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A holistic approach for value-added interaction modelling in flexible manufacturing systems

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Abstract

The current digital change within production can be perceived as the answer to the changed customer needs and environmental conditions. A comprehensive expansion of intelligent and networked production facilities enables complementary networking and agile adaptability at the operative production level. The change in production is accompanied by a changing role profile and task spectrum of the employees. The staff together with the involved machines and supporting IT services create a changeable production network, which thus is composed of heterogeneous participants. In order to master the production tasks and to ensure the effective work distribution within the agile production process modifications, the development of a method for interaction modelling of heterogeneous participants in the production network is shown in this paper. The method offers a holistic understanding of the complex problem: in its successive development, it addresses the users in the engineering phases. The main goal of the method development is the adequate interaction modelling and allocation in the light of the heterogeneity of the participants. The future scenario of autonomous agile manufacturing demands a new method of developing flexible and value adding methods for interaction modelling, which is shown in this paper.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Automation, digitization and Industrie 4.0 are current drivers of innovation and offer new opportunities and challenges for research, business and society in general [1,2]. Megatrends such as customer-specific individual products and a greater variety of variants, right down to shorter product lifecycles, place new demands on the production of the future. Consequently, consumer demand for products will become more dynamic and complex, primarily in terms of the variety and quantity of individual products produced [3,4,5].

Thus, production needs to react faster to changing market requirements and be more adaptable. Not only the effort for production line reconfiguration should be minimized, but also the integration of new or the modification of existing workstations and equipment should be done quickly and with little effort. These dynamic changes within the overall production context imply the need for an adequate coordination of the production processes [3]. The adaptability of the production facilities as well as the adaptability of the entire value chain must take these diverse requirements into account. From a technical perspective, Industrie 4.0 describes the potential road to an industrial internet of things (IIoT) starting with the entry of cyber-physical systems into production and an autonomously acting production ecosystem [6]. Hence, together with the change to Industrie 4.0, the great potentials are not to be found in the optimization of individual domains anymore, but in a cross-domain understanding [1].

Despite the lasting technical progress, the role of human employees is still essential. Although the amount of data in production is increasing in Industrie 4.0 development, the information needs of the employees were not sufficiently met.

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In addition, employees on the shop floor are also not able to contribute their experience and information [7]. In the face of an increasingly modular production environment, interactions or especially the development of new interactions between humans, machines and IT-Services will make a decisive contribution to the effective reconfigurability of production networks [5].

2. State of the Art

2.1. Flexible production networks

To be able to react to changed conditions and demands on the production of the future [8], industrial development, which has so far focused on (cost) efficiency, needs new impulses [1]. The entrepreneurial and economic perspective describes a partly disruptive change towards the development of highly flexible value chains and new business models based on innovative services [9]. From a technical point of view, the change is abstractly characterized by the development of rigid production units into production units capable of change [10]. Wiendahl et al. present different levels of changeability at production level, which are described in the dimensions of changeability of services and changeability on enterprise level [4].

Conversion and reconfigurability are established in the varied areas of industrial production and are already implemented in strategies such as modular systems and series or component platforms [11]. The future focus is thus shifting from variant-rich mass production to customized production in small batches down to batch size one [3]. In the future, production facilities will at least be used flexibly to enable a versatile production and an agile value creation strategy [4]. The ability to change production must be designed in an appropriate way in order to circumvent the current limitations caused by high financial and time-consuming expenditures for plant adaptation.

According to Nyhuis, modularity, universality, mobility, scalability, and compatibility must be considered as the key drivers in the development process [3]. Future production processes and their production facilities must therefore be designed according to these paradigms in order to continue operating efficiently and competitively [12,13].

2.2. Industrial internet of Things, Services & People

Internet of Things (IoT) is the logical extension of the basic idea of the Internet and transfers its intention to connect people to physical units and physical units with each other [14,15]. For the year 2025, the number of integrated devices in IoT is expected to reach about 75 billion worldwide [16]. The Industrial Internet of Things (IIoT) can be viewed from various perspectives. IIoT transfers the paradigm of IoT to the industrial sector and stands for the cross-level networking of entire production plants and individual sensors [17,18]. The technical development of low-cost sensors contributes to broad vertical networking in the sense of IIoT [19]. This perspective profits significantly from the development of network-compatible cyber-physical systems.

