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Human-centric, sustainable and resilient optimization of secondary processes in production

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Abstract

Digital assistance systems mainly enhance core processes in production such as assembly. Yet digitalization of secondary processes like error management are often insufficient. This results in manual efforts and complex decision-making for employees. Therefore, optimization of these processes is vital. However, current process digitalization methods neglect Industry 4.0 key objectives: human-centricity, sustainability and resilience. Therefore, this paper presents a method for optimization of secondary processes for digitalization with focus on these three objectives of Industry 4.0. As a result, a guide for an efficient digital transformation of secondary processes in production is established.

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1. Introduction

In Industry 4.0, cyber-physical production systems (CPPS) are enabled by real-time communication and networking to make intelligent decisions with a high degree of autonomy. The aim is to efficiently produce individualized products meeting highest quality standards [1,2]. As a result, the degree and depth of automation and digitalization of automotive production processes increases constantly. This means that employees are progressively confronted with new technological solutions on the shop floor. However, when introducing core Industry 4.0 technologies such as the Industrial Internet of Things, Artificial Intelligence or Big Data Analytics, the primary focus often lies on economic goals. Although automation, digitalization and supporting technologies are increasingly being used in production, there is a consensus that humans will remain an essential part of the production [3]. Nevertheless, humans are still confronted with significantly higher demands in terms of coping with complexity and must have the ability to abstract and solve problems. However, changes in the workplace are placing

significantly higher demands on employees in terms of coping with complexity and the ability to abstract and solve problems [4]. Current challenges such as the increasing shortage of skilled labor, demographic change and the climate crisis are added to these challenges of humans in production. Thus, the principles of Industry 4.0 are reaching their limits.

Especially the necessary integration of people into the paradigm of modern, resource-efficient, and resilient production with close integration into digitalized processes is not taken into account [5]. The use of digital and adaptive assistance solutions is only considered in the core assembly processes. Secondary processes such as error management or quality assurance, on the other hand, have a low level of digitalization [6,7]. As a result, the concept of Industry 4.X is introduced, which is further explained in section 2.1. It focuses on the challenge of a non-human-centric Industry 4.0, especially with regard to secondary processes.

However, secondary processes are essential to enable the setup and machining processes and thus create the basis for adding value. The efficiency and speed of secondary processes are crucial for ensuring efficient assembly. The low level of

digitalization therefore continues to lead to a high level of manual effort and an additional load on employees.

As a result, an assistance system is required to provide digital support in manual secondary processes for assembly employees. However, practical projects show that before digitalization, an optimization of processes is required. This includes improvement from an ergonomic and labor management perspective before information about the secondary process should be digitally mapped in an assistance system. Thus, this paper presents an approach for human-centric, sustainable and resilient optimization of the digitalization of secondary processes in production. To this end, the paper defines the target vision for Industry 4.X and presents a method for potential analysis, which forms the basis for process optimization of secondary processes in production.

2. Related work

2.1. Target vision of Industry 4.X

Industry 4.X is based on the existing paradigm of Industry 4.0 and extends it through a transformation to sustainable, human-centric and digitally resilient production. This includes a responsible digitalization strategy that not only aims to optimize costs or maximize profits but also improves the well-being of all parties involved: Investors, employees, consumers, society and the environment. The key objectives are to increase the human-centricity, sustainability and resilience of assembly [8]. The resulting target vision, including the sub-goals of the target dimensions, is shown in Figure 1.

This trinity of the target vision is important for assembly. However, human-centric design is particularly relevant in final assembly, as people will remain the focus of assembly in the future [3].

According to the DIN standard, EN ISO 9241-210, human-centric design is defined as the "approach to design and development that aims to make interactive systems more usable by focusing on the use of the system and applying knowledge and techniques from the fields of ergonomics and usability" [9]. The consideration of human-centricity as a target dimension in entrepreneurial activities rarely has a direct influence on profitability but has positive effects in the long term [10]. Human-centricity was defined with the following eight sub-goals: freedom from stress, ergonomics, motivation, learning facilitation, usability, needs orientation, user experience and technology acceptance.

