, but system usability must be a continuous focus during the whole design process. Ideally, a design team starts with an early prototype of a planned system and evaluates the usability of the system with typical tasks performed by typical users. These quantitative evaluations eliminate the most severe usability issues early in the development. Then, future iterations of the system with functional prototypes can focus on other and minor usability issues, but again with actual users who perform typical tasks with the planned system. Figure 14.1 shows a schematic presentation of this cyclic process.

14.2.1 Metrics, Procedures and Empirical Approaches

This section outlines a few but still the most central usability methods for user-centred design. An in-depth description and additional methods can be found in Dix et al. (2003) or Courage and Baxter (2005).

Methods for developing and evaluating user interfaces can be divided in methods with and methods without involvement of prospected users. Methods without user involvement, such as *heuristic evaluation* (when experts evaluate if interfaces meet certain heuristics), *GOMS* (a method for estimating the expected performance, similar to Methods-Time Measurement—MTM), or *cognitive walkthroughs* (human factors experts identify usability issues by predicting how users would solve tasks) are not covered in this article. They are a valuable addition to every development process, yet many issues will remain uncovered, if prospected users are not included during the design phases.

Paper prototyping Paper prototyping is a low fidelity prototyping technique that allows the gathering of user feedback on an interface in early stages of the design and before the software implementation starts. The proposed user interface is drawn on paper and discussed with users. Their feedback can be integrated at once and interface suggestions can be drawn and discussed immediately. Replacing parts of the simulated screen with new layers can simulate interactive interfaces and the traversal through multiple screens. Paper prototyping is best applied in early stages of the design, when the general interface is designed. But even in later stages individual changes, new dialogs and screens can quickly be designed and evaluated using this technique.

Rapid prototyping This method carries forward the concept of paper prototyping. This may include "clickable" interface mock-ups in a presentation tool, or functional screen prototypes.

Wizard-of-Oz This method allows the evaluation of interfaces even if the respective backend functionality is not yet available, by observing the user's interaction with the prototyping system and simulating its outcome. For example, a paper prototype can "control" a machine, if a hidden observer simulates the user's interaction with a remote control.

AB-tests To understand if different interface alternatives result in higher speed, higher accuracy or higher user satisfaction different design alternatives can be compared by presenting both to a set of users, either within-subjects (every user uses every interface) or between-subjects (each user evaluates just one interface). Measures may be objective measures, such as task performance and learnability, or subjective measures, such as users' perceived efforts.

Note that the feedback acquired changes with the perceived completeness of the interface: Paper prototypes are perceived as easy to change, thus users often request fundamental changes, while applications that appear complete are apprehended as difficult to change, hence the articulated feedback is often restricted to wording, colour choices, and other trivialities.

The methods presented are a necessity for building usable, understandable, learnable, goal-oriented, task-adaptive, efficient and satisfying software for production systems. They should as a matter of fact belong to the standard toolbox of all stakeholders included in the technical development process. To identify and obliterate usability pitfalls and to assure that the software captures the users actual needs, these and similar methods must be applied frequently during the design process. However, to unfold their full potentials, human factors experts must also be included in this process, as they are able to detangle individual differences in effectiveness, efficiency and user-satisfaction that are caused for example by motivation, personality, or cognitive abilities. These then allows a fine-grained tuned or individually tailored user interfaces.

14.2.2 Case Studies—Examples of the Potential of Exploring Human Factors

The following three exemplary cases present "success stories" in which the methodology of user-centred design and human factors research was applied in the area of production systems.

The first case quantifies the influence of poor usability on efficiency while interpreting large data sets in supply chain management. The second case outlines how human factors relevant for good job performance in supply chain management can be identified. The third case describes how an adequately designed worker support system can relocate the focus between speed and accuracy depending on the task.

Case 1—Visual and Cognitive Ergonomics of Information Presentation

Managing the follow of material in supply chain management depends on both, the ability to perceive, understand and interpret given data correctly, as well as the presentation of the data. To understand how insufficient data presentation and bad usability impacts the decision quality, we conducted a formal *AB-test*. We measured the decision speed and decision quality in dependence on human information processing speed and the presentation form (poor and good usability constructed as small or medium font sizes in a tabular presentation of supply chain data). The study revealed that poor usability obviously decreases the overall performance. Strikingly though is the finding, that poor usability disproportionately impairs people who have a lower information processing speed, while faster information processors can compensate poor information presentation. This finding highlights the necessity of user-centred and participatory design, as software developers, interfaces designers and contributing mechanical engineers usually do not realize the negative effects of poor interfaces on decision speed and decision quality, as they are able to compensate the negative effects, while the end users often are not. Frequent user tests with methods as presented above will reveal these barriers even in early stages of the design.

