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Modular, Digital Shopfloor Management Model – A Maturity Assessment For A Human-Oriented Transformation Process

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Abstract

Currently digitization and Industry 4.0 are some of the most important trends influencing production processes and companies. In a lot of companies Shopfloor Management (SFM) is used to manage production and sustain as well as grow a strategic leadership through lean and efficient processes. Its main goal is to bring focus back to the shopfloor, where value-adding processes are performed, and to increase the connection between managers and shopfloor workers. In light of the aforementioned trend towards continued digitization, this produces a field of tension in which a trend enabling increasingly remote control of production through new digital solutions meets a principle focusing on being on site as well as intensive communication. Combing both aspects can prove to be complex as can be seen by studies showing a wide distribution of SFM in a selection of German production companies, but with exceptionally low usage of digital technology.

A significant cause of this is the overwhelming number of possible aspects of Industry 4.0 increasing the difficulty of selecting manageable ideas, aggravated by a lack of integration of necessary employee and organizational change. Purpose of this paper is, therefore, to propose a theoretical basis for a digitization of SFM through the development of a model including disjunct aspects of SFM as well as a maturity index providing a means to discern different levels of digital solutions. To provide a practical viewpoint in addition to the theoretical basis, concrete SFM methods are collected and mapped to fitting areas as well as maturity levels of the underlying model. Additionally, a two-step questionnaire is conceived to allow for a selective proposition of said methods to derive an implementation sequence. All aspects of the approach are finally validated with an example company.

Keywords

Digital Shopfloor Management; Lean Leadership; Human-oriented Shopfloor Management

1. Introduction and Motivation

Current trends like globalization, individualization and shorter product life-cycle times are causing qualities like adaptability and flexibility to become more and more important [1]. Highly efficient and flexible production systems with a flexible organisation as well as satisfied and motivated employees are required. However, in a survey conducted by Staufen AG in 2019, 70% of companies state that changes are predominantly imposed from above and only 43% of respondents state that their organizational structures are designed to be flexible and changeable [2]. This contradicts the vision of decentralized design and optimization as well as changeable companies and at the same time leads to a low acceptance of the methods used in the production system [3]. Technology is thus no longer the limiting factor, but human mutability [1]. Besides technological changes such as plug-and-produce or self-organized production, Shopfloor Management (SFM), hence, is a key enabler of a flexible and adaptable company, for example through allowing increased transparency on the shopfloor [4]. In particular, it supports short-cycle decisions that are associated with organizational and human adaptability.

Because of the progressive digitization and increasing implementation of Industry 4.0 the concept of SFM faces a large number of changes, creating new potentials. These are, however, often accompanied by concerns of employees [5]. At the same time, digital networks also possess inherent risks for example in the form of data security, long latency periods and information overload [6]. Additionally, due to the many ways in which Industry 4.0 is currently affecting companies, it must be analysed how SFM can be meaningfully expanded through digitization in order to promote decentralized decisions in production [7,8].

The goal of this paper is to provide an approach to combine Industry 4.0 and SFM including all affected dimensions (technological, human and organizational) in change. Therefore, in section 2 available literature concerning a theoretical basis for the digitization of SFM is analysed. Based on the existing models the modular digital SFM model including a maturity index is presented in sections 3.1 and 3.2. To expand the theoretical view towards a real-world application, concrete digital methods are then added in section 3.3. To allow for a further customization of the implementation process a two-step questionnaire is presented in section 3.4 enabling the allocation of a company within the theoretical model and deriving suitable steps towards increasing the digital maturity level. In section 4 the approach is exemplary applied to a production company and given recommendations for a digital SFM transformation are shown. Finally, the approach is discussed and potential for future research is shown.

2. State of the art

In order to allow for a structured evaluation of available research towards (digital) SFM as well as implementation approaches, a set of criteria is defined as a first step. The first one is the availability of a method tool box (C1). This is necessary to narrow down the immense amount of possible solutions within Industry 4.0 and build a basis for a concrete plan of steps to integrate digital solutions into SFM [9]. This also allows to fully integrate the peculiarity of digital change processes. The second criterion is the integration of concrete aid towards implementation of (digital) methods (C2). As mentioned before, digital solutions not only come with technical challenges, but implementation also has to consider organizational as well as human challenges, which ought to be considered to fulfil C2 [10]. Criterion C3, the availability of an assessment (tool), aims a supplying a means to generate a, as much as possible, reproduceable strategy towards implementation for companies instead of being limited to a theoretical view. Approaches should also incorporate a multi-level maturity index (C4). This allows to separate different levels of digital solutions whilst still placing them along a linear guideline steering the digitization [11].

