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Published in:
Digital Business

DOI (link to publication from Publisher):
10.1016/j.digbus.2023.100063

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Clausen, P. (2023). Towards the Industry 4.0 agenda: Practitioners' reasons why a digital transition of shop floor management visualization boards is warranted. *Digital Business*, *3*(2), Article 100063. https://doi.org/10.1016/j.digbus.2023.100063

Digital Business 3 (2023) 100063

Contents lists available at ScienceDirect

Digital Business

journal homepage: www.elsevier.com/locate/digbus

Towards the Industry 4.0 agenda: Practitioners' reasons why a digital transition of shop floor management visualization boards is warranted

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ARTICLE INFO

Keywords:
Industry 4.0
Manufacturing
Shop floor management
Visualization boards
Digital transition

ABSTRACT

Under the umbrella of Industry 4.0 (I4.0), manufacturing companies have implemented various digital solutions, improving productivity. Shop floor management (SFM) is the core management instrument in manufacturing and is a precondition for implementing new systems. In recent decades, visualization boards (VB) have played a significant role in facilitating SFM. Following the I4.0 agenda, tremendous investments in manufacturing technologies have been spent to enable data-driven decision-making to support SFM in monitoring and controlling manufacturing. However, it does not seem that the digital transition has reached the SFM practice yet. Currently, most manufacturers rely on analog VBs. One would think, that applying such an analog tool limits the opportunities to harvest the full potential of the digital investments to improve SFM conditions. This paper aims to shed light on this gap by contributing to the existing literature on digital SFM by adding to the discussion on how the role of analog VBs as an SFM instrument is changing due to the digital transition of manufacturing. The research follows a case study approach, including 16 cases that illustrate the use of current VBs to facilitate SFM in 16 international companies. The findings demonstrate an SFM model (The Danish SFM model) which indicates that VBs are indispensable tools to facilitate SFM. Given the functionalities of current digital VBs provide limitations, analog VBs still prove useful to the SFM practice. Despite practitioners are experiencing challenges within their digital transition of SFM VBs, the findings highlight eight reasons why a digital transition is warranted.

1. Introduction

The extraordinary investments in new digital technologies enabled by Industry 4.0 (I4.0) are evolving manufacturing to become more automated, computerized, and complex (Grooss, Presser, & Tambo, 2022; Holopainen, Ukko, & Saunila, 2022; Kusiak, 2018). Manufacturers are transitioning towards an industrial era built upon the utilization of data to perform advanced analytics to optimize products and processes (Deepu & Ravi, 2021; Kusiak, 2018; Wang, Ren, Li, & Zhang, 2021). With this digital transition, new conditions to monitor and control the manufacturing shop floor are available (Wang et al., 2021). As stated more than two decades ago by Ou-Yang and Chang (2000), the shop floor management (SFM) practice should be aligned with the whole manufacturing information-flow, where all data and information sources should be considered simultaneously to work optimally. This has been a difficult achievement due to the high level of manual processes (Jwo, Lin, & Lee, 2021; Zhuang, Liu, & Xiong, 2018), where most shop floor information is shared through face-to-face conversations or with pen and paper on physical communication aids (Li, Fast-Berglund, & Paulin, 2019) such as visualization boards (VB).

VBs are fundamental technology-enabled resources used to facilitate SFM in manufacturing. The VBs represent the manufacturing data to make operations visible (Beynon-Davies & Lederman, 2017) to provide the shop floor practitioners with the information they need to monitor and control the manufacturing. Following the digital transition of manufacturing, data are increasingly becoming the focal point in handling shop floor tasks (Jwo et al., 2021), in which the onus of responsiveness lies in the SFM controlling and monitoring functions (Kumari & Kulkarni, 2016). Therefore, one would expect that the focal tools for facilitating SFM would align with the digital transition (Li, Fast-Berglund, Dean, & Ruud, 2017; Meissner, Grunert, & Metternich, 2020; Torres, Pimentel, & Duarte, 2019).

To date, it does not seem that SFM VBs have been aligned with the digital transition of manufacturing. Following Pötters, Schindler, and Leyendecker (2018) and Clausen, Mathiasen, and Nielsen (2020), the adaptation rate of digital SFM VBs is low. Their studies reveal an adaptation rate below 20%, indicating that the digital transition of VBs is nascent. Despite a low adaptation rate of digital VBs, manufacturers

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https://doi.org/10.1016/j.digbus.2023.100063
Received 2 February 2023; Received in revised form 12 May 2023; Accepted 27 May 2023
Available online 30 May 2023

are keeping analog VBs close to their hearts. Upon taking a walk along the shop floor, you will notice how well analog VBs are applied to facilitate SFM (Mathiasen & Clausen, 2019). The challenges of relying on analog VBs arise because they depict historical data and exclude the opportunity to visualize real-time data and perform advanced analytics (Meissner, Müller, Hermann, & Metternich, 2018). The literature revolving around a digital transition of VBs is rather scarce, and it does not provide practical evidence as to why the digital transition of VBs is a necessity, nor prove why the current ones should be technologically outdated.

Given the immense development of digital technologies enabled by I4.0, the conditions to achieve full connectivity among systems are now an extreme focus. With this, "smart shop floor", and "digital SFM" has attracted wide attention and become active research topics by operations technology management researchers such as Zhuang et al. (2018), Li et al. (2019), Torres et al. (2019), and Meissner et al. (2020). Several conceptual papers suggest improvements for optimizing VBs via digital initiatives (see Fast-Berglund, Harlin, & Åkerman, 2016; Meissner et al., 2018; Meissner et al., 2020; Torres et al., 2019), still they refrain from clarifying what functionalities a digital VB should provide, nor report on the practical experiences with a digital transition of VBs. In relation, no prescriptive knowledge on how to accomplish a digital transition of VBs seems available. Therefore, it appears relevant to clarify this gap by identifying the practical experiences of applying analog and digital SFM VBs in the manufacturing context of I4.0, to provide practical evidence of whether a digital transition of VBs is on the manufacturing agenda. Furthermore, this arise the challenging question of whether a digital transition of shop floor VBs is a necessity?

Motivated by this need, this paper investigates the attributed role of VBs in facilitating SFM in the context of I4.0. The research draws upon 16 cases illustrating the use of VBs in 16 manufacturing companies in Denmark, all owned by international companies. With the unit of analysis on the SFM practice, the cases explicate the use of analog and digital VBs to facilitate SFM. The following research question guides the study: "*What role do shop floor practitioners attribute to VBs in facilitating SFM?*" With this research question, the study aims to contribute to the existing literature on SFM by adding to the discussion on how the role of analog VBs as an SFM instrument is changing due to the digital transition of manufacturing.