Resilience in companies describes the organization's ability to adapt to internal and external changes and disruptions in a volatile economic environment [11]. To strengthen the resilience of individual manufacturing companies, it is necessary to identify potential disruptive factors at an early stage in order to be able to react appropriately to immediate disruptions and learn from these experiences.

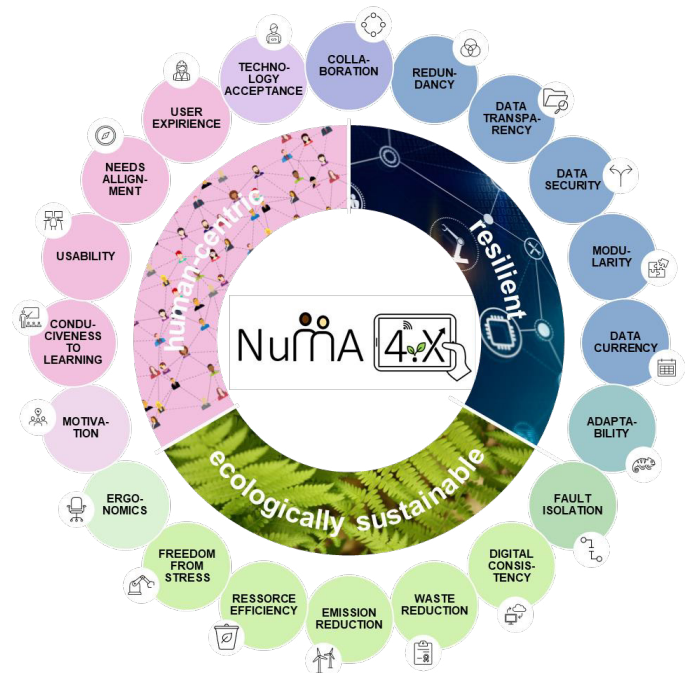


Fig. 1. Target vision of Industry 4.X (NuMA 4.X research project)

Two basic phases can be identified that enable manufacturing companies to manage disruptions effectively: (1) reaction and (2) anticipation [12]. The identified sub-goals of digital resilience are collaboration, redundancy, transparency, data security, modularity, data currency, adaptability, fault isolation, and digital continuity.

Sustainability is becoming increasingly important [13]. The German Federal Ministry for Economic Cooperation and Development defines sustainability or sustainable development as the fulfilment of the needs of the present in such a way that the opportunities of future generations are not restricted. A distinction is made between three dimensions of sustainability: economically efficient, socially just and ecologically viable. Due to the increasing relevance of ecological sustainability in the industry, the focus here is on this in particular. [14]

2.2. Methods and tools for process optimization

Numerous methods and tools exist within process optimization, which are described in various basic literature. The methods have strongly influenced each other and in some cases share common principles and values. Nevertheless, they have different emphases and differ considerably in their approaches and implementation strategies. An overview of methods for process optimization depending on the complexity of the problem and the involvement of employees is provided by HOFMANN [15]. Other methods are for example Continuous Improvement Process (CIP) [15], Kaizen [16], Six Sigma [15], and Business Reengineering [15] (see Figure 2). For a detailed explanation of these methods, please refer to the literature cited. Furthermore, methods can include different tools such as the modelling standards BPMN 2.0, EPK & eEPK or SIPOC [17].

| Methods | Promoting the involvement of employees | Consideration of human-centricity | Consideration of digital resilience | Consideration of ecological sustainability | Applicability for secondary processes of production |
|---|--|-----------------------------------|-------------------------------------|--|---|
| CIP | ● | ◐ | ◐ | ◐ | ◐ |
| Kaizen | ● | ◐ | ◐ | ◐ | ◐ |
| Six Sigma | ◐ | ○ | ○ | ◐ | ○ |
| Business Reengineering | ○ | ◐ | ◐ | ◐ | ○ |
| Lean Management | ◐ | ○ | ◐ | ◐ | ○ |
| Phase model by HOFMANN | ◐ | ◐ | ◐ | ◐ | ◐ |
| Shopfloor optimization by TRIPATHI ET AL. | ◐ | ◐ | ◐ | ○ | ◐ |
| LARG framework by AMJAD ET AL. | ◐ | ◐ | ● | ● | ◐ |

