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Influence of work design elements on work performance and work perception – an experimental investigation

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Abstract

Future work systems will be highly computerized and cognitively challenging. In order to design these systems being both productive and human-oriented, further work design research in the specific area of cyber-physical production systems (CPPS) is needed. Thus, we conducted an experimental investigation on three work design elements in CPPS. Within the experiment, the participants were asked to solve model manufacturing scheduling tasks which go along with a questionnaire. In this paper, we present the results of the study and a preliminary analysis on the effect of several work design elements on work performance and work perception.

Keywords: Cyber-physical production system; Industrial internet of things; Work area design; Experimental investigation

1. Motivation

The rise of cyber-physical production systems (CPPS) changes the way humans will work in future workplaces. They enable new types of (smart) production organization which are accompanied by increased computerization and process automation. Consequently, the CPPS will have an impact on human work. For example, workers will have to deal with smart glasses, wearables, tablets, exo-skeletons, and more as their standard work equipment. The success of the work related to these devices will be strongly depending to their acceptance by the users [1, 2].

Besides, as a consequence out of the increased level of automation, the task allocation between humans and machines will change. Experts expect hybrid production systems in the future, in which humans and machine work collaboratively [3, 2]. This brings the human-machine-interaction into main focus. The interfaces between the human and the automated parts have to be a supporting and reliable means for information exchange [4].

For facilitating and supporting human-oriented work in CPPS, it is necessary to establish new work area design principles. But how do designers create future workplaces in a suitable way which enables both an optimization of management key figures and humane work conditions? In order to contribute to the solution of this research problem, we suggest to conduct work design experiments. A combination of observation and questioning parts as being the main methods of work design research shall be applied on CPPS work design ideas. Thus, data about their performance and perception can be obtained and used for designing human work in CPPS.

We propose to use a variable, low-cost experiment platform as a basis for the experiments which we initially presented in [5]. As a subsequent step of our research we performed a first experimental investigation on three CPPS work design ideas. In this paper, we present the setup of our investigation and an analysis of the results. Further, a discussion about the study's outcome and our ideas for follow-up studies are made.

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2. Work design requirements and starting points in CPPS

In the last decade, several studies have dealt with the effects of human work conditions on both the physical and mental state of workers and on management key figures. The authors identified correlations between humane work design actions (e.g. ergonomic design of the workplace or cognitive simplification of complex tasks) and beneficial effects (e.g. enhanced job satisfaction or better product quality) [see, e.g., 6, 7, 8]. As a result of a cost-benefit analysis of ergonomic workplace improvements in industry, researchers found mainly positive effects on work conditions and short redemption times of the investigated actions [9].

These publications show the positive influence of work design but have been published mainly before the introduction of CPPS. Consequently, research has to set the focus on work design again considering the changing manufacturing systems. Human work places will experience intense changes due to the implementation of CPPS. To begin with, easy and repetitive work will diminish but new jobs will be created around maintenance and control of the smart production systems. Studies claim that humans will be still important in the future factories although the share of automated processes will rise [2]. Thus, the production sites will not be deserted but organized as hybrid systems. Here, humans and machines will work collaboratively in order to link and control the automated parts of the manufacturing process with the non-automated parts. This way, the production organization meets both the market requirements and the human abilities. For example, a fully automated manufacturing of complex and manifold products would result in a highly complex and expensive process. Therefore, separated automated processes should be considered, which are extended and connected by the human workers in a flexible way [2].

Consequently, one of the main challenges is the design of the human-machine-interface. Its design determines the performance of the human workers. The persons which work at or collaborate with the cyber-physical production machines need to fully understand and control the system. Only this way they can perform correct work actions, which are in line with the automated production design [3, 10, 11]. Hence the interaction quality will be a critical success factor for CPPS. Via the interfaces, the work persons should get access to information about the current state of the production process and further data they need in order to solve problems and fulfil their tasks. This brings up the research question how the user interfaces at human work stations have to be designed for facilitating both a good work performance and work perception by the users. Here, further research in the area of work design is necessary.

How to find starting points for CPPS work design research? A recent study on the potentials of human-computer-interaction in a CPPS context adds a framework of challenges and solution approaches respectively possible related work design actions [12, 13] (see table). Here, we grouped them into three main topics: “Interface design”, “Information display” and “System design”. Each category provides several exemplary work design actions.