The findings demonstrate an SFM model (named The Danish SFM model) which indicates that VBs are indispensable tools to facilitate the SFM practice. Although analog VBs seem to provide limited functionality to handle shop floor tasks, they still prove useful for the SFM practice, as they allow flexibility when handling tasks related to problem-solving or continuous improvement. The study mirrors a low adoption rate of digital SFM VBs, in which only four of the 16 companies have started the digital transition of their VBs. Despite a low adoption rate, approximately 80% of the companies report that a digital transition of the SFM VBs is of high priority and is considered a means to stay competitive, as the handling of several shop floor tasks is sensitive to time, to why real-time data visualizations are needed to support the SFM practice. To this end, the findings identify eight reasons why a digital transition of SFM VBs is warranted and do further indicate that the digital transition is showing slow progress because practitioners possess limited experience with digital transitions on the shop floor and are challenged by low technological maturity levels within their company.

In the following manuscript, first, the theoretical background of the study is presented followed by the methodological considerations. Then, the empirical data are clarified, followed by an analysis and discussion of the results. Lastly, the limitations, including the conclusions of the paper, are presented.

2. Theoretical background

On the manufacturing shop floor, VBs are perceived as the fundamental tool for facilitating SFM at daily meetings taking place in the production space (Beynon-Davies & Lederman, 2017; Fast-Berglund et al., 2016; Torres et al., 2019). It seems that VBs (also referred to as communication boards by Bateman, Philp, and Warrender (2016)), a material thing (Ewenstein & Whyte, 2009), guide the actions and social interactions of practitioners through their functionalities when conducting SFM (Bechky, 2003; Galsworth, 2017; Germonprez & Zigurs, 2009; Hertle, Siedelhofer, Metternich, & Abele, 2015).

A walk around manufacturing companies reveals widespread use of VBs to facilitate everyday management and communication (Clausen et al., 2020; Torres et al., 2019). Providing the right information to the right people in the right way and in an efficient manner is difficult (Eaidgah, Maki, Kurczewski, & Abdekhodaee, 2016). To ease this task, VBs are among the most applied communication tools that coexist on the shop floor (Iuga, 2017). As the shop floor is an information-heavy environment, practitioners are loaded with various pieces of information every day, thus, they need to be able to understand what information is relevant and exclude the rest.

According to current trends, *visualization* in SFM can be defined as the slogan "five minutes on the shop floor instead of fifty management minutes of presentation" (Iuga, 2017, p. 1). Hence, the goal of VBs on the shop floor is to transmit information to practitioners and provide directions to improve the workflow most efficiently (Beynon-Davies & Lederman, 2017; Eaidgah et al., 2016) by exposing problems and enabling improvement when making decisions (Bateman et al., 2016). However, the functionality of VBs differs from their physical shape and characteristics.

Following Eaidgah et al. (2016), the outcome of SFM is highly influenced by the functionalities of the VB. Thus, the importance relies on the accessibility of data and how the data is portrayed, as the communication paves the way for converting data and information into visual meaning; that is to be understood by the team practices on the shop floor. As SFM relies on collaboration among various types of practitioners across the shop floor, everyone must understand the information being communicated; otherwise, they cannot execute efficient decision-making when handling shop floor tasks.

2.1. SFM VB functionalities

The use of VBs in the broader manufacturing context has been growing in recent years to deal with the fact that the shop floor has become a more complex environment to perform operations (Bateman et al., 2016; Li et al., 2017; Meissner et al., 2020; Torres et al., 2019). However, VBs are not a new phenomenon on the shop floor (Hertle et al., 2015): Visual management plays an essential role in operations management disciplines, specifically in lean manufacturing and implementation, performance management, and strategy development (Bateman et al., 2016; Imai, 1997; Liker & Meier, 2006; Parry & Turner, 2006). Hertle et al. (2015) are one of the few that have addressed and conceptualized SFM as one industrial practice revolving around VBs. *Das Darmstädter Shopfloor Management-Modell* presented by Hertle, Tisch, Metternich, and Abele (2017) is based on German studies and describes SFM as a feedback loop involving practitioners and dialogues taking the outset from data and information presented on VBs. The use of VBs within *Das Darmstädter Shopfloor Management-Modell* takes the outset in the problem-resolution process clarified in an earlier paper by Hertle et al. (2015).

The VB has been developed by lean practitioners and applied as a communication tool to assess management effectiveness for many years (Parry & Turner, 2006). However, most VBs are updated through manual means, as they appear as analog dashboards (i.e., whiteboards) with various printed sheets of information attached (Fast-Berglund et al., 2016). Several types of SFM VBs exist on the shop floor to monitor and control the manufacturing (e.g., performance management boards (*KPI boards*), controlling and monitoring boards (*Takt time boards*), and continuous improvement boards (*Kaizen boards*)). For that reason, the functionalities of a VB and the information displayed vary. For instance,

performance management boards typically visualize performance measures, such as the current state of production, service provision, or processes. These data are typically presented in graphical outputs of metrics, financial ratios, or key performance indicators (Parry & Turner, 2006). In situations where complex tasks arise, additional visualization tools (e.g., A3 storyboards, flowcharts, control charts, Pareto and fishbone diagrams) guide and support the practitioners (Tezel, Koskela, & Tzortzopoulos, 2009; Hertle et al., 2015: Eaidgah et al., 2016). However, to Meissner et al. (2020), conducting SFM meetings by applying analog VBs can be considered wasteful because it seems that practitioners spend too much time preparing for the meetings by collecting and processing data manually.

From an overall perspective, despite the context, the various types of VBs serve the same purpose of providing information transparency that supports practitioners by identifying problems and providing a common understanding when conducting daily or weekly short-time framed SFM meetings (Eaidgah et al., 2016; Meissner et al., 2018). In other words, the role of SFM VBs is to serve as a communication tool (Hertle et al., 2015).

The use of VBs is linked to the handling of shop floor tasks, such as dealing with unplanned events before they gradually spread and exacerbate a situation (Torres et al., 2019; Zhang, Xu, Sun, & Yang, 2015). For instance, having access to manufacturing data in real-time via a VB makes it possible to respond to deviations quickly (e.g., machine breakdowns, absenteeism, and rework due to quality issues) before an unplanned event affects the production flow. Therefore, ideally, VBs should enable a fast, responsive SFM practice where data is visualized in real-time across the manufacturing. The VBs should also provide an opportunity to conduct advanced analytics to support the decision-making process.

The ability to handle shop floor tasks in the context of I4.0 is increasing the demand on the current functionalities of analog VBs by having data in real-time (Holm, 2018; Meissner et al., 2020). The ability to provide full transparency for operations on the shop floor seems to be a demand for the future (Deepu & Ravi, 2021; Li et al., 2019; Zhuang et al., 2018). Without access to the right tools to handle shop floor tasks, practitioners will experience certain limitations and not gain a full overview and job control (Iuga & Rosca, 2017; Li et al., 2019; Wickramasinghe & Wickramasinghe, 2016).