Case 2—A game-based Business Simulation to Understand Human Factors in Supply Chain Management

Supply chains are sociotechnical systems with high dimensional and nonlinear solution spaces. The performance of a supply chains is not only determined by technical factors (e.g. shipping times, replacement times, delivery strategies, lot sizes, order costs, etc.) but also by the abilities of the human operators who needs oversee the possible choices and make good decisions in this complex solution space. To identify the factors that contribute to a better understanding of the supply chain and to develop methods that help supply chain managers to make better decisions in shorter time we developed a series of supply chain games (Brauner et al. 2013; Stiller et al. 2014). The business simulation games are virtual test beds with multiple uses: First, they are a flexible tool to identify and quantify human factors that contribute to efficiency and effectivity in managing information in logistics and supply chain management, by systematically varying the difficulty of the game and investigating how different human factors (capacity, processing speed, motivation, self-efficacy, personality traits) relate to game performance. Second, through experimental variation the user interface and/or provided decision support tools, the benefit or costs of these can be evaluated and quantified within the test bed before the proposed changes are implemented in commercial applications. Third, the relationship between in-game performance and performance in the job as supply chain mangers can be used to develop interactive methods for personnel selection with an increased accuracy.

The design of this research and evaluation framework followed the design principles presented above and several of the usability methods presented above were applied. The following sections describe the iterative development process and some of the methods used during the process.

The development of the business simulation game was a collaborative effort between the four disciplines mechanical engineering, communication science, computer science and psychology. Each of the four disciplines contributed methods in order to on ensure the simulation model's validity on one side and the good usability and suitability for psychometrical evaluations on the other side.

At the beginning of the project the experts form each discipline discussed the game model and the relevant indicators for inferring the simulated companies status. Then the *paper prototyping* technique was used to arrange the indicators to form the user interface of the game. In a second step a low-fidelity software prototype of the game simulation was realized and the previously selected indicators were populated with data from the simulation model and the experts evaluated the suitability of the indicators and the simulation model. Third, the game was implemented as a web application and the design of the user-interface ware strictly based on the earlier prototypes and influenced by technical considerations. Forth, during one user study feedback from external usability experts was gathered and their suggestions were integrated in the game. A subsequent user study attested that the user interface refinements led to an increased profit of the simulated company as the users hat a better overview of the performance indicators and were able to make better decisions. Throughout the design process feedback was gathered from other experts and test users and the user interface and the game model was refined accordingly. Figure 14.2 shows the development progress of the game across three prototype levels.

Case 3—Augmented Reality Worker Support Systems

The third test case of including human factors research and design methodologies in production engineering is the design and evaluation of a work support system for carbon-fibre reinforced plastic manufacturing (CFRP) (Brauner et al. 2014).

The CFRP production process relies on manual production steps in which multiple layers of carbon fibre cloth have to be aligned in specific orientations. The overall stability of a CFRP part is prone to misalignments and a mismatch of 5° reduces the mechanical stability of a component by 50 %. These defects can only be

Fig. 14.2 Different development stages of the Supply Chain Simulation Game (*left* paper prototype, first layout of the interface, *centre* rapid prototype in a spread sheet applications for evaluating the game's model, *right* final user interface of the game)

detected late in the production process, which yields in extra costs for the process steps between origin of the error and the detection.

To increase the stability of the process we designed a worker support system that alleviates the variances in the orientations of the carbon fibre cloths. The system captures the orientation of the currently placed layer and provides auditory and visual feedback to the worker. Later iterations of the prototype may be realized stationary in the assembly cell or on mobile augmented reality systems, such as Google Glass.

An evaluation of a *rapid prototype* of the system with the *Wizard-of-Oz technique* (compared four different feedback modalities against each other (no feedback, auditory, visual, and combined feedback). The key finding is that providing no feedback yielded in the highest speed and the lowest accuracy, while combined auditory and visual feedback led to slowest speed and highest accuracy. Hence, a target-oriented design of worker support systems can nudge workers to either increase the speed of the production process or to increase its accuracy (speed—accuracy trade-off).

