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DIGITALIZATION OF MANUFACTURING: CHASING VISUALIZATION BOARDS PROVIDING FUNCTIONALITY TO HANDLE CONTEMPORARY SHOP FLOOR TASKS

PhD dissertation

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To my dad, Erik

From one curious engineer to another

CURRICULUM VITAE

Pernille Clausen

Pernille Clausen graduated with an MSc in Technology Based Business Development from the Department of Business Development and Technology, Aarhus University, Denmark, in June 2018. Pernille completed her Master's Thesis while interning for the machining company RIVAL A/S studying how to take the company closer to the digital age represented by the Industry 4.0 agenda.

While chasing digital transitions when interning for RIVAL A/S, Pernille developed an interest in the industrial digital transformation domain in the academic field of operations management. This interest landed Pernille a research assistant position at the Department of Business Development and Technology after graduating, leading her to a PhD position in the same department in September 2019.

As a PhD candidate, Pernille investigated digital transitions on the shop floor management level in manufacturing in collaboration with industrial partners, particularly exploring how to develop visualization boards to handle contemporary shop floor tasks in a smart manufacturing setting. During the three-year research study, Pernille has been engaged with a large global manufacturing company in the renewable energy sector, where she has spent much time in their plants in Denmark and the United Kingdom.

ABSTRACT

Technological evolution has supported economic growth in manufacturing for more than 250 years. Manufacturing is evolving, and it is bound to take place in different forms. To drive this industrial revolution, several strategies have been launched. At current, one such strategy is Industry 4.0 (I4.0). I4.0 is presenting a technology-driven agenda in which data availability to ensure interoperability across boundaries internally and externally within the manufacturing is on focus. By taking advantage of current and emerging digital technologies, the promise of I4.0 is to generate value either by improving existing processes or enabling new ones.

When the I4.0 agenda was first introduced in 2011, many researchers discussed the related "new" technologies and their impact on manufacturing by presenting practical use cases identifying positive and negative side effects. However, prescriptive knowledge regarding completing a digital transformation has leapfrogged the shop floor level. Moreover, several researchers within the operations management (OM) domain claim that the ongoing technological development presented by I4.0 has increased the complexity of current production system, providing new demands for facilitating shop floor management (SFM).

During this three-year study, several companies considered digital frontrunners have contributed with practical use cases of presenting their struggles to complete a digital transition of SFM visualization boards (VB) to handle related shop floor tasks. This PhD project aims to address these related issues, proving a normative theory for guiding the digital transition. To do so and to make a contribution to both literature and practice, the research is founded on two pillars:

- **Exploration** to clarify the current understanding of the research topic, which accounts for the comprehensive empirical foundation, adopting a task-technology-theory perspective to identify the functionalities for a VB to handle contemporary shop floor tasks.

- **Explanation** to clarify the desired state of the research topic by analyzing the empirical data within testing and evaluating the developed solutions to contribute with theoretical and practical implications.

This dissertation represents a collection of four appended papers, which in their combined form, present the progression of the research activities accomplished during the three years. All four papers are empirically driven and have been performed in collaboration with the industry to conduct a research project that reflects the practical realities in manufacturing to match the need for proving rigorous academic contribution and relevant guidelines for practitioners. The close collaboration with the industry provided the opportunity to empirically test and evaluate digital SFM VBs.

The related findings ensured that this dissertation contributes to the OM research domain, mainly to its technology management knowledge bases, by discussing the interplay between the digital transformation of shop floors and the usability of VBs in two main ways. First, by highlighting relevant insights concerning the digital transformation of manufacturing shop

floors, such as the forces for and against a digital transition of SFM VBs, and by demonstrating the usability of current VBs. Secondly, by proposing four prerequisites for developing digitalized VBs providing functionality to handle contemporary shop floor tasks.

DANSK RESUMÉ

Den teknologiske udvikling har supporteret den økonomiske vækst i produktionsindustrien i mere end 250 år. Produktionsindustrien er i eksplorativ udvikling, og denne udvikling tager form i mange afskygninger. Siden den industrielle tidsalder debuterede er mange strategier blevet introduceret. I dag definerer den fjerde industrielle tidsalder nutidens produktion. Den tilhørende strategiske agenda går under navnet Industri 4.0 (I4.0), hvor nye digitale teknologier er momentum for realisering af denne. I4.0 præsenterer en vision om at sikre fuld data tilgængelighed med henblik på at skabe gennemsigtighed, ikke kun i produktionsmiljøet, men på tværs af virksomheden - både internt og eksternt. Med en ambitiøs agenda skaber I4.0 mange digitale løfter om øget værdi gennem forbedring af nuværende processer eller gennem aktivering af nye med digitale teknologier som byggesten.

Da I4.0 først blev introduceret i 2011, har mange forskere sidenhen diskuteret de tilhørende digitale teknologier og identificeret deres positive og negative brugssituationer. Desværre, ser det ud til, at forskningsbidragene vedrørende digitale forandringer på produktionsgulvet er blevet overset, da begrænset normativ viden vedrørende dette eksisterer. Samtidig påpeger flere forskere inden for operations management (OM) feltet, at den teknologiske udvikling affødt af I4.0 øger kompleksiteten af nuværende produktionssystemer, hvilket har genereret nye betingelser for håndtering af ledelse(n) på produktionsgulvet.

Gennem dette treårige forskningsprojekt har flere virksomheder, som alle anses for at være digitale frontløbere, bidraget med praktiske use-cases omhandlende udfordringer ved implementering af digitale styringstavler på produktionsgulvet for håndtering af operative opgaver. Dette PhD - projekt har til formål at identificere og adressere de relaterede udfordringer til dette ved at bidrage med normativ viden om, hvordan produktionsvirksomheder kan overkomme denne udfordring. For at gøre dette og skabe bidrag til både teori og praksis er forskningsprojektet bygget på to grundsten:

- **Udforskning**, hvor formålet med denne proces er at redegøre for den nuværende ”problem situation” ved at få en dyb forståelse for forskningsemnet gennem en omfattende eksplorativ empirisk drevet undersøgelse. Teoretisk er et task-technology-fit-framework adopteret til, at identificere de funktionaliteter en digital styringstavle kræver for at kunne at håndtere de nutidige opgaver på produktionsgulvet.

- **Forklaring,** hvor formålet med denne proces er at redegøre for den ønskede brugssituation for brug af digitale styringstavler på produktionsgulvet. Dette sker gennem analyse af test og evaluering af de fysiske løsningsforslag sat op for at genere en løsning til forskningsproblemet. I denne proces identificeres de teoretiske og praktiske bidrag.

Afhandlingen præsenterer en samling af fire videnskabelige artikler, som i fællesskab viser den progression forskningsprojektet har haft gennem den treårige periode. Alle fire artikler er empiriskdrevet og er udarbejdet i samspil med produktionsindustrien med det formål at matche

kravet om at skabe akademiske bidrag, som afspejler den virkelige brugskontekst på produktionsgulvet. Dette er lykkedes, da tæt samarbejde med produktionsindustrien har muliggjort at teste og evaluere de generede løsningsforslag i praksis.

Forskningsresultaterne har sikret, at denne afhandling bidrager til OM forskningsdomænet tilhørende technology management videns-basen. Ved at diskutere sammenspillet mellem den digitale omstilling på produktionsgulvet og brugen af nuværende- og digitale styringstavler. Forskningsprojektets hovedbidrag udfolder sig på to måder: Først ved at adressere relevante emner som influerer på digitale implementeringer på produktionsgulvet såsom de influerende kræfter for og imod en digital omstilling til styringstavler og ved at demonstrere brugbarheden af nuværende- og digitale styringstavler. Derefter ved at foreslå fire forudsætninger forud for udvikling og implementering af digitale styringstavler besiddende de rigtige funktioner til at håndtere de nutidige opgaver på produktionsgulvet.

ACKNOWLEDGEMENTS

"Life takes on meaning when you become motivated, set goals and charge after them in an unstoppable manner"

When writing the project motivation when applying for the PhD position, I started the letter with the above quote provided by the politician, Les Brown. Now I am at the end of chasing my goal for my three-year PhD adventure, and what an adventure it has been! This journey – and the outcome of this thesis – would not have been possible without several people's direct and indirect support. I would like to thank them sincerely.

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PAPER II:

Clausen, P. Ready, Steady, Go! Digital Shop Floor Management Visualization Boards as a means for survival in Industry 4.0. In review in *Journal of Manufacturing Technology Management*. **Submitted February 2022**.

PAPER III:

Mathiasen, J. B., Clausen, P. (**resubmitted August 2022, 3rd revision**) Chasing digitalized visualization boards: Achieving fit between visualization boards and shop floor tasks. In 3rd review in *Journal of Operations Management*. **First submitted September 2020**.

PAPER IV:

Clausen, P., Henriksen, B. (2022). Teaching Old Dogs New Tricks - Towards a Digital Transformation Strategy at the Shop Floor Management Level: A Case Study from the Renewable Energy Industry. *Lecture Notes in Mechanical Engineering* Springer, Cham. 746-753 https://doi.org/10.1007/978-3-030-90700-6_85

Supporting papers (not included in this dissertation)

PAPER a:

Clausen, P., Mathiasen, J. B., & Nielsen, J. S. (2018). Barriers and enablers for digitizing Shop Floor Management boards. *2018 Global Wireless Summit (GWS) IEEE,* 1*,* 288-293. IEEE. https://doi.org/10.1109/GWS.2018.8686591

PAPER b:

Clausen, P. (2019). Digital Decision Support Systems for Enhanced Human Based Decision-Making at the Shop Floor Management Level. *2019 Portland International Conference on Management of Engineering and Technology (PICMET),* IEEE*,* 1, 1-7. https://doi.org/10.23919/PICMET.2019.8893509.

PAPER c:

Clausen, P., & Mathiasen, J. B. (2019). Doing shop floor management: a Pragmatist Take on working practice at shop floor level. *26th EurOMA Conference: Operations adding value to Society*, IEEE*,* 2460-2470.

PAPER d:

Nilsson, A., & Clausen, P. (2019). Digital Maturity: Transitioning from Analogue to Digital Shop Floor Management Board Meetings. *2019 First International Conference on Digital Data Processing (DDP),* IEEE, 104-111. https://doi.org/10.1109/DDP.2019.00029.

PAPER e:

Clausen, P., & Mathiasen, J. B. (2020). Next Generation Shop Floor Management: Investigating the managerial prerequisites for a digital transition. In *The 27th EurOMA Conference: Managing Operations for Impact,* IEEE, 1223-1232.

PAPER f:

Mathiasen, J.B, Clausen, P., Tambo, T. (2022). Digitization of shop-floor management and communication: technology-facilitated work-place leadership. **Submitted** to *Scandinavian Journal of Management* in July 2022. Have previously been in review in *Scandinavian Journal of Information System*.

PAPER g:

Mathiasen, J. B., & Clausen, P. (2019). Digitising shop floor visualisation boards: A missing link in the Industry 4.0 Era. In *Transdisciplinary Engineering for Complex Socio-technical Systems,* IOS PRESS, 10, 189-198. https://doi.org/10.3233/ATDE190123

PAPER h:

Clausen, P., & Mathiasen, J. B. (2021). Visualization boards at the shop floor management level in manufacturing: Providing practitioners the information they need to control and cope with uncertainty. In *The 28th EurOMA conference*: Managing the “new normal”: The future of Operations and Supply Chain Management in unprecedented times, IEEE.

PAPER i:

Mathiasen, J. B., & Clausen, P. (2022). Doing transdisciplinary studies through the lens of Intervention Based Research. In *Advances in Transdisciplinary Engineering,* IOS PRESS, 28, 697-706. https://doi.org/10.3233/ATDE220703

PAPER j:

Clausen, P., & Mathiasen, J. B. (2022). Digital visualisation tools to bridge communication across manufacturing – a transdisciplinary journey. In *Advances in Transdisciplinary Engineering,* IOS PRESS, 28, 505-514. https://doi.org/10.3233/ATDE220681

1 Chapter – Introduction

As the dissertation title indicates, this chapter sets the scene for chasing visualization boards (VB) providing functionality to handle contemporary shop floor tasks in a digitalized manufacturing setting. First, the motivation and background of the research project are clarified, followed by a presentation of the research objective and questions. The chapter closes by elaborating on the thesis structure and defining the project's most frequently applied terms to increase its readability.

1.1 Motivation and background

> "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."

Shop floor manager, Alpha.

VBs are fundamental technology-enabled operations management (OM) resources that are used in manufacturing companies to ensure the effective execution of manufacturing through shop floor management (SFM) (Parry and Turner, 2006; Bateman et al., 2016; Torres et al., 2019). VBs are a visual abstraction of the physical reality on the shop floor and contain data to make work actions visible to guide the handling of shop floor tasks which revolves around maintaining a swift and even production flow (Schmenner and Swink, 1998; Beynon-Davis and Lederman, 2017). Due to the contemporary digital transformation of shop floors (Buer et al., 2020), VBs are assumed to receive more impact in SFM (Bateman et al., 2016).

This project represents a close collaboration with the industry. The above citation illustrates why the author has been motivated to chase VBs providing functionality to handle contemporary shop floor tasks for three years: Practitioners lack practical guidelines to follow.

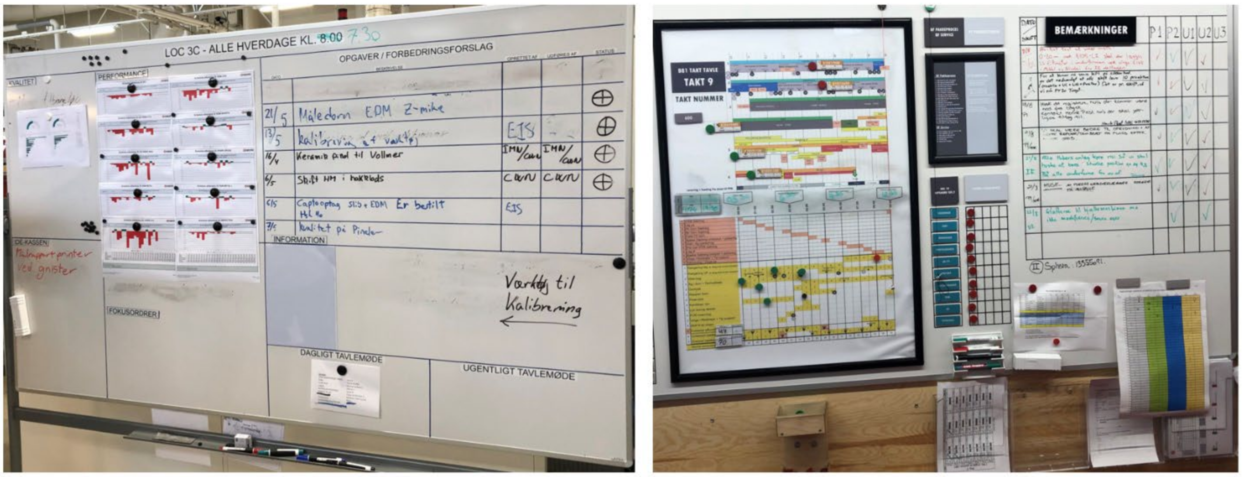
For more than 250 years, technological evolution has supported economic growth in the manufacturing sector (Xu et al., 2018) and several strategies have been launched to drive the industrial revolution. One such strategy in recent times is the fourth industrial revolution (Industry 4.0 (I4.0)), a term coined by Klaus Schwab in Germany in 2011 (Xu et al., 2018). Under the umbrella of I4.0, the term *smart manufacturing* is highly applied by researchers and practitioners to describe the production of tomorrow (Kusiak, 2018; Dai et al., 2019; Flores et al., 2020).

Smart manufacturing intends to enable a fusion of physical and virtual worlds through cyber-physical systems (Buer et al., 2020; Wang et al., 2020a; Jwo et al., 2021) by combining advanced manufacturing capabilities and digital technologies (Helu et al., 2016). It covers several research domains and has attracted the attention of several researchers who have reported their findings in the literature (Kusiak, 2018). Unfortunately, the number of theoretical studies and contributions is still more significant than the studies providing empirical evidence in the OM research domain (Cagliano et al., 2019). However, empirical-driven technology-oriented research is not a recent development in OM, and it currently exists in many forms, including digital manufacturing technologies with the threshold in I4.0, such as Internet of Things, Big Data, and System Integrating (Heim et al., 2021).