2.2. Digital SFM VBs

The increase in the complexity of modern production systems put forward by I4.0 has put new demands on the SFM practice (Li et al., 2019; Kumari & Kulkarni, 2016; Wang, Yew, Ong, & Nee, 2020) and led to the need for proper communication of information to support practitioner cognition at the shop floor (Li et al., 2017; Li et al., 2019). The fast-developing technologies of today have largely solved the problem of conveying information. However, one of the current challenges that technology has not solved in manufacturing is an improvement of the ineffective delivery of information to the workforce in close-range communication environments, such as the SFM team practices (Tezel, Koskela, & Tzortzopoulos, 2016). It is often the case, that information is not delivered in the right translated format, which makes it difficult for operators to make information operational, as the information visualized on the VBs is too complex to understand. Considering that there is an abundance of new information technologies, practitioners should embrace these opportunities to simplify information sharing on the shop floor (Li et al., 2019).

Several digital business intelligence (BI) data reporting tools for improved data visualization to support SFM exist, and these have been undergoing rapid development in the last ten years. Such tools are now present on the shop floor and have started a digital transition of the SFM VBs. Today, digital VBs consist of hardware, such as a computer or TV screen, that visualizes BI software that illustrates various performance measures (Clausen et al., 2020; Fast-Berglund et al., 2016). Due to the rapid development within this area, the customization within these products increases, making the solutions appealing to more companies. Some of the most applied BI tools for data visualization to support SFM are Looker, InetSoft, Microsoft Power BI, Tableau, Datapine, Oracle BW, and SAP HANA (Aston, 2021; Haije, 2019).

Using digital solutions provides opportunities to conduct advanced manufacturing data analytics to enhance operational decision-making (Buer, Strandhagen, Semini, & Strandhagen, 2021). For instance, having performance data visualized in real-time makes it possible for practitioners to deal with stochastic problems faster, as they will gain more transparency towards the ongoing processes on the shop floor. Being able to react immediately to problems will not only lead to a more efficient SFM practice but also provide the opportunity to help companies remain competitively viable (Buer et al., 2021; Holopainen et al., 2022; Meissner et al., 2020; Zhuang et al., 2018). Nevertheless, currently, the application of digital VBs does not seem to be widespread on the shop floor (Clausen et al., 2020; Li et al., 2017; Pötters et al., 2018). In general, the digital transition of manufacturing seems to be slow, as many companies are still in the early stage of implementing digital solutions and are at a more fundamental level than I4.0 (Buer et al., 2021). Following Meissner et al. (2020), the companies lack understanding and practical experience in handling information-technologies on the shop floor.

A study performed by Clausen et al. (2020) reveals some of the forces *against* and forces *for* applying digital VBs. The forces *against* include having an immature technological capability characterized by poor data quality and complex IT infrastructures that contain inconsistent IT systems that have a high level of vulnerability if the IT systems fail. Furthermore, the habitual way of conducting SFM also leaves practitioners behind in digital development (Clausen et al., 2020). The identified forces *for* applying digital VBs include eliminating time-consuming manual updates and automating the data treatment, collection, processing, and communication. Furthermore, having data available in real-time enables the data and information to flow easily across the manufacturing floor, enhancing inter-organizational transparency through increased interoperability (Clausen et al., 2020; Meissner et al., 2020). Hence, with the current technological possibilities of connectivity and visualization, companies should consider reducing the number of manual procedures by undergoing a digital transition. In other words, the traditional analog VBs used for SFM are considered potential targets for digitization and digitalization (Lorenz, Powell, & Netland, 2019; Meissner et al., 2020).

3. Research design and setting

The research herein draws on a case study approach, which seems appropriate to study the exploratory research question (Goffin, Åhlström, Bianchi, & Richtnér, 2019). A qualitative inquiry seems suitable to clarify the research topic, as the digital transition of manufacturing challenges extant theoretical assumptions across several domains. Furthermore, given that the research setting deals with a unique context (the SFM practice) it is believed that using a case study approach allows for generating novel insights.

More specifically, the study follows the Dubois and Gadde (2002) abductive approach to case studies, where an empirical understanding is developed while exploring the theoretical concepts of the subject. This ongoing iteration between theory and empirical data seems suitable, as it paves the way to move between the data collected from the case companies and the ongoing conceptualization of the role of SFM VBs in the context of I4.0. Accordingly, this study strives for theory elaboration based on abductive logic rather than theory testing or generation.

The research question was studied in 16 global manufacturing companies, all with a location in Denmark. To ensure high quality within the empirical data, the cases were chosen for appropriate theoretical reasons (Goffin et al., 2019), in this case, based on the companies' active interest in the digital transition of SFM VBs. Prior to the study, the

author engaged with the case companies at a conference entitled "The future of production" hosted by Aarhus University, Denmark. All the companies illustrated interest in the research topic due to their participation in the conference track "Digitization of lean visualization boards", which consisted of a lecture and a workshop. In total 38 companies participated this session. The criterion of selecting cases for this study among the 38 companies, was inspired by Stake (2000) principles of formal case sampling to represent a targeted population of cases, which could provide a detailed understanding of the role of SFM VBs in the context of I4.0.

The 16 companies were selected based on two criteria: *i) variety, and ii) an opportunity to learn from the cases*. Having a wide *variety* in the sample size is considered essential to fulfilling the purpose of this study, as former studies reveal significant differences between larger and smaller production environments for digital transitions on the shop floor (see Buer et al., 2021). Moreover, the *opportunity to learn from the cases* is an essential criterion for selecting the cases. The selected companies had to invest a considerable amount of time letting the author observe SFM meetings and connecting the author to relevant respondents to conduct detailed interviews. Through a larger number of cases, 16 in this case, it was believed that the investigation would provide a higher level of reliable information, as the investigation covered several cases to study the topic (Abercrombie, 1984).

The empirical data collection consisted of semi-structured interviews (Bryman & Bell, 2011) and observations of SFM meetings that included various types of VBs. An interview guide directed the semi-structured interviews. The interview guide was continually modified as the research progressed until the end of the data collection, which is consistent with the systematic combing approach by Dubois and Gadde (2002). The questions asked had their threshold in the research question and were constructed on behalf of the theoretical conceptualization achieved from reviewing relevant literature. Before observing SFM meetings, the author could ask a few questions to the informant(s) for the interview(s). This allowed the author to generate a basic understanding of the SFM practice, to why the first questions within the interview guide revolved around the types of SFM VBs applied, and to clarify whether the SFM practice was structured through standardized principles. With this preliminary understanding, the author was able to check whether the interpretation provided by the informant(s) aligned with the observations of practitioners applying the VBs to facilitate SFM meetings. In companies with more than one interview, the author was allowed to do a quality check on the interview answers. The author exploited this opportunity in cases, where the informants could not provide a clear answer, or the observation(s) conflicted with an informant's answer.

