Assessing the Impact of Information Assistance Systems on a Worker Level

A Pre-Study towards an Evaluation Framework

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ABSTRACT

A growing amount of information assistance systems is implemented within production environments as simple tasks are increasingly automated and more complex knowledge work is required by the staff. However, considerations to implement those technologies have mainly focused on productivity measures on the work process level, so far, putting aside human factors concerning the affected workers. In our paper, we design and conduct a laboratory experiment to systematically assess both these aspects while using three different kinds of information assistance systems for the same assembly task. The insights from this pre-study build the basis for a first concept of a generalized evaluation framework to assess the impact of any kind of information assistance system on both productivity measures and human factors on the worker level. In the end, the role of such an evaluation framework for companies in the midst of technology implementation processes is considered to support its application in practice.

CCS CONCEPTS

• Human-centered computing → Human computer interaction (HCI) → HCI design and evaluation methods → Laboratory experiments

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KEYWORDS

Information Assistance Systems, Productivity, Human Factors, Experiment Design, Evaluation Framework

1 Introduction

1.1 Motivation

An increasing amount of technologies is implemented within production environments to support human workers during the execution of work tasks. These technologies can range from smart devices as small as smartwatches over powered exoskeletons to so-called cobots (collaborative robots). Within this range, the purposes of the technologies vary alike from information assistance or decision-support to mechanical assistance or the enhancement of the worker's own physical powers. Whereas simpler handling steps in manufacturing tend to be automated, workers still have to deal with an increasing amount of complex knowledge work [1]. In these cases, information assistance systems can help to coordinate the information flow that is necessary for the execution of the work tasks. They aim at providing the right information at the right time at the right place. Ideally, this means counteracting any kind of information and therefore cognitive overload or strain of the worker [2]. Thus, the information assistance systems should help to reduce the complexity of the work tasks instead of adding complexity due to the handling of the system itself. Such information assistance systems become more and more feasible and applicable in productive industrial environments like, for example, the application of AR (augmented reality) in product development [1]. Such applications are mainly implemented due to productivity considerations on the work process level [3]. However, aspects considering human factors and thus, factors that influence individual productivity on the worker level, have not been addressed in this context that frequently, yet. Nevertheless, these important factors become increasingly focused on [4]. Therefore, this paper wants to contribute to the assessment of information assistance system's impact on both levels, productivity and human factors, by proposing the concept of a suitable evaluation framework for practitioners. This effort is part of the European *Horizon 2020 ECSEL* research project *Integrated Development 4.0 (iDev40)* and its work package on *Skills & Workplaces 4.0 and Smart Collaboration in ECS (Electronic Components and Systems) Value Chains*, where, amongst other aspects, the impact of different digital and technological solutions on the workforce are investigated and design concepts are derived to improve them with regard to the human factors.

1.2 Methodology and Structure

Following the presented motivation for this work in Subsection 1.1, our main research questions (RQ) are:

RQ1 – How can the impact of information assistance systems on both technical-procedural and human aspects during the task execution be systematically assessed?

RQ2 – How can an evaluation framework for information assistance systems be situated within a company's implementation approach for new digital technologies?

To address these RQs the remainder of the paper is organized as follows. In the successive Subsection 1.3 relevant notions used in this paper such as information assistance systems, productivity and human factors are clarified. Similar evaluation approaches and frameworks in literature and practice for this purpose are then discussed in Subsection 1.4. Section 2 presents the design, realization and results of the pre-study conducted as a laboratory experiment to address RQ1. For this purpose, an assembly scenario with information assistance via different technologies was simulated, including video and AR applications. Based on the conclusions drawn from the pre-study, we propose the design of a generalized evaluation framework for information assistance systems in Section 3, focusing on RQ2. Section 4 concludes the paper in discussing the applied methods, the results of our work so far as well as its limitations. Furthermore, it gives an outlook on the challenges lying ahead and on the respective activities.