Legend: ○ Not considered ◐ Slightly met ◑ Partly met ● Mostly met ● Validated & fully met

Fig. 2. Evaluation of existing methods for process optimization

These identified methods and tools were examined with regard to the three target criteria of human-centricity, digital resilience and ecological sustainability. They were subsequently analyzed in terms of their suitability for secondary processes, taking into account five main requirements: Employee involvement, human-centricity, digital resilience, environmental sustainability and applicability for secondary processes (see Figure 2). These main requirements are part of a catalog of requirements for methods to optimize secondary processes before digitalization. This catalog is derived from challenges for the optimization of secondary processes, considering the target vision of Industry 4.X.

In practice, however, both methods and tools for process optimization are mainly used for core processes [6]. In particular, they neglect the three target dimensions. To optimize secondary processes in production before their digitalization, there is a need for a method that considers the target vision of Industry 4.X and can be applied to secondary processes at the same time.

3. Process optimization of secondary processes

To digitalize manual processes and utilize assistance systems, it is necessary to analyze the processes' individual potential first. On this basis, processes are optimized and prepared for digitalization.

3.1. Potential analysis

As a first step, a method for an initial potential analysis for process digitalization is required. This is based on the as-is analysis of the secondary processes and the specification of the target vision of Industry 4.X. Figure 3 shows the potential analysis method for process digitalization.

The first step of the method is the *pre-prioritization of processes based on strategic importance* due to the effort involved in process modeling. Next, the *process modelling* of the prioritized secondary processes takes place.

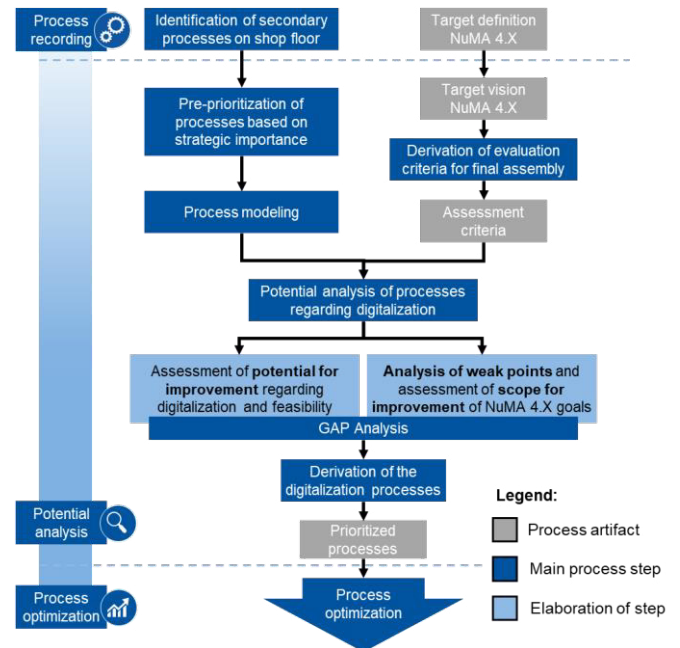


Fig. 3. Potential analysis for process digitalization

This is followed by a detailed assessment of the potential for improvement of the secondary processes in terms of their digitalization and feasibility as part of the actual potential analysis (*Potential analysis of processes regarding digitalization*). To this end, *evaluation criteria* for the potential analysis of the processes are defined in advance based on the target vision of Industry 4.X. As part of the research project, the following evaluation criteria, which were defined with interviews and discussions with experts from the automotive industry, are used to assess process relevance: personnel commitment, repetition frequency, material volume, complexity, and operational significance. These evaluation criteria are weighted in a pairwise comparison with the involvement of representative process participants. Next, the ability to improve the respective secondary processes is evaluated with participants. A weak point analysis is carried out using the process models and a qualitative assessment of

