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Framework for describing functions of digital technologies in manual assembly systems

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Abstract

The integration of digital technologies to promote digitization is essential for the competitiveness of manufacturing enterprises. As part of the production process, the manual assembly is subject of this digitizing change process. According to recent studies the integration of digital technologies is primarily limited to scenarios in larger enterprises or prototype applications. For companies with a manual assembly segment at a lower level of digitization these scenarios, adequately aggregated, potentially contain important insights related to the choice of appropriate digital technologies. An investigation of these scenarios, for example in the form of a qualitative study, therefore seems appropriate. In advance of such an investigation, however, the scope of the investigation, the manual assembly area, must be modeled in order to be able to depict specific situations in the scenarios under investigation. Secondly, the spectrum of digital technologies currently used in manual assembly must be identified and described. The latter is the topic of this paper. The authors of this paper aims to create a framework for describing and classifying digital technologies in manual assembly on the basis of their functions.

Keywords

Digitization; Digital Technologies; Manual Assembly; Framework; Transformation

1. Introduction

Digitization and the associated use of digital technologies are not very advanced yet in the area of manual assembly [1]. In particular, the selection of matching digital technologies (related to the company's goals, the personnel and organizational situation in the assembly area, etc.) represents a challenge for many enterprises [2], [3]. Recommendations for supporting the selection of digital technologies, generated by concepts, models and consulting services, are available in abundance. However, these come with certain disadvantages. The existing consulting services invole high costs [4], are only available regionally or are limited in terms of their scope (e.g. assistance systems, data acquisition) [5], [6]. Self-assessment approaches focus either on a larger domain (enterprise, production area) or a smaller domain (specific work station) and therefore do not allow any precise conclusions to be drawn about the selection of digital technologies in manual assembly [5]. The challenge of providing specific recommendations for action by self-assessment approaches with regard to the identification of appropriate technologies is partly due to the diversity of digital technologies. In addition, there are a large number of factors that characterize the individual situation of a company operating a manual assembly system. [7] However, there are already a number of documented (e. g. [8], [9]) and also non documented best practice cases. An examination of these cases can provide insights into how the enterprises conducted the technology selection process and what factors they considered in the process. These findings can be used to develop an approach that enables other enterprises with manual assembly systems to select the right digital technology for their use case. In this context, a form

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of explorative research seems to be appropriate [10]. The reason for this is the not too high state of knowledge (although not a low one) regarding the selection of digital technologies for manual assembly. Also, an investigation of this type would strive to gain in-depth understanding of the selection process of digital technologies, which also supports an exploratory investigation. In addition, according to preliminary research, the number of available cases is small. In sum, a qualitative investigation in the form of a case study is considered an appropriate form of investigation. In the apron of this investigation apart from the definition of the general boundary conditions the considered scope of investigation in form of the manual assembly system must be described in a structured way. Another essential aspect is an identification and description of the digital technologies that are potentially applicable in this investigation scope and their functions and properties.

In this paper, as a first step for this qualitative investigation, the digital technologies potentially applicable in the manual assembly area and their functions and properties are described in the form of a framework. For this purpose, a clear understanding of the subject areas and terms will be presented first. This involves digitization (2.1) and digital technologies (2.2) as well as the area of manual assembly (3) as the scope under consideration. This is followed by a summary of the relevant findings from the previous sections and a description of the boundary conditions that apply in further explanations (4). This is followed by an analysis of the functions used by digital technologies in manual assembly (5), taking into account the defined boundary conditions. Finally, the framework developed is presented in the same section.

2. Understanding of digitization and digital technologies

2.1 Digitization

First of all, it can be stated that the term digitization is not clearly defined [11]. However, a distinction can generally be made between two common forms of interpretation of this term. On the one hand, the original understanding in the form of the transformation of analog data into digital data [12]. On the other hand, digitization is understood as a transformation process or trend related to a specific system [13]. A system in this context can represent an entire society, a business network, an enterprise, an enterprise department or just a work system. Digital technologies are an essential part of this transformation process [13], [14], as well as the the transformation from analog data to digital data.The intention of the digitization process or the associated use of digital technologies can be, firstly, the automation of processes in the system to be transformed, or, secondly, a more human-centric approach in which humans are supported in the execution of processes through the use of digital technologies [15], [16]. Since this transformation process is individualized depending on the characteristics of its reference system [3], [17] there is no generally applicable description of a procedure or universal representation of a digitized enterprise or department in the literature [16].

