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Bastian Pokorni*, Carmen Constantinescu*,

*Fraunhofer IAO, Fraunhofer Institute for Industrial Engineering

Abstract

In manual assembly processes, the information flows during the process are becoming increasingly complex. Digital assistance systems will play an important role in the future by supporting employees and cooperating with them in order to increase productivity, ergonomics, and flexibility. Digital assistance systems must be designed in such a way that they optimally support the abilities of the employees in an adaptive manner. This paper presents an approach to systematically analyze assembly processes with the focus on employee needs and experiences based on Customer Journey Mapping. This approach helps Industrial Engineers to design productive and accepted digital assistance systems for smart factories.

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1. Motivation

Information flow-related losses in production today lead to significant losses of value creation and at the same time result in unattractive jobs. Complete, timely, up-to-date, comprehensible, and accurate information is crucial for efficient processes and work tasks. Otherwise, there will be expenses due to search times for information, resulting in downtimes and/or rework activities due to incorrect execution [1,2]. For production tasks, a large number of information objects must be provided to enable optimal processing [3]. In manual assembly processes, this means the provision of e.g., work instructions, BOMs, drawings, maintenance schedules. Multi-directional information flows, in which the employee not only consumes information but also generates data and information, will be more important in the future.

The increasing number of product variants means that employees must be able to handle more products. Shorter product life cycles increase the situations in which employees are facing new products which leads to more frequent training processes. Different employees within the organisation have different experiences, qualifications, and skills. This creates a different need for information and assistance. The increasing product complexity with simultaneously rising quality requirements leads, among other things, to higher cognitive burdens for the employees [4].

To optimise information flows within production, companies are already using digital assistance systems. In Germany every second company already has digital assistance systems in use or is considering introducing them [5]. The design and layout of such systems will be of particular importance in the future. Industrial Engineers, IT-experts and users must design assistance systems in an integrated process. Both the hardware design (input/output hardware) and the interaction are the focus of planning. Digital assistance systems must be designed for the optimally and adaptive support of the employees [6]. When designing assistance systems today, however, the complexity of the planning task results in many obstacles that companies must overcome. First and foremost, in addition to planning and implementation strategies, companies lack of employee acceptance and the ability to assess the benefits of using assistance systems [6].

The analysis of the relevant literature shows that no methodologies, models, procedures, and approaches exist to
systematically analyse, visualise and determine the need for assistance in existing manual assembly processes based on the respective user requirements.

This paper is structured as follows. Chapter 2 provides an overview of the relevant basics and terminology. Chapter 3 presents the chosen solution approach based on Customer Journey Mapping as a new modelling language in context of digital assistance systems. Chapter 4 shows the components of this new methodological approach and how it can be used. Chapter 5 presents a validation example from the automotive industry. The concluding remarks are given in chapter 6.

2. Basic work and terminology

2.1. Manual assembly processes

Manual assembly includes all tasks and operations to join parts and components by manual processes through a human operator [7]. Manual assembly comprises four different elements: identifying, placing, fitting, and securing the parts. In addition, characteristic sub-functions can be assigned to each function [8].

2.2. Digital assistance systems within manual assembly

The term assistance system refers to all systems that support employees’ work tasks [9]. In manual assembly, digital assistance systems support the worker by guiding him during his assembly activities with software support and, if necessary, checking the results. The aim of the assistance is to increase productivity and quality and to make the assembly process transparent, traceable, flexible, and safe [5,10].

Employees are supported in their ability to react, think, and draw conclusions when carrying out their work tasks [11, 12, 13]. There are different technologies in practice, such as Augmented Reality to support operators’ cognitive capabilities based on their experiences [14].

Also, different approaches for designing digital assistance technologies have been proposed either from technological perspectives [15,16] or from human perspectives [6,17,18].

2.3. Customer Journey Mapping

Customer Journey Mapping is a process-oriented, visual user experience method for structuring and conceptualizing human experiences, which has been applied in software development, sales and marketing processes or service engineering for analysing and optimising so called touchpoints between the customer and the company [19]. It helps companies understand how customers use and perceive the different channels and touchpoints with the company and how they fundamentally envision that experience. This knowledge can be used to create the "optimal" customer experience in terms of the expectations of key customer groups [20].

To achieve these goals, there are five necessary process steps defined that build on each other:

- Definition of scope and goals
- Identification of touchpoints (internal and external view)
- Evaluation of the currently existing design
- Development of optimisation actions
- Measurement of the impact of that actions (for the touchpoints) [21]

2.4. Research gaps

The design of digital assistance systems is becoming increasingly important due to the growing complexity of assembly products and the resulting increase in the complexity of information flows and changes in work tasks. In addition, digital assistance systems can provide capability support for employees in work processes through new interaction and visualisation technologies. At the same time, the complexity and the demands on the design process of such human-machine systems are increasing with the performance and diversity of the technologies.