When screening the OM literature related to SFM in the context of smart manufacturing, it does not seem that undergoing a digital transition is inevitable (Roscoe et al., 2019; Koh et al., 2019). Several OM researchers (like Li et al. 2019; Luthra et al. 2020; Cimini et al. 2020) claim that technological development has increased the complexity of modern production systems, which has put new demands for facilitating SFM. In addition, the use of emerging communication and information technologies is touted as a necessity on today’s manufacturing shop floor (Buer et al., 2020), as the company’s ability to stay competitive is linked to its capability of capturing and unlocking relevant information efficiently and effectively (Roscoe et al., 2019). With data increasingly becoming the focal point in handling shop floor tasks (Jwo et al., 2021), new digital technologies for improvement of the data lifecycle (data acquisition, data preprocessing & storage, and data visualization) have been proposed (Dai et al., 2019).

The increased focus on utilizing production data has reshaped how shop floor tasks should be handled (Cagliano et al., 2019). OM researchers argue that interconnection and interoperability by implementing cyber-physical systems on the shop floor enable the necessary functionalities to handle contemporary shop floor tasks, as the handling requires data-driven support systems for the practitioners to rely on (Helu et al. 2016; Cimini et al., 2020; Buer et al., 2020). However, support systems on the shop floor are not new; for several decades, companies have relied on visualization tools that transmit cues triggering reflection and interaction to guide the handling of tasks.

Visualization tools on the shop floor function as a communication aid to support practitioners in handling tasks (Parry and Turner, 2006; Bateman et al., 2016). These visualization tools take shape as VBs (Lorenz et al., 2019), and their functionality differs from their physical form and characteristics (Bateman et al., 2016). For many years, VBs have formed part of the industrial information representation, and it clearly appears that practitioners have taken these VBs to heart. For example, upon walking along the shop floor, you will notice how well these VBs are incorporated into the production space (Mathiasen and Clausen, 2019). To provide an example, Picture 1 illustrates two types of VBs for handling shop floor tasks: a performance management VB for performance evaluation and reporting (picture on the left) and a takt-time VB for monitoring and control (picture on the right).



Picture 1. Example of VBs to steer SFM meetings in manufacturing. Source: own pictures.

VBs usually appear as analog dashboards (i.e., whiteboards) with various printed sheets of information attached (Fast-Berglund et al., 2016; Li et al., 2017; Lorenz et al., 2019). The VBs are used to steer daily meetings to operationalize SFM using visual stimuli to guide practitioners in handling tasks, such as monitoring and controlling to maintain a swift and even production flow (Bateman et al., 2016; Steenkamp et al., 2017). However, to keep up with today's smart manufacturing environments, the shop floor is moving towards digital solutions, where data and information related to monitoring and controlling shop floor tasks comes from multiple and heterogeneous sources (Steenkamp et al., 2017). Communicating this information to shop floor practitioners can thus be presented more effectively on digital solutions than analog VBs (Steenkamp et al., 2017; Li et al., 2017; Torres et al., 2019; Meissner et al., 2020). The challenges of relying on analog VBs arise because they depict historical data, leaving out the opportunity to enable real-time production transparency, which excludes the opportunity to react to variation when it occurs (Meissner et al., 2018; Torres et al., 2019). In addition, due to their analog physical shape, they enable limited interoperability, which limit the ability to operate in conjunction across boundaries in the manufacturing.

For the last couple of years, several OM researchers have paid attention to the digital transition of SFM VBs (e.g., Fast-Berglund et al., 2016; Torres et al., 2019; Meissner et al., 2020). Several conceptual papers address the benefits of having a digital transition of SFM VBs, and claim that VBs with analog functionalities are too wasteful (Meissner et al., 2018; Lorenz et al., 2019; Meissner et al., 2020). Few OM researchers have provided practical use cases elaborating on applying digital SFM VB, which has proven some of the expected benefits put forward in the conceptual papers (see Hultin and Mähring, 2014; Steenkamp et al., 2017; Li et al., 2017; Østerlie and Monteiro, 2020). However, these OM researchers refrain from clarifying the extent of the digital transition by not opening up the black box of technologies; their findings only seem to concern the usability of the VBs, providing no practical guidelines for overcoming the transition.

Following Holmström et al. (2019), the implementation of digital solutions in manufacturing depends on the physical and technological characteristics and the digital encapsulation of data and information processes. Although, the above-mentioned studies contribute with valuable information, it is impossible to clarify whether the studied VBs are dig**iti**zed or dig**itali**zed, which seems relevant, as the diffusion of digital technologies manifests with significant differences (Holmström et al., 2019). To provide clarification of the ongoing digital transition of SFM VBs, the author adopts the definition of digitization and digitalization put forward by Holmström et al. (2019, p. 728):

> "The diffusion of digital technologies can manifest as *digitization* (the straightforward replacement of discrete processes or tools with digital analogues) or *digitalization* (the use of digital information to fundamentally revisit intra and inter-organizational decision-making, processes, and architectures)."

With the increased focus on providing access to data and information for the handling of contemporary shop floor tasks, as asserted above, a solution for a VB that supports practitioners with the necessary functionalities is warranted. Given the few practical use-cases on this research topic, it remains unclear whether current VBs are technologically outdated, although literature indicates that smart manufacturing shop floor implementations should range above the level of digitization (see Dai et al., 2019; Buer et al., 2020; Cimini et al., 2020; Jwo et al., 2021). However, regardless of whether shop floor data are big, reliable, or in real-time, the data depicted on a VB is only applicable if the data is conveyed into information, information into visual meaning, and visual meaning into common knowledge among the involved practitioners. Nonetheless, the question of how to develop and implement SFM VBs that provides the functionality to handle contemporary shop floor tasks remains unanswered.

Motivated by this need, the author has studied the use of analog VBs to handle contemporary shop floor tasks in 18 manufacturing companies prior to investigating implementations of digital VBs in three large manufacturing companies; in one of these, the author has been a part of the development of digital VBs through intervention for more than two years. The research method pursues a Design Science (DS) approach (Simon; 1973; 1996), drawing on an abductive logic (Dewey, 1938). Moreover, the research contribution is aimed at the OM research field related to its technology management (TM) knowledge bases, in which the study follows the design principles within this domain.

Furthermore, OM researchers, such as Van Aken et al. (2016), Moghaddam et al. (2018), and Cimini et al. (2020), have identified the definition of optimal interactions between humans and technology as a research gap in the literature for smart manufacturing implementations on the shop floor. To address this research gap, the study conceptualizes a VB and the OM system it operates within as sociotechnical constellations, which aligns with a stream of OM researchers (Van Aken et al., 2016; Cagliano et al., 2019; Cimini et al., 2020). The following section elaborates on this PhD project's research objective, which serves as the anchorage point for this three-year research study.

1.2 Research objective

According to the gaps that emerged from the OM literature concerning implementations of smart manufacturing solutions on the shop floor, this project aims to investigate the "SFM VB-shop floor task nexus" through a digital transition of VBs. Overall, this project intends to provide the reader with an understanding of how to overcome the practical problem of providing shop floor practitioners with the information they need to facilitate SFM and thereby handle contemporary shop floor tasks. The main research objective is articulated as follows:

How to develop visualization boards providing functionality to handle contemporary tasks on a smart manufacturing shop floor

By "smart manufacturing shop floor" the author refers to the facilitation of SFM in which the handling of related shop floor tasks depends on digital technologies. In order to come up with a suggestion for solving the practical problem, a DS research approach is adopted, as the author aims to generate a solution by creating an artefact (a VB providing functionality to handle contemporary shop floor tasks) where the solution reflects the lessons learned during the three-year study period. The research activities are divided in two stages in which the first stage, work package (WP) 1, explores the current understanding of the research topic, while the second stage, WP 2, explains the desired state. Each WP accounts for different research activities, which poses five research questions (RQ) to shed clarity on the research objective. Table 1 presents the RQs belonging to each WP.

WP 1 - Explore the *current understanding* of the research topic
RQ1: What is the current adaptation level of digital SFM VBs?
RQ2: What forces influence the further adaptation of digital SFM VBs?
RQ3: What role do shop floor practitioners attribute digital VBs for facilitating SFM?
WP 2 - Explain the *desired state* of the research topic
RQ4: What are the prerequisites for achieving fit between SFM VBs and contemporary shop floor tasks?
RQ5: What are the preconditions when considering a digital transformation at the SFM level?

Table 1. The applied RQs to investigate the research objective.

All five RQs appear in the appended papers, **PAPERs I-IV**. For WP 1, **PAPER I** addresses RQs1+2, and **PAPER II** addresses RQ3. For WP 2, **PAPER III** addresses RQ4, and **PAPER IV** addresses RQ5. The next section accounts for how this thesis is structured.

1.3 Thesis structure

This PhD thesis frames the culmination of three years of work. The thesis is constructed on a collection of papers, of which four papers are included as the direct reference work to answer the research objective presented in the previous section. Furthermore, ten additional scientific papers have been developed during the project. These supporting papers (see **LIST OF APPENDED PAPERS**) are all linked to the PhD research activities; Figure 1 illustrates how these are connected to the work presented in this thesis by shortly describing their contribution.

The thesis is divided into six chapters, presenting a zoom-out view of introducing the PhD research. The in-depth descriptions of the research activities are reported in the appended papers, **PAPERs I-IV**. While the appended papers are the synthesis of the research activities performed, this thesis aims to contextualize these by aligning and discussing them from a broader perspective during the "cover" accounting for the six chapters.

First, *Chapter 1*, the **Introduction**, presents the motivation and background for this research project. The chapter clarifies the research gap, objective, and questions, which constitute the research backbone, to define the overall research frame.

Chapter 2, the **Theoretical foundation**, defines the theoretical positioning of the PhD research and elaborates on the theoretical domains applied to examine the SFM VB-shop floor task nexus by presenting current use cases of digital transitions of SFM VBs. Furthermore, the theoretical framework applied to study the fit between VBs and contemporary shop floor tasks is clarified.

Chapter 3, the **Research methodology**, presents the scene for the methodological choices the author has made to address the research objective of this PhD project first by clarifying the project's philosophical stance and research approach, then by evaluating the methodological choices made.

Chapter 4, the **Research findings**, addresses the findings related to the conducted research activities by presenting the main findings and contributions from **PAPER I-IV** answering **RQ1-5**.

Chapter 5, the **Discussion**, discusses the research findings by reflecting on its theoretical and practical implications, the limitations of the study, and addressing few of the further research thoughts.

Lastly, *Chapter 6*, the **Conclusions**, provides finalizing answers to the research objective by describing how the research project fulfilled/not fulfilled the research objective.

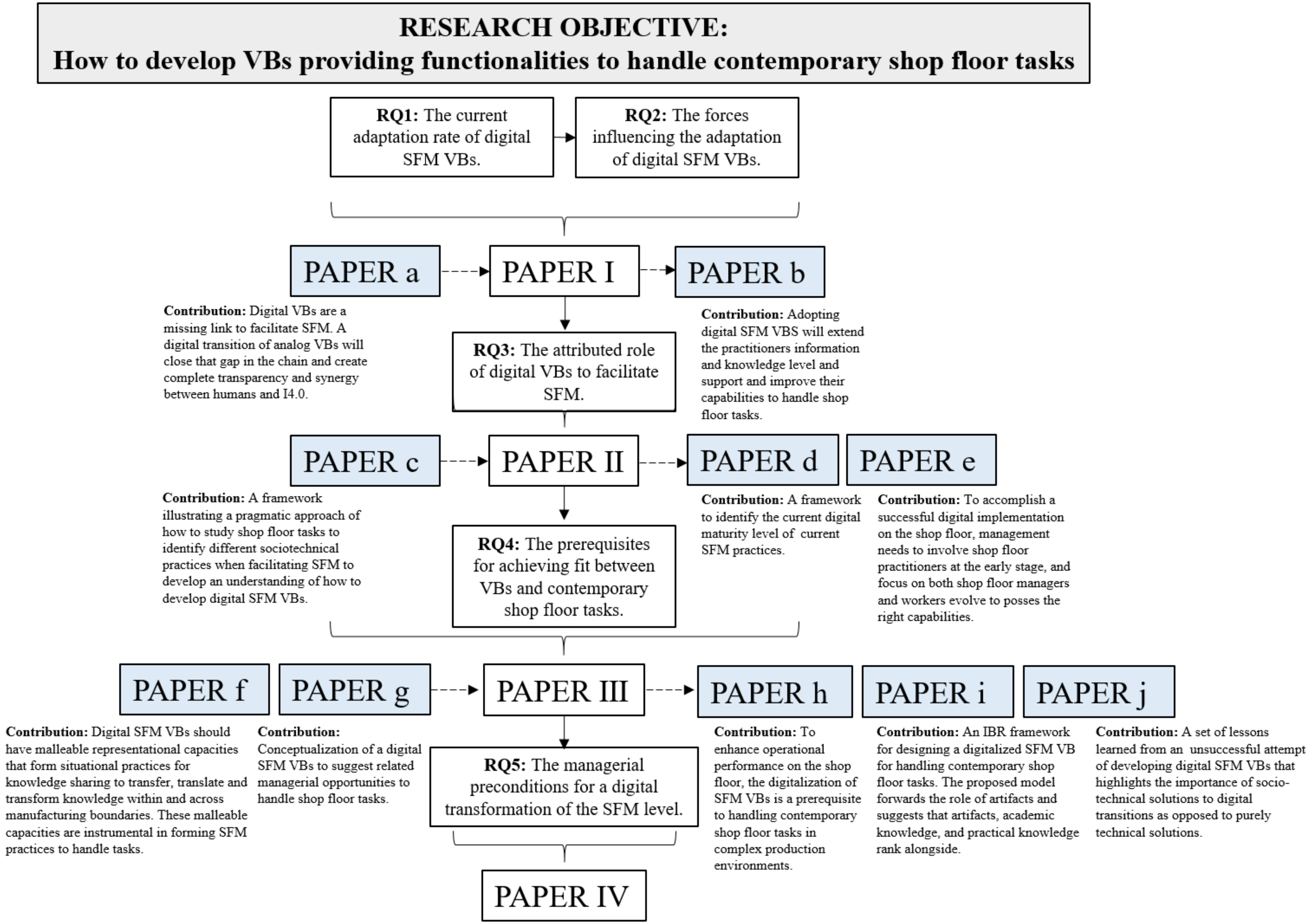


Figure 1. Appended papers and their relation to the research objective and RQs.

1.4 Definitions

This thesis uses frequent terms during the PhD project from the OM and TM domains. Table 2 aims to provide a shared understanding of their usage during the project to ensure the reader understands the context in which the terms are applied.

Term	**Definition**
Shop floor management (SFM)	Refers to the managerial practice on the shop floor in manufacturing, which grounds the research context for this project. The facilitation of SFM deals with handling contemporary shop floor tasks via VBs, please see **Section 2.2**.
(Contemporary) shop floor tasks	Shop floor tasks are of fundamental interest in this project, as the handling of these reflects the operational performance of the manufacturing. "Contemporary" refers to the shop floor tasks in which the handling of these are affected by smart manufacturing implementations.
Visualization board (VB) (also referred to as a SFM VB)	The visualization tool applied to facilitate SFM and handle related shop floor tasks, please see **Section 2.2.3**.
Digital	The term "digital" is applied in its broad sense when referring "everything digital" – the use of "digital" does not distinguish between digi**tiz**ed and digi**taliz**ed functionalities.
Digitized VB	A VB providing functionalities that mirror a straightforward replacement of discrete processes or tools with digital analogues.
Digitalized VB	A VB providing functionalities to use digital information to fundamentally revisit intra and inter-organizational decision-making, processes, and architectures.
Current VBs (analog and digi**tiz**ed VBs)	Refers to the identified VBs of which literature have reported practical use-cases (the VBs that have been empirically explored prior to the intervention).
Emerging VBs (digi**taliz**ed VBs)	Refers to the VBs put forward by literature and empirical findings providing the necessary functionalities to handle contemporary shop floor tasks in a smart manufacturing context.

Digital transition	Going from analog to digital VBs refers to a **transition** process of improving existing technologies and processes rather than adopting a completely new system for handling shop floor tasks. At first, the transition is not considered a **transformation** process of genuinely disrupting current SFM procedures for handling shop floor tasks. Please notice that the author refers to a digital transition of SFM VBs when investigating RQ1-4, whereas RQ 5 considers the transition a transformation process, when exploring the managerial preconditions.
(Shop floor) practitioner	Practitioners are referred to as the people actively engaged in the research topic on the shop floor. Practitioners does typically refer to shop floor managers and workers.
Shop floor manager	Refer to the managerial roles on the shop floor. Shop floor managers include different specialist roles such as work station leader, workcell leader, and lean manager.
Shop floor worker	Refer to the ordinary workers (typically blue-collar labor) on the shop floor, in contrast to the managers in charge.