1.3 Terminology

1.3.1 Information Assistance Systems. Information assistance systems as we understand them are technology- or software-based systems that provide workers with any kind of information or data required for their tasks. This information can be mainly displayed visually, via audio and/or via haptic input using different technologies and hardware components. For more detailed examples refer to [3], e.g.

1.3.2 Productivity. The "classic" microeconomic concept of productivity examines the ratio of real output to real input, as also described e.g. in [4]. In our case, in resemblance of well-established manufacturing key performance indicators (KPIs) like in [5], we consider mainly assembly time and quality as productivity measures on the individual worker level.

1.3.3 Human Factors. In our context, human factors mean those aspects that are both responsible for the physical and mental well-being of the workers as well as their motivation and individual productivity at last. Especially the latter is also focused on in e.g. [4]. Within this paper, we focus mainly on the human factors such as stress level, overstrain and self-confidence.

1.4 Similar Approaches

From a manufacturing point of view there exist KPI measurements that already focus on worker efficiency or that could be adapted to a worker level without much effort [5]. With regard to human factors there also exist well-established measurement instruments such as described in [6–8]. Finally, measurements concerning technology use or human-machine interaction can be found e.g. in [9]. However, combining those three fields of interest at a specific manufactural context in practice is less common but yet increasing. Some concrete examples are shown by the efforts in research projects like e.g. *InAsPro*, *Factory2Fit*, or *iDev40* [4,10, 17]. In this context of increased personalized technology use on the shop floor, considerations concerning privacy and worker acceptance further come into focus as well [4].

2 Pre-Study

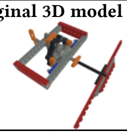
To address RQ1, a pre-study was set-up as a laboratory experiment. It represents the first iteration of the design of an evaluation framework considering both technical-procedural and human factors while using an information assistance system. The purpose of this pre-study was to get a first clue about the conclusion and construct validity of our design [11] to be able to further strengthen the design if needed afterwards. I.e., we wanted to get first insights if there even are relationships as we expected, and that we are actually able to measure the constructs that we want to measure. The design of the experiment, its realization, results, conclusions and suggestions for improvement are described in detail in the following subsections.

2.1 Design

2.1.1 Conceptualization. Derived from RQ1 and regarding our applied terminology, we wanted to investigate the following aspects in our pre-study and with regard to the usage of information assistance systems: From the user's point of view, we were interested in the perceived comprehensibility of the information depicted via the assistance system, mental requirements, stress level during the usage as well as success assessment. From a technical-procedural point of view the assembly time assessed over different categories of activities (e.g. assembling, idle, etc.), i.e. applying work sampling method, and the quality of the assembled product were of interest. Additionally, individual aspects that might have a direct or indirect influence on the results should be investigated, such as age, gender, profession and professional experience, prior experience with MR (mixed reality), with assembly tasks in general, with *LEGO Technic*, and possible (current) physical constraints like e.g. visual impairments. With regard to the information assistance under investigation, three alternatives were considered. First, within *iDev40*, the *Virtual Vehicle Research GmbH*, located in Graz, Austria, developed a demonstrator AR-application for *Microsoft*'s *HoloLens* [1]. With this *HoloLens* application an assembly worker is able to see animated assembly instructions in 3D space within his or her real environment. The worker has additionally the possibility to investigate the assembly model from different viewpoints by walking around the hologram and by pausing, forwarding and repeating the animation or even enlarging or repositioning it in space. Due to the confidentiality of real CAD models of companies, a CAD model based on *LEGO Technic* is used, namely a planetary gear (Table 1). Second, based on the animation of the *HoloLens* application a video assembly manual on a tablet computer was used, that can also be paused, forwarded or repeated. And finally, the effect of paper-based instructions, chronologically depicting screenshots of the video animation of the assembly of the CAD model, should be investigated. Table 1 further depicts how the user is able to interact with the manual and how the information is displayed by the respective system. Whereas all three of the investigated systems "only" use a visual display of information. I.e., no sounds or haptic responses such as e.g. vibrations are applied.