A further perspective is provided by the efforts of the Industrial Internet Consortium, which regards the Industrial Internet of Things as a holistic concept for future production [20]. The concept, also abbreviated as Industrial Internet, thus forms the US-American counterpart to Industrie 4.0 [21]. While IoT primarily addresses the needs of users and enables new solutions through the integration of devices, IIoT has a strong technical focus in its implementation, which is primarily concerned with the connection of sensors and systems and their data use. The IIoT-concepts have in common that they do not sufficiently integrate people [22].

With increasing networking of production facilities on the shop floor and the rising volume of machine and process data, a continuous connection to IT-systems and services will be established to enable effective data use and plant control. The postulated dissolution of the automation pyramid in accordance with the paradigm shift to Industrie 4.0 is based precisely on this holistic networking [23]. This increasingly complex network requires an adequate integration of people – from both the customer and employee perspective [24]. The IIoT approach is therefore not a comprehensive concept and needs to be extended to include people and (IT) services: The Industrial Internet of Things, Services and People - IIoTSP [25].

2.3. Digital factory

With the digital factory and the Industrie 4.0 movement, new approaches to holistic computer support for production are to be developed under changed technical and economic conditions and with the changed understanding of Internet culture [26]. The Digital Factory according to VDI4499-1 is the generic term for the use of digital tools for holistic production management.

The focus of the digital factory is on production planning and factory design, the transition areas to product development and design, and subsequent production [27]. The change to flexible manufacturing through modular production is followed by a shift of activities from the upstream planning and development area to the shop floor resulting in the ability to react dynamically to ad hoc changes [28].

According to [11], industry and science lack suitable methods for the holistic integration of tools in the development phase and, above all, in the production itself. However, it is precisely these methods that are necessary to enable a seamless exchange of information between the engineering disciplines and the heterogeneous tools and plants [29].

3. Development of a holistic and value-added method

The digital change within the production environment leads to complex interactions between the future classes of production participants – in the sense of the IIoTSP, namely human, machine and IT-system. The influences of these heterogeneous participants will take on a decisive role both within the operational activities and in the area of pre-programmed development activities within the production process development. For these development activities, as well as for the operative activities directly on the shop floor, there is a lack of comprehensive process models to control the increasing complexity of the heterogeneous production network – especially interactions between heterogeneous participants [30].

Due to the lack of a comprehensive definition and the strongly context-dependent understanding of the terms in this interdisciplinary field, the definition for the term of heterogeneous production networks and the participants is essential for further consideration.

Heterogeneous production networks are characterized by the value-adding cooperation of diverse participants. The participants support individual requirements and skills from different domains (Things, Services & People).

Participants in the production network contribute in an active or passive role to the execution of the production process. Especially in the context of a modular and flexible production, heterogeneity in the sense of IIoTSP is to be expected, which is covered by heterogeneous characteristics and needs of the participants.

With the transformation to autonomous production, a superordinate vision is presented implying a mutability of the production facilities and the process orchestration. In this transformation, activities are transferred from engineering to the operative field of activity. The adequate support of the employees of the operative production level is ensured by means of a user-centered and interactive IT-system, which contains an automated interaction modelling element. In the following the development of a comprehensive and value-added method for interaction modelling is explained.

The development step of interaction modelling represents a novel content and work step within the established development models. For the classification of the process step, general product life cycle models (such as [31]) – in which interaction modelling can be integrated into the production development phase – or specific factory-related life cycle models [27] can be used. In the VDI4499-2 life cycle model, the step of interaction modelling can be integrated into the life cycle phase of the planning of the production facilities. Figure 1 shows the detailed division of the workload within this phase.

With the introduction within the life cycle of factory development, the essential process interfaces of the newly developed method can be captured. The essential interfaces to the preceding process steps are to be seen in the definition of the production process and the definition of the heterogeneous production participants – including human, machine and IT-related participants.