The interface design has to be human–oriented. For example, an attractive design and a collaborative creation process of the interfaces could lead to an enhanced acceptance and work performance by the users. Here, innovative appliances or gamification can be used.

Another field of action is the information display on the interfaces. The amount of information should be context-sensitive to reduce complexity and avoid errors. In this regard, an adaptable information display could be used. This way, more or less information could be displayed with respect to the user’s personal requirements and his current task.

When considering the total CPPS design, the human role has to be well defined. Human workers, who are interconnected to autonomous production parts, need to be able to fully understand the functioning of the CPPS. Further, their jobs in the system should be designed according to ergonomic and work psychological criteria.

Table 1. Fields of action for work design actions in CPPS [13].

Field of action	Exemplary work design actions
Interface design	Attractive interfaces
	Human-centered development
	Enhancement of user experience and motivation
	Adaptability and usability
Information display	Suitable display of information
	Availability of manifold information
CPPS design	Comprehensible autonomous organization
	Humane job design

Summarizing, a suitable human-machine-interaction will be a core issue of work design in CPPS. The human-machine-interaction is part of every socio-technical system, where humans and technical systems collaborate. It enables an interdependent communication between the user and computational or mechanical tools and is used for work accomplishment. The user communicates via interfaces with the computer or machine [14]. In order to design and evaluate this dialogue, DIN (German institute for standardization) offers a rules framework as shown in Table 2. They consider several criteria, such as “suitable”, “self-descriptive”, or “controllable” as being relevant for interface design [13, 15]. Here, also examples for implementing these criteria are given.

The exemplary actions and dialogue principles of tables 1 and 2 have been the main input for setting up our work design experiment platform and the first experimental investigation.

Table 2. Design principles [15].

Design principle	Example
work suitable	Limit display to reasonable options only
self-descriptive	Use of intuitive design or help functions
controllable	Use of undo options or multiple handling options
users’ expectations	Use of field-specific design and wording
fault-tolerant	Highlighting of errors or use of plausibility checks.
adaptable	Customizing options for menus or toolbars

3. Experiment platform

A suitable method to answer work design research questions is the conduction of work design experiments [16]. By experiments, work design researchers are able to test different work design setups regarding their effects on both the work itself and the workers. We propose to use a variable, low-cost experiment platform to easily (pre-)test work design ideas. The experiment platform shall be applicable to a wide range of work design starting points. Due to its separation from the production process and its re-usability, researchers are enabled to gain insights on the effects of particular work design ideas in an easier way [5].

The experiment platform is mainly based on a Raspberry Pi 2 B microcontroller in combination with a 7-inch touch display. That component is mounted on a cubical box. On the top side of the box we created an opening which we use for cable feedthrough. Inside of the cubical box a battery, an XBee unit, an LED strip, and wires are stored. We use a standard USB powerbank for power supply of the whole system. The XBee unit is a radio module for a reliable data transfer and meant to be used for an optional communication between two or more experiment systems. Additionally, the LED strip is used for illuminating the experiment system and can be used as a part of the experiments, e.g. as a supporting visible effect. Besides, we installed an USB power port outside of the box to have an easily reachable charging option. A USB WiFi is used for setting up the experiment and for data exchange with the investigator's computer [5].

Fig. 1. Experiment platform.

The experiment software is a self-developed Python program. The participant is able to communicate with the system via the touch display. Prior to the experiment, the investigator sets up the work task or the work setup to be investigated. During the experiment, the system automatically collects data about the participant's performance (observation) and records answers in the questionnaires (questioning). After the experiment, a results file is provided to the investigator. Figure 1 shows the system. Due to the use of popular electronic components, such as the Raspberry Pi or a USB power bank, the experiment platform is very affordable. Because of its modular design, the Raspberry Pi based platform can be modified and extended easily [5].

An experiment process follows a sequence of pages, which are shown on the touch display. A sequence consists of questionnaire, text, information and task pages. They can be arranged in any order. The participant faces these pages step by step and can move back and forth along these pages (with restrictions). Depending on the page type, the participant receives instructions, is asked to answer questions, is asked to fulfil a task or to solve a problem. The answers, results, and solutions are recorded by the experiment system. Further, several key figures such as the time spent on every page or the number of touches on every page are measured. All data is stored in a results file [5].