The first type of identified literature are analogue SFM models. An exemplary approach is provided by Kiyoshi Suzaki, which describes an extensive basis for the transformation of a company from a "traditional" way of management to a "modern" SFM [12]. By using examples and experiences a simple implementation approach is provided. He, however, only describes the change necessary for each single aspect of production as well as the ideal result, whereas a concrete implementation strategy is only slightly addressed. Another comparable approach is chosen by [13]. In addition to both an overview over methods of SFM as well as detailed explanation for each aspect, Conrad et al. also facilitate a concrete SFM implementation by embedding the methods in a step-based implementation strategy with clear instructions. As a further aid multiple concrete design examples of different methods are given to be used as inspiration for custom implementations. All approaches, however, lack an integration of digital change in SFM. All of the identified approaches for analogue SFM mainly address C1 and C2 by providing different (analogue) methods to implement SFM as well as addressing necessary changes in the human and organizational perspective. None, however, feature an assessment tool or, due to their analogue focus, a maturity index.

The second type of identified literature addresses digital SFM. These can be divided into approaches being based on analogue models as well as newly developed models. Brenner, for example, starts off with a description of analogue SFM [14]. He then uses these parts as an agenda to demonstrate different exemplary ways to digitize processes. A similar approach is chosen by Meißner et al. [15,16]. Building upon their existing SFM model, they first define a target state and thereby enhance the analogue model with digital aspects that support and ease the use of it. Additionally, they propose traditional change management models for strategic change combined with tailored recommendations as a way to introduce digitalization to the shopfloor. A different approach is chosen by [17] as well as [18]. Instead of starting with an existing SFM model, Rauch et al. develop a description of a final goal stage concerning the digital abilities for SFM [17]. They then describe the different methods having to be implemented to achieve the final state. Bock et al. [18] also design their approach without an analogue model, but instead define four different maturity levels for digital SFM ranging from analogue to autonomous. Instead of proposing defined steps for achieving the target state, they offer an extensive description for them. This in turn allows them to be used as a form of vision, for which to achieve individual steps need to be taken (like different software modules or functions). Most of the identified approaches not only address technical challenges, but integrate all necessary aspects with few authors also defining (basic) maturity indexes (e.g. [4]). Similarly, only a minority of the identified literature offers concrete methods for achieving the proposed visions (C1) and in turn also assessment tools to derive methods to be implemented (C3).

A third type of relevant literature like the works of Liebrecht et al. [19] and the practical framework for SFM implementation by Hartner et al. [6] are about implementation procedures for digital solutions. As can be seen by the recommendation of [16] to implement digital SFM with strategic change management methods, digitization often means fundamental change for employees and companies in general. As [8] mention, technical changes are often more advanced compared to social and organisational change processes. To overcome this inequality, they propose an iterative framework for implementing dSFM integrating the technical, organization and human dimension. They thereby add a human-centered perspective to the predominating technical views of digital SFM. All approaches in this area, however, lack concrete methods for SFM and only propose general digital methods, if at all (C1). Yet, they sometimes offer maturity indexes (like [11]) and mostly address the necessary change in the organizational as well as human dimension (C4 and C2)

As can be seen in Figure 1, there is no current research activity towards a complete approach fulfilling all defined criteria and enabling a step-by-step processes to digitize SFM based on giving concrete method recommendations. Therefore, we present a modular SFM model, which supports decentralized decisions like process optimization or short-time production steering. This model includes maturity index as well as a toolbox that presents dSFM methods for each level of a digital SFM, combining the theoretical viewpoint given with the underlying model with real-world application through concrete methods, that can be implemented in companies. The approach is further enhanced in regards to real-world applicability by a human-oriented dSFM maturity assessment, which calculates the actual stage of dSFM in a company and therefore determines an individual development process for the company towards a target dSFM-stage based on the proposed methods located in the theoretical model.