Summarizing all three cases, utilizing methods from user-centred design and human factors research reveal a deeper understanding of the behaviour of human workers on different levels of production processes. The methods facilitate the development of better systems and applications for production processes in shorter time. Adequately designed system can influence the production processes by shifting the trade-off between speed and accuracy by giving carefully designed feedback. Furthermore, some methods allow an explanation and prediction of individual differences in speed, accuracy, performance and motivational factors that might either contribute to better designed and better targeted software systems or to more specialized recruiting and training processes for the employees.

14.3 Beyond—How to Amend Productivity with Quality of (Work)Life—the Vision

The truly understanding and consideration of human factors for the realisation of human and humane working environments is a critical issue. Though it might be still more critical when facing the upcoming generation Y (Martin 2005). According to Bakewell and Mitchell (2003), this generation can be characterized along five types: the "*recreational quality seekers*", the "*recreational discount seekers*", the "*trend setting loyals*", the "*shopping and fashion uninterested*" and the "*confused time/money conserving*". This new work force generation (born after 1977) brings thus another working and performance attitude to high wage countries. It is less the mere concentration on work or system performance alone, only addressing pragmatic and productivity aspects of technology, it is far more, value-oriented, hedonic and highly fulfilling working conditions that characterize the challenges of high performance cultures in the near future.

Two keystones for this reformation of productivity might be shortly outlined, one refers to a more technical one, the pattern language to enable interdisciplinary teams, the other one is more visionary and relates to the working climate of the future Generation Y.

14.3.1 Enabling Communication in Interdisciplinary Teams

A common problem among interdisciplinary teams is the lack of a shared language and misconceptions about the other methodologies. Established systems for enabling interdisciplinary communication in teams are *pattern languages*. Christopher Alexander's seminal work suggested these languages as a method to enable different stakeholders in urban planning (e.g. architects, civil engineers, city planers and residents) to collaboratively design the living space (Alexander et al. 1977). Each pattern describes a solution for recurring problems, defines a shared iconic name, captures the forces that argue for and against the given solution and refer to other patterns that relate to the solution, either as possible alternatives (horizontal) or superordinate and subordinate patterns (vertical). A network of interlinked patterns then forms a complete pattern language. Other disciplines adopted pattern languages as a tool to capture disciplinary knowledge, but sacrificed the aspiration for participatory design. In computer science the "Gang of Four" introduced software design patterns (Gamma et al. 1995) that quickly revolutionized the communication between experts in software engineering. In mechanical engineering (Feldhusen and Bungert 2007) suggested a pattern language to manage archetypal engineering knowledge, but again, this pattern language captured engineering knowledge by and for experts. It shows that pattern languages exist for various domains, but still Alexander's original goal to enable all stakeholders to jointly develop holistic solutions got astray.

Thus, a dedicated pattern language for the design of production systems may enable truly participatory design in production engineering and a more efficient collaboration among interdisciplinary teams. The goal of this language must be to empower all stakeholders to understand the constraints of a given problem and overview the set of possible solutions. This language could cover individual competencies and methods of the contributing disciplines and will enable interdisciplinary teams to collaborate more efficiently on future production systems.

14.3.2 Motivators for High Performance Cultures

Recurring again to the generation Y, the novel attitude of workers might also requests a change within the performance culture in the production and work environment. In this perspective, the quality of "good interface of technology" relies on affective and hedonic aspects of work and production—attributes emphasizing individuals' well-being, pleasure and fun when interacting with technology and technological systems, the quality and the design of products, but also the well-being of teams, working groups as well as the well-being of society, focusing on social morality, working ethics, work-life balance, environmental justice, or life style. To this end, the relationship of users and technological products and their working environment is of importance and the making sense of user experience. In addition, the work experience and domain knowledge of workers, end users and consumers of technology or technical systems is of high value (and is so far, mostly ignored). It seems indispensable for efficient production environments to focus on human factors in order to enable highly motivated and high performance teams not only steering with the traditional motivators—money, pressure, or competition—but rather to focus on the internal motivation of workers to contribute to the system effectiveness by including their knowledge and their expertise within iterative product development cycles.

Naturally, the relationship between leaders and workers need to be reformatted accordingly. Efficient teams then should be characterized by transparent group communication, a commonly shared information policy and the appreciation of ideas and innovations created by working teams. This team culture though requires trust in both, the team leader and the workers and might be a overdue performance driver of current working environments in enterprises that might ensure sustainable high performance cultures on the long run.

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