2.2 Digital technologies

The term “digital technology” is a comprehensive term for various technologies. The term is further associated with technologies from the fields of information and communication technologies, identification technologies and automation [18]. However, there is no uniform understanding of digital technologies that describes which specific technologies fall under this term. Commonly named specific technologies in this context include cloud computing, big data, 3D printing, and sensors [14], [19], [20]. In addition to these technologies, a large number of other technologies are classified as digital technologies. They are used to achieve objectives associated with digitization, such as increasing transparency [21], improving the flow of information and increasing flexibility, but also to pursue networking or rationalization purposes within a system [13]. Definite manifestations of these digital technologies are technical systems, often referred to as digitization solutions or digitization applications. In order to create a uniform understanding of digital technologies, [18] have developed a framework, which describes digital technologies on the basis of their general functions in the context of the lean production system. These functions are the storage of data (Storing), the processing of data (Processing), the gathering of data (Gathering), the provision of data and information (Providing), and the transmission of data and information (Communicating) [18].

3. The department of manual assembly

The term "manual assembly system" is used here as the reference system for the subject of manual assembly. The assembly system is a subsystem of production in which objects are assembled into products or assemblies [22]. It is a socio-technical system - a system consisting of interdependent technological, organizational and personnel subsystems [23]. The assembly system itself is composed of assembly stations, which are socio-technical systems likewise [22], [24]. The organizational form of the assembly system is determined by the movement of the assembly object, the movement of the assembly station and the degree of work distribution [25],[26], [27]. Within the assembly stations, the assembly task on an assembly object is performed by human operators and technical systems as part of an assembly process (Figure 1) [28].

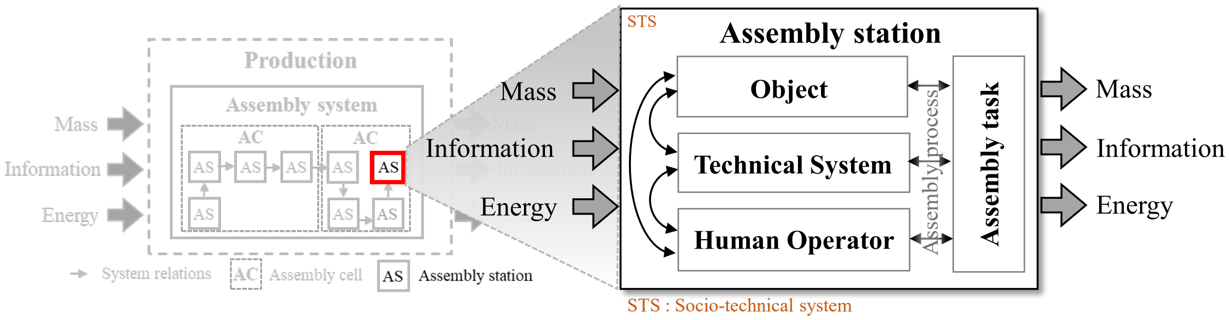

Figure 1: Illustration of an assembly station in relation to an assembly system

Within this assembly process, the sub-functions of the assembly function (joining, handling, controlling, adjusting and special operations) are performed [25], [26]. Other functions that support the assembly process are provided for example by the material supply system and the information system. The material supply system is associated with the functions of storage, commissioning, and transportation [22], [25] whereas the information system supports the function of assembly with the functions of acquisition, provision, communication and processing, as well as storage of data [29].

4. Conclusions and definition of boundary conditions

Section 2.2 explained that there is no general consensus on which explicit technologies fall under the term "digital technology". An approach was outlined in [18] which describes digital technologies on the basis of their functions. This approach and the functions described therein (gathering, providing, storing, processing and communicating of data and information) are adopted in the following to describe the digital technologies relevant for manual assembly systems. An advantage of this approach is the possibility of grouping several technologies under one function [30], [31], [32]. Furthermore, this ensures a long-term validity of the description [18]. It can be assumed that digital technologies will change in their explicit form. However, the functions of technologies are presumably subject to a lower frequency of change.

