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Enabling the Operator during the Design – Application of a User-Centered Design Approach in Automotive Assembly Lines

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Abstract

In Industry 4.0, workers' input and requirements have often been neglected when designing and implementing assistance systems on assembly lines. In our previous work, we presented the application of a user-centered design process and its first validation, ensuring the participation of assembly line operators. The current paper provides further insights into the validation of our approach during the requirement definition and operator feedback regarding the prototype design. Our approach has proven applicable in an industrial setting and impactful in terms of acceptance through the operator. Therefore, the validation of our approach revealed a strong potential for its application in other industrial use cases.

Keywords: User-centered design; Human-centered design; Assembly lines; Digital assistance systems

1. Introduction

While the focus of Industry 4.0 applications was mainly on technological aspects like digitalization, intelligent connectivity, and economic factors, the European Commission proposed a shift toward Industry 5.0 in 2020 [1]. The goal of Industry 5.0 are systems that are human-centric, resilient, and sustainable [1]. In this vision, workers' expertise is necessary to develop these systems, which leverage human creativity and expertise while empowering workers to create a human-centered industrial environment [2]. The importance of the user in the system design and development was already a focus of the user- or human-centered design [3]. It is essential to involve workers in the design process to ensure these systems meet their requirements and address relevant problems [4].

The practical application of this concept in industrial assembly lines still needs improvement. As mentioned in our previous work [5], user-centered design approaches are still not included in the design of digital assistance systems on assembly lines [6]. The fact that the end users are not integrated into the development can lead to neglecting users' requirements [7]. To empower operators, we proposed an approach that involves the operator in all phases of the design process for new digital assistance systems (see Figure 1). This process and the results from the context analysis were presented in our previous paper [5]. Building on that, our present paper focuses on validating the proposed applied user-centered approach by presenting results for the other three phases of the design cycle (requirement definition, prototype design, and evaluation) based on its usage to design a digital assistance system for operators on an assembly line in the automotive industry.

The following section will discuss the application of user-centered design and the results of the previous context analysis. Afterward, we will show the methods used and results obtained during the other three phases of the design process. Finally, we will overview lessons learned and discuss future work.

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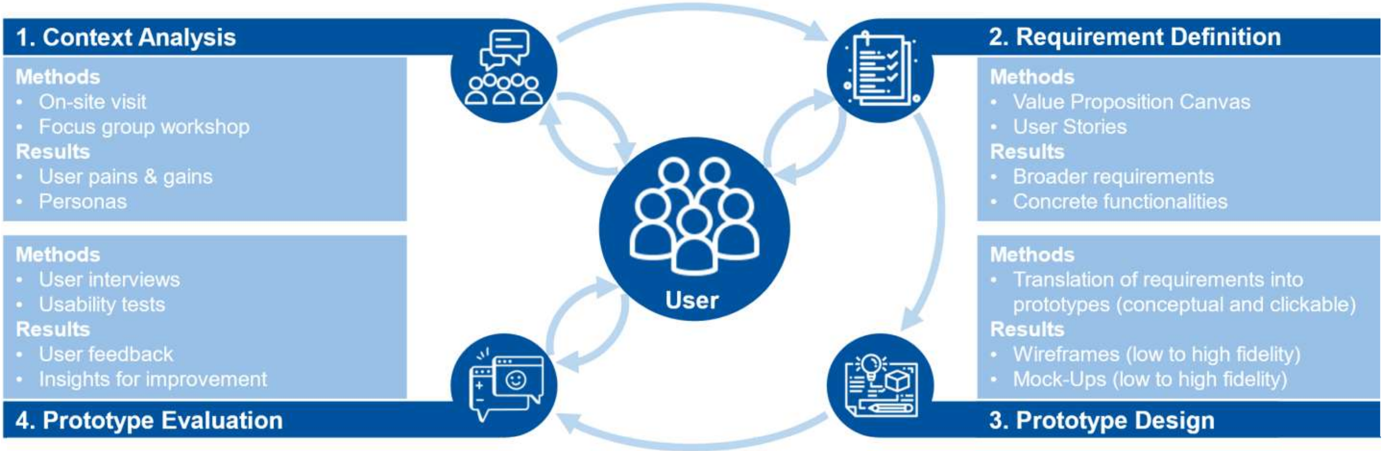

