Development of a Human-Centered Implementation Strategy for Industry 4.0 Exemplified by Digital Shopfloor Management

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Abstract. Existing implementation strategies for Industry 4.0 and Digital Shopfloor Management often focus on technology. This is accompanied by a lack of transparency regarding production processes and information structures, often preventing decentralised decision-making by employees. Thus, the implementation of I4.0 requires a socio-technical implementation approach that takes human, technology and organization into account.

This work presents a model to implement Industry 4.0 combining the dimensions of people, technology and organization. The approach supports companies in adapting their socio-technical work system to include digitalisation. Taking the example of Digital Shopfloor Management, a socio-technical implementation strategy is developed and associated acceptance methods are derived. This procedure ensures that the potential of Industry 4.0 can be achieved and implemented with the help of a socio-technical approach.

Keywords: Human-centered I4.0 · Industry 4.0 · Socio-technical industry 4.0

1 Introduction

Ten years after its introduction, Industry 4.0 (I4.0) is increasingly established in manufacturing companies. According to Bitkom, 62% of companies already using I4.0, but two thirds of the surveyed companies understand themselves as late-adaptors with many potential of increasing use of I4.0 [1]. Exploiting the potential of I4.0 can be improved if initiatives are accompanied by a suitable development of the organization and a human-centered design [2, 3].

Liebrecht's approach of I4.0 implementation strategies, which serves as a baseline, is an important scientific contribution, as it outlines technological, company-specific implementation paths for I4.0 [4]. However, to ensure that these I4.0 implementation paths are sustainable and also met with high acceptance among employees, it is important to consider their ideas, wishes, but also fears and concerns throughout the entire I4.0 implementation project. Satisfied and motivated employees are an important competitive factor, so that human-centered implementation can be a key success factor [5].

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This paper expands Liebrecht's approach [4] to a human-centered target system and acceptance measures to develop an human-centered I4.0-implementation approach. In Sect. 2 existing research are explained before Sect. 3 presents a first idea of the human-centered implementation model of I4.0, which already has developed. Finally the success of the approach is discussed, based on a first application in Sect. 4 and further research work is explained in Sect. 5.

2 State of the Art

A socio-technical approach, therefore, considers the changes of I4.0 as a combination of changes in the domains of human, technology and organization [6–8]. A significant part of the available research provides concrete tools for a technology-oriented implementation of I4.0. They focus maturity models [9, 10], self-checks to identify the potential of I4.0 in companies [11, 12] or methods to identify suitable use-cases from a I4.0-toolbox [4] like Liebrecht. His approach enables a selection of I4.0-methods based on the potential in production key performance indicators. The selected I4.0-methods determines the technological roadmap based on prerequisites and interactions between I4.0 methods. Conclusions about the impact of Industry 4.0 on employees and the organization are rarely discussed in such research [11]. Additionally acceptance methods to increase employee satisfaction, motivation and participation are often not considered, even though they are essential for a successful I4.0 implementation. Supportive methods, i.e. a transparent and informative change management are decisive for a sustainable use and acceptance of I4.0 [13].

Existing acceptance models explain how change processes affect the employee. Few models use a socio-technical approach to define acceptance [13–16]. In this case acceptance is the interaction between a subject (e.g. the employee) and an object (the new technology) in a certain context (e.g. the culture of company) [14]. Therefore, acceptance is not only related to a specific technology, but is an essential factor in the entire I4.0 project and is not exclusively determined by the technology, but also by the conditions in the company, such as the willingness to change or the innovation competence of the employees. Other models describe how acceptance depends on the characteristics of certain types of people [17]. The use of specific acceptance methods are an essential part of a change management process. The aim of change management is to transform the attitude of employees towards a change (e.g. a new technology), from rejection to acceptance, or to maintain an existing acceptance [13, 18]. In case of an active acceptance the employees participate actively in the design or development of the I4.0 implementation project [13]. Levin divides the change process into three phases of change [19]. In different phases, different acceptance methods are relevant. The first phase is the "Unfreeze", which focuses on information and attitude [19]. Followed by the "Change", which focuses on participation and explaining [19]. After the implementation of a new technology the last phase, the "Refreeze", focuses on feedback and continuous improvement to maintain a high level of acceptance [13].