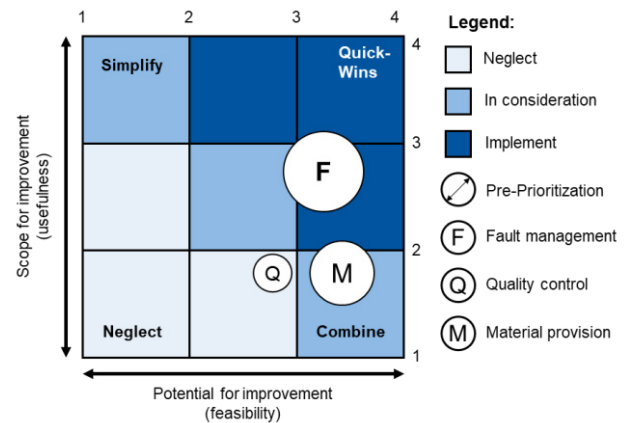


Fig. 4. Portfolio Matrix for secondary processes

the ability and worthiness of improvement using a questionnaire. The aim of this evaluation is to identify the secondary processes with the greatest potential for improvement. This is done as part of a “GAP-Analysis” by directly comparing the individual secondary processes. For this purpose, the secondary processes are classified in a portfolio matrix (see Figure 4) in relation to the previous assessment. As a result, the processes with the greatest potential for improvement are identified and specific actions required for their digitalization are derived.

3.2. Process optimization before digitalization

Building on the method for analyzing the potential of secondary processes regarding their digitalization, a method for optimizing secondary processes is required, that considers the target vision of Industry 4.X. To develop such a method, challenges and requirements for process optimization based on the project content and literature were identified. As RÖGLINGER emphasizes, the resources for digitalization and the associated optimization are limited [18]. This must be considered while developing the method. It was also identified that employees play a decisive role in digitalization and the associated process optimization, as their participation and acceptance are essential for the success of digital initiatives. [19]

Based on this, the consequences of the challenges for the methods of process optimization were derived in the form of a catalog of requirements. For process optimization to be successful, despite limited resources, it must be feasible while maintaining an economically viable cost-benefit ratio. Furthermore, the methods of process optimization must enable the involvement of employees, be practice-oriented, and easy to understand. They must also be applicable to secondary processes in assembly. Table 1 shows an overview of all requirements derived from the challenges.

Table 1. Requirements for methods of process optimization

| No. | Requirements |
|-----|--|
| 1 | Low-effort feasibility of the method |
| 2 | Holistic view of processes |
| 3 | Measurability through clear criteria |
| 4 | Adaptability of the method |
| 5 | Consideration of human-centricity within the method |
| 6 | Consideration of digital resilience within the method |
| 7 | Consideration of ecological sustainability within the method |
| 8 | Promoting the involvement of employees |
| 9 | Practical relevance of the method |
| 10 | Defined presentation of interim results |
| 11 | Applicability for secondary processes in production |

To identify existing methods of process optimization and approaches that consider the target vision of Industry 4.X, a systematic literature search was performed. In addition to the conventional methods of process optimization, the approaches of HOFMANN [13], TRIPATHI ET AL. [20] and AMJAD ET AL. [21] were also identified and examined in this literature search. [20] To identify the deficits of the existing methods, the analyzed

methods were evaluated concerning the fulfilment of the list of requirements for process optimization methods. Figure 4 shows that none of the generally known approaches to process optimization fully meet the requirements. In particular, the requirements regarding the consideration of the target vision of Industry 4.X and the applicability of secondary processes in assembly remain almost unfulfilled. It is therefore clear that a new approach is needed to optimize secondary processes in production before digitalization, considering human-centricity, digital resilience, and ecological sustainability. Based on the identified deficits of existing methods of process optimization, a method for optimizing secondary processes is explained in Section 4.