Figure 1: Applied User-Centered Design Process [6]

2. Challenges and Requirements of Applied user-centered Design

User-centered design considers the user and his needs to be the center of system development [8]. The classical user-centered process follows four distinct phases [9]: first, the **context analysis**, which focuses on the users, their tasks, and the context of use; then, the **requirements definition**, where requirements for the system are defined based on the user needs; third, the **prototype development**, where a system is designed based on these requirements; and lastly, the **evaluation** of the developed prototype.

Applying user-centered design is advantageous, for example, by making the system more intuitive, reducing users' cognitive load [10], and requiring less documentation and user training [11]. However, using it in industrial settings has been challenging [12]. Possible barriers are time constraints, the fact that the systems' usability is not seen as a development priority [13], and, among others, a missing understanding of the users and a lack of guidance and support in applying user-centered design [14].

Our previous paper presented the process for applying user-centered design to develop a digital assistance system for operators at an automotive assembly line [5]. This process is shown in Figure 1. The aim was to involve these operators as much as possible in the development process. The process is summarized in the following: In the first phase, the current state of the assembly line, along with the pain points and problems the operators face, are identified through on-site visits and focus group workshops. Within the first phase of this method, the pain and gain points of the users and personas are identified, alongside a generally better understanding of the production environment and workers' day-to-day lives and work. These results are used in the second phase of the process to define the operator's requirements. With the help of methods such as a value proposition canvas and user stories, the functionalities of the digital assistance system are extracted from the defined requirements. The defined functionalities are prototyped in phase three as wireframes and mockups with different fidelity grades. Based on the prototype designs in the last steps, user interviews and usability tests are conducted to improve the prototype's design based on user feedback. The work in the different phases is conducted in close collaboration with the users, leading to their direct involvement in the design process and an optimal result close to their requirements [5].

2.1. Context of the Case Study

Our previous work [5] presented the described method and validated its first phase based on an application at an automotive assembly line. Within the first phase of the process, a focus group workshop with 12 participants (assembly line operators, team coaches, and supervisors from the management team) was conducted. Based on this workshop, five clusters of pain points were identified, such as lack of communication between team coaches and operators for topics such as support requests, etc. Seven clusters of gain points were defined, such as good teamwork or positive feedback for work well done. Additionally, three personas were defined (a junior, a senior assembly operator and a team coach). Through the focus group, insights on the problems that operators face were gathered, as well as their wishes. Although not each pain point and request can be addressed in the digital assistance system prototypes, the workshop results were insightful, and the participants were motivated to be involved in the development process. Based on these results, the necessity of addressing the participants' input along the phases of our method and involving them in iterative optimization of the results of each phase was highlighted [5].

2.2. Aim of the present paper

While our previous paper described the applied human-centered design process, the use case, and the context analysis, the present paper focuses on the other three phases of the process (requirement definition, prototype design, and prototype evaluation). Thus, the methods used during the requirement definition, prototype design, and a first workshop for the prototype evaluation are presented, as well as the results obtained during these phases. Additionally, lessons learned during the application of the process are discussed.

3. Method

The following section will describe the approach and methods used during the requirement definition and prototype evaluation phases, as well as a feedback workshop conducted as the first step of the prototype evaluation.