In order to restrict the scope of the investigation and to reduce complexity, only the concept of a "manual assembly system" will be considered in the following. This includes all relevant inner elements, tasks and processes as well as the interfaces to other relevant systems. The information system and the material supply system are therefore not considered directly in the scope of the investigation.

5. Development and description of the framework

In this section, an analysis of the relevant and currently used individual functions of digital technologies in manual assembly systems is carried out. This forms the basis for the intended development of the framework. The general functions of digital technologies have already been described in sections 2 and 4. In the following, digital technologies are identified, specified and described with regard to their occurrence and their characteristics in the manual assembly system in the context of the set boundary conditions (Figure 2).

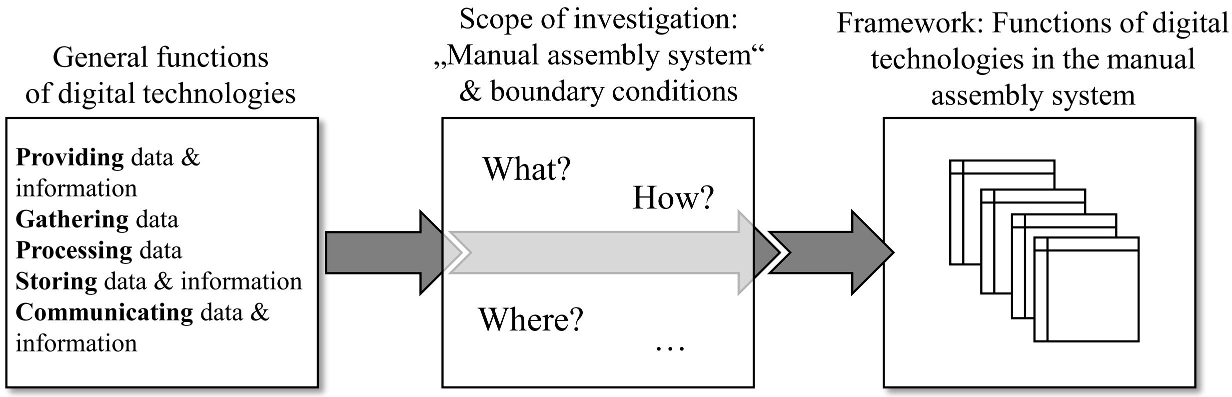

Figure 2: Description of the approach to the development of the framework

5.1 Functions of digital technologies in manual assembly systems

The functions to be identified and described occur in existing practical applications and can therefore be consideres as “known functions”. Accordingly, a detailed description of the functions of relevant digital technologies can and should be provided, which is also in the sense of the informative value of the subsequent qualitative investigation. A rather abstract or iconic representation of functions as in the context of a universal technology selection process (e. g. [31] and [33]) is not pursued.

Identifying and describing the functions of digital technologies requires a structured **procedure**. Therefore, an orientation to the attributes for characterizing work functions according to [34] has been carried out. According to this approach, a work function can be characterized by type (“What?”, “How?”, & “Who?”), duration (“How long?”), occurrence behavior (“When?”) and place of occurrence (“Where?”). However, a work function is always performed by a human. Since in the context of this paper functions of technologies and not of humans are discussed, adjustments have been made to these characteristics. Accordingly, only the following attributes are relevant for characterizing functions of digital technologies: The **type of function (“What?” & “How?”)** and the **place of occurrence of the function (“Where?”)**.

Literature research was mainly conducted to identify the relevant functions. Common databases and platforms (e. g. Science Direct, Research Gate, Springer) were screened using keywords such as "digitalization "+"manual assembly" and "Industry 4.0"+"manual assembly". In addition, current and relevant research projects and related publications were scanned on the websites of project managers and funding organizations. Furthermore, an initial review of relevant and documented projects from consulting institutions such as the competence centers active in Germany was carried out. Further information was obtained from observations of the manual assembly line operated in the learning factory of the Chair of Production Systems in Bochum.

In the previous section, the **boundary condition** was formulated that only the manual assembly system and its interfaces to other systems would be considered in this investigation. This results in an initial reduction of the relevant general functions of digital technologies (Figure 3).