To implement the method for optimizing secondary processes in production, it is necessary to select the appropriate process optimization tools for the respective process steps. Therefore, a catalog of requirements for process optimization tools was formulated based on the catalog of requirements for process optimization methods. For example, a method can only enable the involvement of employees, if this is made possible by the selected tools. Low-effort feasibility as a requirement for process optimization methods is also directly linked to the effort required to use the process optimization tools. Table 2 shows seven requirements for process optimization. Based on this catalog of requirements, the process optimization tools described by DUMAS (c.f. section 2.2) were evaluated [17]. Similar to the evaluation of the process optimization methods, the fulfillment of the requirements was evaluated qualitatively and the tools for implementing the method were selected on this basis.

Table 2. Requirements for process optimization tools

| No. | Requirements |
|-----|--|
| 1 | Low-effort applicability of the tools |
| 2 | Adaptability of the tools |
| 3 | Consideration of the Industry 4.X target vision by the tools |
| 4 | Participative approach |
| 5 | Practical relevance of the tools |
| 6 | Transparent results |
| 7 | Applicability for secondary processes in production |

4. Method for process optimization before digitalization

As derived in chapter 2, a method is needed that takes into account the target vision of Industry 4.X and can be applied to secondary processes at the same time in order to optimize them before they are digitalized. Therefore, after presenting both the target vision (section 2.1) and the potential analysis (chapter 3), the method for process optimization before digitalization is presented in this chapter.

Figure 5 shows the process model for the concept of process optimization of secondary processes in production before digitalization. The process model considers both the target vision of Industry 4.X and the selection of suitable tools.

The first step in the method for optimizing secondary processes, considering the Industry 4.X target vision, is to review the secondary process and the results of the upstream steps in the digitalization process. The review of these results

leads to a common understanding of the process as a whole, based on which the following steps of the process optimization method are executed.

| Steps of the method for the optimization of production secondary processes taking into account the target vision of Industry 4.X | Tool selection |
|--|-----------------------------|
| 1) Review of the production support process with the greatest digitalization potential, including a list of all weak points | - |
| 2) Weighting of the target dimensions | Pairwise comparison |
| 3) Evaluation of the weak points of the selected process | Process-FMEA |
| 4) Identification of the requirements of the process participants and internal process customers | User Stories |
| 5) Root cause analysis of the most critical weakness | Ishikawa diagram |
| 6) Development of improvement measures for the identified causes | Ishikawa diagram & LPI |
| 7) Evaluation of the improvement measures | Effort-benefit matrix |
| 8) Derivation and documentation of the target process | Process profiles & BPMN 2.0 |
| 9) Evaluation of the success of the optimization through the weak point assessment | Process-FMEA |

Fig. 5. Optimizing secondary processes before digitalization

The subsequent weighting (Step 2) of the target dimensions within the method serves to record the individual preferences of the users of the method. The use of pairwise comparison enables a participatory but low-effort approach. This allows the weighting to be determined as input for the subsequent steps of the method.

Once the target dimensions have been weighted, the weak points, identified by the method for assessing the process digitalization potential, are evaluated in terms of their relevance (Step 3). This step is essential to ensure that the method meets the requirement of low-effort implementation, as the evaluation of the weak points is used to prioritize their solution. Through the process FMEA, a prioritization of the elements and thus the goal of this step of the method is achieved. The process FMEA procedure also ensures a participatory approach and enables the consideration of the target vision of Industry 4.X as a whole.

Following the evaluation and selection of weak points, the requirements of the process participants and internal process customers for the target process are recorded (Step 4). Internal process customers are persons or departments that use the results of previous phases of the process as input and process them further. The task of the representatives is to ensure that the perspective of the stakeholder group is considered. This allows to further detail the target vision of the optimization. Furthermore, the recording of requirements also serves to support the development and evaluation of improvement measures in later steps, as the recorded requirements are used as a guideline. User stories are particularly suitable for carrying out this step of the method. Compared to other process optimization tools, these are very participative and less time-consuming. User stories allow the requirements for the target process to be recorded in a human-centric manner.