The port to the following process steps essentially consists of the realization of the actual interaction, the commissioning of the production equipment for the considered process section and the reengineering due to agile requirements. These have a decisive influence on the information outputs of the developed method.

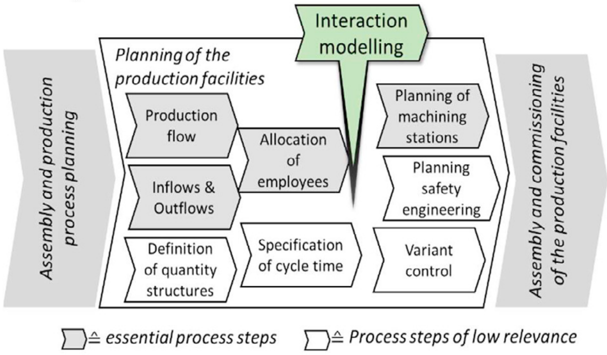

Fig. 1. Integration of the interaction modelling into the life cycle model of the digital factory

The next step in the development of the descriptive method for interaction modelling is to work out the analysis and definition of the main causes of complexity that have an influence on the modelling in the field of heterogeneous participants. The main causes of complexity can be classified into the areas of information flow, information form and information content regarding input into and output from the interaction modelling method.

The main causes of complexity about the flow of information can be seen in various preceding processes from different sources and by different agents. The main causes of complexity of the subsequent processes related to the information flow are mainly due to the large number of possible information users and their different requirements. The main cause of complexity in relation to the form of information is to be found in the variety of different formats and notations in process development. Due to the versatile further use of the method results for interaction modelling in different subsequent processes and software-technical systems, an equally human as well as machine-readable form of the information is to be chosen, in which an essential cause of the form related complexity consists. The reasons for the complexity caused by the content of the information are essentially due to two factors.

Firstly, the flow of information from upstream processes, i.e. passive information acquisition, is insufficient. Information that is transferred from previous process steps is called passive information acquisition; additional information that is required for the method function is defined as active information acquisition.

Adequate interaction pattern formation and allocation requires further information, which is subsequently carried out within the active information acquisition. Regarding content, another cause of complexity is the interpretation of the incoming information, i.e. understanding the incoming information is not trivial and requires a solution strategy [32]. The interpretation of information depending on the specific context is also one of the causes of complexity at the interface of subsequent processes. Due to the broad field of method applications in industrial production, different context information scenarios must be considered. The application context in the following process areas, however, refers equally to the decision-making process in order to be able to create and model an adequate level of interaction - the process is thus self-referential in itself [33].

In the next steps, the incoming information is analyzed and, if necessary, supplemented and prepared. The information content within the passively acquired information is limited to process-related and participant-related information and then transferred into a structured process description, such as UML or BPMN 2.0. Due to the strong reference to the heterogeneous participants in the method development, the structured assignment of the participants and their roles is an essential part within the structured process description. In addition to the process-related information of passive acquisition, two major information deficits are recorded within active information acquisition for concretization. The description of the participants of a potential interaction includes the determination of the participant type (human, machine and service), the production process and individual interaction roles. The context of the interaction determines its design. The boundary conditions within industrial production are potentially fundamentally different. The description of which interaction patterns in the selected concrete application represent possible interactions for problem solving is an important concretization and represents a significant reduction of complexity for the implementation of the method.

The following preparation of all information inputs represents an essential part of the method for interaction modelling. On the one hand, structured participant models and catalogues are created for this purpose, which contain and make skills and requirements or needs of all available participants. On the other hand, the possible interaction patterns are collected in the application context, i.e. in the concrete production scenario. The individual, structured interaction patterns represent the possibilities for interaction between the defined participants. Thus, the patterns act as tools contributing to a high degree to reducing complexity.