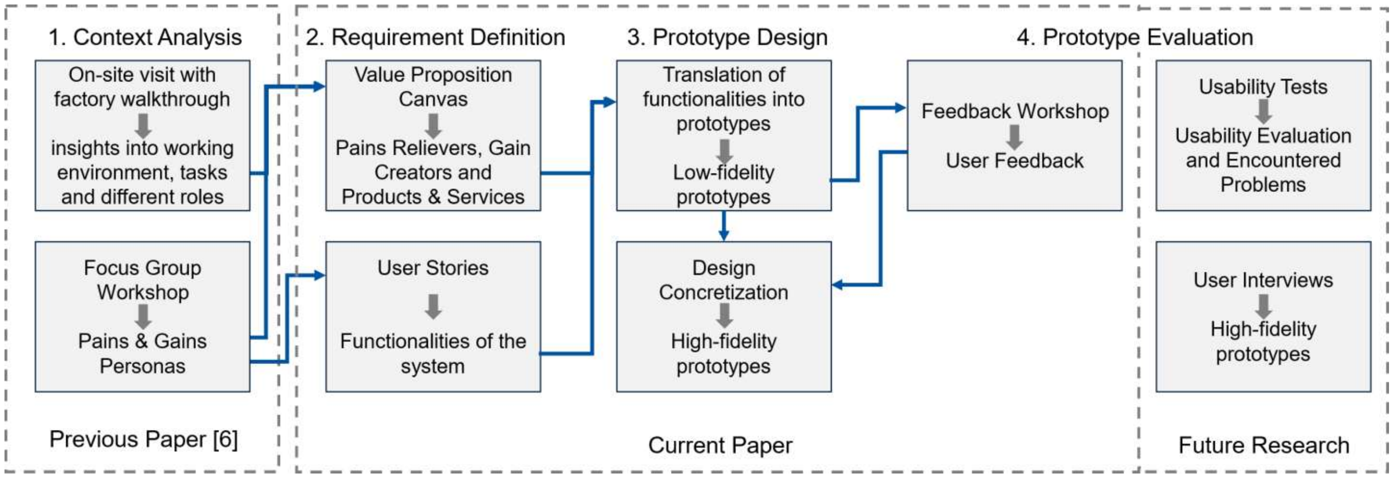

Figure 2: Applied User-Centered Design Process [6]

3.1. Requirement Definition

At the beginning of the Requirement Definition phase, the pain and gain points from the context analysis [5] were used to create a value proposition canvas [15]. This method focuses on the user perspective and the product's value proposition (Figure 3). The goal is to develop a product that helps solve the users' pain points and can enhance their gain points.

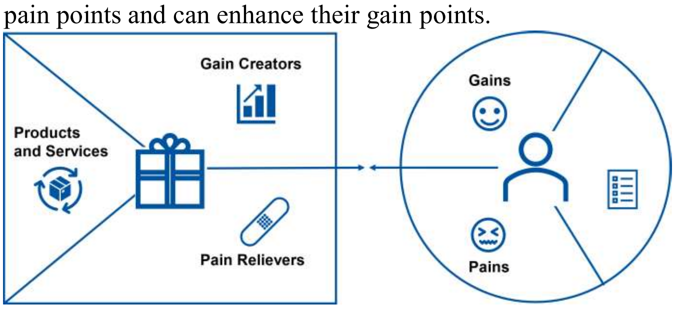

Figure 3: Value Proposition Canvas, adapted from [15]

We developed detailed user stories using the output from the value proposition canvas and our three pre-defined personas [5]. User stories describe the functionalities of software that will be valuable to the user and are one of the most prominent ways to define such requirements [16]. The user stories consisted of a user description, the task the user wants to perform, and the user's goal. Additionally, acceptance criteria were formulated that contained the starting situation, the action being taken, and the outcome of that action. During the formulation of user stories and choice of functionalities, key personnel from the relevant user groups were closely contacted to ensure their approval of the development direction.

3.2. Prototype Design

A design prototype was developed based on the defined functionalities, adhering to state-of-the-art usability and user experience recommendations. To reduce the time until we got feedback on our ideas and to avoid developments in a direction that wouldn't be usable later on, we created design prototypes of different fidelity levels before implementing these ideas. We started with a low-fidelity prototype to sketch some ideas for various system functionalities. We got feedback from a small group of employees over multiple meetings, during which we noted their input. After several feedback iterations, we gradually enhanced the prototype and raised its fidelity.

3.3. Prototype Evaluation

We conducted a focus group workshop to validate the prototype, assess the development direction, and gather feedback and input from workers, team coaches, and managers. Six participants took part, combining insights from the perspectives of operators, managers, and IT personnel.