Table 2. Frequently applied terms and their definitions.

2 Chapter - Theoretical foundation

This chapter presents the theoretical background of the PhD thesis, with the aim to elaborate on the theoretical position of this study and identify theoretical gaps in prevalent literature. First, the chapter establishes an overview of the applied theoretical domains that illustrate the WP structure's interplay. Secondly, the main literature applied to explore to the research topic is accounted for in individual sections. Lastly, the emerged key literature gaps is summarized.

2.1 Theoretical positioning

As earlier explained in **Section 1.2**, this PhD project serves to solve a practical problem. The research problem is positioned in the OM research field, standing toward the TM domain. Hence, the study draws on OM research to examine the SFM VB – shop floor task nexus and combines this understanding with TM research to investigate the digital transition of SFM VBs. However, in addition, the author is facing a research problem between intersecting domains, which, according to Kumar et al. (2018), can be tricky as it can be hard to establish in which theoretical domain the contribution will be. Additionally, given that this thesis aims to solve a practical problem that ranges across transdisciplinary boundaries, the goal is to generate a contribution that makes academic research relevant to practitioners in both domains (Holmström et al., 2009). Following Holmström et al. (2009), bridging practice and theory is not easy, as the theoretical research interests do not always coincide with practice. Hence, generating a contribution that bridges theory and practice is not feasible if the theoretical boundaries for the study are ill-defined (see Holmström et al., 2009; Kumar et al., 2018).

Solving a practical problem requires interaction with the real world (practice) to create knowledge (Van Aken et al., 2016). To overcome practical problems and generate knowledge, several OM researchers (Holmström et al., 2009; Van Aken et al., 2016; Oliva et al., 2019) suggest a DS approach. DS is focused on developing "a means to an end", and Holmström et al. (2009) exemplify this by relying on the work of De Treville et al. (2008). The example explains that practitioners deal with ill-defined problems every day, and the solving hereof would not change if the academics suddenly disappeared (Holmström et al., 2009). Hence, practical problems need to be explored according to the physical context before they are explained and solved. DS affords such a process of exploration through design which combine empirical and theoretical investigation through an iterative process (Simon, 1973). This study follows such DS approach to develop an artifact (a SFM VB providing functionality to handle shop floor tasks), which reflect the way theory has been reviewed to address the research topic; **Section 3.2**, elaborates on this.

At the outset of the study, the author possessed a limited understanding of the research problem, making it impossible to define the theoretical boundaries and clarify the positioning of the contribution. To understand what lies at the interface between OM and TM, the author initiated an exploration that constitutes the research activities in WP 1. In line with OM researchers (like Caniato et al., 2018), the exploration is grounded in an a priori construct of the author's preliminary understanding of the research problem. For the theoretical exploration, the author decided to perform a narrative literature review (Baumeister and Leary, 2017) to develop an understanding of the research context's theoretical background of SFM to clarify the functionalities of VBs. From the literature review, in combination with the empirical understanding, it gradually became apparent what theoretical areas the problem was related to, which directed the author towards the TM domain. In line with DS, the exploration was followed by a combined exploration/explanation phase, which constitutes the research activities in WP 2, and, in the end, led the author to propose a design solution to answer the research objective (Holmström et al., 2009).

While reviewing the literature related to the research findings in WP 1 and WP 2, it became clear that the OM and TM literature about this research problem is relatively scarce and heavily fragmented; a partnership between OM and TM on this topic is lacking. Although literature claims that OM and TM have a long story of academic partnership (Kumar et al., 2018; Heim et al., 2021), Heim et al. (2021) claim that TM research can be considered a recent development for OM, as former research lacks the proper orientation making it relevant for OM. According to the same authors, TM research in OM should concern with how technologies affect operational processes, which makes the details regarding the mechanics, or of the code embedded within these technologies, less interesting. Figure 2 illustrates a top-layer perspective of where the research topic is placed between the theoretical domains and when they were explored in the study.

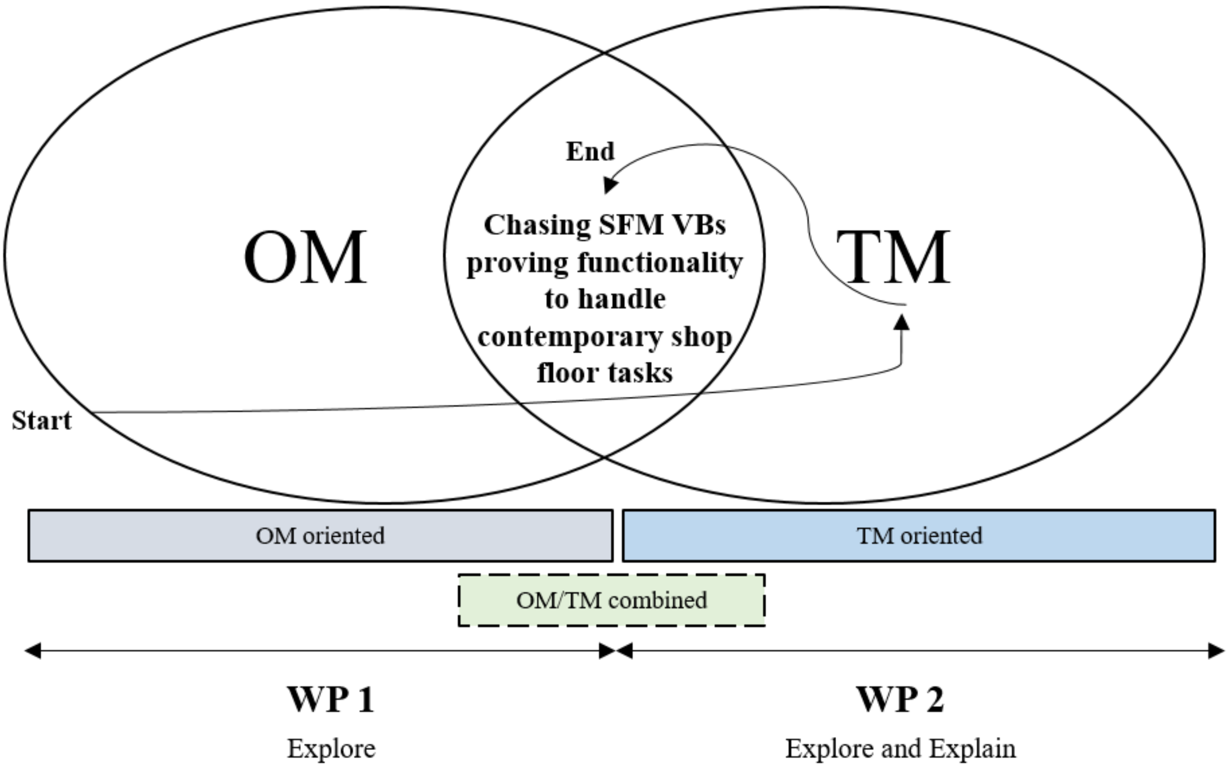


Figure 2. Top-layer perspective of the research problem's position according to the theoretical domains.

From Figure 2, it is shown that the theoretical exploration of the research topic took its outset in the OM domain. Gradually during the exploration, the author was directed toward the TM domain. As the interfaces between the two domains were ill-defined for this research problem (the green box in Figure 2), the author was first able to identify the theoretical interfaces after screening the OM and TM literature separately. The arrows in Figure 2 aim to illustrate this process.

The following sections establish the theoretical background of the thesis. First, the literature on SFM is reviewed to shed light on the functionalities of VBs, and the review ends with a short summarization before addressing the literature related to digital SFM and digital transition of SFM VBs.

2.2 SFM - the pulsating heart of manufacturing

"Shop floor" is a well-used term in manufacturing and refers to the operational level where physical actions such as producing and packing products occur. The expression "shop floor" origins from the Japanese word "Genba," and it addresses the place where value is created (Hertle et al., 2015). To emphasize the importance of the shop floor, Humphlett (2016) refers to it being the heart of the manufacturing. Moreover, the shop floor is defined as the point of convergence between information flows, material flows, and flows of follow-up activities (Zhuang et al., 2018). The practitioners operating on the shop floor mainly consist of a blue-collar workforce. In contrast, shop floor tasks are accomplished by standard procedures, manual processes, and monatomic task control without any technical support to guide the practitioners when handling tasks (Holm, 2018). Both in industry and in academia, the managerial practice on the shop floor refers to the term SFM (see Peters, 2009; Hertle et al., 2015; Torres et al., 2019). Several definitions and alternative viewpoints on SFM exist in the literature (Torres et al., 2019), but academia does not formalize a constituent description (Hertle et al., 2016; Meissner et al., 2018).

Hertle et al. (2015) are one of the few that have addressed and conceptualized the SFM as one industrial practice and define SFM as:

- Performance dialogues – discussions of key performance indicators
- Continuous improvement discussions
- Physical management present on the shop floor
- Physical meetings to follow up on improvements
- Utilizing the full potential of employees – focus on competency development
- Visualization tools – visualization of relevant performance figures for monitoring and controlling

The elements represent the system in which the practical problem this study aims to solve is grounded. Generally, OM systems are socio-technical constellations (Van Aken et al., 2016). In line with OM, SFM is considered a socio-technical system with technical and social components. In addition, the author adopts a practice-based perspective on SFM, as it is put forward as a dispersed nexus of social activity (practitioner-led activity) and material things (VBs) where both practitioners and the VBs have an influencing role in forming SFM (see Nicolini 2012). To clarify the research context, the next sections elaborate on the SFM literature in the contexts of performance management & continuous improvement, the management meeting practice, and VBs as put forward by Hertle et al. (2015).

2.2.1 SFM - a lean offspring focusing on performance and continuous improvement

Although SFM seems to be a modern term, due to its late introduction in 1991, it was presented in Womack et al.'s (1990) release of "The machine that changed the world." The fundamental principles of SFM can be traced back to the 1940s when it had its offset in Lean Manufacturing (Hanenkamp et al., 2013; Eaidgah et al., 2016; Torres et al., 2019). In lean, SFM has for decades played a key role in controlling performance and driving continuous improvement processes (Hanenkamp et al., 2013; Larteb et al., 2016) by having standardized "follow-up" meetings daily in the production environment (Li et al., 2017). For several years, SFM has improved companies' operational performance significantly (Larteb et al., 2016). The performance criteria related to SFM are designated key performance indicators (KPI) and origin from the Toyota Production System. Several shop floor tasks are linked to the KPIs discussed within the SFM practice and following Liker and Meier (2006) and Larteb et al. (2016), the five most common KPIs are safety, quality, productivity, costs, and delivery.

The KPIs play a crucial role in SFM, as they cover the shop floor tasks for maintaining a swift and even production flow (Schmenner and Swink, 1998; Meissner et al., 2018). In line with the definition of SFM put forward by Hertle et al. (2015), it appears to be clear that SFM is dedicated to optimizing performance, and Löwe (1993), Peters (2009), and Illing (2012) support this statement by stating that the objective of SFM is the optimization of KPIs.

Optimization of KPIs is expressed through the handling of shop floor tasks. A precise definition of shop floor tasks does not exist (Wang et al., 2020a) as they revolve around the KPIs implemented in the manufacturing. The OM literature distinguishes between several categories of shop floor tasks (Stoop and Wiers, 1996); however, as this study emphasizes the SFM activities happening on the shop floor, the tasks related to monitoring and controlling (Slack and Brandon-Jones, 2019) are in focus, as they represent the tasks after releasing orders for manufacturing.

To present an overview of the variety of shop floor tasks related to monitoring and controlling the shop floor, a narrative literature review (Bryman and Bell, 2007) has been performed; the review should not be considered comprehensive, nor is it essential that it be so. The narrative review is summarized in Table 3.

Shop floor task examples	Subramaniam et al. (2005)	Subramaniam et al. (2009)	Zeng et al. (2013)	Ji and Wang (2017)	Zhang et al. (2017)	Alcaide-Munoz et al.	Mourtzis and Vlachou	Zhuang et al. (2018)	Wang et al. (2020a)	Wang et al. (2020b)
Machine maintenance, failures & repair	x	x		x	x		x	x	x	x
Monitoring variation in material flow	x	x		x	x				x	x
Performance evaluation and reporting	x	x	x			x	x		x	x
Cope with quality issues		x						x	x	
Safety control & assurance									x	
Cope with unplanned absenteeism	x									
Communication tasks			x			x	x			
Rework & rewrite working procedure	x									
Coordination tasks	x	x		x	x	x	x	x	x	x
Monitoring production variation	x	x	x	x	x		x	x		
Improvement of performance		x	x		x	x				x

Table 3. Identified shop floor tasks related to the SFM activities after releasing orders for manufacturing.

Based on the author's interaction with the field, the listed tasks in Table 3 typically revolve around three significant categories of shop floor tasks: performance management, continuous improvement, and takt-time compliance for controlling and monitoring a swift and even production flow. However, handling shop floor tasks is highly influenced by the environment in which the tasks are handled. The following section addresses the physical practice of conducting SFM.

2.2.2 SFM - a physical meeting practice

SFM covers a broad field of activities and objectives (Peters, 2009), appearing through the definition of SFM portrayed by Hertle et al. (2015). Hertle et al. (2017) have developed a model structuring SFM, The Darmstadt shop floor management model. The model describes SFM as a feedback loop where shop floor meetings with dialogues and discussions are central to supporting operative targets such as the shop floor tasks related to monitoring and controlling the production. The meetings are supported through performance management-, problem-solving-, and continuous improvement activities, and these are accomplished frequently (Meissner et al., 2018; Torres et al., 2019).

Shop floor meetings are physical, regular meetings conducted using SFM VBs involving practitioners of a particular production area (Torres et al., 2019). The meetings follow a standardized scheme where the start time, agenda, duration, participants, and support functions are well-established elements. Shop floor meetings are typically divided into three-four layers where the meeting on the first layer (lowest level) takes place on the shop floor and is conducted within a shop floor team level. At the second layer, the meeting is held across teams where a team representative from each area meets (e.g., work station manager) with the production supervisors (e.g., workcell manager) to provide a status. Depending on the organization structure, the status is typically communicated to the higher management level at a third- or fourth-layer meeting. The plant manager and different department representatives, such as quality, engineering, and finance, are typically present at these meetings (Torres et al., 2019).

However, this study focuses on the first layer of conducting SFM meetings, as these meetings take place in the production and aims to reinforce SFM by identifying opportunities for improvements and handling tasks related to monitoring and controlling the production. From now on in this thesis, the first-layer meetings are referred to as SFM meetings.

The leadership on the shop floor reflects the role of SFM as a management tool (Meissner et al., 2018). Work station managers on the shop floor represent the first level of leadership, and they are typically in charge of managing the SFM meetings, being responsible for conducting performance updates, improvement processes and identifying and reacting to problems when they occur (Hertle et al., 2016). The shop floor workers support the manager within his/her team to fulfill these targets through the SFM meetings. At these meetings, a status about the production, disruptions, and problems is given collaboratively (Hertle et al., 2015). The status update is typically linked to several KPIs depicted on a performance management VB. In case of deviations or unforeseen events, shop floor tasks are created, discussed, and solved via a continuous improvement/problem-solving VB. To ensure the execution of tasks, the work station manager needs to build up good relationships with the workers, as the communication needs to be effective in case of need for advice or assistance when handling tasks (Meissner et al., 2015). Based on the work from Liker and Meier (2006), Hertle et al. (2015) have drawn up the problem-solving process related to handling shop floor tasks at the SFM meeting. The process is depicted in Figure 3.