To enhance the credibility of the case studies, the companies selected informants for the interviews. All the informants for the interviews were shop floor practitioners who held job positions as either a plant manager, shop floor manager, lean specialist, continuous improvement manager, or similar. They all possessed extensive experience with SFM decision-making procedures and operations. On average, each company visit lasted two hours. The amount of SFM meetings attended at each company variated from one to four meetings. Notes were taken simultaneously during the observations and interviews. The interviews were not allowed to be recorded. All the notes were discussed with the informants being interviewed to ensure a trustworthy and ethical approach. These aligned notes were used to draw up the minutes.

To refine the data collection, prior to the study, three pilot case studies were conducted (Yin, 2014). The pilot cases were selected to be run in companies where it was possible to observe different SFM meetings applying different types of VBs both with analog and digital capabilities. The pilot cases strived for strong conditions to understand the SFM practice of applying VBs to handle shop floor tasks. It did not seem necessary to expand the data collection after finishing the observations and interviews in the 16 case companies. As no new data was being unearthed; it is believed that theoretical saturation was achieved (Strauss & Corbin, 1998).

Table 1 shows the industries, company sizes (number of employees), revenue (2022), the companies' technological maturity level, the number of SFM meetings observed, and the number of conducted interviews in each of the 16 case companies. To ensure anonymity, the companies are designated as Company 1, Company 2, Company 3, and so on. The evaluation of the companies' maturity level does only reflect the visited manufacturing site. The evaluation is based on the author's understanding and takes the outset in the six *readiness status characteristics for adopting I4.0-related technologies* suggested by Pacchini, Lucato, Facchini, and Mummolo (2019). These are, **Embryonic** (the company has a superficial knowledge of I4.0-related technologies, and no adoption hereof), **Initial** (the company has limited knowledge of I4.0-related technologies, where only a few have been adopted), **Primary** (the company has a good knowledge of I4.0-related technologies, but not all of them have been adopted, **Intermediate** (the company has full knowledge of all I4.0-related technologies, and have already begun their adoption, **Advanced** (the company has full knowledge of all I4.0-related technologies, and all of them have a high degree of adoption, **Ready** (The company has practically all the enabling I4.0-related technologies in a full degree adoption).

3.1. Analysis

The data analysis follows the principles from Merriam (1998) of analyzing case study data. Following these principles, making sense of the data involves consolidating, reducing, and interpreting the empirical data from the case studies and the findings from the review of relevant literature (Merriam, 1998). The process of making meaning follows a pattern-matching analysis (Sinkovics, 2018), in which the empirical data from the 16 case companies was analyzed through comparable patterns. To do so, a framework to guide the analysis was developed. The framework took outset in the German *Das Darmstädter Shopfloor Management-Modell* (Hertle et al., 2017), which made it possible for the author to illustrate the use of SFM VBs from a unified understanding and elaborate on the attributed role of digital SFM VBs by clarifying the practical experiences of applying analog- and digital VB to facilitate SFM.

4. Empirical findings and analysis

4.1. The application of VBs to facilitate SFM

Observations of SFM meetings and semi-structured interviews were conducted in 16 manufacturing companies, which made up the empirical foundation for the inquiring logic applied in this study. In general, each SFM meeting took 10–20 min on average. If practitioners took notes, they were either recorded on A4 paper or written directly on the analog whiteboard by hand. Table 2 presents an overview of whether analog or digital SFM VBs were applied in the 16 companies and whether the digital transition of VBs is on the agenda within the company.

4.1.1. Application of analog SFM visualization boards

As shown in Table 2, all 16 companies applied analog VBs to manage SFM meetings and handle related tasks, including discussing key performance indicators, coordination, and accomplishing decision-making. All observed analog VBs were standardized through lean management principles and consisted of whiteboards on which various physical printouts, such as Excel spreadsheets, graphs, Word documents, and similar, were attached. Notes, symbols, and additional visualizations to support communication were drawn by hand using markers with different colors. All companies applied the VBs daily or weekly when having SFM meetings in the production environment. In some companies, the VBs were applied more than once per day (e.g., having team shifts or in case, frequent performance monitoring and controlling was

Table 1
The manufacturing companies enrolled as cases in this research study.

Company	Industry	Size	Revenue	Maturity level	SFM meetings	Interviews
1	Brewery	40,000	$9.95b	Primary	3	1
2	Industrial chemistry	30,000	$13.02b	Primary	3	3
3	Meat processing	26,000	$9,48b	Initial	3	2
4	Renewable energy	27,000	$9.81b	Intermediate	4	3
5	Pump solutions	19,300	$4.92b	Advanced	3	3
6	Skylights	10,000	$3.29b	Intermediate	2	2
7	Tobacco	7600	$1.25b	Primary	1	1
8	Plastic pipe systems and solutions	6000	$2.9b	Initial	3	1
9	Smart metering solutions for energy and water	1300	$440 m	Primary	1	2
10	Advanced mission-critical solutions	1250	$320 m	Initial	1	1
11	Iron casting	1100	$220 m	Initial	2	2
12	Cutting tools	700	$51.25 m	Primary	1	1
13	Windows and doors	550	$97,62 m	Primary	2	2
14	Bolts	200	$35.9 m	Initial	2	1
15	Fish processing	140	$3.1 m	Primary	1	1
16	Acoustic panels	120	$77.13 m	Advanced	1	1

Table 2
Overview of the application of analog and/or digital SFM VBs at the 16 case study companies.

Company	Analog VBs	Digital VBs	Digital transition of VBs on the agenda
1	Yes	Yes	Yes
2	Yes	Yes	Yes
3	Yes	No	Yes
4	Yes	Yes	Yes
5	Yes	Yes	Yes
6	Yes	No	Yes
7	Yes	No	Yes
8	Yes	No	Yes
9	Yes	No	Yes
10	Yes	No	Yes
11	Yes	No	Yes
12	Yes	No	No
13	Yes	No	Yes
14	Yes	No	Yes
15	Yes	No	No
16	Yes	No	No

needed for the production set-up).

The role of analog VBs to facilitate SFM in the 16 Danish companies, shared many similarities. For that reason, it was from the pattern-matching analysis (Sinkovics, 2018) possible to develop a model illustrating the role of analog VBs to facilitate SFM, see Fig. 1.

In contrast to *Das Darmstädter Shopfloor Management-Modell* (Hertle et al., 2017), the SFM model illustrated in Fig. 1 (The Danish SFM model[1]), explicitly demonstrates the centric role of VBs to facilitate SFM, by reporting on the VB's specific use and purposes.

The findings report that the VBs are involved in multiple formats to support the SFM practice. From Fig. 1, VBs are applied to support four different stages within SFM meetings. In stage 1, the VBs are applied for pre-planning purposes and updated with new information. In stage 2, the VBs are used as an aid in communicating the performance status, here performance management/lean VBs were typically applied, see Picture 1.

In stage 3, the VBs are applied in handling shop floor tasks, in which they appear as physical tools to solve problems. In stage 4, the VBs are a part of the non-formal space enabling continuous improvements, in which the VBs possess malleable functionalities targeting to embrace whatever is brought up. Picture 2 illustrate an example of problem-solving- and continuous improvement VBs applied in stage 3–4.