Table 1: Specifications of the assessed information assistance systems.

Original 3D model [12]:



Manual	Paper	Video	AR
Medium	Printed paper	Tablet computer (video player)	AR glasses *HoloLens* (AR application)
Content	Screenshots of each 3D model assembly step with arrows as markings	Animated video of the assembly of each part of the 3D model	Animation of the 3D model assembly steps, projected into the user's physical environment
Interaction	Haptic (turning pages)	Haptic (pressing buttons and/or sliders to control the playback of the video)	By gestures and/or voice commands (in English) to control playback, size and position of the animation
Information display	Visual (2D space)	Visual (2D space)	Visual (3D space)

The choice of information assistance system represents the independent variable, whereas the user's human factors as well as the technical-procedural aspects are the dependent variables. The individual aspects are expected to probably represent moderating variables, influencing the relationship between the information assistance and the dependent variables.

2.1.2 Experiment Design. The pre-study was designed as a laboratory experiment. It consisted of three groups, to which the participants were assigned to randomly. One group was considered to be the comparison group. This was the group using the paper-based manual, as it was considered to represent – or at least come close to – the status quo. The other two groups were using the video manual and the AR application. In the end, for all three groups observations were made using the same measurement instruments. This design is formally called a posttest only randomized experiment [11]. To assess the individual aspects of the participants that are expected to have an influence (moderate) the dependent variables, questions addressing their age, prior experiences and other aspects were asked before the start of the experiment (Table 2; originally in German). During the assembly the researchers took and noted the overall time needed for the task, as well as differentiated between "net" assembly time and other types. The quality of the assembly was noted in the end by counting the number of misplaced parts compared to the manual. Additionally, the quality of the assembly process was assessed by counting the number of re-work steps executed by the participant. The purpose of these assessments is to measure the technical-procedural (or productivity) factors during the task. In the end, the other dependent variables in our model, the human factors, were also assessed via a questionnaire encompassing questions about the participants' experienced requirements, stress, overstrain and other factors (Table 2; originally in German).

Table 2: Assessments used in the pre-study.

Assessments	Before	During	After task execution
Tools and measurements	Questionnaire: age, sex, course of studies, semester, experience with VR, AR, assembly in general* and LEGO*, fine motor skills*, spatial thinking*, visual impairments	Stop watches: overall time, assembly time Observations: number of errors, number of re-work steps	Questionnaire: requirements*, comprehensibility*, helpfulness*, stress level*, overstrain*, confidence to succeed*, handling*, comfort* and maximum possible duration of usage (only AR)

*measured on a 6-point Likert response scale from lowest = 1 to highest = 6

2.1.3 Sampling. Generally speaking, the population we are interested in to evaluate the impact of information assistance systems on are shop floor workers in the industry. However, for this first pre-study we drew on resources that were more easily reachable for us. Therefore, we reached out to students of the Faculty of Business Administration and Engineering at the Zittau/Görlitz University of Applied Sciences by addressing them directly. The first six respondents were then selected. Although the sample seems different in characteristics to the actual workers of interest, in some cases, especially in the field of management science, students have not been proven to differ significantly in their behavior from actual managers, as e.g. shown in [13]. Also, although the applied nonprobability sampling method poses further threats to the external validity of the results [11], and thus the representativeness, it seems arguable in favor of a first pre-study.

2.2 Realization

All six participants subsequently executed the same assembly task with the help of the respective information assistance system assigned to each of them. The experimental set-up was as follows:

The *LEGO Technic* parts and the respective manual were set-up on a big table in a seminar room at the faculty building, representing the worktop. Before the start of each experiment the respective participant was asked to fill in a questionnaire covering the individual aspects (Table 2). Afterwards, one of the researchers explained the procedure and the task they had to execute. In case of the use of the AR application a more thorough introduction to the *HoloLens* was necessary and a demo to learn its navigation was used. During each experiment, four to five researchers were present at some greater distance at the other end of the worktop to make notes and to assist in urgent cases (especially during the usage of the *HoloLens*). The *HoloLens* itself, as well as the AR application and the video manual were provided by the *Virtual Vehicle Research GmbH* (Sub-Subsection 2.1.1), from which one senior researcher was also present and helped with its usage. The assembly task consisted of two parts, whereas the first one was considered to be easier than the latter. Combining both parts in the end resulted in the desired planetary gear (Table 1). In the end, another questionnaire, covering the human factors (Table 2), was filled in by the participants.