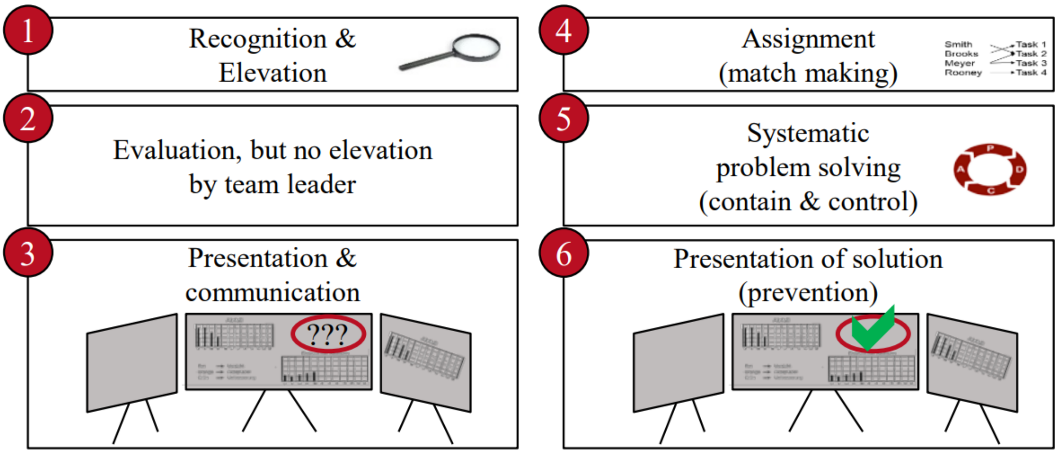


Figure 3. The problem-solving process related to handling shop floor tasks at the SFM meeting. Source: Hertle et al. (2015).

It starts with a recognized problem, either detected by a shop floor manager or a worker, or through the target state performance update (e.g., KPI deviations) being escalated at the SFM meeting (step 1). Afterward, an evaluation is performed, deciding whether the problem should be considered a task for the team to handle (step 2). If yes, the problem is clarified through a brief presentation on a VB, and the person(s) present at the meeting having high awareness about the problem communicates relevant information via the VB functionalities (step 3). If it is impossible to handle the tasks related to the problem immediately, tasks are assigned to specific team members (step 4). The team members assigned to handle the task initiate a problem-solving process, typically involving additional visualization tools (e.g., A3 storyboards, PDCA charts, flowcharts, Pareto and fishbone diagrams) to guide and support this process (Tezel et al., 2009; Hertle et al., 2015: Eaidgah et al., 2016) (step 5). As the final step, the solution is presented on a VB at a follow-up SFM meeting where the focus is to prevent the problem from reoccurring (step 6). As it appears from Figure 3, VBs play a central role in facilitating SFM, especially regarding handling shop floor tasks. The functionality of VBs in SFM is elaborated on in the next section.

2.2.3 Visualization boards: making work actions visible to guide handling tasks

VBs are fundamental technology-enabled OM resources used in many manufacturing companies to facilitate SFM. The use of VBs has been growing in recent years to deal with the fact that the shop floor has become a more complex environment in which to perform operations (Bateman et al., 2016; Torres et al., 2019; Luthra et al., 2020). VBs are considered of paramount importance for the handling of shop floor tasks (such as the shop floor tasks listed in Table 3) (Parry and Turner, 2006; Bateman et al., 2016), as they can display data to make work actions visible and guide the handling of tasks (Beynon-Davis and Lederman, 2017).

A VB functions as a visual abstraction of the physical reality on the shop floor where its functionality is to transmit cues triggering reflection and social interaction to guide the workers' handling of shop floor tasks. Several different SFM VBs exist, e.g., performance management boards (KPI VBs), control boards (takt-time VBs), and continuous improvement boards (kaizen VBs); the functionality of VBs differs from their physical form and characteristics. In its physical form, most VBs consist of printouts, such as Excel or Word documents put on a dashboard, a whiteboard, or similar (Fast-Berglund et al., 2016). These VBs depict analog representations. According to OM researchers, the functionalities of analog VBs are characterized by an analog "power of the pen" approach (Bateman et al., 2016) providing easy-to-understand information (Parry and Turner, 2006) to keep the meetings brief and effective (Liker and Meier, 2006).

Visualization of data guides the handling of tasks (Fullerton et al., 2014) and knowledge creation. The data visualized on the VB is only applicable if the data is conveyed into information and visual meaning (see Steenkamp et al., 2017). If the information is not easy to understand, it will not become knowledge for the workers to rely on when handling tasks (Bateman et al., 2016; Beynon-Davis and Lederman, 2017). A study by Bateman et al. (2016) illustrated that effective use of VBs enhances communication among the team members and their ability to handle tasks. However, it might be that the VB informs workers differently, which affects the handling of tasks (Beynon-Davis and Lederman, 2017). For that reason, it is crucial to ensure that the VBs do not provide an ineffective communication of information.

VBs are in this thesis addressed as a technological tool for group interaction (like Zigurs and Buckland, 1998 and Cagliano et al., 2019). Following Paiva et al. (2008), knowledge is an individualized construct, but how people embody knowledge also involves social interaction (like Blumer, 1969). At the SFM meetings, knowledge-sharing unfolds as social interaction in which the workers have reflective "conversations" with the data visualized on the VB. This entails that the conversations when handling tasks are pending on individual reflection (Paiva et al., 2008), meaning that each worker might have different understandings of the visualized data on the VB (Beynon-Davis and Lederman, 2017), which might lead to different intentions (Mathiasen, 2017). In addition, the data visualized on the VBs must release a common understanding; otherwise, it does not seem effective. To eliminate divergent understandings, the visualized data should, through rules and standard reference frames, appear common enough to make the workers recognize and “translate” the VBs equally.

2.2.4 Summary

To summarize and to shed light on the functionalities of VBs, the literature on SFM has just been presented. The review constitutes the main findings from the OM literature related to this topic in the theoretical exploration in WP 1. When reaching this stage in the study, it became obvious that the OM and TM literature related to the research topic is fragmented. Figure 4, a revised illustration of Figure 2, visualizes how the author saw the research problem being positioned between OM and TM at the end of the theoretical exploration in WP 1.

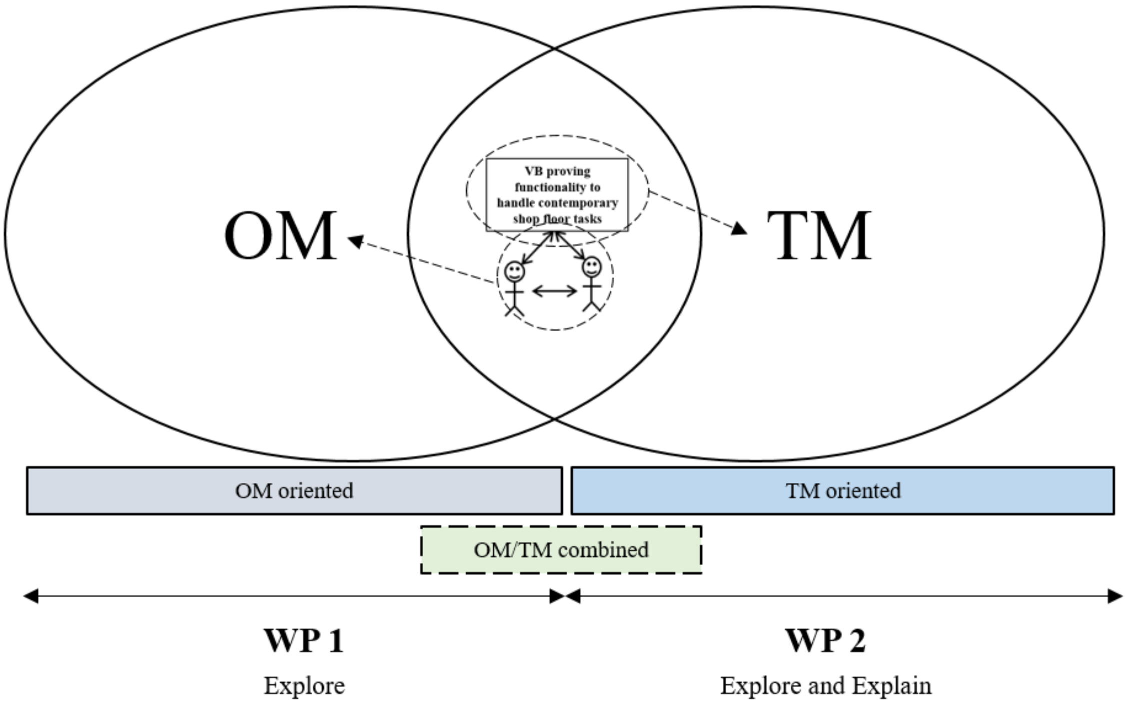


Figure 4. Top-layer perspective of how the author identify the research problem’s position after theoretical exploration in WP 1.

Based on the narrative literature review, the author defined SFM as a socio-technical practice consisting of a VB (a technological tool) and practitioners (shop floor managers and workers). The interplay between these components is that the VB cues information that triggers reflection and social interaction when handling tasks at SFM meetings. A very limited number of OM researchers touch upon the research problem, considering both the social and technical components. It seems that the OM literature addressing the research topic is heavily related to the social components of the SFM practice, where the focus is on the operational processes and how these affect the people and performance.

The OM literature does not pay much attention to the digital transition of SFM VBs. However, it provided direction on where to look in the TM literature. On the contrary, the TM literature seems to have the opposite focus, namely on how the technology work, not paying much attention to the social components. According to Van Aken et al. (2016), there is an unbalance in equally dealing with both the social and technical components in OM research: it seems to be a tendency to perceive socio-technical systems as entirely technical or social. The same authors describe this being a key OM research issue. Accordingly, the project's theoretical positioning and conceptualization of SFM VBs providing functionality to handle contemporary shop floor tasks in a smart manufacturing context rely on Van Aken et al.'s (2016) "engineering-OM transfer" to handle this problem, which both requires OM and TM knowledge (for elaboration, see **PAPER III**).

The following section clarifies the theoretical viewpoints on why a digital transition of SFM VBs is considered a prompting research area in OM and TM and identifies the related theoretical gaps this study aims to contribute.

2.3 The digital turn of the manufacturing shop floor

I4.0 has, since its introduction in 2011, delivered several digital promises to manufacturing to enhance the conditions of managing operations on the shop floor. The term *smart manufacturing* is often applied to describe this context, and Mittal et al. (2019, p. 1342) define the term as "…a set of manufacturing practices that use network data and information and communication technologies for governing manufacturing operations." Several TM researchers apply smart manufacturing to describe the next generation of production systems (like Kusiak, 2018; Dai et al., 2019) and report examples of how digital technologies are implemented on large scales to enhance performance on the shop floor.

Many OM researchers have provided findings illustrating that the digital turn of the manufacturing shop floor has increased the complexity of modern production systems, which has put new demands on facilitating SFM (see Luthra et al., 2020; Cimini et al., 2020). A study performed by Torres et al. (2019) illustrates how digital information technologies, such as having access to reliable data in real-time, are considered a requirement to ensure that practitioners always have transparency of ongoing operations to recognize problems and react to turbulences rapidly to eliminate deviations in the production environment.

The OM literature has, for some years, highlighted smart manufacturing implementations on the shop floor as a key challenge (Van Aken et al., 2016; Moghaddam et al., 2018; Cimini et al., 2020), as only a few indications of how to address such interactions between humans and technology are available. Although few suggestions are available, the author will take advantage of these to guide the research activities to support the theoretical contributions to the combined OM/TM domain. The next section presents the current literature addressing digital SFM related to the digital transition of VBs.

2.3.1 Digital SFM VBs

The digital turn of the manufacturing shop floor has drawn the attention of TM researchers (like Zhang et al. 2017) and OM researchers (like Torres et al. 2019; Meissner et al. 2020) to explore whether current VBs are sufficient to keep up with today's SFM conditions. However, the literature addressing how to tailor SFM VBs to the smart manufacturing context is scarce, and it seems that an empirical study to investigate the SFM VB – shop floor task nexus is warranted.

In a conceptual paper, Meissner et al. (2018) map the positive and negative effects of having a digital transition of SFM (see **Section 4.1.1**); however, these findings are not based on empirical studies on the shop floor. Yet, in Meissner et al. (2020), the authors argue that current

SFM meetings are wasteful and should be improved through digitalization. As for example, some shop floor practitioners spend around 60% of their time collecting and processing data in preparation for SFM meetings (Meissner et al., 2020). In addition, a study performed by Pötters et al. (2018) reveals that only 17.5% of manufacturing companies rely on digital systems to facilitate SFM, which might be because full access to shop floor data is only available to 5% of companies (Kandler et al., 2020).

Although it seems that most companies still rely on analog VBs to facilitate SFM, the literature does report a few practical use cases of digital VBs enabling digi**tiz**ed functionalities. For example, Hultin and Mähring (2014) illustrated the benefits of digital VBs for handling planning tasks and performance management tasks at a university hospital, implementing lean principles of workflow visualization. Following their results, digital VBs provide transparency of the physical reality on the shop floor and enable handling tasks across boundaries. Another study by Steenkamp et al. (2017) supports these findings and highlights the benefits of having access to real-time data, which also aligns with the findings from Østerlie and Monteiro (2020), as their findings show useful representations to handle performance management tasks by combining real-time data and advanced data analytics. However, these OM researchers refrain from clarifying the extent of the digital transition by only concerning the VB's usability. Their findings do neither touch upon how to overcome a digital transition, and whether their solutions overcome the critical challenge of improving the ineffective transfer of data and information to the shop floor practices.

Following Jwo et al. (2021), data are increasingly becoming the focal point in handling shop floor tasks, in which the onus of responsiveness lies in the SFM controlling and monitoring functions (Kumari and Kulkarni, 2016). Hence, SFM controlling and monitoring relies on access to data and information. With VBs being the technological tool responsible for visualizing data and information, their functionality to afford practitioners the ability to handle contemporary shop floor tasks depends on physical and technological characteristics and the extent of digital encapsulation (Holmström et al., 2019).

According to TM researchers (like Ganev, 2017), improving the functionality of technological tools (such as VBs) requires both front-end and back-end development. The front-end development involves what is visual for the user (i.e., the display visualizing digital representations). In contrast, the back-end development involves the development of what is invisible to the user, such as developing databases and servers, installing sensors for automated data treatment (Dai et al., 2019). To enable VB functionality to visualize real-time data and to utilize data to perform advanced analytics (e.g., predictive analytics), a complete digital encapsulation is required, including automating the data treatment throughout the lifecycle of the shop floor data (from data collection to data visualization) (Dai et al., 2019; Qi et al., 2021).

To answer the research objective of chasing a VB providing functionalities to facilitate SFM in today's smart manufacturing context, it seems necessary to study the functionalities of both current VBs (analog and digitized) and emerging VBs (digitalized). Although the literature provides examples of analog SFM VBs being outdated systems, it remains unclear whether both types of current VBs, technologically, are outdated, as the literature praises a complete digital encapsulation for enabling fit.

To study fit, the project draws on the task-technology-fit (TTF) theory (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998), where the exploration of *fit* is equivalent to the functionality of VBs that allows practitioners to handle contemporary shop floor tasks. The TTF theory generally assumes that the degree of fit affects the practitioners' performance (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998; Browning, 2010) and, in this case, the handling of shop floor tasks. The following section presents the conceptualized TTF approach applied in this project to explore fit.

2.3.2 Exploring TTF of SFM VBs

The TTF theory has been adopted to study the usability of current and emerging VBs to identify the prerequisites for achieving fit between VBs and contemporary shop floor tasks. Several OM researchers (like Bendoly and Cotteleer, 2008; Browning, 2010; Cagliano et al., 2019) have applied the TTF theory to examine the fit between technological systems and related tasks. This research addresses technology as a tool for social interaction (like Zigurs and Buckland, 1998; Cagliano et al., 2019), which is in line with the identified approach of handling shop floor tasks (see **Section 2.2.2**).

A TTF study performed by Browning (2010) argues that handling tasks depends on what a person can see and understand. Hence, it does not matter whether data are in real-time or reliable if the data depicted on the VBs is not translated into common knowledge among the involved people (like Paiva, 2008; Beynon-Davis and Lederman, 2017, see **Section 2.2.3**). Proper visualization and communication of data is, for that reason, both important for the knowledge creation of practitioners and their performance, as knowledge creation and social interactions go hand in hand in when handling tasks (Blumer, 1969; Schön, 1983).

This study draws on the prior work of Zigurs and Buckland (1998) and Browning (2010). Zigurs and Buckland (1998) present a taxonomy with three different types of fit consisting of three functionalities, which, when combined, enable a group to accomplish tasks (like handling shop floor tasks). The functionalities are communication, structure, and information processing. Given the clarification of shop floor tasks and shop floor VBs in **Section 2.2**, this study defines the functionality of VBs as a tool having the sufficient representational capacity to facilitate: 1. *Communication within and/or across shop floor boundaries,* 2. *Structure in terms of accomplishing shop floor tasks,* and 3. *Information processing related to accessing and manipulating information.* Figure 5 presents the applied TTF framework to guide the study of exploring fit.