It was frequently observed that the companies applied different VBs to complete stages 2–4. Some companies went through stages 2–4 as a standardized routine for completing the SFM meeting. In contrast, others applied additional VBs (problem-solving- and continuous improvement VBs) when needed. For that reason, there is not applied a "fixed" number of VBs characterizing a standardized routine of facilitating SFM. However, in all the companies, performance management/lean VBs were applied, and it seemed that these types of VBs were of the most importance, as they were the information source for all ongoing activities in stages 2–4. In most companies, the various types of VBs were in the same area. This area was typically referred to as the "war room". Having the VBs located in a war room seemed to ease the transition from the performance status (stage 2) to handling shop floor tasks or discussing continuous improvement suggestions (stages 3 and 4).

What specifically was depicted on the VBs, typically depended on the production set-up within the companies. With this, the observed SFM meetings were held with different agendas. Although all companies applied performance management VBs/lean VBs to conduct "a general" performance status of the main KPIs, as illustrated in stage 2, some companies supplemented the performance status meeting with additional VBs, such as takt-time VBs, to align monitoring and controlling tasks. Typically, these meetings were held on slightly other premises than those only involving performance management/lean VBs, as a different type of shop floor practitioners might be involved. Here, the duration time of conducting the SFM meetings may differ as well.

The observations revealed that all companies had one thing in common: the "power-of-the-pen" syndrome seemed to penetrate the SFM practice. Here the author noticed, that "by-hand" actions on the VBs enabled large flexibility, as quick drawings and other visual illustrations eased the communication between the involved practitioners. Hence, how information is physically presented on the VBs is crucial to guarantee a unified understanding that ranges across the shop floor. Moreover, all 16 companies expressed that conducting the SFM meetings physically, stimulates a good and social work environment, as the meetings allow time to meet colleagues across the shop floor. However, from the interviews, several negative viewpoints were related to the use of analog VBs. Table 3 presents the interview data (direct quotes translated from Danish) clarifying on the shop floor managers' opinions of applying analog VB to facilitate SFM.

4.1.2. Application of digital SFM VBs

Table 2 reveals that companies 1, 2, 4, and 5 apply digital performance management/ lean VBs to facilitate SFM. Companies 1, 2, 4, and 5 are operating on different technological maturity levels (see Table 1), which also mirror the results of the digital transition of their SFM VBs. For instance, companies 4 and 5, being at a higher technological maturity level than companies 1 and 2, have invested substantial resources in SFM digitalization. While the digital transition of SFM VBs in

[1] The SFM model illustrated in Fig. 1, has been entitled "The Danish SFM model".

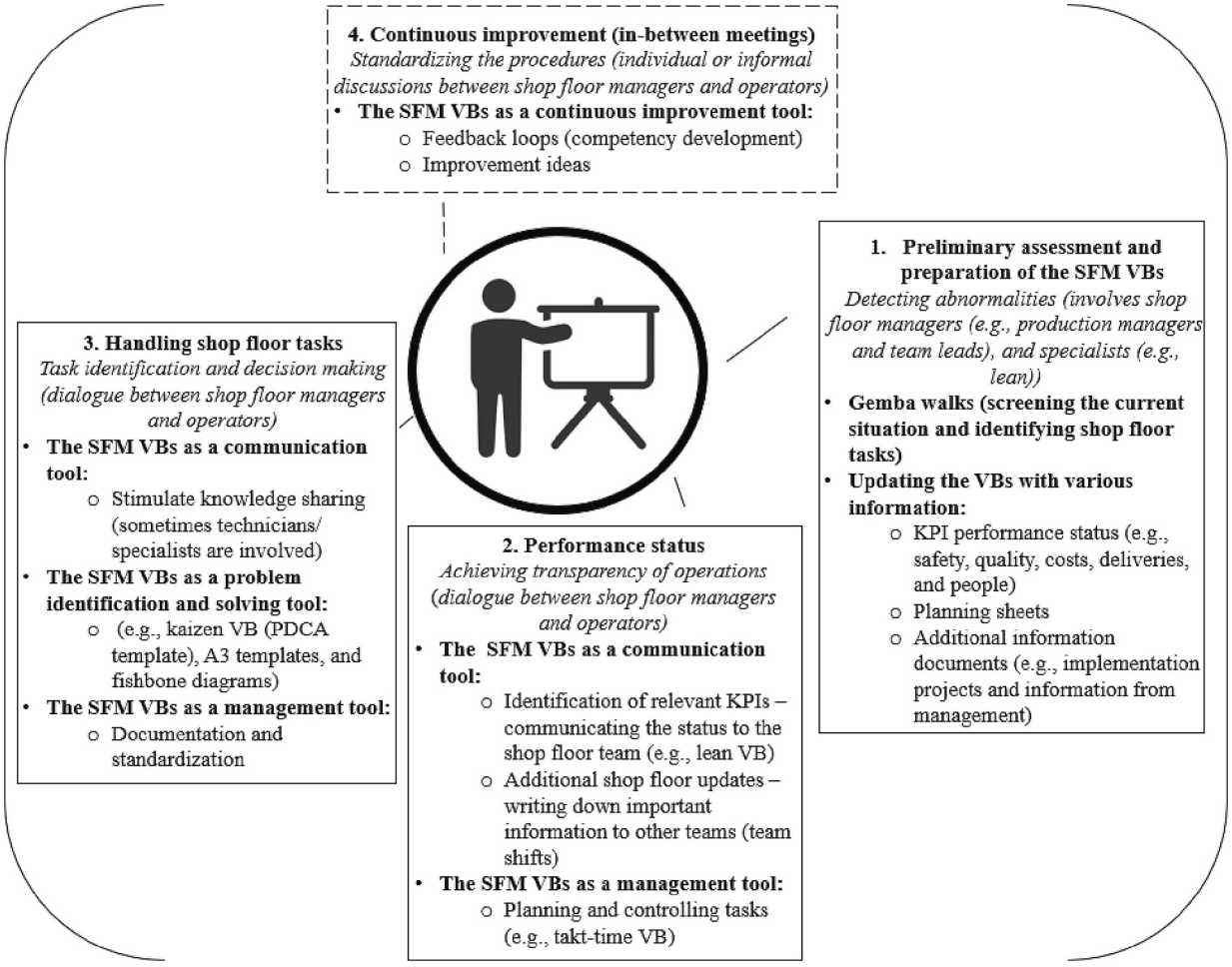
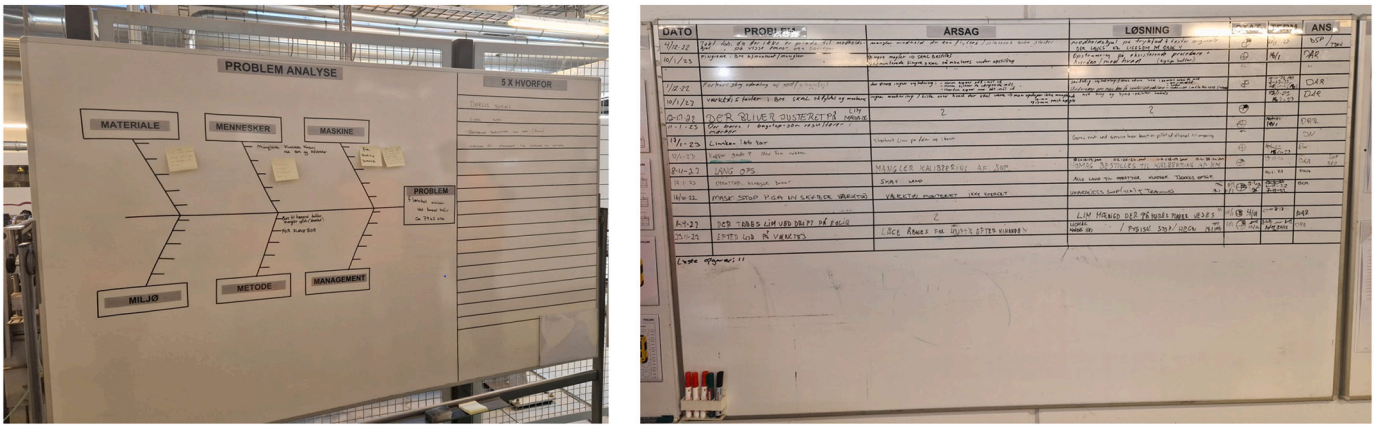