2.3 Results

2.3.1 Observations. Our participants were on average 28 years old, mainly male, and studying mechatronics, mechanical or industrial engineering, or business administration on average in the 4th semester. Two of them had already experience with virtual reality (VR) glasses, whereas none of them had already experienced AR. On average they judged their experience in assembly in general with a score of 4.2 and with *LEGO* of 3.7. Their fine motor skills were assessed by themselves on average with a score of 4.2 and their spatial thinking with a score of 4.3. Only two of the participants had minor visual impairments. Starting with the technical-procedural aspects of the dependent variables, we can definitely observe a treatment effect in terms of needed time for assembly (Figure 1). However, the effect is negative instead of positive, and therefore different than it might have been expected. I.e., the use of the video or AR manual increases the needed time for the assembly compared to the paper-based manual (status quo). At the same time, the handling of the AR manual is the highest. The amount of re-work done did not change over the different groups.

Considering the human factors, the requirements of the assigned task were overall considered to be low ($\mu = 2.2$). This corresponds quite well to the low scores on stress level ($\mu = 1.8$) and overstrain ($\mu = 1.5$), as well as the high score on confidence to succeed with the task ($\mu = 5.7$). However, these self-reported measures of the participants do not necessarily correspond to the observations that the researchers made during the experiment. This is especially true for one participant, who can somehow be considered as an outlier due to his or her relatively high value on needed time for the assembly (7.3min) and the lowest score of all participants on fine motor skills (2). The participant seemed to be extremely nervous and overstrained in handling the *HoloLens*.

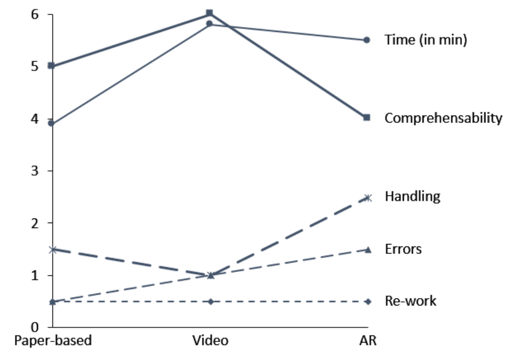


Figure 1: Effects on different dependent variables.

2.3.2 Conclusions. The divergent results between the self-reported measures on human factors and the observations made by the researchers during the task execution are probably heavily biased due to the presence of several researchers during the experiment, causing social desirability in their answers. An explanation for the best performance in terms of assembly time and errors by using the paper-based manual could be (1) that the participants are less used to video and AR manuals in this context, and/or (2) that the task was too simple to benefit from 3D animations or being able to walk around the model – instead, these navigation aspects were tending to hinder the task execution. Therefore, the question remains, if video or AR manuals are more beneficial for more complex tasks, frequently or only slightly changing models [1] and/or if there was more training time to get familiarized with these technologies. In terms of technologies, another challenge arises as we can assume that the hard- and software will become more comfortable and user-friendly over time. I.e., it is more reasonable to try to evaluate the application of (in our case) e.g. AR in assembly instead of evaluating the actual hardware. In terms of human factors, this could be maybe achieved by a differentiated questioning. Whereas, the technical-procedural aspects will probably always be linked to the actually used hard- or software. Nevertheless, the pre-study is able to give us first indications about the effects of different information assistance while also showing streams for improvement of the design and its realization. All in all, the results also further stress the need for such an envisioned evaluation framework as it proves that the implementation of innovative digital technologies, such as AR, might not necessarily mean an increase in productivity nor well-being of the workers.