● Fully fulfilled

◑ Partially

○ Not fulfilled

Criteria \ Research Approaches	[12]: Suzaki	[13]: Conrad et al.	[14]: Brenner	[15], [16]: Meißner et al.	[17]: Rauch et al.	[18]: Bock et al.	[4]: Lanza et al.	[19]: Liebrecht et al.	[6]: Hartner et al.	[8]: Kandler et al.	[11]: Schuh et al.
Method tool box (C1)	◑	◑	●	◑	●	◑	◑	◑	◑	◑	◑
Concrete aid towards implementation (C2)	●	◑	◑	◑	○	○	◑	●	○	●	◑
Assessment tool (C3)	○	○	○	●	○	○	○	○	○	◑	○
Multi-level maturity index (C4)	○	○	○	○	○	●	●	○	○	○	●

Figure 1: Overview of identified literature (Picture by authors)

3. Methodology

3.1 Development of the underlying model

As suitable model is the necessary basis for the assessment of the current state as well as the vision and, thereby, allows to derive the next steps towards improving maturity [20]. However, as can be seen in the previous chapter, many theoretical models only feature a limited scope, either missing human and /or organizational perspective or only partially addressing the challenges stemming from digitization of SFM.

Therefore, the initial step towards conceiving an approach for achieving digital SFM is the development of an adequate model. For this, the concept of SFM by [4] is used as a basis to be evolved. Analogue SFM already is not only a collection of methods to be implemented, but also includes a wider view with fundamental change to organizational structure enabling necessary change for successful SFM processes [12]. Additionally, the human perspective also plays a big part for achieving a functioning SFM as well as digitization in general [21,22]. Both perspectives are already rudimentarily featured in the underlying model by [4]. It is, however, lacking the integration of digital aspects at its core. To address this and following the approach by [19], all six areas are separated into "enabler"- as well as "potential"-categories. The enablers include areas allowing new potentials to be achieved, whereas the "potentials" offer a competitive advantage when implemented. Accurate data is the basis not only of digitization, but also of analogue SFM [23,12]. When digitizing data, however, many aspects have to be considered like data security, the distribution of automatic vs. manual data collection as well as efficient storage [24–26]. These aspects are integrated into the model by adding the separate **data** area. Another important enabler-area is **IT-enablers**, which contains the technical basis of digitization. This also has to be integrated separately as there are many different possibilities of achieving for example widespread networking of digital systems. Yet, old infrastructure, varying standards etc. can pose big risks for safety, scalability or other important future success factors [9,15]. The last enabling area is **Key Performance Indicators** or **KPI** which is already used by [4]. These provide the main instrument to achieve transparency on the shopfloor, an important aspect allowing all employees to participate and ease the identification of malfunctions [27,12]. In the developed model, the define the gateway between data and usable information for the potential areas.

To keep the model compact, for the "potential"-categories, some of the dimensions of the model of [4] are grouped together. One area is thus defined by combining **Meetings & Knowledge Exchange**. Meetings play an important role in structuring communication and as a basis for other processes in SFM [4,12]. The digitization of this area has to be carefully balanced to not lose focus on the shopfloor for example by employing digital meetings to replace regular presence [6]. To allow for the integration of all employees in SFM, a continued qualification and exchange of knowledge is necessary [13,12]. This will also play a big role in successful digitization and offers vast possibilities through digital evolvement [28,29]. The area of **Measures & Problem-Solving** integrates another important part of SFM. Through continuous identification and solving of problems and realizing improvement potentials in production processes, its efficiency can be increased. This plays an important role in the ability of SFM to secure and increase competitive advantage. Through new possibilities of data processing etc. in this area, these processes can be significantly enhanced, but also face problems through a risk of lacking integration of employees in automatic processes and therefore declining readiness in participating in continuous production improvement [14]. Participation of employees however will also play an important role in future problem solving [30]. The last area of the model is defined as **Resource Control**.