Fig. 1. The Danish SFM model. The role of analog VBs in facilitating SFM.

Picture 1. Example of a performance management VB applied in stage 2 in The Danish SFM model.

companies 1 and 2 draws on simple Microsoft solutions consisting of Excel and VBA software with only minor changes to the local IT architectures, companies 4 and 5, have together with an external supplier developed solutions that interface with their ERP systems and MES systems by implementing Microsoft Azure SQL databases to allow accessibility of data across the shop floor. Microsoft Power BI software is applied in companies 4 and 5 to visualize data. While the physical appearance of the digital VBs in companies 1 and 2 is a mirror image of



Picture 2. Example of a problem-solving VB (picture on the left) and an example of a continuous improvement VB (picture on the right).

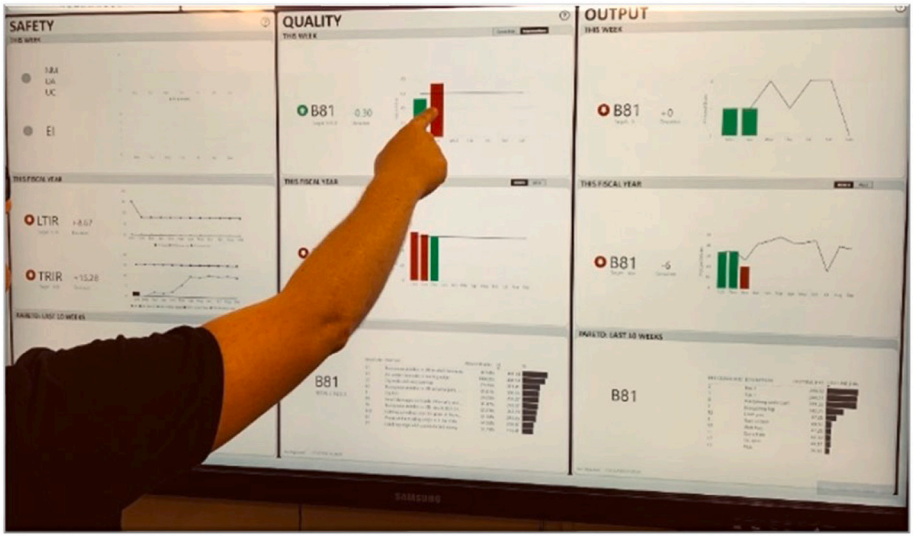
Table 3
Interview data. The view of applying analog VBs to facilitate SFM.

The view of applying analog VBs to facilitate SFM
1. "The physical meeting around the board stimulates a good working environment."
2. "It is labor-intensive to ensure that the whiteboards are updated."
3. "Retrieving data manually from various systems is time-consuming…we must access several different systems."
4. "The whiteboards are too spacy; they take up too much space."
5. "Information is only available for a limited time", "Printouts and handwritten notes on boards are discarded when it is updated for the next meeting."
6. "All the paper sheets attached to the VBs are confusing…too many attachments disturb the eyes and make it hard to keep focus…too many things are going on.", "We are overloaded with information."
7. "There is limited information sharing across the production as people need to physically attend the meeting to receive the update."
8. "There is low trust in the data…old data is not useful in all situations", "We make decisions relying on outdated data."
9. "It is a waste of time." "Evaluating outdated performance data is not effective."
10. "It provides flexibility during meetings.", "We make quick drawings by hand.", "We are influenced by the power-of-the-pen principle."

their analog VBs, the digital VBs in companies 4 and 5, provided a few new functionalities due to the accessibility of information being improved. While the hardware of the digital VBs consisted of a computer/TV screen, located outside operational areas in companies 1, and 2, industrial screens were applied by companies 4, and 5 making these digital VBs robust to be in operational areas. Picture 3 depicts the digital performance management/lean VB developed in Company 4.

Companies 1, 2, 4, and 5 have all in common being large international corporations dealing with complex IT infrastructures, where multiple ERP systems and subsystems create information silos, making it challenging to extract relevant data. For that reason, the companies still apply analog VBs, as they, from a technological perspective, are not ready to deal with all types of decision-making situations based solely on their current digital VBs. However, the target is to replace all analog VBs within a five to seven-year timeframe. The companies implemented digital VBs in 2017, 2018, and 2019. At the outset, the objectives were to:

- Improve documentation (strict requirements to legislation documentation in the food and chemistry industry).
- Achieve better operational decision-making, mainly due to the benefits of using real-time and reliable data.
- Reduce or even eliminate the time spent on handling and visualizing data.
- Allocate more time to improving the understanding of the key performance measures discussed at the SFM VB meeting.
- Facilitate coordination and decision-making across the shop floor.
- Allow remote participation (practitioners should have the option to attend meetings online, as participation should not be dependent on being physically present).



Picture 3. The digital performance management/lean VB in Company 4 (Microsoft Power BI software).

The digital transition of the SFM VBs in companies 1, 2, 4, and 5 did not fulfill the objectives listed above, and nor do the companies consider their transition being complete. All four companies reduced the time spent preparing SFM meetings. Furthermore, the digital VBs created awareness among shop floor practitioners. Increased curiosity made several of the shop floor practitioners explore the opportunities enabled by the VB software.