2.3.3 Suggestions for Improvement. It can be more reasonable to assign the participants nonrandomly but based on their individual characteristics to ensure comparable homogeneous groups – resulting in a quasi-experiment. With greater number of participants and homogeneous groups, it would also be possible to investigate the effects of the moderating variables, i.e. the individual characteristics such as age, sex etc., on the dependent variables. The general observations of the researchers during the experiments were that these individual factors could play a very important role on the outcome variables. Besides one participant who scored low on fine motor skills and needed the most time for the assembly, another participant checked his or her assembled model thoroughly before handing it in, which also resulted in more time needed. To assess such aspects more objective and established psychological tests like the *I-S-T 2000R (Intelligenz-Struktur-Test 2000R)* [14] could be applied before the assignment to the groups. With regard to the realization of the experiments itself it makes sense to arrange the assembly parts for all participants beforehand to give them the same starting position. Also, more complex or frequently changing models as well as time pressure and/or incentives are reasonable to be implemented as well to simulate a more realistic work environment. To further investigate training or learning effects with the information assistance systems, experiments at different points in time and/or a final round of assembly without a manual could be reasonable. To avoid any bias in the observations induced by the researchers or observers themselves, the questionnaires, explanations and experiments should be conducted without the presence of any researcher at all, if possible. This can be achieved through digital and standardized surveys and instructions as well as e.g. video transmission from the room where the experiment takes place to the room where the researchers are located. Especially with regard to (sensitive) human factors and possibly biased observations due to social desirability effects in answering, technology-enabled evaluation methods can help to achieve greater objectiveness or even consider aspects that would not be possible without. To gather the required data the technology under investigation itself can be used or, where necessary, additional equipment can be applied. Concerning evaluating human cognitive and mental exhaustion, [15] showed that when participants are confronted with a mental calculation, it is visible in their eyes long before they admit, that they cannot solve it. In our case, one way to implement this aspect is to use the API of the *HoloLens 2* and gather data on the participants' eye movements. Pose estimations, face recognitions or even the evaluation of heart rates can be further applications. E.g., [4] already proposed an evaluation scenario to recognize overstrain that could be further built upon. Our assessment-related suggestions for improvement are depicted in Table 3.

Table 3: Improvements in the assessments due to the observations during the pre-study (marked blue/italic).

Assessments	Before	During	After task execution
Tools and measurements	*Online survey*: age, sex, course of studies, semester, experience with VR, AR, assembly in general* and LEGO*, fine motor skills*, spatial thinking*, visual impairments, *psychological questionnaires assessing personal traits or similar*	*Videotaping*: overall time, assembly time, number of errors, number of re-work steps, *pose estimation, face recognition* *Smart watches: skin conductance, heart rate, answering psychological task-related questions "on the fly"* *Smart glasses: eye-tracking*	*Online survey*: requirements*, comprehensibility*, helpfulness*, stress level*, overstrain*, confidence to succeed*, handling*, comfort* and maximum possible duration of usage (only AR)

*measured on a 6-point Likert response scale from lowest = 1 to highest = 6

However, all these data-driven applications also require ethical considerations in terms of data privacy of sensitive personalized information of the workers [4].

3 Framework Concept

Building upon the conclusions and suggestions for improvement from our pre-study, we further specify a first, generalized evaluation framework to systematically assess the impact of information assistance systems on worker level in practice. Table 4 states the intended purpose and user group of the evaluation framework, whereas Figure 2 depicts the high-level conceptualization of the framework with the aspects covered within our pre-study marked blue/italic.

Table 4: Purpose and addressed user group of the evaluation framework.