4. Experiment setup and analysis

The first investigation on the influence of work design elements in cyber-physical production systems dealt with the influence of three particular design elements of the user interface on work performance and work perception. The investigation took place using the experiment platform. The sample consisted of n=9 participants which were recruited among the scientific staff of the university. All of them are researchers or graduate students at the faculty of production engineering. Four participants are female, five participants are male. Their age ranges from 24 to 35 years. Two participants did the experiment in English language since they were no native German speakers. The German and the English version of the system are identical regarding design, given information, structure and task composition.

After a short welcome by the investigator, the participants were asked to work on the experiment on their own, only relying on the information given on the introduction and description pages. Each participant did the experiment in the same environment without any interruption and without any time limit. The system was placed on a table and each participant worked on it sitting.

The experiment consisted of a sequence of pages as described in section 3. In total, we performed a sequence of 8 different tasks with a following questionnaire each. Prior to the first task a test task was shown, which was meant to let the participants get used to the user interface of the experiment system. All investigated work design elements were part of the test task. There was no data recorded for the test task. Further, the participants filled out a skills questionnaire regarding their knowledge on machine scheduling and cyber-physical production systems. This information was used for a general classification of the participants. Extensive psychological data or background information of the participants was not recorded.

Each task consisted of a task description page where the given scheduling problem was displayed in tabular form. Here we varied between a task description with an illustrating machine graph or without (first design element: “illustration”). Afterwards, a task page was displayed which consisted of small rectangles as job parts which could be moved by drag-and-drop onto a scheduling chart. Here we varied between a highlighting of suitable rows in the chart according to the dragged job part and no highlighting (second design element: “assistance”). After completion of the scheduling problem by placing all job parts on the scheduling chart, the participants proceeded to the questionnaire page. Here, the participants were asked four questions dealing with their perception of the previous task regarding motivation, task complexity, or task difficulty. Finally, they proceeded either to a feedback page first or directly to the next task description page. The feedback page contained a graphic of an optimal scheduling plan and a quantified comparison of the participant’s solution and the optimal solution (third design element: “feedback”). Figure 2 illustrates this process.

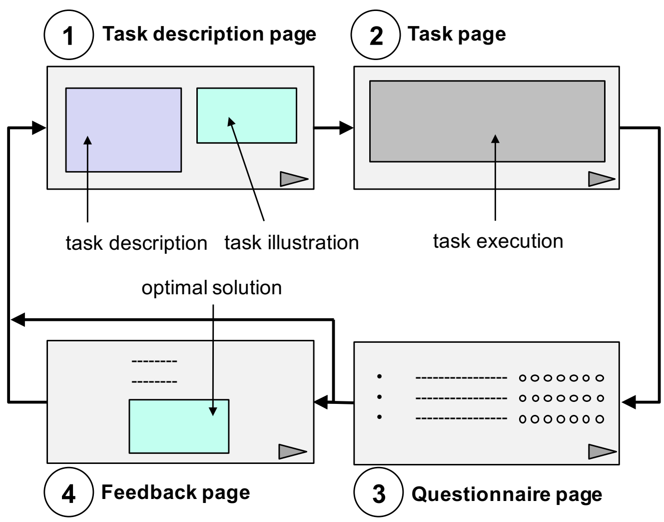

Fig. 2. Experiment sequence.

Moreover, Figure 3 shows the content of an exemplary task description page of the investigation. Here, the task description contains both a list of the jobs, which have to be scheduled, and a list of the available production machines, which shall be used for job processing. The lists provide information on the number of jobs, on the number and type of job parts each, on the number of machines, and on the type and processing times of the machines each. The production network is illustrated by a flow diagram.

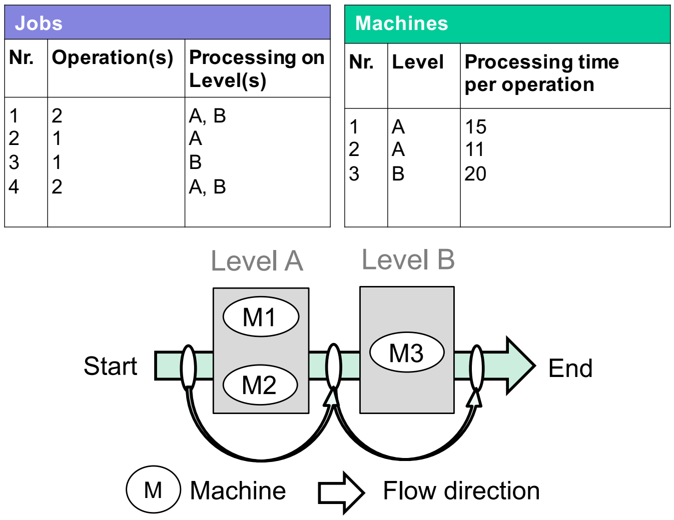

Fig. 3. Task description page.