Known human-machine planning methodologies tend to consider later design phases and include visual design, output and screen displays as well as the design of meaningful dialogue guidance. However, none of the methodologies allows for the basic design of digital assistance systems. None of the methodologies describes how user integration and the detailed elicitation and processing of user requirements can be realised in the context of manual assembly processes.

Companies need an approach to understand and modelling user and business requirements at the same time and to determine digital assistance potential within the manual assembly processes.

3. Approach

The basic idea of the solution approach is the transfer of the Customer Journey Mapping method to the application area of digital assistance systems in manual assembly processes. The Customer Journey Map describes the relationship between a customer and a company in a defined period by means of suitable visualisation. For the given goals the Customer Journey Map must be adapted and extended in such a way that it enables the industrial engineering to record and visualise a manual assembly process, to determine the respective information flows and interactions, and to take into account the user and business requirements, needs or show their discrepancies in order to determine the right digital assistance functions on this basis. At the end the process is improved holistically. With this approach, user needs are already considered during the participative process analysis. This is an innovative approach compared to conventional methods of assembly process analysis.

4. Assembly Journey Mapping for understanding, planning and configuring Digital Assistance Systems

Compared to the conventional approach of Customer Journey Mapping, several changes have been made in the Assembly Journey Mapping. One main difference is the integration of several perspectives. Instead of one persona representing the customers, there are at least two personas. These represent the perspective of the assembly operator and the company/management perspective. In addition, new
measurement criteria had to be selected. Unlike the classical understanding of touchpoints in Customer Journey Maps, now the touchpoints represent the points of contact of an assembly operator with the assembly process and the information and communication technologies within that process. Therefore, measurement criteria are needed for the analysis that are suitable for examining an assembly task.

There is another change in the visualisation. Instead of one Customer Journey Map, there are two Assembly Journey Maps within the framework of the process model: The Assembly Journey Map for the as-is analysis and the Assembly Journey Map for the future state with the use of digital assistance functions. The process model consists of six iterative steps:

1. Persona definition
2. Workstation and work task analysis
3. Assembly Journey Mapping
4. Configuration of digital assistance system
5. Future state definition
6. Evaluation of planning results

**Step 1: Persona definition**

In the first step, all personas must be created from whose perspective the manual assembly process is to be examined. The process model includes at least two perspectives: the business perspective and the employee perspective. For higher diversity, the employee perspective should include different worker ages and backgrounds. All analyses and future state developments are based on these perspectives.

**Step 2: Workstation and work task analysis**

In the second step, the current workplace and the assembly task analysis are examined. The purpose of this step is to get an overview of the current situation and to understand the assembly tasks and to decompose these into individual activities. This step serves as preparation for the following as-is analysis. The examination of the workplace and the assembly tasks is ideally carried out on site and should help to get a realistic idea for the later analysis from the personas’ point of view.

**Step 3: Assembly Journey Mapping**

In the third step, the actual state of the assembly tasks is analysed in participation with the employees. First, the relevant activities of the assembly tasks are defined. This step shows the touchpoints of the assembly operator with the assembly tasks and the corresponding activities. As shown in Figure 1, for each process step there will be an analysis of the basic data, e.g., goals, process times, criticality of the activities and needed skills. This information provides a better process understanding. Then the user requirements or human needs are captured. This means that the employees’ experiences with the process are assessed. The information needs and interaction patterns are also recorded. Finally, the task allocations between human and the system are recorded. The Assembly Journey Map is completed with the analysis of the process performance as an expression of the business perspective.

**Step 4: Configuration of digital assistance system**

After the as-is analysis, suitable digital assistance system potentials for the assembly activities are derived in the fourth step. This is intended to optimise individual activities or the entire assembly process. Based on the analysis and the respective requirements, the team must interpret which assistance functions would improve the condition regarding the defined goals. Taxonomies can be used for configuration. Figure 2 shows the defined taxonomy for configuration of the digital assistance functions according to the identified potentials.
Step 5: Future state definition

After the selection of digital assistance functions, the fifth step is the future state definition. In this step, the assembly process is defined, considering the changes caused using selected assistance configurations. First, the activities for the assembly tasks are redefined. The future state Assembly Journey Map shows the interconnection of the activities and the digital assistance system with all defined functions. Then the assembly process is analysed and assessed again with the help of the persons regarding all requirements and defined goals.