As described by Ganschar et al., the human will still be the centre of the modern fabric [31]. Thus, employee perspective acts as a base for the model, being represented by necessary qualifications as well as acceptance. To fully reflect necessary changes in the organizational dimension, the model is supplemented by the areas of organizational guidelines as well as lean leadership. The complete model with all areas and dimensions (see 3.3) can be seen in Figure 2.

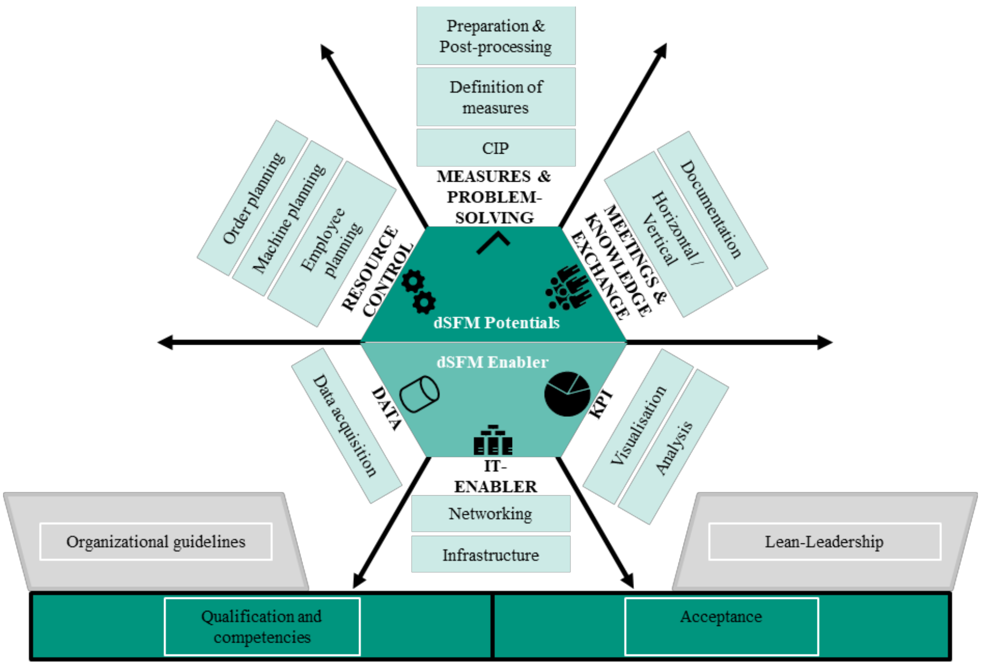

Figure 2: Developed SFM model already with dimensions described in 3.3 (Picture by authors)

3.2 Development of a digital SFM Maturity Model

As an addition to the developed model, a suitable maturity index is conceived, which is based on the study of [4]. The matrix by [4] containing the three criteria (I4.0 levels as defined by [11], real-time capabilities and level from analogue to automated) is thus transformed into a linear model. Therefore, the basic distinction between analogue, digital and automated is used and slightly renamed. Since certain methods warranted a closer distinction between digital and analogue, a fourth level called "digitized" is introduced to form the final maturity index [15]. "Analogue" includes methods without any kind of digital support, whereas "digitized" is mostly used for methods with basic digital support (like digital lists). "Digital /

connected” includes methods with complex digital support and connective features, but only “smart / autonomous” contains methods with extensive digital support, where algorithms etc. gain partial decision competence and / or forms of intellect.

3.3 Collection and allocation of concrete (digital) SFM methods

SFM according to the definition by Liebrecht et al. is an independent method or management tool [32], whereas in the context of the Lean-Philosophy SFM is described as an understanding of leadership [23]. Addressing the inhomogeneous definition of SFM and to address criterion C1 a major structured literature search is performed to identify existing methods of (digital) SFM. The research is focusing on already existing methods for the SFM but includes ideas and visions as well. Therefore, the identified methods range from being widely implemented already in lean companies (like Shopfloor Boards used to visualize KPI’s [23]) to being highly innovative and thus not having been implemented in most companies yet, like trend analytics to predict deviations of KPI’s [9]. A complete overview of all identified methods can be seen in Figure 3.