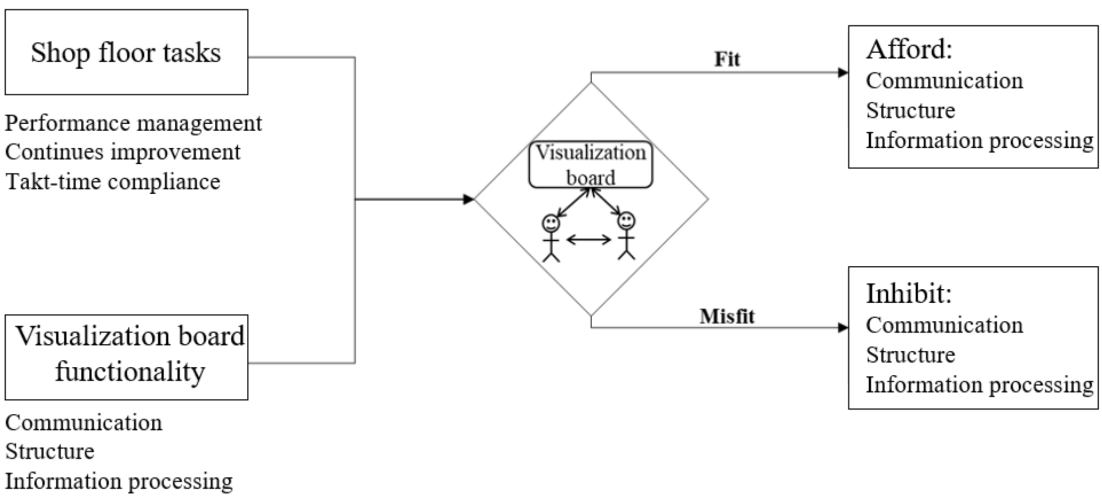


*Figure. 5 Task-Technology-Fit Framework. Source: (Mathiasen and Clausen, 2022 (**PAPER III**)).*

Following the left side of Figure 5, shop floor tasks are divided into performance management, continuous improvement, and takt-takt compliance (see **Section 2.2.1**), and VBs provide communication, structure, and information processing functionality. In the middle of the figure, a rhombus illustrates how the fit between shop floor tasks and the functionality of a VB as a tool enables social interaction, knowledge creation, and knowledge sharing among the involved people. The misfit/fit situations are defined by the following principles from pragmatism (Dewey, 1938). Here, the author focuses on actions (the handling of tasks) and the outcome hereof. To provide an example, fit affords *communication functionality* that provides interaction across shop floor boundaries, *structure functionality* that supports practitioners in complying with standard operating procedures, and *information processing functionality* that allows access to data and permits data analyses to be performed. In contrast, misfits occur if the VB functionality inhibits communication, structure, and information processing.

2.4 Overview of the identified main literature gaps

When screening the key literature related to the research topic investigating SFM VBs providing functionality to handle contemporary shop floor tasks, with an emphasis on a digital transition of analog VBs, several literature gaps occurred, and these reflect:

- A need to provide clarification on the ongoing digital transition of SFM VBs. Current studies do not clearly distinguish the diffusion of **digital** technologies within the digital transition of SFM and VBs, making it impossible to clarify the technological functionalities.
- Current literature does not reflect the practical realities on the manufacturing shop floor, as most studies present conceptual viewpoints.
- The OM literature addressing smart manufacturing implementations is concerned as a key challenge, as few indications of how to address the interaction between humans and technology are available, as the OM and TM domains are heavily fragmented. This indicates a need to suggest an approach to transcend boundaries between these domains.

3 Chapter - Research methodology

This chapter sets the scene for the methodological choices the author has made to address the objective of this PhD dissertation. The chapter opens by linking the philosophical stance presenting the theoretical perspective to the philosophical grounding. Next, the author's approach to the research design is elaborated through an overview of how the project has evolved during the three-year study period. In closing, the chapter outlines the conducted research activities and clarifies the rationales by justifying the choices made and discussing the relevant quality criteria. This chapter does not present a detailed description of the selected methods for collecting and analyzing data; these descriptions are available in the appended papers.

3.1 Philosophical stance

The philosophical stance behind research projects varies, as they include different assumptions of the constitution of the world. Following Orlikowski and Baroudi (1991), a researcher can never undertake a value-neutral philosophical stance, as the research context contributes to the construction of the worldview. For that reason, the following section briefly presents the research field in which the PhD project navigates to clarify the philosophical positioning hereof.

The PhD project subscribes to the OM research field, a theoretical domain that consistently has been regarded as a problem-solving discipline dealing with practical problems by interacting with the real world (Meredith, 2001; Holmström et al., 2009; Van Aken et al., 2016; Kumar et al., 2018). OM is tied to implications for technical science and social science components, making OM systems sociotechnical constellations (Van Aken et al., 2016). Given that the objective of this project is targeting to develop a solution on the manufacturing shop floor that involves both people and technology, a practice-based perspective (Nicolini, 2012) on SFM is adopted to understand the "world" the practitioners operate within. Hence, the author has addressed the project by seeking an understanding of the SFM practice by exploring how practitioners interact, as meaning and reality are social constructs constructed by them (Kim, 2001).

In line with the mentioned characteristics of OM, the PhD project is framed within an interpretive orientation, emphasizing the creation of knowledge through understanding and meanings (see Holmström et al., 2009). For the interpretive way of thinking, ontological and epistemological assumptions are intertwined, as the approach is dependent on constructivist ontology (Orlikowski and Baroudi, 1991). The research project is grounded in constructio**nism** augmented by pragmatism (e.g., Dewey, 1933; 1938). The adopted belief implies that the world is constructed and reinforced by humans through action and interaction. For that reason, the author aims to create understanding through the PhD project by interfering with practitioners on the shop floor by interpreting their activities and events by recounting them. This viewpoint aligns with the weak view of constructionism put forward by Orlikowski and Baroudi (1991).

The PhD project pursues a DS research approach. Following the work of Herbert Simon (1988; 1996), Simon's ideas are actively applied in several research fields, including OM (e.g., Holmström et al., 2009), in providing formal design guidelines. In compliance with DS (Oliva, 2019), the study draws on an abductive logic (Dewey, 1938) to generate prescriptive knowledge of overcoming the practical problem investigated in this project.

3.2 Research design – an action/intervention-based Design Science journey

While natural sciences concern how things are and social sciences concern how society works, DS concerns how things should be by creating artifacts to solve practical problems (Holmström et al., 2009). As this PhD project aims to develop a solution where the question "Will it work?" will become highly relevant, the knowledge generated in this project is pragmatic due to an action-oriented approach (Oliva, 2019). Following Holmström et al. (2009), DS offers much for those OM researchers who are problem-solvers rather than observers and evaluators of the practitioners' problem-solving activity. Given that this PhD project requires artifact development to ensure empirical exploration to generate a solution, the DS methodology is suitable to fulfill this requirement as it uses design to generate legitimate knowledge to solve practical problems.

In OM, DS is conducted under different rubrics and equated with action research (AR), as the goals of these endeavors are the same: problem-solving through artifact development (see Holmström, 2009; Oliva, 2019). Both DS and AR come under the broad heading of "practice-based research" (Mcniff, 2013), a practitioner-led approach. To create knowledge of the practice, the researcher must bear in mind that the environment of exploration is a case of people working collaboratively to improve practice through learning, meaning that the research is conducted through a collaboration with practitioners, and the results are determined by how it all unfolds when being explored (Mcniff, 2016). Engagement with practice should be considered a collaboration relationship to produce knowledge that advances science while apprising the practice (Van de Ven, 2007).

According to Mathiassen (2002), collaborative practice research often serves dual imperatives in research goals and activities, which also applies to this research project. As presented in Chapter 1, this PhD project constitutes two WPs and each of these accounts for several research activities. Table 4 gives an overview of the purposes of WP 1 and 2.

Work package 1	Work package 2
Purpose: Explore the *current understanding* of the research topic	**Purpose:** Explain the *desired state* of the research topic

Table 4. Purpose overview of WP 1 and WP 2.

Figure 6 outlines the research framework for the PhD project. The framework is inspired by principles from Vidgen and Braa's (1997) research framework for collaborative research practices following an AR approach. As shown in Figure 6, two WPs organize the research activities. The arrows in the framework account for the stages within the applied DS approach: Interpretation, Intervention & Design, and Field test & Evaluation. To investigate the problem, the author constructed a working hypothesis ahead of WP 1 to guide the research activities to enlighten the problem. In line with other OM researchers, the working hypothesis was influenced by an a priori construct of the author's observations and reflections on the research field (Barratt et al., 2011; Caniato et al., 2018). The research activities, pursued to secure a broad understanding of the research field, to ensure that the author was provided with a profound understanding; an understanding achieved through interpretation. The knowledge generated in WP 1 was applied to set the direction for the research activities in WP 2. An intervention-based research approach (IBR) was adopted to undertake the role of a problem-solving researcher; this seemed necessary to fully integrate the research activities into practice to accomplish the proposed solution's design, test, and evaluation. For both WPs, the knowledge generation ran in an iterative loop between empirical data and scientific literature. The following section accounts for the research activities in WP 1 and WP 2.

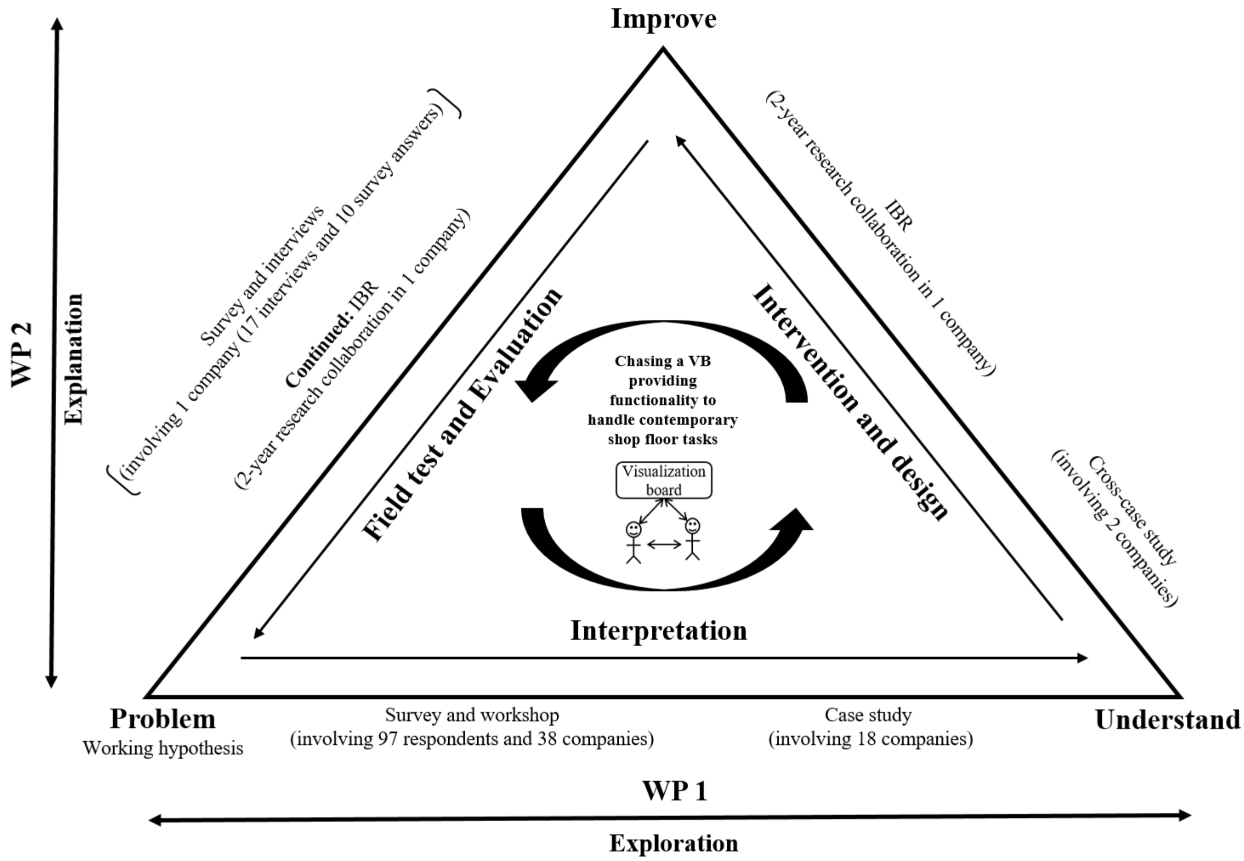


Figure 6. The PhD research framework. Inspired by Vidgen and Braa (1997).

3.2.1 Work package 1

The research activities in WP 1 provided the author with an understanding of the research problem. Exploring the current state was initiated by first conducting a preliminary study to define the boundaries within the PhD project (*research study 1*) and, second, investigating the problem in practice to achieve a throughout understanding to set a direction of how to design the research activities in WP 2 (*research study 2*). Table 5 provides an overview of research study 1, and the findings are published in **PAPER I**.

WORK PACKAGE 1 – Research study 1 (PAPER I)			
Aim	**Research questions**	**Methodology**	**Data sources**

Achieve a preliminary understanding of the research topic by exploring the current adaptation level of digital SFM VBs	**1** "What is the current adaptation level of digital SFM VBs?" and **2** "What forces influence the further adaptation of digital SFM VBs?"	Mixed-methods	Survey data - **97** respondents. Workshop with **38** companies. Scientific literature

Table 5. Overview research activity 1 – WP 1.

A mixed-method approach was adopted for the preliminary study to provide the author with an understanding of the research topic (Creswell, 2017). A hypothesis was put forward to guide the research activities, and Figure 7 illustrates the research design.

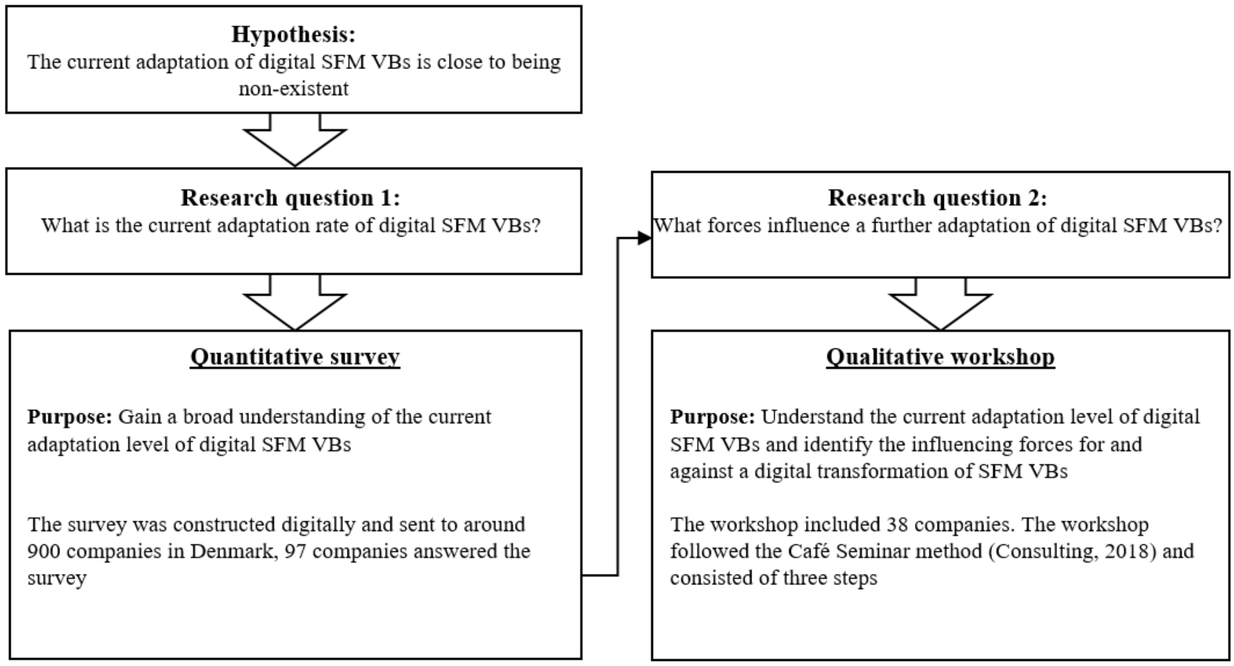


Figure 7. The research design for research study 1 in WP 1.