With the current digital VBs, the four companies were able to facilitate decision-making across the shop floor, as people were allowed to participate remotely. However, they only experienced a limited increase in taking data-driven decisions, as they did not have full access to data. The companies experienced that the digital VBs were sufficient for undergoing stages 3 and 4 (cf. Fig. 1) in terms of reporting on relevant data, but not in delivering flexible solutions for drawing visualizations. It was often the case, that analog whiteboards were used to handle these stages, as the practitioners favor an analog-material writing space to make up drawings for handling solving-problem tasks or initiating continuous improvement suggestions. In these situations, it seems that the SFM practice benefits from the "power-of-the-pen syndrome." Although software allowing flexibility in making "by-hand" drawings are available, several managers made it clear, that the processes in stages 2–4 should not be advanced or take up too much time being why the analog principles still are favorable. A manager from Company 4 declares "Most of our production staff are not comfortable spending too much time doing activities involving a computer…Introducing *too much new digital* will be challenging…We stick to those procedures we are successful with…".

In general, it seems that digital VBs seem to be sufficient in handling simple shop floor tasks, such as conducting performance updates and requesting support when facing unplanned events. However, when dealing with more advanced problems that require analyses that combine more data sets or rely on real-time data, such as handling resource allocations, the digital VBs do not seem sufficient in their current state. Nevertheless, companies 1, 2, 4, and 5 were confident that they will accomplish the above-listed objectives, as digital functionalities digital within the VBs are necessary to gain full control of shop floor operations. Practically, all four companies mentioned that they felt limited by their immature and inconsistent IT infrastructure to move forward, which needed to be improved before they could proceed with the digital transition of their VBs.

4.1.3. Application of digital SFM VBs in the future

Although digital SFM VBs are only applied in companies 1, 2, 4, and 5, all companies, besides 12, 15, and 16, have "a digital transition of SFM"as part of their future strategy as they are considering replacing their analog VBs with a digital version. However, the pursued goals of applying digital SFM VBs fluctuate significantly among the companies. Table 4 summarizes the empirical findings of the drivers of transitioning towards digital SFM VBs.

Table 4
Identified drivers of transitioning from analog to digital SFM VBs.

The drivers of applying digital VBs to facilitate SFM
• Go "paperless" (eliminate disturbing elements: too many physical printouts cause information overload, and several hours a week are spent on manual updates).
• Save physical space on the production floor (limit the number of VBs: one VB to facilitate SFM meetings.
• Have SFM meeting notes stored automatically (capture valuable knowledge).
• Improve knowledge and information sharing across the shop floor and at departmental levels (increase organizational interoperability).
• Achieve transparency of all operational procedures (early problem detection).
• Enhance data-driven decision-making and problem-solving
• Participate in SFM VB meetings remotely.
• Develop skills (more responsibility on the shop floor).
• Become proactive to minimize deviations from the plan using real-time data and advanced analytics.

4.2. The role of digital SFM VBs

Following the empirical material, the role of SFM VBs is expressed through the functionalities of the VB. As shown in Fig. 1, the overall role of a VB is to be a communication tool that can release different functionalities, depending on its form. Most of the companies applied analog VBs to facilitate SFM. Despite analog VBs being prone to several disadvantages (e.g., labor-intensive to update VBs, data is not in real-time, and limited information-sharing across the shop floor), analog VBs are essential for the social aspect of conducting SFM. It seems the physical presence of the VBs stimulates a good environment, as it invites the shop floor practitioners to meet and catch up. Moreover, applying analog VBs demands physical presence and has enabled the trust in the "power of the pen" approach of providing structure and communication.

Approximately 80% of the case companies expressed that the current functionalities within the analog SFM VBs are insufficient to support decision-making when handling shop floor tasks. For that reason, a digital transition of the SFM practice is warranted. Although both the analog and digital VBs in their current form do not "deliver their full potential," the practitioners will not be without the VBs. VBs are heavily incorporated in the shop floor environment and have for many years been a part of the habitual procedures of conducting SFM. As a result, the VB has gained high material value and functions as the SFM "totem pole". For shop floor practitioners, the VB is not just a material object. VBs are the central objects in facilitating SFM that is and must be continued to be driven through social interactions. Hence, VBs are indispensable tools.

To sustain the current role of the SFM VB, shop floor practitioners acknowledged that the VBs must adapt to the current technological trends evolving in manufacturing. A shop floor manager from Company 4 made the following statement: "For some years, we have invested in more smart machinery as the company wants to unfold as a modern manufacturer. The drivers for this investment rely on a desire to obey the digital promise of utilizing production data efficiently to enhance performance. Our current analog VBs are no longer sufficient; their non-digital functionalities are outdated, making us unable to handle the required tasks." With this, it appears that the functionalities within analog VBs will not remain sufficient to handle the increasing complexity on the shop floor.

From Table 4, the companies identified several drivers for initiating a digital transition of the VBs. The drivers cover the aspects of becoming "paperless" by eliminating paper printouts, saving space on the shop floor, and addressing new functionalities a digital VB could provide (such as visualizing data in real-time, allowing communication across units, and providing analytical capabilities). Interestingly, only 25% of the companies already initiated a digital transition of analog performance management/ lean VBs. The digital VBs for these companies are characterized by a 1:1 conversion of the analog VB to be replaced. The digital version did not provide any intelligent functionalities, such as visualizing data in real-time or offering advanced analytical capabilities, but they proved beneficial in reducing the preparation time and making information available across the shop floor. Furthermore, the digital VBs were efficient when dealing with simple tasks, such as identifying failure trends through enhanced visualization features and direct access to data files.

In general, the current state of the digital transition of the SFM VBs does not mirror the expectations set out by the companies. Given the experienced barriers related to the digital transition, companies 1, 2, 4, and 5 could not develop a solution that met their requirements. Despite the companies having spent several resources on attending seminars, workshops, and fairs on this specific topic, the companies did not find solid evidence of how to guide the digital transition of their VBs. As a result, for instance, in Company 4, the different plants developed local solutions, not applicable globally across the company. Hence, the solutions were only to be deployed where it was developed. Furthermore, the skills required to develop these solutions were mostly obtained

through self-learning or through internal non-standardized training workshops directed by shop floor managers or similar.

A shop floor manager from Company 2 declares "Although it has taken a few years to figure out how to develop a digital version of the performance VB, we have experienced that the most important criteria to become successful is to involve the operators in all parts of the development… In the end, we gave up on chasing an optimal plan to steer the digital transition, which made us comfortable with a learning-by-doing process." Given this, it seems that the companies are aware that the practitioners should be involved and obtain new competencies, but still, in general, the companies appear to be miles away from the finishing line, as they lack standardized guidelines to guide the transition. However, despite the challenges related to the digital transition, the transition seems to be an urgent goal, as they are experiencing a need for digital VB functionalities to handle certain shop floor tasks.