Industry 4.0 has been researched from an implementation perspective, with models that reflect technological dependencies [4, 9, 10, 12], and an acceptance perspective, describing the effects of I4.0 implementations on employees [13] or required skills for

I4.0 change management [17]. Hence, there is a lack of a human-centered implementation model that takes into account human, organization and technology and, thus, combines acceptance models, target systems, interactions between I4.0-methods and acceptance methods and necessary changes in the internal organization. To fit the idea of a step-by-step approach, control point, so-called implementation gates (IG), are required. At this IGs, the further steps in the implementation of I4.0 and the appropriate acceptance methods are determined according to the results of a situation and potential analysis, which determine the company's readiness for I4.0 and the success of a human-centered I4.0-implementation.

3 Human-Centered, Step-By-Step I4.0 Implementation

The procedure being developed (Fig. 1) is similar to quality gates in a development process [20]. I4.0 implementation means an implementation of a selected set of different I4.0-methods and their prerequisites. At regular points at the beginning and during implementation, progress is reviewed with a human-centered target system and a situation and potential analysis. At these implementation gates (IG) the necessary technological, organizational and human readiness level for the continuation of the I4.0 implementation is determined.

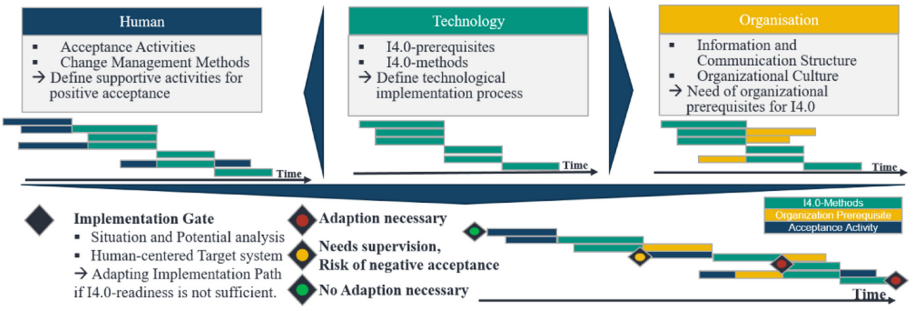

Fig. 1. Approach of human-centered, step-by-step I4.0-implementation, which regard an I4.0-implementation as interaction of human, technology and organisation

Based on Liebrechts approach the relevant I4.0-methods are selected [4]. The selected I4.0-potential methods determine the prerequisite baseline and related I4.0-methods to be implemented previously, which form the initial and technological implementation process [4]. Before the implementation process starts, the initial situation and potential analysis is performed in IG0. In this IG0 the readiness for the implementation of the selected I4.0-methods is evaluated in human, organization and technology. Result of this analysis in IG0 is an I4.0 roadmap completed with necessary organizational and acceptance methods. For a successful implementation of some I4.0-methods there is a need of adapting the organizational structure of the company [11]. The organizational readiness determines the successful progress of predetermined organizational factors [11], which are described in the I4.0-profiles of Liebrecht [4]. If the determined organizational readiness does not fit the organizational prerequisites of the first methods, the implementation

process therefore must be modified with special organizational methods like decentral communication structure, standardized information flow or even a decentral organizational structure. Based on the I4.0-method profile about suitable acceptance methods of the I4.0-methods and the willingness to change of employees the implementation process is completed with the relevant acceptance methods. Finally, the defined implementation process is structured with further Implementation Gates, to fulfill the requirement of a step-by-step approach with recursive evaluation of employee acceptance and the ongoing readiness for the implementation of the further and selected I4.0-methods. The whole implementation process can be structured into individual milestones (e.g., the completed implementation of selected I 4.0-methods) or, in the simplest form, into time intervals (e.g., quarterly).

To evaluate the progress of implementation and the next steps the situation and potential analysis is used at each IG to reevaluate the readiness of I4.0 as well as the acceptance of the I4.0-project. If the analysis detects deficits, the implementation sequence between the actual IG and the following IG will be modify with organizational, technological I4.0-methods or/and acceptance methods. Aim of the analysis in the human domain is the evaluation of the the success of the applied acceptance methods. Therefore a target systems (Fig. 2) is first defined. As shown in Fig. 2, this target system focuses on employee productivity, which has a decisive influence on the production targets of time, costs, quality and flexibility. Target figures like satisfaction, acceptance, self-organization and ergonomics have a high impact on the employee productivity [21]. Employee participation during the implementation process has a decisive effect on the four target figures. Satisfaction is primarily influenced by motivation, while acceptance is driven by explainability and privacy. Usability has a decisive influence on ergonomics and, together with employee integration, automation and transparency, a strong influence on employee self-organization [22].