Step 6: Evaluation of planning results

In the sixth and final step of the process model, the planned configuration or alternatives will be evaluated. By comparing the as-is state and the future state of the Assembly Journey Maps, it can be evaluated whether the defined goals could be achieved or not. Depending on this result, it can be decided whether a digital assistance system should be implemented for the analysed assembly process.

5. Validation

The validation was carried out at an automotive manufacturer. The validation should check the practicability of the Assembly Journey Mapping process model together with the employees and, on the other hand, provide indications of the benefits of a human-centered approach in the process analysis and digital assistance system planning. The validation team consisted of assembly operators, foremen, management staff and Industrie 4.0-planners.

First, a process analysis was carried out to select the process to be considered for the journey mapping. For this purpose, a work process analysis of the assembly process, teaching process and failure management process was carried out. For the analysis by using the Assembly Journey Map, the process of the failure management was selected. The selection of this process was based on two perspectives:

1. High importance of the process for the company by evaluating the criteria as follows: quality, costs, time, integration, complexity, qualification, and flexibility.
2. High importance for the employees by evaluating the criteria as follows: well-being, joy of work, social needs, self-fulfilment, need for safety, ergonomics, motivation, and usability.

In the following, an unplanned disruption in the automotive assembly process and the associated control of information flows to remedy the disruption as well as the resulting stresses on the employee are examined. The occurrence of various critical situations during the process is assumed. The problem under consideration involves an incorrect or defective variant part on the final assembly line which is identified by the assembly operator on his pre-commissioned workpiece carrier and cannot be assembled by him. The required spare part is basically available in the factory and thus a remedy is possible.

The employee cannot bring the part forward from a downstream workpiece carrier, so that another person becomes responsible for providing the spare part. Next, the employee has to decide whether the part has to be assembled at the assembly station in question and therefore a line stop is necessary, or whether it is possible to assemble the part later at another assembly station or in rework. For this purpose, the belt stop of the relevant section is visualised on a screen in the production area. Subsequently, the employee must inform the reworker and his foreman about the problem that has occurred.

The employee will try to reach the reworker or the foreman by verbal communication and searching. Subsequently, the reworker orders the required spare part in the logistics department from the responsible logisticsian by phone and the foreman or reworker documents the malfunction that has occurred and the defective component.

The logistic operator fetches the missing part from the warehouse and brings it to the corresponding station on the assembly line, where the employee or reworker can assemble the part and finish the assembly line stop.

This process flow was analysed on site using the Assembly Journey Map.

Figure 3 shows the simplified map for the analysed failure management process. Subsequently, eight relevant subprocesses and the associated sub-processes are defined and assigned to the four different functions/personas “assembly operator”, “reworker”, “foreman” and “logistic operator”.

Especially when several different persons are involved in solving the problem collaboratively to make a necessary contribution, their consideration is of great importance. In this context, it must be considered that the different persons may have different interests and needs with regard to the problem that has occurred, which may have a negative impact on the implementation of the process.

Three different time periods are visualised in the process:
1. Time period from the identification of the malfunction to the belt stop, in which the belt is running but the employee is busy solving the problem (yellow)
2. Time period in which the line stops until the solution is found, and no production takes place (red)
3. Open time period, from which the line stops and production resumes (green)

The visualisation of the process times is intended to contribute to increasing the transparency of the process regarding the process parameter time, which has been identified as critical in this respect.

In the following, the evaluation of the identified assistance potentials focuses in particular on the identification and understanding of possible cause-effect relationships between the "gap in the process" and the problem from the employee's point of view, i.e., the comparison of user and business requirements, which is of central importance for the design process of the system by using Digital Assistance Taxonomy (see Fig.2). At the end, a map for the target state with the selected digital assistance functions was created, discussed, and evaluated with the expert team.

6. Conclusion

The overall conclusion of the expert workshop is that the developed process model fulfils the basic objective of this work, namely the identification of digital assistance potentials from the user's point of view and, from the process experts' point of view, is relevant for use in production. In addition, it became clear in the workshop that the Assembly Journey Map developed in the process model were perceived by the experts as easy to understand, easy to read, clear and easy to communicate. Furthermore, it can be concluded from the findings in the workshop that, compared to formal procedures for analysing work activities, an analysis tool adapted to the employee that makes it possible to record digital assistance potential from the user's point of view is important for optimising the design of work activities. The user experience and the consideration of emotional and psychosocial influences of the work system on the person as well as their consequences for human action are considered effective criteria for the identification of digital assistance potentials.

However, process-oriented drivers such as costs, quality and time are considered overriding criteria, which is why there should always be a deficit in the process for the needs-oriented implementation of a worker assistance system.

References