Purpose	Evaluate one or more information assistance systems with regard to productivity and human factor measures to be able to make grounded decisions about whether or not to implement a system for specific work tasks
Users	Decision-makers responsible for work(place) design within a company, such as e.g. (HR) managers, lead engineers, or supervisors in general

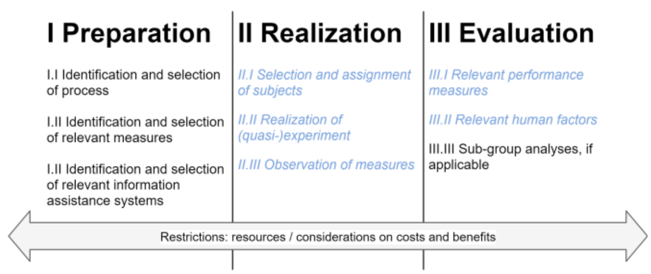


Figure 2: High-level conceptualization of the evaluation framework.

Considering the proposed 6-step digitalization approach *Planning for Digitalization (P4D)* in [10] as a generalized and holistic approach to digitalize companies' processes by implementing new technologies, our suggested evaluation framework would help to assess the appropriate digital technologies in step 4 of *P4D* to improve the preliminarily identified processes in need. The evaluation framework itself is divided into three stages: preparation, realization, and evaluation. In accordance to the approach in [10], in the first stage, the relevant process, where the information assistance system should be implemented, has to be identified and selected. Examples for methods to identify relevant processes can also be found in [10]. Afterwards, the relevant measures (and therefore also measurement instruments) to base the final decision on have to be identified and selected as well. This paper and cited publications can support as a first orientation to do so. Finally, relevant information assistance systems can be selected based on the prior considerations on processes and measures to be improved. The overview in [3] can be supportive for this step. The realization stage essentially represents all the considerations also explained within this paper with regard to the design of a suitable (quasi-)experiment. The same holds true for the evaluation stage, where the beforehand selected measures will be analyzed and used for the decision-making. Additionally, in case of enough participating subjects, distinctions could be made between different groups of workers (e.g. elderly vs. younger), resulting in individualized solutions in the end. After the evaluation and selection of a specific technology to implement, choosing measures to empower the employees to use this technologie, if applicable, would be required (step 5 of *P4D*), before finally the implementation of the new technological solution is realized (step 6) [10]. In the end, cost and benefit considerations do not only play a role in the final decision on implementing new technologies [16], but as a consequence are also restricting the realization of the evaluation framework in the same way.

4 Discussion and Outlook

In this paper, we stated in Section 1 the need for evaluating information assistance systems on both productivity and human factors levels within its intended context before implementing them. Therefore, we designed and presented a laboratory experiment as a first pre-study towards a general evaluation framework for information assistance systems in industry in Section 2. We got indications that these experiments can be helpful to systematically asses both levels of interest. Furthermore, the results underpinned the need for such an evaluation framework, as new digital solutions might not necessarily mean enhancements of productivity or human factors. Nevertheless, there is still space for improvements. Based on the results and insights from the first iteration of the framework design we also proposed advancements such as further technology-enabled evaluation methods and possibilities of generalizing it to other applications and contexts (Section 3). Therefore, the necessary next steps in developing a generalized evaluation framework will be the implementation of the suggested improvements and applying them in field experiments as well as evaluating different kinds or newer models of information assistance systems (e.g. *HoloLens 2*). The further inclusion of respective decision-makers into the evaluation of the framework itself will also be very relevant. These goals will be further pursued within both the European ECSEL projects *iDev40* and *Power2Power*. Wherein, in the latter, possible evaluation scenarios at hand are the use of e.g. tablet computers to make logistics processes leaner, or the implementation of remote maintenance support via AR to minimize downtimes and travel expenses. An important aspect and challenge to be considered in further developing the framework is its feasibility to be accepted and used by the decision-makers that are responsible for the implementation of new technologies such as information assistance systems in the production process. It should be easy to understand and to use by keeping the necessary efforts to apply it as small as possible while simultaneously still ensuring meaningful insights on both, productivity and human factors levels. Additionally, further evaluation methods that are enabled by the technologies themselves like e.g. the tracking of eye movements or heart rates have to be designed as responsible as possible ensuring ethical standards such as e.g. data privacy to find acceptance among the affected workers [4].

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