On the task page all job parts are displayed as moveable rectangles; here the color indicates the number of the job. The main part of this page is used for the scheduling chart, where the job parts have to be placed by the participants.

The experiment was set up with a full factorial design [17, 18]. We investigated three factors („illustration“, „assistance“, and “feedback”) with two levels each (“on”, “off”), resulting in a 2^3 design with 8 experimental conditions (see table 3). Every participant (n=9) went through all experimental conditions with a different task for each condition. Consequently, we got 72 datasets out of which 9 solutions belong to each experimental condition respectively. The order of the tasks and the experimental conditions was fully randomized for each participant. We recorded data for several response variables (1: number of touches, 2: duration, 3: solution quality, and 4: questionnaire answers). The questionnaire was designed according to the bipolar 7 point Likert scale and consisted of four questions (see table 4). We analyzed the experiment by calculating the main and interaction effects of all factors for every of the response variables [17, 18]. Further statistical analysis, such as a multivariate analysis of variance, was not performed due to the character of the experiment as a pilot study.

Table 3. Factorial experiment design.

Experimental condition	Factors			Response variables
	Illustration	Assistance	Feedback	1 2 3 4
1	on	on	on	
2	on	on	off	
3	on	off	on	
4	off	on	on	
5	off	off	on	
6	on	off	off	
7	off	on	off	
8	off	off	off	

Table 4. Perception questionnaire

Question	first response anchor	second response anchor
Please rate the difficulty of the machine scheduling problem!	very low	very high
Was it easy for you to solve the task?	not at all	completely
Are you satisfied with your solution?	not at all	completely
Please rate the quality of your solution of the machine scheduling problem!	very low	very high

5. Results

For the first factor (“assistance“) we recorded only small changes over the majority of the response variables resulting also in small main effects. This indicates that the highlighting of the suitable rows in the scheduling chart was not influencing the work performance of the participants. Regarding the questionnaire answers we identified effects regarding the simplicity perception, satisfaction and quality estimation. Thus, we can conclude, that the factor “assistance” tends to be influencing the work perception in a negative way (simplicity perception, satisfaction, quality estimation) since the numbers lowered for the “on” condition compared to the “off” condition of the “assistance” factor.

For the second factor (“illustration“) we recorded remarkable changes of the response variables “duration” and “solution deviation” resulting in slight main effects. Since the response variables were negatively influenced by the factor we conclude that the illustration of the task with the flow graph has a negative effect on the work performance of the participants. Regarding the questionnaire answers we also identified negative effects on the simplicity perception and satisfaction. Thus, we can conclude, that the factor “illustration” tends to be influencing the work perception in a negative way.

For the third factor (“feedback“) we again recorded changes of the response variables “number of touches”, “duration” and “solution deviation” resulting in slight main effects. In contrast to the previous factor, this time two response variables were positively influenced by the factor. Thus, we conclude that giving a feedback to the participants after the completion of a task has a positive effect on the work performance for the next task. Regarding the questionnaire answers we identified negative effects on the simplicity perception, satisfaction, and quality estimation. Hence, we assume that the factor “feedback” tends to be influencing the work perception in a negative way as well. See also Figure 4 for the mentioned effects of all factors. It shows the main effects for all response variables caused by the factors. The “on” and “off” values equal to the overall means of all experimental conditions, for which the corresponding factors were turned on or off respectively.

The interaction effects are very similar to the main effects. The majority of them varies between no effects and small effects with the exception of two particular cases: The combination of “assistance” and “feedback” tends to have significant negative effect on the “solution deviation” and the “satisfaction”.