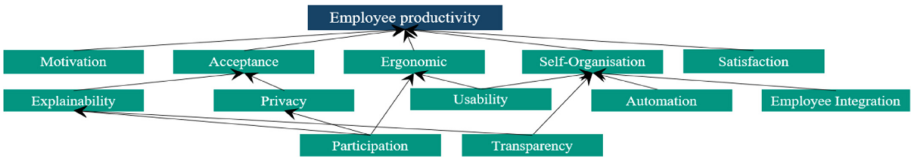

Fig. 2. Human-centered target system for the evaluation of implementation success

All individual targets correspond to the feelings of employees and, therefore, are suitable to evaluate the I4.0 implementation with a human-centered perspective. Because of the recurring evaluation, a trend in the target system can be determined. This allows conclusions about the success of the acceptance methods which have already been implemented. For evaluation, the employees are surveyed during implementation each week with short and standardized item-test [23]. Hence, the surveyed employees do not directly evaluate the target variable, but instead individual items, which describe the target variable. Based on the NASA TLX [24] and the model of Van de Lan [25] psychological items for each target variable are defined. These items are used in the questionnaires to evaluate the acceptance of employees during the I4.0-project. The items surveyed differ across questionnaires, but are later asked again, allowing us to determine a trend in each

of the target variables. The employees rate each item from 1 (no agreement) to 4 (strong agreement). Since such employee surveys are often prevented by a staff council, the evaluation can also be carried out by few managers or the project manager. However, a manager can only assess the target variables on behalf of their staff, which is why this should be avoided as an independent evaluation form. If during the implementation the satisfaction declines due to a low level of participation, more acceptance methods in employee participation must be used. Otherwise a lack in transparency could be solved with more acceptance methods of information.

To match suitable acceptance methods with I4.0-methods, all defined I4.0-methods of Liebrecht are complemented with perception indicators that indicate how the methods are perceived by employees. These indicators were developed with the help of interviews and workshops with experts, employees and managers. Especially from the negative perception, important acceptance factors can be derived for suitable acceptance methods before, during and after the implementation. For a straightforward selection of suitable acceptance methods, these are also described in a standardized manner (Fig. 3). These profiles explain the acceptance method as well as their mode of action, their applications and their usability in the phases of change management.

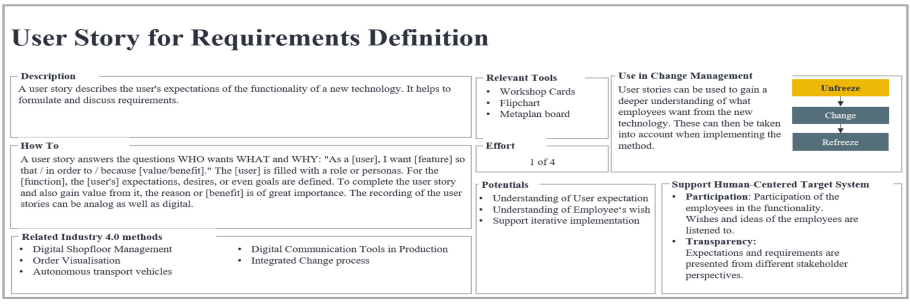

Fig. 3. Example of a description of an acceptance method profile

Suitable acceptance methods for the next implementation steps are selected at the implementation gate (IG). These IG's represent milestones during the implementation where the success of the I4.0-implementation is determined and the next steps for achieving the envisioned I4.0-vision are derived.

4 Practical Application – First Insights

The presented method is currently being developed and piloted with a manufacturing company. The company implements a digital shopfloor management (dSFM), which is part of the company specific I4.0-vision. Therefore, in September 2020 an initial situation and potential analysis of the human-centered implementation approach was conducted. Due to the large barriers of an employee survey, this was carried out in a 2-day workshop. The participants were 1 production manager, 2 department managers, 3 team leaders and 6 employees. The organizational and technological readiness were evaluated during a

workshop. For each defined prerequisites of dSFM the defined Implementation Level [4] which define how far a specific method is already implemented, was evaluated. Each I4.0-prerequisite was linked to one of the fore topics in the technological readiness and the Implementation Levels were summed up. The organizational readiness was evaluated by the opinions of the participated experts in the Workshop. Liebrechts defined I4.0-method profiles show for each method organizational prerequisites. These defined organizational prerequisites were the basis for the discussion to define the organizational readiness in qualitative manner.