The quantitative survey provided a broad understanding of the current adaptation level of digital SFM VBs, thus not resulting in a detailed account of the phenomenon. Hence, the learnings from the survey results strived to ensure a sufficient understanding before conducting the qualitative study. The survey was distributed to around 900 companies (not limited to manufacturing companies). In total, 97 companies answered the survey. The survey results were assigned meaning through analysis and interpretation; however, before it was possible to draw any conclusions to the appertaining RQ, the results needed an elaboration which the qualitative workshop intended to provide. The qualitative workshop was hosted by Aarhus University's Department of Business Development and Technology. Both private and public companies interested in the research topic were invited to participate in the workshop, including all companies that answered the survey. 38 companies participated in the workshop, and approximately 85% were manufacturing companies. For the full elaboration of the methodological considerations, please see **PAPER I.** The knowledge generated from the preliminary study directed research study 2 whereas Table 6 provides an overview of research study 2; these findings are presented in **PAPER II**.

WORK PACKAGE 1 – Research study 2 (PAPER II)			
Aim	**Research question**	**Methodology**	**Data sources**
Create an understanding of the "current state" by clarifying the role of VBs to facilitate SFM in a smart manufacturing context	"What role do shop floor practitioners attribute digital VBs for facilitating SFM?"	Case study and narrative literature review	Observations in **18** manufacturing companies. Unstructured interviews in **4** manufacturing companies Semi-structured interviews in **14** manufacturing companies. Scientific literature

Table 6. Overview research activity 2 – WP 1.

The research study takes a qualitative approach drawing on a narrative literature review and a case study. Adopting Dubois and Gadde's (2002) abductive approach to case studies provided unique means of theory elaboration by utilizing in-depth insight into the empirical phenomenon and its context. Figure 8 illustrates the research design.

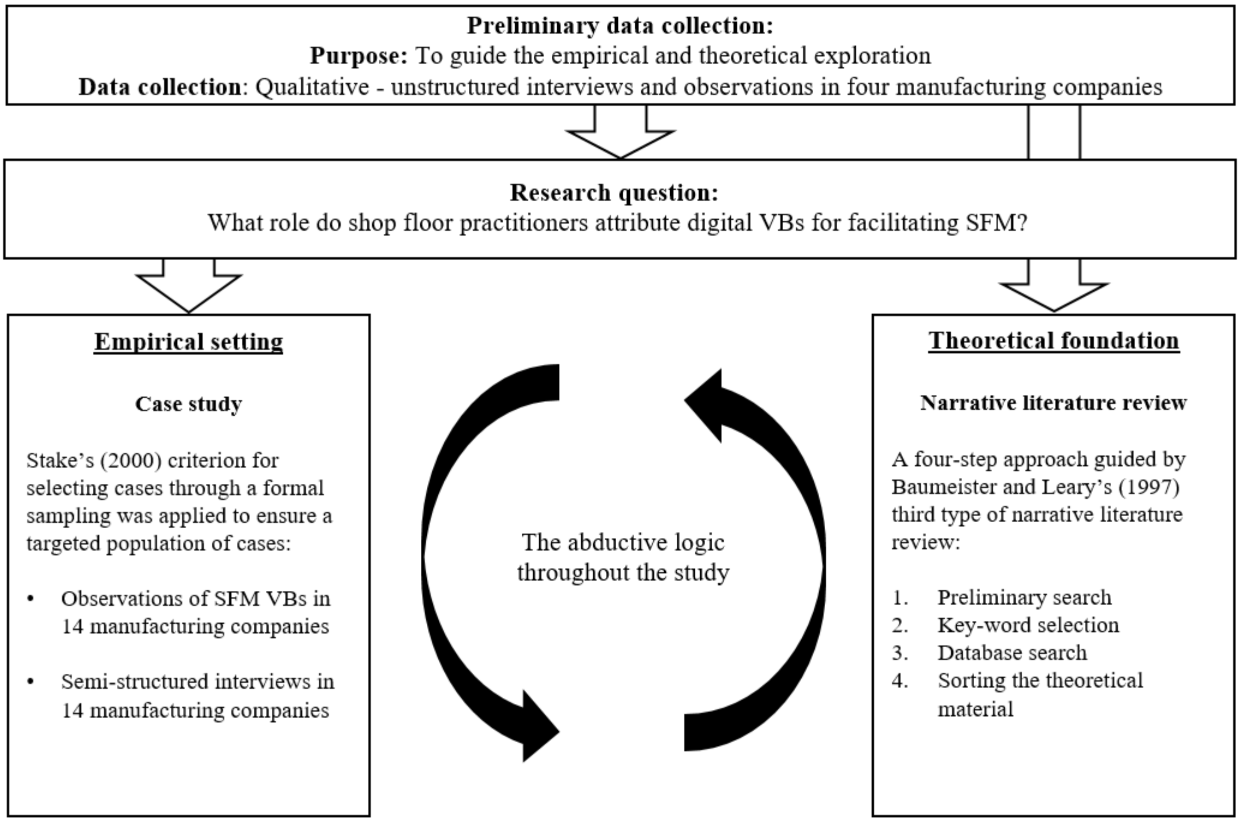


Figure 8. The research design for research study 2 in WP 1.

Prior to the case study and the narrative literature review, a preliminary data collection was conducted to guide the theoretical exploration of the research topic. Grounded Theory principles directed the preliminary data collection following Charmaz (2020). The theory investigation followed Baumeister and Leary's (1997) third type of narrative literature review and was guided by a four-step approach, in which the preliminary data collection constituted the first step. The narrative literature review aimed to shed light on the background, functionalities, and role of SFM VBs, which provided the author with insights into what was currently known about VBs in the SFM practice to support the author's knowledge base when exploring the RQ in the 14 case companies. Table 7 provides an overview of the manufacturing companies enrolled as cases for the preliminary data collection and in the case study. For the full elaboration of the methodological considerations for research study 2 in WP 1, see **PAPER II**.

Company	Industry	Size	Observations	Interviews
Preliminary data collection				
A	Brewing	40000	3	1
B	Renewable energy	23000	2	1
C	Steel, metals and technical goods	1400	1	1
D	Windows and doors	550	2	2
Case study companies				
1	Industrial chemistry	32000	3	3
2	Meat processing	26000	3	2
3	Renewable energy	23000	4	3
4	Pump solutions	19300	3	3
5	Skylights	10000	2	2
6	Tobacco	7600	1	1
7	Plastic pipe systems and solutions	5000	3	1
8	Smart metering solutions for energy and water	1300	1	2
9	Advanced mission critical solutions	1250	1	1
10	Iron casting	1100	2	2
11	Cutting tools	700	1	1
12	Bolts	200	2	1
13	Fish processing	140	1	1
14	Acoustic panels	100	1	1

*Table 7. Overview of the enrolled manufacturing companies in research study 2 – WP 1. Source: (Clausen, 2022 (**PAPER II**)).*

3.2.2 Work package 2

The research activities in WP 2 aim to explain the desired state of the research topic by designing, testing, and evaluating a solution to answer the research objective. Two research studies explain the desired state. Research study 1 identifies the prerequisites for developing a solution that accommodates the desired state by proposing, testing, and evaluating a solution affording fit between a VB and contemporary shop floor tasks. The second research study conceptualizes the managerial preconditions for generating a digital transformation strategy to guide the handling of digital implementations on the shop floor. Table 8 provides an overview of research study 1; the findings are disseminated in **PAPER III**.

WORK PACKAGE 2 – Research study 1 (PAPER III)			
Aim	**Research question**	**Methodology**	**Data sources**
Proposal, testing and evaluation of SFM VBs providing functionality to handle contemporary shop floor tasks	"What are the prerequisites for achieving fit between SFM VBs and contemporary shop floor tasks?"	Cross-case study and IBR	Observations and semi-structured interviews in **2** manufacturing companies. Semi-structured interviews in **2** manufacturing companies IBR in **1** manufacturing company for a two-year period - (observations, unstructured and semi-structured interviews, workshops, project meetings, presentations, reports) Scientific literature

Table 8. Overview research study 1 – WP 2.

As Lewin (1946) defined, AR involves an iterative cycle framework of problem identification, planning, acting, and evaluating; this viewpoint aligns with DS approaches for OM research (Oliva, 2019). The process implies a methodology of intervention and, more specifically, yielding lessons about a specific problem situation: knowledge that is important as it permits the situation to be further improved (Oliva, 2019). Research activity 1 follows such an approach. The author adopted intervention as a research strategy to get nearer to explaining the research topic's desired state.

IBR is a practical OM research approach (Van Aken et al., 2016; Oliva, 2019; Chandrasekaran et al., 2020) to handle practical problems systematically, especially when the solution proposals from prevalent theories contradict the practitioners' understanding of the problems and solutions. IBR should neither be considered an isolated event nor a single action. Therefore, the author's involvement in the two-year intervention should be considered a series of actions. The series of actions accomplished during the IBR enable a gradual transition from analog VBs (the current state within the company) to digitalized VBs (the desired state within the company). The study draws on the “means-end relation” (Simon, 1988; Holmström et al., 2009) to explore this gradual exploration; see **PAPER III** for the full elaboration. Figure 9 illustrates the research design.

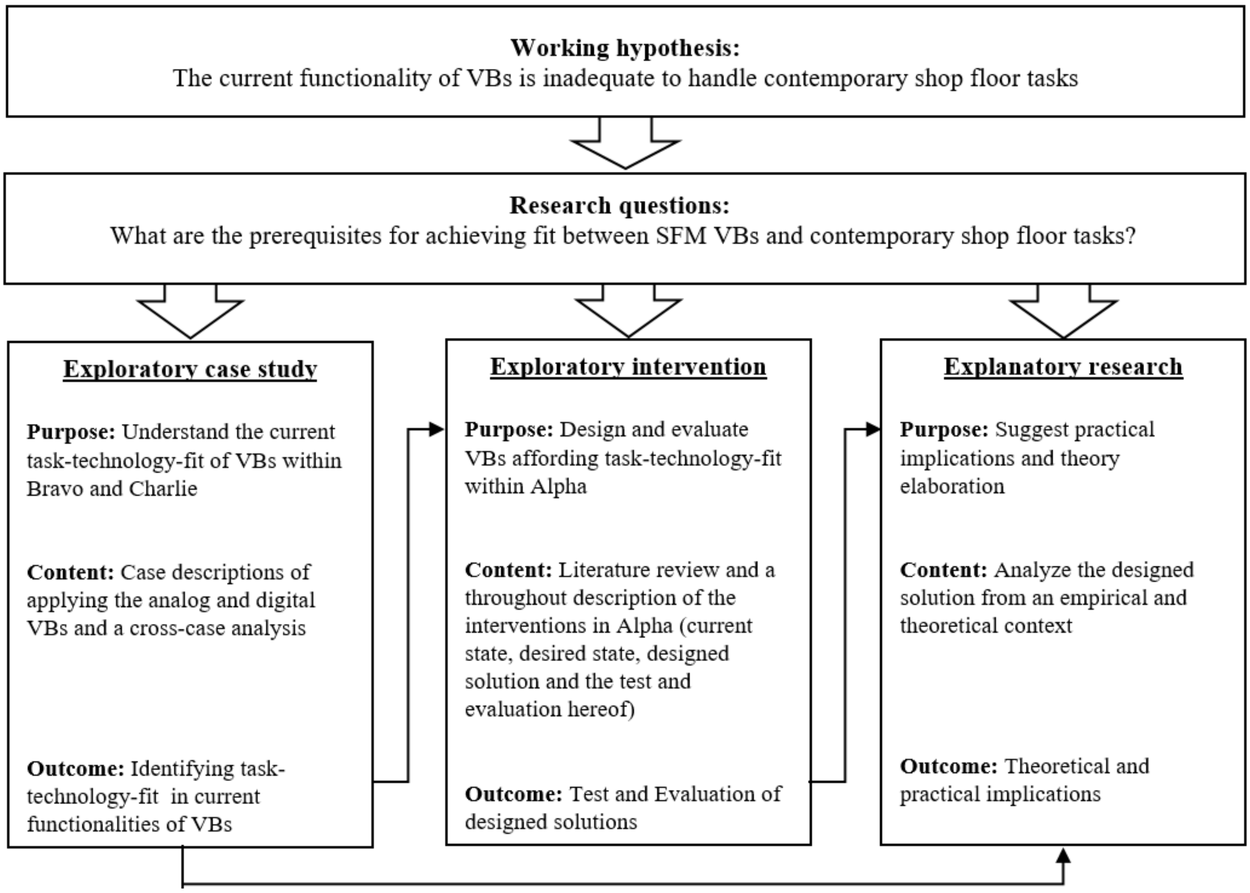


Figure 9. The research design for research study 1 in WP 2.

To explore fit between contemporary shop floor tasks and functionalities of VBs for identifying the prerequisites enabling fit, the study draws on TTF theory (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998). In compliance with the IBR approach, the study draws on abduction (Oliva, 2019; Chandrasekaran et al., 2020). The study explores a working hypothesis and a RQ in three manufacturing companies, designated Alpha, Bravo, and Charlie. Ahead of the intervention, an explorative cross-case study was conducted on Bravo and Charlie. The intervention in Alpha constitutes a longitudinal study where the author has been actively involved in the company for a two-year period. Alpha has followed this PhD research project from its beginning and established a research collaboration with the author, as they wanted to pursue a digital transition of their SFM VBs. Tables 9 and 10 provide an overview of Alpha, Bravo, and Charlie and the author’s research activities.

Company	**Industry**	**Size**	**Observations**	**Interviews**
Bravo *Applies analog and digital VBs to handle shop floor tasks*	Pump solutions	19300	3	3

Charlie *Applies analog and digital VBs to handle shop floor tasks*	Industrial chemistry	32000	3	3

Table 9. Overview of the author's research activities in Bravo and Charlie – research study 1 – WP 2.

Company		Industry		Size
Alpha *Applies analog VBs to handle shop floor tasks*		Renewable energy		26000
Observations	**Interviews**	**Presentations**	**Workshops/meetings**	**Reports**
Approx. 30	Approx. 70	4	Approx. 40	6

Table 10. Overview of the author's research activities in Alpha – research study 1 – WP 2.

For the full elaboration of the methodological considerations for research study 1 in WP 2, see **PAPER III**.

The success of developing digital SFM VBs depends on the company's digital transformation strategy, as completing a digital transformation involves the whole organization within a company. Meanwhile, in developing digital SFM VBs in Alpha, the author investigated the preconditions for developing an operational digital transformation strategy to support implementing digital solutions on the shop floor. Table 11 provides an overview of research study 2; the findings are published in **PAPER IV**.

WORK PACKAGE 2 – Research study 2 (PAPER IV)			
Aim	**Research question**	**Methodology**	**Data sources**
Conceptualization of the preconditions for developing a digital transformation strategy at the SFM level in manufacturing	"What are the preconditions when considering a digital transformation at the SFM level?"	Mixed-methods	Semi-structured interviews in one manufacturing (Alpha) Survey data Scientific literature

Table 11. Overview research study 2 – WP 2.

The research study is based on a mixed-method approach (Creswell, 2017), representing a single-case study combining semi-structured interviews with a survey. An abductive approach was adopted to guide the study; scientific literature considering the research topic and the author's preliminary understanding of the topic generated the knowledge to design the interview guide. The abductive approach allowed the author to go back and forth between theoretical and empirical data. 17 managers, all being considered representatives of the digital transformation strategy within Alpha, were interviewed to shed clarity on the RQ. Afterward, a survey was constructed based on the interview data and distributed to the interviewed managers to verify and derive a generalized overview of the findings. Figure 10 illustrates the research design.