The first focus of the workshop was the dashboard, as this is the standard screen shown during most of the production process while the system is not in active use. Thus, it was necessary to gather input from production line operators regarding what information would help them in their work and is important enough to be displayed during production. Also, what functionalities must be linked directly on the limited dashboard space rather than being selectable via a menu? Next, the functionalities were presented, and participant feedback was gathered. Immediately afterward, the participants tested a clickable version of the design prototype. Moreover, each participant received a paper version of the prototype to mark problems they encountered, take notes on, or propose changes. Subsequently, the group discussed and documented their experiences, questions, feedback, and difficulties. Lastly, the suitability of the prototype for the three personas was discussed: whether or not the three personas would be satisfied to use this prototype and what features are missing or need to be changed to satisfy the three personas.

4. Results

As shown in Figure 2, this paper will present the results from the requirement definition and the prototype evaluation, as well as the first results from a feedback workshop conducted during the prototype evaluation.

4.1. The role of the user and the level of expertise determine the requirements

We used the pain and gain points gathered during the context analysis [5] for the value proposition canvas. These have been briefly summarized in section 2.1. To enhance the gain points, the following gain-creators were formulated: a high system reliability needs to be ensured, the system should enable more straightforward and structured planning, it would be positive if the system would strengthen team spirit and cooperation and provide possibilities for self-educated decisions and assumption of responsibility, the system should provide feedback on performed work. To address the pain points, the following pain-relievers were compiled: Enabling more transparent communication between team coaches and operators, supporting a more traceable flow of information, reducing bureaucracy while avoiding paperwork, and providing opportunities for more variety during work. Product and services are the third category on the product side of the value proposition canvas. Here, the following items were defined: a communication tool to exchange information with the team coach and receive feedback on one's performance, the option to initiate workplace rotations independently, the provision of workplace information and factory updates, and lastly, the digitalization of paper forms.

In addition, user stories were formulated to derive the functionalities from the user’s requirements for our three personas: A young operator who is open to new technologies but not experienced in the workings of the company, an older operator who is experienced but not as open to change and new technologies and lastly a persona for a team coach who wants the work to be more structured and the team members to have more responsibilities on their own [5]. Our interdisciplinary development team created 21 user stories: seven regarding the first persona, six for the second persona, and five for the team coach. Additionally, three user stories contained information derived from all personas. For some functionalities, describing them in one user story was sufficient. Most of the functionalities, however, required more than one user story, as they were too complex to describe in one story. For the young operator persona, the user stories contained different aspects of a support functionality, enabling them to contact their team coach about a problem and its criticality, as well as receiving an indication that the request has been noted and the estimated time needed to consider the request. Additionally, there were user stories about a digital application of forms like vacation requests, receiving updates on the current production, and reporting quality problems or defects. For the older operator, the user stories focused on receiving feedback on the quality of work, a usable system with gamification elements, video training in case of changing production steps, and the provision of information regarding new developments in the factory. The user stories of the team coach persona concerned topics that enabled easier planning and flexibility through functionalities for the station planning, digitized employee check-in, an overview and ranking of incoming support requests, and a mobile application for the system, but also information and entertainment functions for the time during breaks. Lastly, the three overarching topics were the digitization of paper forms and longwinded processes, self-initiation of workplace rotations, and functionalities for breaks, such as a canteen overview.

4.2. Functionalities requested by the users

Based on the results from the requirement definition, the following functionalities were derived for the operator side of the system:

- Support functionality for informing the team coach about problems on the assembly line and assessing their criticality
- Digital vacation request
- Updates from the assembly line and general factory updates
- Quality feedback based on performance along the shift
- Video training on demand with different difficulty levels to support when changes are implemented on the assembly line
- Quality check in case quality problems or defects from other workstations are noticed
- During breaks, an overview of the canteen menu and the calendar with essential company dates
- Requests for workplace rotations to enable the operators to exchange stations on their own
- Employee check-in

Analogously, the following functionalities were identified for team coaches:

- Overview of incoming support request and their priority, option to order them according to importance and assess their wait time
- Overview and notification for triggered quality checks
- Break mode
- Option to grant or deny requests for workplace rotations that both participating operators approved
- Overview of employee check-in that can also be used for drag-and-drop station planning
- Smartphone overview of the application

Based on the functionalities mentioned above and in close collaboration with the operators, feedback was gathered, and the initial wireframes were implemented using Figma [17], a collaborative application for designing interface prototypes. After the wireframe development, mockups were implemented based on the workers' feedback and user experience guidelines from the literature. The implemented mockups were then assessed and evaluated in workshops to identify which functionalities of both roles could be technically implemented.

4.3. Feedback Workshop

Concerning the dashboard design, the importance of an intuitive layout and the need to quickly understand and use it was highlighted by the workshop participants. It was stressed that the usage of the tablet must not lead to overhead for the operators. The information displayed needs to be readable at first glance, and it also needs to be legible from a few steps away. Thus, as little text as possible should be displayed, supported by pictures or icons to enhance readability and clarity. Here, the icons must be understandable for assembly operators, e.g., an IT headset might not be the best choice to symbolize a support function, as the operators currently don’t associate problem-solving during production with video calls, IT helpdesks, or phone centers. The assembly operators don't have time to read longer texts while production is ongoing. Thus, displaying instructions, explanations, tasks, or checklists is not helpful, as there is no time to read these during regular operations. Still, some information is requested to be displayed on the dashboard, e.g., whether or not the current model is a special variant that needs a rarely used part, the time until the next break, some performance statistics, giving feedback not only on problems and mistakes but also on positive milestones and lastly links to the most important functionalities.

The functionalities that should be linked directly on the dashboard were "support" to report problems hindering production and communicate with team coaches, "material order" to request additional parts, and "quality check" to raise issues noticed from previous production steps. The other functionalities were placed in a menu, as they are not critical to access quickly when production is running.

The feedback for the different functionalities was positive overall. However, various points of improvement were raised regarding the support function. Sending a request should be possible in only two clicks for usage during production. This makes it challenging to include detailed information in the ticket. Additionally, the number of categories to classify the request needed to be reduced to three catch-all categories: "production error", "material error", and "other" to avoid uncertainty when choosing a category.

For the persona of the young operator, the system was rated as a vast improvement to the current status quo, and the workshop participants assumed that the persona would be content with the prototype. Participants agreed that the persona would be happy to receive more information and feedback and would appreciate the more accessible and transparent communication with his team coach. These aspects were expected to be of great importance for the persona. The participants said the young operator would also appreciate the possibility of reporting problems independently. The users argued that, as this persona is very open to new technologies and changes in current processes, he should be the easiest to satisfy. On the other hand, the participants described the older operator's persona as more cautious towards new technologies. Therefore, it was highlighted that the system's usability, ease of use, and intuitiveness are of utmost importance. The fact that internal company news and announcements can be displayed via the system was appreciated by the operators present during the workshop, and the introduction of a calendar showing dates like company holidays was suggested. Regarding the third persona, the informative value of the input from the workshop was limited due to a lack of participants with a similar role in the evaluation workshop. However, the other participants believed that the team coach persona would appreciate the system, as it would make their work more organized and enable a better overview, e.g., of the order of operator support requests. It would also lead to fewer interruptions in their work.

5. Discussion

As most of the proposed applied user-centered design process has been completed so far (Figure 1), the authors would like to offer some opinions, reflections, and lessons learned about worker involvement in the design process for a digital assistance system for employees in automotive assembly lines. This will be structured following a SWOT analysis [18]. This method presents a self-evaluation regarding factors from within, Strengths and Weaknesses, as well as from without, Opportunities and Threats:

Starting with the strengths of the presented approach: First and most importantly, the workers were able to offer valuable insights and feedback during all of the design phases. Some functions, like the Quality Check functionality, would not have found their way into the prototype without their feedback. The participants mentioned that they highly appreciated the possibility of giving input, being asked about their opinions, and being considered and valued. They expressed their satisfaction with how their previous input influenced the design. It is also expected that the system has high usability and is easy for operators to learn and understand, though this must still be checked in usability tests.