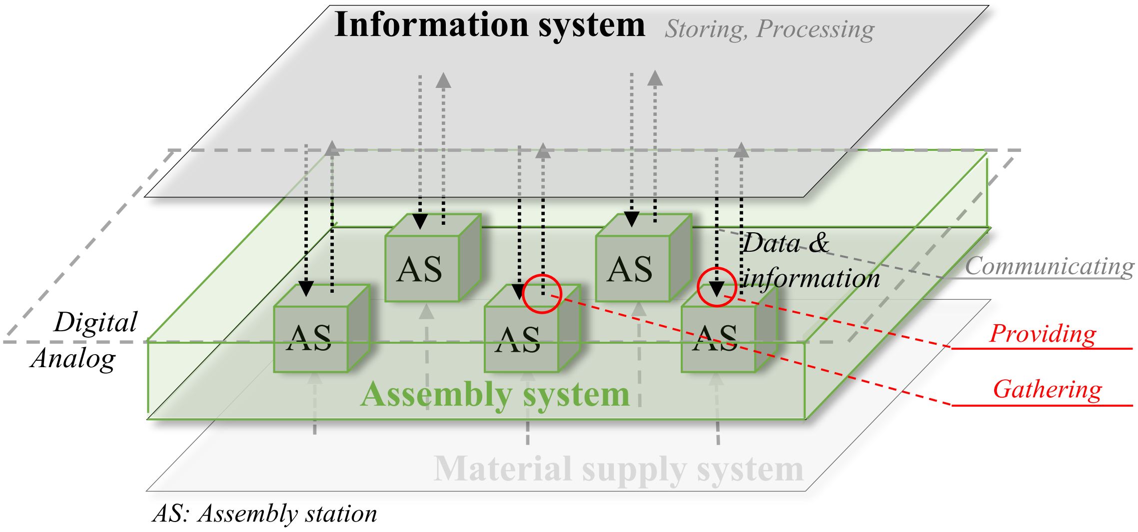

Figure 3: Locating the general functions of digital technologies in the scope of the investigation (marked red)

The functions of processing, storing and communicating data and information are assigned to the information system [29] and are therefore not considered further in the following functional description. Gathering data and providing data and information remain relevant for further discussion. These two functions will now be identified and specified according to type and location of occurende as part of the procedure already described.

The question of **"What?"** in the context of characterizing the **type of function** has already been answered in general terms with "data" in the case of the "gathering" function. In order to describe the functions in the context of manual assembly as precisely as possible, it is necessary to specify in more detail below what data is actually involved. Since the number of generally gathered data in manual assembly systems is large and the manifestations of these data are manifold [3], a classification of the relevant data is carried out first. In this context, some approaches already exist (e.g. [6], [35] [36] and [37]). Based on these approaches, the identification and classification is performed. The classification is done with respect to the reference element of the data. A distinction is made between order-related, assembly object-related, process-related, human-related and logistics-related data. The following table (Table 1) shows some concrete examples of these data classes.

Table 1: Classification and specific data in manual assembly systems in context of the function „Gathering“

Classification	Specific data
order-related	order status, quantities, times, …
assembly object-related	weight, dimensions, image, …
process-related	malfunctions, worker experience, reject, proportion of good parts, unloading position, unloading sequence, joining force, …
human-related	satisfaction, ergonomic strain, attendance, …
logistic-related	stock at the assembly station, weight of the carrier, number of unloading processes, number of insertion processes, missing parts, ...

Furthermore, the **type of function ("How?")** is specified. Existing approaches from the field of digital assistance systems as well as from the areas of sensor technology and production data acquisition form the basis for own explanations. Examples are [28], [35], [38], [39], [40] and [41]. Taking these approaches into account, a distinction is made here between optical data acquisition (e.g. by cameras or light barriers), acoustic data acquisition (e.g. by microphone), mechanical data acquisition (e.g. by scales, vibration sensors) and electromagnetic data acquisition (e.g. via interfaces). Furthermore, in relation to the type of function and the question of "How?" the degree of automation of the acquisition is differentiated. Here, a differentiation is made between manual acquisition and automated acquisition [35], [39], [42].