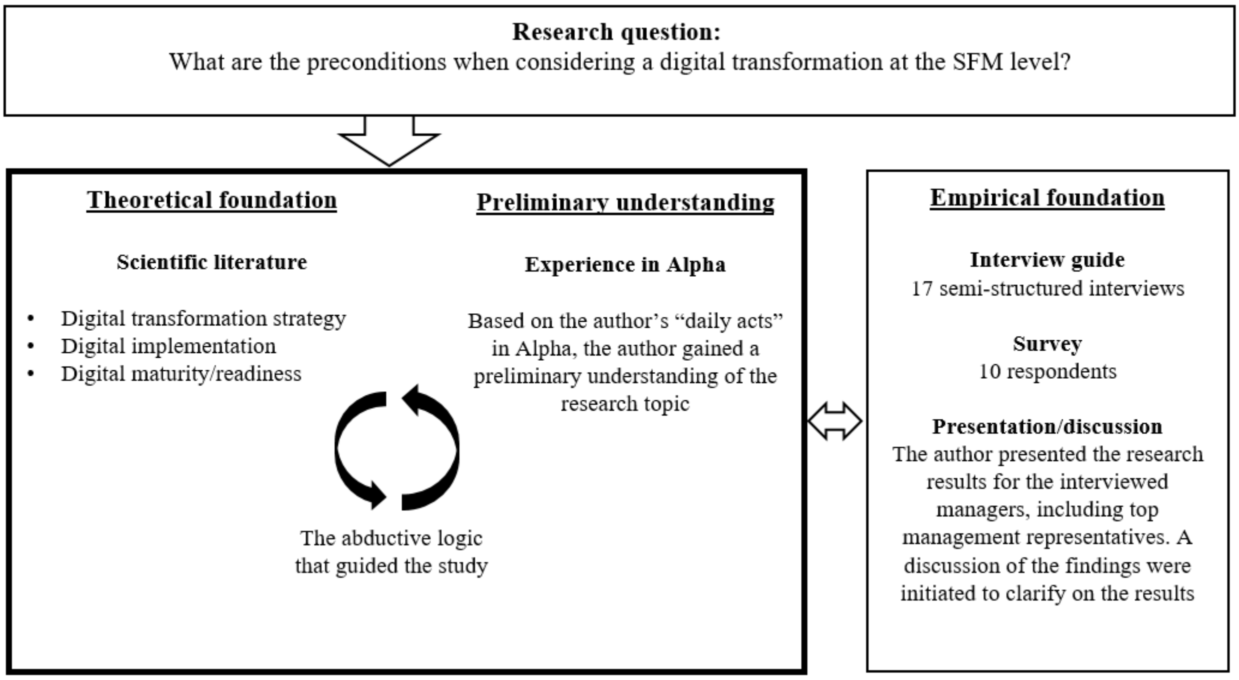


Figure 10. The research design for research study 2 in WP 2.

Through interpretation of the interview and survey data, an answer to RQ was generated. The author presented the results to the respondents, including representatives from top management in Alpha. The discussion discovered new essential elements, which the author added to the research results. For the full elaboration of the methodological considerations for research study 2 in WP 2, see **PAPER IV**.

3.3 Evaluation

By adopting a DS approach, the author has, through an action-intervention behavior, explored and explained how to develop SFM VBs providing functionality for the handling of contemporary shop floor tasks in a smart manufacturing context. The research design had to comply with the conditions for solving a practical OM problem. However, by directly intervening with the practical problem through collaboration with practitioners on the shop floor, the author believes adopting a DS approach provided the best conditions for solving such a practical problem.

Based on the abductive logic which guided the knowledge generation during the PhD project, the findings have contributed by adding normative theory to the existing OM literature on how to answer the research objective. Furthermore, the research results have generated practical implications providing direction on how to steer digital transition/transformation projects on the manufacturing shop floor.

3.3.1 Research quality

To ensure the trustworthiness of the research findings, the author has ensured the research quality by following several relevant quality criteria. The following sections elaborate on how the author has implemented these within the quantitative and qualitative data collections.

3.3.1.1 For the qualitative research

Guba's (1981) four quality criteria model for trustworthiness in scientific qualitative research has been applied to account for the rigor of the research.

Credibility: Internal validity processes ensured that the collected data from interviews, meetings, and observations were aligned with the involved practitioners to ensure trustworthiness; either by getting notes validated or through the constant engagement of practitioners or dissemination (e.g., presentations).

Transferability: The transferability or applicability of the findings was achieved through several approaches to ensure external validity. Adopting a mixed-method verified the qualitative findings through quantitative approaches. Those research activities which did not follow a mixed-methods approach relied on theoretical saturation principles, or cross-case analyses were performed.

Dependability: Through dissemination activities (oral or written presentations), the author received constructive feedback on whether the research enabled consensus concerning the findings and performed analyses and conclusions. All contributing papers presenting the research findings have been in rigorous peer review processes. The reviews have enabled a higher research quality and ensured the validity of the findings and their contributions to theory and practice.

Confirmability: The author has been aware of the possibility of generating biases, given the action-intervention role she has possessed of being an actor in the research. To maintain an objective role and to avoid bias, research data has been triangulated, ensuring that the research data applied to generate results are constructed by the practitioners.

3.3.1.2 For the quantitative research

Following the principles from Bryman et al. (2008), two quality criteria for quantitative research have been applied to account for the research rigor.

Validity: During the PhD research activities, two surveys were developed and applied as a "measuring instrument/tool." The survey results were discussed with the respondents afterward to generate a meaningful interpretation of the data to ensure that the research outcome from the surveys ensured appropriate interpretations of the results. In both cases of applying surveys, the intention of their usage was not to let the results stand-alone, other related studies performed by the author supported the interpretation of the generated survey results.

Reliability: Before launching the survey for data collection, the survey questions underwent an external validation process, which consisted of a test to ensure people understood the RQs equally to enhance the reliability of the study. However, it is unlikely that the same results would be generated today due to the time difference and general environment changes from when the survey data were generated until today.

3.4 Summary

This PhD research project relies on a DS approach to solve the research objective of developing a SFM VB providing functionality to handle contemporary shop floor tasks. During this chapter, the philosophical stance and the research approach have been justified as a means for the research strategy covering the three-year-long research project. The research strategy suggests a DS approach emphasizing an exploration/explanation approach. Within the exploration phase, an understanding of the research problem was achieved, which guided the further exploration and explanation. During the explanation, the author evolved an action/intervention-based role, as the intervention was necessary to understand the research problem truly. In the end, the explanation gave the author the necessary knowledge to build an artifact to overcome the practical problem this project tends to solve. The next chapter, Chapter 4, reports these results.

4 Chapter – Research findings

This chapter accounts for the research results generated from the activities presented in the previous chapter, Chapter 3. The results are disseminated in **PAPER I-IV**, in which this chapter aims to summarize these findings. In addition, the contributions are clarified and linked to the research objective. Given that this thesis follows a bipartite WP structure illustrating the nature of the research project, the main contribution is a culmination of the outcome of the research activities conducted over a three-year study period. To ease the understanding, this chapter follows a structure reflecting the WP constellation illustrated in **Section 3.2 in Figure 5**. Figure 11 represents a modified illustration of Figure 5, which is used to present the research findings and clarify the contributions.

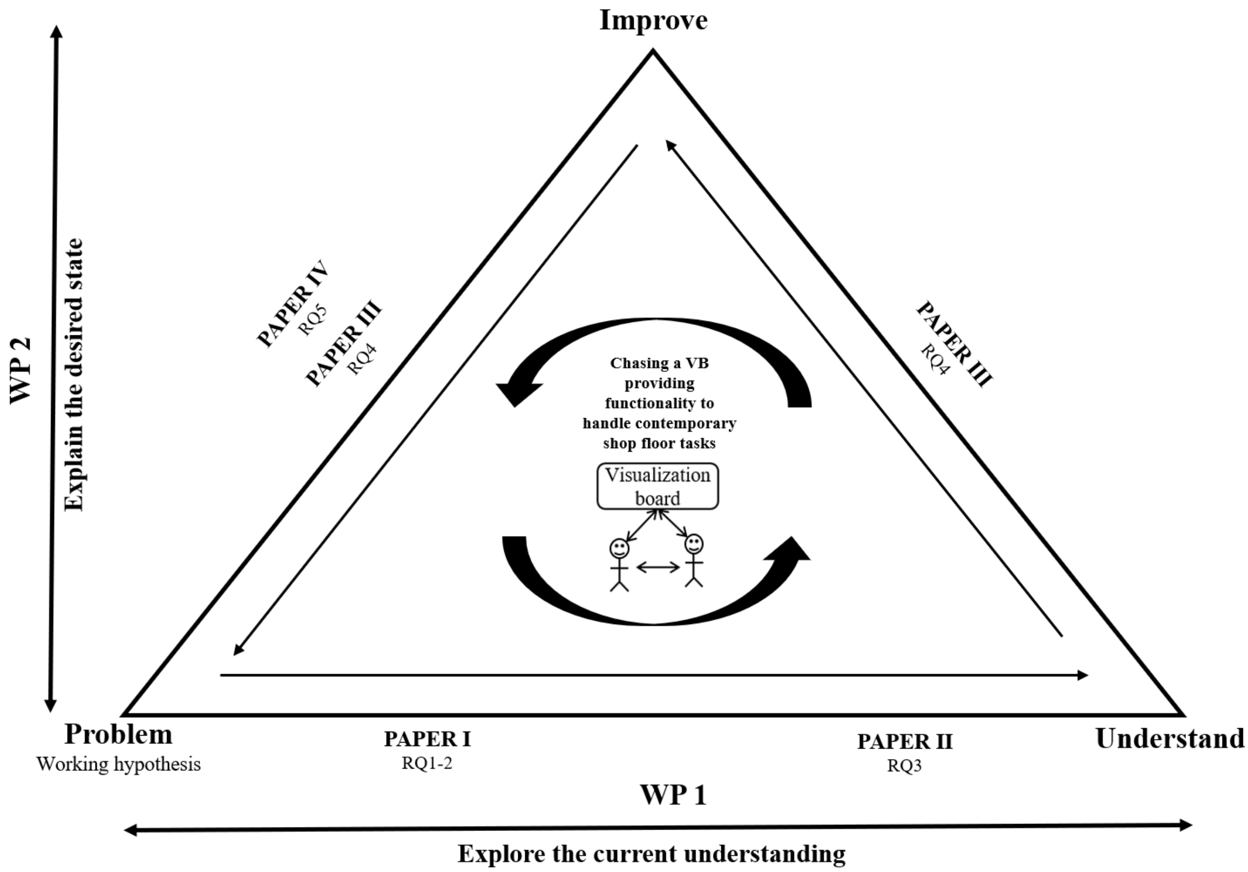


*Figure 11. The results generated through PAPER I-IV to answer the research objective. The figure is a modification of Figure 5 (**Section 3.2**).*

The first section (**Section 4.1**) addresses WP 1, which explored the current understanding of the research problem. This was the first step towards answering the research objective. The research results generated in WP 1, which constitute the answer to RQs1-3, are briefly introduced with emphasis on their relevance to the research objective. Subsequently, the results for RQs1-3 are presented individually, elaborating the theoretical and managerial findings. Likewise, **Section 4.2** elaborates on the results generated in WP 2 using the same approach as in **Section 4.1**.

4.1 Exploring the current understanding of the research problem (WP 1)

At the outset of this PhD project, the author possessed a limited understanding of the research problem. The motivation to contribute to solving the research problem was grounded on a "hunch" derived from the author's experience in the research field. It therefore seemed natural that the initial research activities aimed at providing an in-depth understanding of the research topic, with the findings forming and guiding the further activities of fulfilling the research objective. This is the aim of the research activities in WP 1.

Emerging SFM VBs – are they for real and how so?

Due to the contemporary digital transformation of shop floors (Buer et al., 2020), SFM VBs are assumed to have a greater impact on monitoring and controlling the managerial activities on the manufacturing shop floor (Bateman et al., 2016). However, in line with several OM researchers, the digital transformation has leapfrogged the shop floor level, leaving practitioners with outdated manual procedures to perform SFM (Mathiasen and Clausen, 2019).

Holm (2018) and Luthra et al. (2020) highlight that the ongoing digitalization increases the complexity of conducting shop floor operations, and if not maintained, it will create an unmanageable situation for handling the SFM. In other words, the presence of I4.0 on the shop floor requires a new way of working (Holm, 2018; Li et al., 2019; Torres et al., 2019). This means that shop floor practitioners must move forward from their current SFM approaches, which rely on the Toyota Production System philosophy introduced to manufacturing in the 1950s.

However, the literature on the digital transition of SFM VBs is limited, and only a few have attempted to identify the practical realities in this area (Meissner et al., 2018). Suggestions on how SFM practices should evolve to accommodate the I4.0 shop floor agenda are relatively widespread, and no studies report on the practical implications of a digital transition of SFM VBs. Against this background, it seems relevant to identify the current adaptation level of digital SFM VBs in order to investigate how widespread the use is and what forces influence the adaptation. RQs1-2 explore this, and the following sections summarize the related findings published in **PAPER I**.

4.1.1 The current adaptation level of digital SFM VBS (RQ1)

Research background

A working hypothesis claiming that the current adaptation level of digital SFM VBs is nearly non-existent was the basis for the research. We (the authors in **PAPER I**) performed a quantitative study to verify or reject this hypothesis. Since the purpose of the study was to gain a broad understanding, 900 companies across various industries (not limited to manufacturing) were invited to answer the survey. The following research findings are derived from the study, representing the 97 companies that responded to the survey; approximately 85% of these companies represent manufacturing companies.

Findings

The survey results indicate that SFM VBs are largely applied tool to handle shop floor tasks; 81.7% of the companies hold SFM meetings daily or weekly, while the remaining 18.3% conduct meetings every two weeks or monthly. Table 12 summarizes the types of VBs applied to facilitate SFM meetings held.

Types of VBs applied at SFM meetings	Percentage %
Performance management	62%
Continuous improvement and problem solving	64%
Other (listed by respondents: planning coordination, communication, task handling)	31%

Table 12. Types of VBs applied to facilitate SFM meetings.

When asking the companies what type of VB was applied in terms of physical form (analog or digital), the adaptation level of digital VBs appeared to be low. Table 13 summarizes the distribution.

Adaptation level of digital SFM VBs	Percentage %
Use both digital and analog SFM VBs	21%
Only use digital SFM VBs	7%
Are aware of digital SFM VBs	75%

Table 13. Adaptation level of digital SFM VBs.

According to Table 13, 75% of the companies are aware of digital SFM boards, but only 21% apply them in combination with an analog version. As less than 10% use digital VBs exclusively to manage their meetings, the adaptation rates of digital SFM VBs are considered low compared to the companies' high application level of SFM VBs.

The companies were asked to specify their answers as to how the digital SFM VBs were constructed. The results revealed that the companies do not have a unified understanding of a digital SFM VB. Table 14 lists the software/hardware descriptions applied by the companies to describe their perception of a digital SFM VB.

Hardware	Software
Industrial big screen	Trello
TV screen	Microsoft Office (Word, Excel, PowerPoint)
PC screen	Microsoft applications (PowerBI and SharePoint)
Laptop	Navision
Projector	InfoSuite
Digital interfaces on machines	Skype

Table 14. Hardware/software definitions of digital SFM VBs.

The answers illustrate that the companies do not yet have a common understanding of a digital SFM VB. For the companies, a digital SFM VB is a PC or TV screen with embedded software consisting of standard Microsoft Office programs, such as Word or Excel. None of the companies mention advanced intelligence tools for analytical purposes to support the handling of activities during a meeting. It seems that the companies do not take advantage of the possibilities offered by digital computing capabilities when applying digital VBs to facilitate their SFM meetings; only a few companies answer that they use PowerBI and Trello to enhance information visualization.

The results of the survey yielded interesting findings; however, it was not possible to obtain a complete understanding of the survey results in their quantitative form. Further investigation was therefore needed, and, moreover, the survey results raised new questions to be addressed. A follow-up study was conducted to examine the forces influencing a further adaptation of digital SFM VBs.

4.1.2 The forces influencing a further adaptation of digital SFM VBs (RQ2)

In a conceptual paper, Meissner et al. (2018) have mapped the benefit and disadvantages of digital SFM. Their findings target performance management, problem-solving management (continuous improvement), and leadership on the shop floor, not limited to the digital transition of SFM VBs, as it encounters all related activities to the SFM feedback loop (see Hertle et al., 2015). Their findings of the benefits and disadvantages are interpreted as influencing *forces for* and *against* a digital transition of SFM. In this study, the *forces for* are defined as the opportunities to achieve full data transparency to enhance the competitive situation in the short and long term, while the *forces against* are the hindrances in the form of immature data foundations and practitioners' missing capabilities to apply digital technologies. We summarized the work of Meissner et al. (2018) through a force field analysis (Johnson et al., 2014) to provide a simplified overview of their results. The results are shown in Table 15.

Influencing forces in the digital transition of SFM	
Influencing *forces for*	Influencing *forces against*
• Real-time and reliable data • Improved data accessibility • Improved data transparency • Early problem detection • Data-driven decision making • Enabling communication via network • Improved data foundation • Improved competitiveness	• Cultural barriers • Low competence level • Data blindness • Resource demanding • Time-consuming • Unstructured data storage • Limited organizational support • Low utilization of data

*Table 15. Forces for and against a digital transition of SFM. Source:(Clausen et al., 2020 (**PAPER I**)).*

Although the findings in Table 15 touch on both positive and negative side effects of digital SFM, the practical implications are limited; they provide a good basis but require empirical investigation to increase the understanding of the research problem. To provide clarity of the theoretical and empirical findings, the authors invited the responding survey companies to participate in a workshop to shed clarity on RQ2. The following section presents the related findings published in **PAPER I**.