Maturity Index: Analogue Digitized Digital/Connected Smart/Autonomous

Method Category	Assigned digital Shopfloor Management Methods		
DATA (16 Methods)	Analog acquisition of process data Creation of analogue system information Creation of analogue tool information Data collection, design and classifying Data security of machines and systems Cyber protection of stored data	Digital acquisition of process data Creation of digital system information Creation of digital tool information Central availability of data Business intelligence solutions Resource localization and tracking	Availability of real-time data Wearables Acquisition via mobile app Data Mining
IT-ENABLER (12 Methods)	Enterprise Resource Planning Clear and unique proofs of identity Integration of existing production facilities Manufacturing Execution System	Shopfloor Operating System Object identification Future-oriented communication networks Cyber-physical systems	Intelligent data collection Server Homogenization of communication protocols Mobile devices
KEY PERFORMANCE INDICATORS (KPI) (19 Methods)	Shopfloor Board KPI Charts (SQCDP) Drilldown Bottleneck walk display KPI design and classification Needs-based information through filtering	Digital Shopfloor Board Value stream-based KPI display Digital Drilldown Virtual image of production Digital visualization of machine states Live-Sankey-Diagram Andon Boards	KPI via mobile app Automatic target-performance comparison Adaptive visualization on the Shopfloor Board Adaptive visualization for the employee Shopfloor augmented reality Dynamic target corridors
MEETINGS & KNOWLEDGE EXCHANGE (12 Methods)	Analogue documentation Shopfloor meeting Defined escalation paths Bulletin board	Recording of the meeting Digital information platform Digital Shopfloor meeting Digital communication between employees	Digital bulletin board Voice recognition Intelligent shop floor management agenda Intelligent provision of knowledge
MEASURES & PROBLEM-SOLVING (18 Methods)	Analogue list of measures Analogue fault monitoring system Integration of problem analysis methods Deviation management Analogue CIP-Board Kaizen event PDCA Circle	Digital list of measures Digital fault monitoring system Integration of digital problem analysis methods Digital catalog of measures Digital CIP-Board	Intelligent failure management Automatic root cause analysis Smart Analytics Intelligent problem-solving process Intelligent deviation management Automatic analysis of improvement suggestions
RESOURCE CONTROL (14 Methods)	Analogue Heijunka-Board Maintenance planning Analogue machine allocation Analogue shift plan Qualification matrix	Digital Heijunka-Board Digital maintenance planning Digital machine allocation Digital shift plan Digital qualification matrix	Shift allocation via mobile app Intelligent maintenance planning Intelligent machine allocation Intelligent shift plan

Figure 3: Overview of identified methods and corresponding area and maturity level (Picture by authors)

Methods from the research period having been classified relevant are then transformed into standardized profiles, which enable clear and fast summary of the elements necessary for a successful implementation and application of the shopfloor method. These profiles are summarized in a modular SFM toolbox similar to Liebrechts Industry 4.0 toolbox [32]. The profiles contain various information in regards to expected effects and benefits for SFM and production in general, but also surrounding effects like employee reaction / necessary qualification as well as needed organizational adaption. This addresses the criterion C2 by enhancing the method description with organizational and human perspective. The methods are then initially mapped to the most appropriate model area and maturity level. To allow for an even more precise allocation, the areas are separated into dimensions like “Documentation” and “Horizontal / Vertical” for the category “Meetings & Knowledge Exchange” based on a clustering of contained methods.

3.4 Development of a digital SFM Maturity Assessment

In order to allow the assessment of a company’s current level of maturity concerning digital SFM as well as rate their vision, a short as well as detailed questionnaire is developed following the approach of Schumacher et al [33]. Their work is an ideal basis as it is a combination of numerous maturity assessment concepts and is easily transferred to SFM and its digitization. Instead of a single survey, however, in our approach two different questionnaires are used. This two-level approach allows interested companies to answer a short Quick Check and receive more general recommendations including suitable methods to be implemented as a rapid way to develop towards digital SFM. Users needing an in-depth guidance can then answer detailed questions regarding the previously identified lacking area(s) of SFM.