Finally, the **potential occurrence locations ("Where?")** in the manual assembly system were identified for the "**Gathering**" function. These are mainly one or several assembly stations. However, in addition to this decentralized approach, data can also be captured from a central location in the assembly system (e. g., central terminal for capturing order data). [43]

After the discussion of the "Gathering" function, the identification and description of the function of **providing data and information** in manual assembly systems ("**What?**") follows. Here, again, the first step is to identify which specific data and information are available according to literature and current application scenarios. These were also assigned to specific classes. In analogy to the "Gathering" function, the data and information are also classified in the case of “Provision” function with regard to their reference element in the manual assembly system. Reference sources for the own explanations are for example [28], [29], [40] and [44]. Data and information are assigned to the following classes: Order-related, assembly object-related, assembly task-related, process-related and logistics-related. The following table (Table 2) lists these classes with specific examples of data and information.

Table 2: Classification and specific data and information in manual assembly systems in context of the function „Providing”

Classification	Specific data and information
order-related	order number, quantities; worklist, planned order start, planned order completion, key performance indicators (e. g. current productivity), …
assembly object-related	bill of material, construction drawing (2D, 3D), circuit diagramm, images, …
task-related	assembly instruction, work plan, additional information (e. g. worker experience), test plan, assembly part position, force to be applied, …
process-related	abrasion, malfunctions, …
logistic-related	stock, object position, …

Also, an identification of the **type of provision ("How?")** common in manual assembly systems is performed. A distinction is made here between visual, acoustic and haptic provision [38], [40] [45]. Furthermore, following the approaches [40], [46] and [47], the type of provision is differentiated into manual or automatic provision.

Once again, individual or several assembly stations have been identified as the **place where data and information are provided ("Where?")**. However, the provision can, just like the gathering, also take place at a central location in the assembly system. [8], [48]

5.2 Presentation of the framework

The created framework shows potentially applied and relevant functions that can be performed by digital technologies in manual assembly systems according to the state of the art. The framework also takes into account that the design of the functions "provision" and "acquisition" is specific depending on the information and data under consideration. For example, not all information is suitable for acoustic provision. Reasons for this may be differences in the complexity of the information. In the following table (Table 3) an overview of the created framework is presented. The entire filled-in framework cannot be illustrated in its entirety within the bounds of the paper due to its size and the probably resulting lack of readability. The framework is a tool that will be used in the subsequent qualitative investigation. In the course of the investigation of individual cases, functions of digital technologies can be classified in this framework.

Furthermore, this framework can be integrated into a concept to support the selection of digital technologies for manual assembly.

Table 3: Overview illustration of the framework

Function: Gathering				
Function type				**Function location**
"What?"		***"How?"***		***"Where?"***
Data		**Form**	**Level of automation**	
Classification	***Specific***			
order-related	order status	optical, acoustical	manual, automated	central, decentralized: at 1-n assembly stations
	…	…	…	…
assembly object-related	weight	mechanical, electromagnetical	manual, automated	decentralized: at one assembly station
…	…	…	…	…

Function: Providing				
Function type				**Function location**
"What?"		***"How?"***		***"Where?"***
Data & information		**Form**	**Level of automation**	
Classification	***Specific***			
order-related	work list	visual, acoustical	manual, automated	central, decentralized: at 1-n assembly stations
	…	…	…	…
task-related	assembly instruction	visual	manual, automated	decentralized: at 1-n assembly stations
…	…	…	…	…

6. Conclusion and outlook

In the context of this paper, a framework for describing the functions of digital technologies currently used in manual assembly systems was carried out in preparation for conducting a qualitative investigation. Further adaptations and extensions of the framework are possible in order to be able to carry out this qualitative investigation more specifically.

Following on from this, a model for mapping the situation in manual assembly needs to be set up, in which potential factors influencing the selection of digital technologies are outlined. In the context of the actual qualitative investigation, it is then necessary to determine in which constellations of influencing factors which digital technologies are suitable. However, due to the large number of different types of influencing factors, it can be assumed that it will not be possible to examine the interactions of all types in the qualitative investigation. Accordingly, the most important influencing factors must be identified. Furthermore, the already started acquisition of cases will be accomplished and subsequently the actual qualitative investigation will be conducted.

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