The interaction pattern represents necessary information as well as essential characteristics of an individual interaction. The entirety of the interaction patterns is based on a standardized template, resulting in reduced complexity related to the form. The interaction patterns are prepared in a structured, cross-domain catalogue - the so-called interaction pattern catalogue. The catalogue, as the totality of all patterns, thus does not only consist of a loose collection, but rather of a structured representation enriched with data and parameters. The method is developed for interaction modelling between heterogeneous participants and therefore requires holistic, silo-spanning information [34]. The interaction pattern catalogue is a basic source of information and an essential tool for the method's user, which supports and simplifies this holistic problem-solving perspective.

The preparation of the interaction-related content in the developed method refers to the determination of utility and the presentation of possible added values and obstacles from the perspective of the heterogeneous participants involved. This part is designed as a participant and task-related perspective of method-immanent problem solving and is explained in more detail in the description of the Interaction Canvas (Fig. 2).

The synthesis within the method finally merges the one solution-oriented perspective for the evaluation of the added values and obstacles as well as a representation of possible interaction patterns.

The design of the descriptive method development content is completed with the initial information of a proposal for the selection of interaction patterns and their realization. However, an adequate method preparation for the use in interdisciplinary development teams is still missing in addition to the essential causes of complexity. Hence the preparation will be addressed in the method finalization. One part of this step is a flowchart, which will lead the user through the process. The second part is the so named interaction-canvas, which additionally gives the developer team a transparent tool for getting an overview about interactions in the manufacturing process.

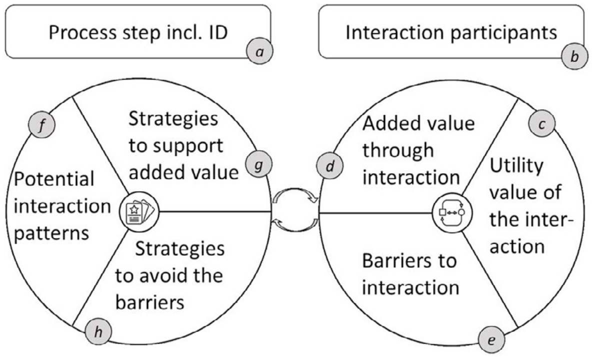

Fig. 2. Interaction-Canvas

The Interaction-Canvas is the final concretization of the development of the value-added method for interaction modelling of heterogeneous participants in production. In a broader sense, the method makes demands on creative modelling and thus has similarities with the tasks in the field of product and business model development. Again, the not adequately defined and agile influences of customers and their needs provide an uncertain basis for decisions. Development in this area are creatively oriented models such as the Business Model Canvas [35] and its specialization on the added value of a product, the Value Proposition Canvas [36].

The canvas is comprised of two main areas:

(a) Allocation to a defined process step in production and assignment of a unique ID (left side)

(b) Identification of the heterogeneous participants involved (right side)

Area *(a)* is detailed by sections *(c)* to *(e)* including the above-mentioned participant and task-oriented perspective of the interaction canvas:

(c) In defining the utility value of interaction, the consideration is not limited to the individual interaction step, but rather includes a space of individual actions that support the utility. The goal of this step is achieved as soon as the benefit of the interaction is recognizable. The extraction of the benefit of a possible interaction to be modelled depends on the participants and the task in the production process that is to be fulfilled by them. Typically, heterogeneous processing teams consisting of experts and users of the different domains or technology silos, a transparent presentation of information and methodical support are essential for creative solution finding in this context.

(d) The analysis is carried out under the boundary conditions and influences of the interaction participants, the interaction benefit and the superordinate process description. As part of the creative process, cross-production process added value can be generated here or the utility values of other sections can be used. The creation of synergies is a direct added value for the respective participants across all participant types. On the human side, additional requests and walking distances as well as cognitive overload [37] are sustainably reduced. On the side of the machines and services there are other requirements. However, these participants also benefit from bundled requests instead of numerous individual requests and, especially in the area of IIoT, from efficient use of the available bandwidths [17].