The evaluation of the Human Readiness were more quantitative and based on the items in the surveys of the human-centered target system. To evaluate the I4.0-competence a second questionnaire was used. Over a period of one week, various competencies were surveyed, with employees having to state whether they possess them and how relevant they are. In addition, interviews were conducted to determine the experience with I4.0 and change projects. After the presentation of the results the experts again rate the readiness level of each topic in the domain Human.

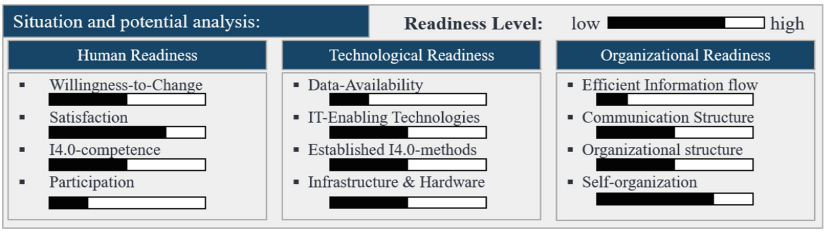

Fig. 4. Simplified results of situation and potential analysis before implementation (IG0)

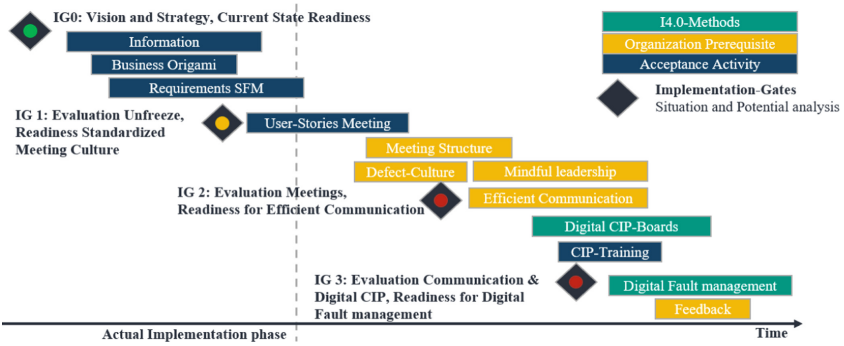

Fig. 5. Adapted human-centred, step-by-step implementation process of dSFM for the first year

Figure 4 shows the result of the analysis at IG0. It shows a high level of I4.0-affinity of employees. A large proportion of participants in the survey see potential in Industry 4.0 for a higher degree of autonomy as well as more flexible and simplified work. This suggests that the surveyed employees increasingly perceive I4.0 as an opportunity and less as a threat. With regard to the willingness to change, it was identified that in the

past not all employees were included in the change processes and that some decisions were confronted with a high level of skepticism or implementations were unsuccessful. Therefore, it is important to inform employees sufficiently and to involve them in the actual change process of I4.0-implementation. The analysis of the technological readiness shows that performance data is recorded, but mainly manually and sporadically. All manual assembly stations are not equipped with sensor-technology or production data acquisition. The experts initially rated the level of organizational readiness as sufficient, but the detailed analysis shows deficits in standardized information flows and communication structures. Therefore, the implementation process was supplemented by standardized information flows and meeting structures (Fig. 5).

5 Discussion and Outlook

Necessary acceptance measures depend to a large extent on the employee groups found in the company. Therefore, the individual acceptance measures must be assigned to these groups and the situation and potential analysis must be supplemented by a methodology for determining the employee groups found in the company.

Ultimately, the human-oriented implementation procedure presented in this work represents an important basis for the further development of I4.0-implementation strategies. In future Work the mostly qualitative approach should be transformed into a measurable approach. Therefore a maturity model for the organizational prerequisites of I4.0 should be developed and be transferred in a standardized questionnaire to enable a quantitative evaluation of I4.0-readiness. In addition the measurement of the human-oriented target system should be evaluated in an additional practical use-case.

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