5. Discussion

The term "smart shop floor" is not a new phenomenon for practitioners, nor for research scholars, as it has been investigated and practiced heavily for nearly a decade (Jwo et al., 2021; Li et al., 2019; Zhuang et al., 2018). However, although practitioners are familiar with I4.0 trends, and they have gained high awareness of these, it appears that practitioners lack experience in accomplishing digital transitions on the shop floor (Lorenz et al., 2019; Meissner et al., 2020). This paper has tried to investigate whether the current SFM practice to facilitate manufacturing relies on outdated means, of looking into whether the use of analog VBs is sufficient to cope with the I4.0 agenda.

Comparing The Danish SFM Model to the German *Das Darmstädter Shopfloor Management-Modell* (Hertle et al., 2015, 2017), the findings in this study specifically dictate that VBs are the onus of SFM and act as the fundamental tool to handle shop floor tasks. Moreover, this paper highlights differences in applying different types of VBs to support SFM. However, the answer of whether analog VBs are technologically outdated remains a hard question to provide an exclusive answer to. On one hand, 80% of the enrolled companies claim that a digital transition of VBs is unavoidable in the pursuit of remaining in a competitive position in the future. Here the practitioners revealed eight drivers (cf. Table 4) contributing valuable insights into the ongoing discussion of what to expect from having a digital transition of SFM VBs (Clausen et al., 2020; Fast-Berglund et al., 2016; Holm, 2018; Meissner et al., 2018; Meissner et al., 2020; Torres et al., 2019). To this end, the empirical findings indicate that a digital transition of VBs applied for handling deviation tasks is warranted, as they require real-time data and advanced analytics to be handled in time. However, some of the tangible reasons identified in this study, such as becoming paperless and eliminating "waste time" on updating the manual VBs, are not new conclusions (see Clausen et al., 2020; Li et al., 2017; Lorenz et al., 2019; Meissner et al., 2020).

On the other hand, it seems that the shop floor practitioners are fond of conducting onsite SFM meetings, in which they feel comfortable sticking with their habitual analog procedures. Here the practice of using a physical pen to make writings or drawings is extremely powerful. The empirical findings provide evidence that practitioners favor the use of analog VBs to go through stages 3 and 4 in The Danish SFM model (cf. Fig. 1). This might lead to an important note of why companies should understand to preserve the flexibility enabled by the power-of-the-pen culture when initiating a digital transition of SFM VBs. Accordingly, this study cannot conclude whether the use of digital VBs would provide sufficient functionalities to handle SFM for practitioners, as current digital VBs do not provide real-time data. However, given the empirical findings, it seems that practitioners could benefit from using both analog and digital VBs in a combined format, as current digital VBs provide limitations when handling problem-solving tasks and continuous improvement tasks. In line with the findings, Parry and Turner (2006) argue that digital solutions might detach the operators from the problem-solving process as the operators are likely to experience increased complexity in handling tasks. Hence, companies should pay attention to the possible unwanted consequences of introducing digital SFM VBs.

Involving a large case sample size of 16 international manufacturing companies representing different industries and company sizes has made it possible to reflect upon whether there is any correlation between the company characteristics and the need to initiate a digital transition of SFM VBs. First, the empirical material indicates that it is most likely large companies that are about to initiate a digital transition. Second, it might be that some of the drivers for initiating a digital transition are determined by the type of industry. For instance, companies 1, and 2 listed "optimize the conditions for documentation", which was driven by the strict requirements to legislation documentation in the food and chemistry industry. Third, it seems that a company should be on a technological maturity level of **Primary** or above, as the digital transition of SFM VBs is related to technological barriers that require experience and competencies in dealing with or handling these. In line with Holm (2018) companies 1, 2, 4, and 5 have determined that they first will be continuing the digital transition when they possess the required conditions. Hence, companies should learn to understand how complex an information-intensive environment the shop floor is, to why completing a digital transition (entailing the objectives listed by companies 1, 2, 4, and 5) is not an easy journey that is to be completed overnight.

Companies 1, 2, 4, and 5 began the digital transition of SFM VBs three-five years ago, and still, they have not reached their outset objectives. Common for all four companies is, that they initiated the digital transition with the idea of it being a somewhat straightforward road, but they experienced the opposite. It seems that most companies are limited by little experience with this topic, and the complexity of their IT architectures to access data. Although researchers have indicated that SFM VBs are potential targets for a digital transition (Fast-Berglund et al., 2016: Torres et al., 2019; Meissner et al., 2020), most of these conceptual papers refrain from clarifying what specific functionalities are needed and nor do they report on practical experiences. To this end, this study does not find proof that all types of SFM VBs are required to undergo a digital transition. Following the empirical material, for instance, in cases where the purpose of the VB simply is to provide a performance status, the use of analog performance VBs seems sufficient, as some performance status meetings do not necessitate relying on real-time data (in case SFM meetings are not held daily). For further research, it would be of high relevance to investigate the specific requirements to complete a digital transition of SFM VBs, where the specific design principles are elaborated for the different types of SFM VBs.

5.1. Limitations

Although this study has identified the attributed role of digital VBs to facilitate SFM in the context of I4.0 and contributes to the theoretical and practical understanding of this topic, the employed method has limitations. Interviews and observations were accomplished at 16 manufacturing companies. Despite this comprehensive empirical material, the empirical material herein does not consist of a comprehensive description of all cases. However, the cases were described from a general perspective based on the understanding of the author. The omission of specific descriptions from the observations and interviews might negatively influence the credibility of the study. Furthermore, the proportion of companies applying digital VBs might seem limited, and more of these cases might have increased the robustness of the study.

6. Conclusions

At the outset, this paper aimed to investigate the role of VBs in facilitating SFM in the manufacturing context of I4.0. The research was guided by the following research question: *"What role do shop floor*

practitioners attribute to VBs in facilitating SFM?"

Based on a case study with 16 manufacturing companies, the following can be concluded: SFM VBs seem to be indispensable tools with multiple functionalities. VBs play a central role in facilitating SFM through various visual means. VBs are communication tools, releasing different functionalities depending on their analog or digital capabilities. The findings illustrate that a digital transition of SFM VBs is on the manufacturing agenda despite low technological maturity levels characterized by immature data foundations and complex IT infrastructures. Within this study, 20% of the companies are comfortable with onsite meetings steered by the very popular "power of the pen" approach, which indicates that a digital transition of SFM VBs is not considered a necessity by all manufacturers. Moreover, some types of analog VBs applied to handle problem-solving and continue improvement initiatives still provide useful functionalities, to why practitioners should consider relying on a hybrid model of applying both analog and digital SFM VBs.

Despite only 25% of the companies have accomplished a transition from analog to digital SFM VBs, digital VBs are considered to play a more significant role in the context of I4.0. 80% of the companies believe that the digital transition will release functionalities that make it possible to comply with the increasing complexity put forward by I4.0. For these companies, a digital transition of their analog SFM VBs is highly warranted.

Declaration of Competing Interest

I hereby declare that the disclosed information is correct, and that there are no known conflicts of interest associated with this publication, and the fact that there has been no financial support that has influenced this outcome. No funding was received for this work.

Data availability

Data will be made available on request.

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