Once the requirements of the process participants and internal process customers have been recorded, the root cause analysis of the weaknesses identified as critical is executed (Step 5). In cooperation with the method users, all causes for weakness are identified and their impact is evaluated. The Ishikawa diagram, or cause-and-effect diagram, was selected to carry out this step of the method. This selection ensures that employees are involved, and that the method is implemented with little effort, as the Ishikawa diagram ensures that the real causes and not only symptoms are considered.

Based on the identified causes, improvement measures are developed in the next step of the method for optimizing secondary processes in production, considering the Industry 4.X target vision (Step 6). To promote acceptance of the improvement measures and the entire optimization project, the derivation of the improvement measures must be documented in a transparent and easily understandable manner. This requires a systematic collection and description of the developed improvement measures, which also serves as the basis for the subsequent evaluation of the improvement measures. Brainstorming and expert interviews allow all participants to suggest ideas, which improves the process of finding solutions. To systematize brainstorming, it is combined with the use of the Ishikawa diagram in which the results are recorded. The list of potential improvements (LPI) provides systematic guidance for documenting the improvement measures developed and is therefore used in parallel.

Regarding the development of the improvement measures, these must be evaluated in terms of their benefit and effort. Based on the evaluation of the improvement measures (Step 7), the measures to be implemented are selected at the end of this step. In this selection, the benefits of the improvement measures are set concerning the effort required to implement them. The participatory approach of the effort-benefit matrix is selected to increase the acceptance of the developed improvement measures and promote the transparency of the results. It is based entirely on the assessment of the employees. By involving all those involved in the optimization, especially those responsible for implementation, the valid assessment of the effort-benefit ratio is ensured. The effort-benefit matrix enables a comparison of the improvement measures, based on which a decision is made as to which measures should be implemented and in what order.

Once the improvement measures have been selected, they must be implemented in a target process. The implementation serves to achieve a common understanding of the changes in the target process on basis of the improvement measures. All members of the optimization team are involved to ensure that changes are transparent and the communication of changes is coordinated and easy to understand. As BPMN 2.0 is a widely used modelling standard, it is used in the documentation of the target process (Step 8). The possibility of a direct comparison of the status-quo and the desired state promotes acceptance of the optimization measures, as the changes are transparent.

After the target process has been documented in detail, it is used to evaluate the success of the optimization (Step 9). This step serves to check the extent of the optimization and serves

as a basis for the decision to iterate the method. To ensure that the developed method can meet the measurability requirement through clear criteria, the same application of the process FMEA is chosen to evaluate the optimization success as in the step of evaluating the weak points of the selected process.

5. Conclusion

The advancement of Industry 4.0 has revolutionized production systems, paving the way for CPPS that are capable of autonomous decision-making. However, the relentless pursuit of economic goals often overshadows the human element in this paradigm shift. The integration of operators into digitally transformed processes is crucial for sustainable and resilient production systems. Despite significant strides in automation and digitalization, secondary processes in production, particularly in fault management and quality assurance, lag in digitalization. This results in undue manual efforts and an increased burden on employees. Addressing these challenges necessitates a human-centric approach to digitalization, focusing on sustainability and resilience. Industry 4.X outlines a target vision emphasizing human-centricity, digital resilience, and ecological sustainability, pivotal for the evolution of assembly processes. It underscores the importance of considering the well-being of all stakeholders and the environment in digitalization efforts.

In conclusion, the envisioned method for optimizing secondary processes represents a significant step towards achieving the target vision of Industry 4.X. By prioritizing human-centricity, digital resilience, and ecological sustainability, it aims to foster these aspects in production systems, aligning with the evolving demands of the automotive industry and broader societal goals. Thus, the presented approach contributes to a human-centric, sustainable and resilient optimization of the digitalization of secondary processes in production and can be transferred to other industries. Despite the method's potentially diverse range of applications, it should be noted that it can also be used in a modified or updated form due to the wide range of methods and tools it contains. Next steps should aim to validate this method in practice.

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