As a first step, a description for the ideal final state of each tuple of maturity level and field of application is created based on the profiles as well as additional literature research. The final states consist of a combination of possibilities offered by the methods in the respective tuple as well as their main advantages when reached. The conceived final stages are then in turn analysed for their most important contents and afterwards transformed into items for the Quick Check based on available literature concerning questionnaire best practices like [34]. For the development of the more detailed questionnaire allowing a more exact rating of the current maturity level, the method profile is used as a source of information and in turn transformed into one or more items describing each aspect of a given method. Closely related methods are as much as possible combined into single items to limit the size and in turn answering time of the questionnaire. The complete process is visualized in Table 1.

Table 1: Example for process from methods to item used to derive items of maturity assessment for the Category of Data Acquisition and Maturity Level Analogue

Step	Content
Input: Methods	Analogue Acquisition of Process Data, Creation of analogue machine datasheets, Creation of analogue tool datasheets, Data Acquisition Design and Classification
Throughput: Ideal final state	Up-to-date information through short cyclical data acquisition, Identification of relevant data, Structured data form and acquisition process
Output: Derived item	Do rules for the classification and structuring of data exist on the shopfloor?

To allow for a comparison of results, answering options were mapped to corresponding maturity levels in the Quick Check and in turn recommendations. For the detailed questions, answering options were mapped to distinct methods or method implementation progress. To finalize the surveys, both questionnaires are then pre-tested. To make sure, that each question is understandable, three different personae are conceived representing different types of users to be expected based on surveys for example from [35]. Main points of each persona are their knowledge about digitalization as well as SFM, which are used to make sure each question is understood the correct way and addresses the correct underlying aspect or method.

4. Application and verification

The presented digital SFM quick check has been applied with an international production company producing measuring devices. It is characterized by a decentralized organizational structure in production with autonomous assembly teams and it’s at the beginning of implementing Industry 4.0. The application was carried out in three sequential steps: In the first step the partner answered the Quick Check consisting of approx. 46 questions, second the calculated maturity levels were discussed in semi-structured interviews with an expert of the company and third the levels were adapted where necessary. The answers given and the calculated maturity levels (see Figure 4) in the Quick Check then fit the described situation of the company.

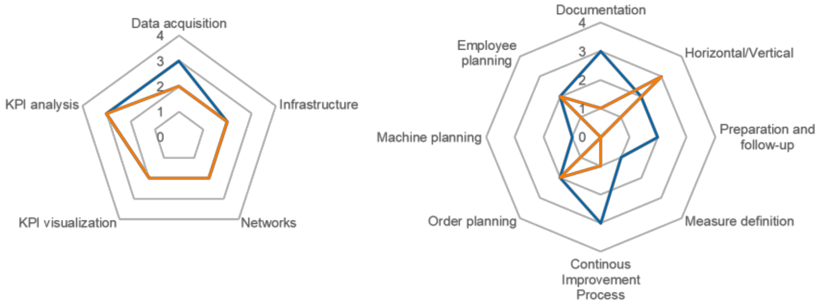

Figure 4: Resulting maturity levels for enabler (left) and potential dimensions (right) from the Quick Check visualized using a Microsoft® Excel graph (blue = target level, orange = current level, Picture by authors)

As being identified in the Quick Check as lacking, the category of Preparation and follow-up was thoroughly examined using the detailed questionnaire. There, the low level was confirmed and it was found, that necessary analogue requirements in the form of structured problem collection and measure documentation was missing. Due to their otherwise comparably high level in the enabler areas, a digital fault monitoring system as well as a digital measure list were recommended to be implemented.

5. Conclusion

The presented modular digital SFM model summarizes single SFM methods. Because of the described maturity levels and the developed assessment for each category the presented approach is a suitable tool for supporting the company-specific (digital) SFM implementation. The exemplified application of the model showed the generally possibility of estimation of the digital maturity. However, some of the single questions need to be reworked, so that a self-assessment will be practicable.

In further research the guidelines of the digital SFM model should be concretised with the help of empirical research methods like item tests and regression analysis. For example, the relevant competences and qualifications must be defined for each employee role in SFM. The corresponding competencies must be available among the employees so that successful SFM processes can be realized. If the maturity assessment is combined with an employee self-evaluation of the human-oriented target system [8] a benchmark study is facilitated, which can be used to determine the success factors of SFM in terms of high employee acceptance and employee productivity.

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