When looking at weaknesses, it must be noted that it was sometimes hard to talk with workers as often as we would have liked, especially if there were problems in the day-to-day work at the production site or ongoing restructuring measures. Therefore, it is essential to have a reliable and well-connected contact person within the factory who can aid with the coordination. Also, appointments and workshops must be planned well ahead of time. If this isn't done, the development will be delayed unnecessarily to make up for it.

The following opportunities are of note: during the design process, we found that employees with double roles or experiences from multiple positions were especially valuable in their input. For example, managers who worked as team coaches and operators before becoming managers and IT personnel who worked as operators on the assembly line beforehand can give valuable feedback, as they know different perspectives well and can draw from a greater well of knowledge to evaluate the design.

If not adequately addressed, the following threats can hinder the user-centered design process: During the development of different functionalities, it is sometimes challenging to balance the needs of various stakeholders from multiple organizations and departments in a multidisciplinary cross-functional project. Also, company policies must be considered, which might lead to changes and adaptations of planned product features. Constraints might also arise from the existing company IT infrastructure. Therefore, aligning with stakeholders from various departments (IT, manufacturing, etc.) and organizational levels, like operators, team coaches, and managers, is essential to ensure that solutions can be implemented smoothly downstream. Additionally, it is vital to collaborate closely with the workers' council to ensure that the workers' rights are represented and protected.

5.1. Limitations of the presented work

There are some limitations we would like to consider. Firstly, at times, access to the workers was more limited than we would have preferred. For example, we would have wanted to conduct additional workshops with operators and team coaches during the requirement definition phase to verify the compiled functionalities and at the beginning of the prototype development while still having a very low-fidelity, maybe even paper-based prototype, to give more operators and team coaches a chance to influence the direction of development. However, this was not possible in the scope of the current project. Still, it is essential to remember that we received worker feedback during these times, as we had some selected personnel in feedback loops. Secondly, no team coaches could participate in the feedback workshop. The prototype version for team coaches might have benefited from additional feedback. Thirdly, not all the functionalities we compiled during the requirement definition and prototype development will be implemented. This might be because of concerns on the part of the workers' council, e.g., for the digital vacation requests, or limitations of the underlying IT infrastructure, e.g., the requests for workplace rotations. This is unfortunate, and we hope these functionalities will be added to future developments and improvements of the digital assistance system.

5.2. Adjustments made to our applied Human-centered Design Process

While applying our proposed approach, we noticed that additional iterative loops are necessary. To accommodate this, we conducted the feedback workshop presented in this paper as a first step of the prototype evaluation. The feedback was then used to enhance the prototype further and fuel the next step towards a higher fidelity of the prototype.

6. Conclusion

The presented work aimed to validate our applied human-centered design approach further. We showed methods and tools to use during the requirement definition, prototype design, and a first step regarding prototype evaluation. Additionally, the results of these phases were presented when the process was applied to create a digital assistance system at an automotive assembly line while ensuring the involvement of the workers during the process. We showed that this approach can be successfully implemented to build an assistance system addressing the workers' needs and requirements, filling this gap in the practical application of a user-centered design approach and towards implementing Industry 5.0.

In our future work, we will conclude our case study with the last phase of the presented approach, the prototype evaluation. We plan to gather input and feedback from operators and team coaches during formal usability tests and structured interviews to prepare our system for deployment on a real production line.

Future research should investigate the interaction with and impact of the system once deployed and gain long-term insights from operators and team coaches. Additionally, the application of our approach is not limited to automotive assembly. It can be transferred to other sectors, especially where human operators are heavily involved and tasks can't be fully automated. This transferability can be further investigated as a relevant line of research.

We aim to broaden the use of human-centered design and the inclusion of workers in design processes by demonstrating this practical application of a human-centered design process in an industrial setting. Thus, we promote the aspiration of Industry 5.0 ideals and more use of user-centered design in industrial settings.

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