(e) The obstacles to interaction are strongly context-dependent and sometimes not obvious. The identification of these obstacles is therefore based on the empirical knowledge of the groups of people involved, such as machine operators, process planners, work planners and development engineers. In order to identify obstacles at this point as well as approaches to solutions in the following methodological steps, interdisciplinary teams should be formed, which use established creative techniques in order to avoid encountering only obvious obstacles and solutions. A complementary systematic approach consists in the analysis of participants' lacking skills in interaction execution. Especially in the IIoTSP environment, these missing skills are often related to the technical equipment and communication capabilities of the technical devices. Human-machine interaction forms a further interface which can provide results regarding the obstacles.

Section *(f)* to *(h)* of the interaction canvas represent the solution-oriented perspective of the interaction modelling method and at the same time form the counterparts of section *(c)* to *(e)*.

(f) In this section, the interaction pattern related analysis and synthesis takes place. The basic suitability of the interaction patterns from the interaction pattern catalogue regarding compatibility with the interaction participants is additionally discussed. In the following step, the potential possible interaction patterns are described in relation to the respective application context.

(g) The section of value-added support strategies represents the value-added synthesis performance of the method. This step contains the direct goal-oriented continuation of the previous processing steps, the value-added-related analysis and complexity reduction *(d)*. The value-added orientation has a great influence on the actual application of the method within the process development. In terms of content, strategies and measures are developed which proactively address the support and implementation of the identified added value.

(h) In this section the different requirements, needs and limitations of the heterogeneous participants are initially examined and their influences on the achievement of the objectives of the task are assessed. Furthermore, the obstacle-oriented synthesis, strategies for overcoming the obstacles and the potentially corresponding problems are developed. These strategies can be logical conclusions from the problem analysis, the experience of the process developers, the result of a creative process or from catalogues. The work step thus represents the direct solution level of the preceding processing steps in *(e)*.

In the final synthesis step, the essential goal-oriented contents for the fulfilment of the task are developed. Based on the analyzed added values, obstacles and strategies to support added values and to circumvent the obstacles, a concrete interaction pattern is proposed. By considering the needs of the participants and the requirements of the production process step, this proposal pursues the concrete purpose of the method and maps it proactively.

The second component of the achievement of objectives lies in the transparent decision-making process and the easily interpretable and changeable presentation.

The development of the interaction mapping using the interaction canvas is designed as a creative method for interactive application in interdisciplinary teams. The development takes place in a workshop, in which the different perspectives and experiences of the different participants of the development team can be included. This method actively supports mastering the increasing complexity of interactions between heterogeneous participants within a production network.

For editing the interaction canvas, it is recommended to transfer the basic structure of the canvas to brown paper or a whiteboard and to make the entries for the respective sections using sticky notes. This procedure supports the agile character of the method and allows to bring in all experiences and the whole know-how of the development team.

4. Conclusion & Outlook

The method for modelling the interactions of heterogeneous participants describes a concrete approach to model the interaction between diverse participants in the sense of the Industrial Internet of Things, Services and People, considering individual needs and requirements. The developed procedure model is designed according to the process classification and the derived interface analysis for application in the development of production processes. The method is thus embedded into the engineering process. To achieve the introduced objectives, various analyses and solution-oriented creative processes are carried out within the method, which require a huge amount of work. In classical production scenarios, this effort is incurred only once during development or engineering.

In the future, however, production will follow the scenario of flexible and modular manufacturing [38]. Individual components and modules within the production will flexibly execute different tasks and, if necessary, interact with each other in new ways. Production will follow the perspective of a service-oriented architecture (SOA). In this scenario, constant reengineering is necessary using the established methods [4]. The workload for the continuous adaptation of the interactions to the changed processes, participants and environmental conditions is very high. Consequently, flexible adaptation considering the needs and requirements of participants has been dispensed with so far [28]. In addition, the influence of heterogeneity of different types of participants increases the complexity and the amount of work required for a participant adequate interaction within the paradigm of changeable industrial production. For this purpose, the method for modelling interactions of heterogeneous participants will be transferred from the engineering process to the cycle phase of productive operation. The step-by-step method adaptation will represent an innovative comprehensive approach that contributes to the achievement of the variable production paradigm.

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