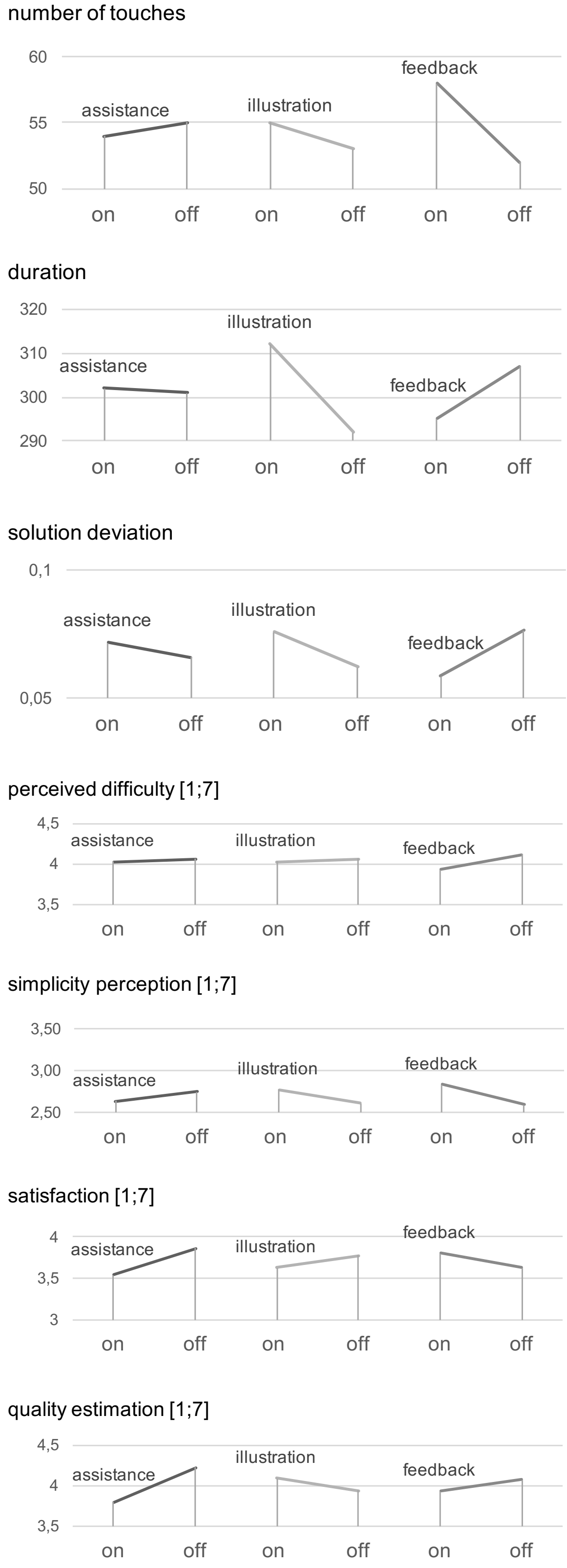

Fig. 4. Main effects plot of response variables.

6. Discussion

Our investigation on three work design elements of user interfaces in CPPS let to results according to our expectations. The factors tend to have different effects on the response variables. While there are just no or very small effects caused by "assistance" and "illustration", we received more noticeable effects due to the "feedback" factor. We assume that this outcome can be explained by the setup of the experiment.

First, the participants spent the majority of the time working on the scheduling problem on the task page. Since the illustration was on the previous page (task description page), the participants did not look at them intensely. Consequently, the "illustration" design element did not result in a significant effect on both the work performance and work perception. This explanation approach could be confirmed by remarks of the participants after the experiments. Further, the "assistance" element could have been affected by error messages on the task page. The participants received error messages when placing job parts wrongly on the scheduling chart (e.g. on already occupied machines, wrong machines, etc.). This way, they always got another type of assistance even if the investigated "assistance" factor was turned off.

In contrast, the "feedback" factor led to interesting and promising results. This can be highlighted by the response variable "solution deviation" and the questionnaire answers for "satisfaction" and "quality estimation". Here, we received a smaller solution deviation for tasks which were solved right after a feedback for the previous task was shown. We assume, that the participants used the information about the optimal solution to correct recurring errors in their schedules at the next task. Besides, the participants got aware of non-optimal solutions (in total, 35 percent of the solutions were optimal) and tried to improve at the next task. Then again, we got negative effects on the "satisfaction" and "quality estimation" items. Here we presume, that the participants started to question their solutions more after receiving feedback. Consequently, they were answering related questions more defensively.

Overall, we consider the investigation as being successful. It showed the influence of different work designs and prove the experiment platform's capability of conducting experimental studies. Nevertheless, we want to highlight that this study shall be understood as a pretest for a larger study. Due to limited number of participants, the presented results should not be considered as statistically proven. In fact, they should be interpreted as indicators for correlations, which require further research. As a next step, we plan to conduct a follow-up investigation with a larger sample and changes in the experiment setup with respect to the lessons learnt during the present investigation.

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