Research background

38 companies (of which approximately 85% represented the manufacturing industry) participated in a qualitative workshop to share their practical experience with current SFM VBs. The workshop aimed to understand the survey results and identify the forces for and

against a digital transition of SFM VBs. The data collected during the workshop (observations and notes from plenary and group discussions) form the basis of the findings that answer RQ2.

Findings

During the workshop, it gradually became clear that the companies lacked a common understanding of the technical requirements and features of digital SFM VBs. Most companies described digital SFM VBs as a digitized constellation of the analog VB (i.e., a one-one conversion of the analog VB being a TV screen or PC screen supported by Microsoft Office software for data and information visualization). None of the companies described a digital VB as a digitalized constellation (i.e., a system with advanced analytical capabilities based on digital information to revisit decision-making processes, e.g., to enhance monitoring and response time). Moreover, the findings indicate that practitioners are not yet aware of the possibilities that a digital VB with digitalized capabilities can offer SFM practices.

Using a force field analysis, the findings from the workshop were translated into the fundamental influencing *forces for* and *against* adapting digital SFM VBs. From a plenary discussion with all 38 companies, it was revealed that only one of the companies present had practical experience with digital VBs to conduct SFM; the rest could only share conceptual insights based on discussions in their companies about whether an investment in digital SFM VBs was profitable or not. However, although their insights do not reflect their practical experience in applying digital SFM VBs, they are considered to be of great value, as they provide an awareness of the pros and cons of adapting digital SFM VBs. Table 16 summarizes these findings.

Influencing forces for adapting digital SFM boards	
Influencing *forces for*	Influencing *forces against*
• Data transparency (no “hidden factory” syndrome) • Data and information sharing via digital network • Elimination of information silos • Less time spent on updating VBs • Real-time/big data enabling efficient decision making • Synchronization of data • Intelligent technologies for decision making • Enhancing human capabilities for decision making • Digitalization is a prerequisite for competitiveness	• High investment • Habitual mindset/procedures • Too inconsistent IT systems • Unsuitable IT architectures • Immature technologies • Greater vulnerability if IT systems fail • Poor data quality in the company • Data blindness • Low commitment to change at SFM level • Managers deprioritizing a digital transition • Low awareness of the opportunities

*Table 16. Forces for and against adapting digital SFM VBs. Source: (Clausen et al., 2020 (**PAPER I**)).*

Table 16 shows that the key *forces for* adapting a digital SFM VB are the different opportunities (not only in the context of the shop floor) to optimize various business processes across the company, as “open” access to data and information is believed to revisit the companies inter-organizational decision-making processes, which is also a prerequisite to stay competitive. The key influencing *forces against* the adaptation of digital SFM VBs are related to the data life cycle of shop floor data (data collection storage, retrieval, analysis, and visualization), as the companies do not have mature IT architectures and IT systems in place. Moreover, the social capabilities are considered a hindering force, as the SFM mindset is stuck in habitual ways of working. In general, the forces against reflect resource-demanding and time-consuming activities. To summarize the findings related to answering RQs1-2, Table 17 shows the specific contribution of the related research activities.

4.1.3 Summary and contributions – RQ1 + RQ2

Aim	Findings	Contribution
WP 1 (research activity 1) – establish a current understanding of the research topic: Identify the current adaptation level of digital SFM VBs and examine the *forces for* and *forces against* a further adaptation.	The current adaptation level of companies applying digital SFM VBs is low (21% follow a hybrid model with both analog and digital VBs, while only 7% use digital VBs). The key influencing *forces against* the adaptation of digital SFM VBs reflect both technical and social issues. The technical issues are related to the data life cycle and immature IT architectures and IT systems, while the social issues are related to managerial capabilities. The key influencing *forces for* the adaptation are related to the opportunities to revisit the inter-organizational decision-making processes through increased data utilization and data sharing via digital networks.	The study contributes to the ongoing theoretical discussion on a digital transition of SFM. The findings have identified the current adaptation level of digital SFM VBs and have shown that further adaptation of these is perceived necessary to stay competitive in today's manufacturing environment. Moreover, the study contributes additional findings on the influencing *forces for* and *against* a digital transition of SFM VBs. These findings reflect practical aspects that the companies should consider when initiating a digital transition of VBs.

Table 17. Overview of the contribution of research activity 1 (WP 1): aim and findings.

4.1.4 The role of digital VBs to facilitate SFM (RQ3)

Despite a low adaptation level of digital SFM VBs, the research findings answering RQs1-2 suggest that digital SFM VBs are needed to stay competitive in the future. Given that the results mirror the white spots in the literature about companies lacking practical experience with a digital transition of SFM, it seems relevant to investigate whether the need for digital SFM, and thus a digital transition, is as emerging as portrayed in the literature. The literature reports limited studies when it comes to the practical realities of the shop floor, which leaves the question of whether a digital transition of SFM VBs is something practitioners are truly chasing, or whether it is a conceptual reflection, as was revealed in **PAPER I**, which found that this topic has only been addressed at a conceptual level.

The literature does not provide practical evidence as to why digital SFM VBs should be considered a means of future survival, it only suggests improvement for optimization. For that reason, it seems relevant to seek answers on the shop floor by investigating what role practitioners attribute to digital VBs in facilitating SFM and whether digital VBs are considered a means of future survival in the context of smart manufacturing. The related findings are disseminated in **PAPER II**; the following section summarizes these findings.

Research background

This study is based on a multiple case study involving 14 manufacturing companies. The manufacturing companies were from different industries and of different sizes to represent a broad population. The empirical material is derived from observations of SFM meetings and interviews with shop floor practitioners.

Findings

Three of the 14 case study companies followed a hybrid model applying analog and digital VBs to conduct SFM; the rest only used analog VBs. The analog VBs were standardized according to lean principles and consisted of whiteboards with various printouts attached, such as Word documents, graphs, and Excel spreadsheets. The digital VBs all represented a digitized version of the analog VBs. Technically, they were based on Microsoft PowerBI and VBA software; however, the content on the digital screen was a mirror image of the analog VB. Given that only three of the 14 companies applied digital SFM VBs, the findings also verify a low adaptation level of these, similar to the results in **PAPER I**.

However, 11 of the 14 companies believe that a digital transition of their analog VBs is necessary; thus, digital VBs are a part of their future agenda. All 14 companies have largely standardized their SFM processes simultaneously. By visualizing the observed SFM model, it is possible to draw a figure illustrating the importance of a VB in facilitating SFM. Figure 12 presents the identified SFM model based on observations and interviews in the 14 companies.

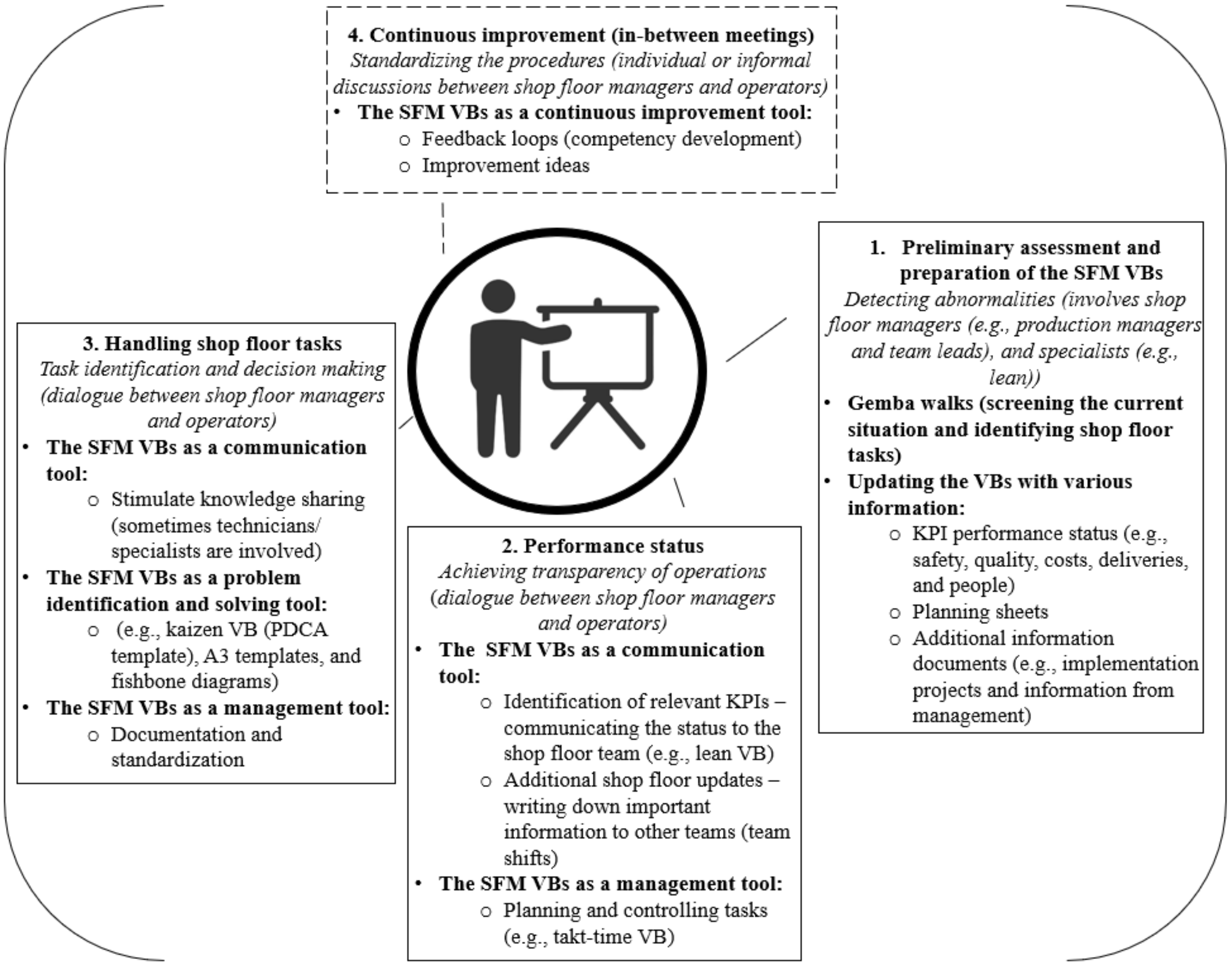


*Figure 12. SFM model. Source: (Clausen, 2022 (**PAPER II**)).*

Figure 12 shows that the VB plays a key role in facilitating SFM; VBs were applied daily or weekly in all companies. It was frequently observed that SFM meetings were held simultaneously at more locations, as each production unit or workstation has its own area to maintain. For alignment across production units or workstations, additional meetings were held, in which the VB also played a centric role. Alignment meetings were typically held outside the shop floor as these meetings include a higher management level.

The SFM model reflects four phases, the implementation of which should not be considered a static process, as all activities are ongoing with no specific start-end time, and the interrelations of activities vary. The SFM model should be considered as an iterative, continuous cycle for improving performance through various tasks related to monitoring and controlling the shop floor. However, all four phases have one thing in common: they all actively involve the use of VBs.

Several VBs were applied to handle the SFM activities; the most common types were VBs for performance management (e.g., a lean VB) and VBs for continuous improvement (e.g., a problem-solving/kaizen VB). Physical discussions around the VB seemed to stimulate a good environment for handling shop floor tasks for all the observed types of VBs. The opportunity to socialize with colleagues across the shop floor contributed to a good atmosphere. However, some of the interviewed practitioners were concerned that replacing the analog VB with a digital version could affect the way physical meetings are conducted today, as a digital VB allows for remote participation. In addition, the practitioners were asked to share their views on the use of an analog VB compared to the drivers motivating a digital transition of the VB. Tables 18 and 19 present these findings.

The view of applying analog VBs to facilitate SFM
• The physical meeting around the VB stimulates a good working environment. • It is labor-intensive to ensure that analog "paper-based" VBs are updated. • Retrieving data for manual printouts to attach to the analog boards requires access to several different IT systems. • Information is only available for a limited time, as printouts and handwritten notes on boards are discarded when the board is updated for the next meeting. • There is limited information sharing across the production shop floor, as people need to physically attend the meeting to receive the update. • There is low reliability of the data, as manually updated data and data not collected in real time negatively affect the decision-making process (decisions are made on the basis of outdated data). • It is a waste of time, because evaluating outdated performance data is not effective. • It provides flexibility during meetings (quick drawings made by hand ease the communication ("the power of the pen" syndrome).

*Table 18. The view of applying analog SFM VBs. Source: (Clausen, 2022 (**PAPER II**)).*

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. • 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 decision making and problem solving through real-time data and more advanced analytics. • Participate in SFM VB meetings remotely. • Develop skills (more responsibility on the shop floor). • Become proactive to minimize disturbances (variation) using data and analytics.

*Table 19. The drivers of applying digital SFM VBs. Source: (Clausen, 2022 (**PAPER II**)).*

For the three companies that have implemented digital VBs (digitized capabilities), the objectives at the outset when embarking on a digital transition of the analog VB were to (from Clausen, 2022 (**PAPER II**):

- 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).

However, the companies did not succeed in developing digital VBs that met all the above objectives. The companies were hindered by technical issues related to the data life cycle and immature IT architectures; this finding mirrors the results derived from **PAPER I**. Nevertheless, despite an unsuccessful attempt, the companies are confident that a complete digital transition of the VBs (with digitalized functionalities) is necessary, as they find that analog VBs are not sufficient to handle the increasing complexity of shop floor tasks. 79% of the case companies state that better use of data is unavoidable, if they want to stay competitive, as they have identified a need to become more proactive in managing unforeseen events such as variation in the production line.

A shop floor manager from one of the case companies declared: “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.” (Clausen, 2022 - **PAPER II)**. From this it seems that VBs are considered an indispensable tool to facilitate SFM by being the primary communication aid on the shop floor (like illustrated on **Figure 12**). The argument is that the VB’s capabilities should evolve along with the other tools (e.g., machinery for production); otherwise, there is no fit. To summarize the findings in answering RQ3, Table 20 shows the specific contribution of the related research activities.

4.1.5 Summary and contributions – RQ3

Aim	Findings	Contribution
WP 1 (research activity 2) – establish a current understanding of the research topic: What role do shop floor practitioners attribute to digital VBs in facilitating SFM?	VBs are indispensable tools to facilitate SFM, as they are used as a communication aid to handle and connect shop floor activities. Given the increasing amount of smart machinery on the shop floor (automated real-time data collections), analog VBs do not seem to provide the right capabilities to communicate this information properly to the shop floor which indicate that the analog VBs do not possess the necessary capabilities to handle contemporary shop floor tasks. Companies have started the digital transition of SFM VBs, but technical issues prevent them from reaching their objective. Although the transition is not a straight path, the companies keep pushing to succeed as they attribute digital VBs as a means to facilitate SFM and to stay competitive in the future.	This study contributes to the existing literature on SFM by adding to the discussion on how the role of VBs as an SFM instrument is changing and why an increased focus on the digital transition of SFM VBs should be emphasized. At current limited prescriptive knowledge of how to develop/implement digital SFM VBs exists.

Table 20. Overview of the contribution of research activity 2 (WP 1): aim and findings.

4.1.6 Reflecting thoughts on the findings in WP 1

Before embarking on the research activities in WP 1, the author did not realize how to define a digital SFM VB, as no clear distinction was made by literature. The author possessed an inexperienced understanding and believed that "digital" in its broad term was a sufficient adjective to describe what this PhD project is pursuing. However, the empirical findings taught the author otherwise when it became clear that many different understandings of digital SFM VBs exist. While prevalent literature on the topic was unclear on the definition of "digital," the author adopted Holmström et al.'s (2019) definition to avoid conceptual ambiguities; for that reason, the notions of digitized- and digitalized VBs have been used to clarify the differences between digital VBs (see **Section 1.1**).

In the involvement with practitioners, it was noticed that current SFM VBs are analog and digital. The digital SFM VB possesses digitized capabilities and has proven to release new functionalities that seem beneficial for conducting SFM. However, the provided functionalities also seem problematic, as they technologically do not provide sufficient capabilities to provide access to reliable- and real-time data that, combined with intelligent systems, enable new possibilities for visualizing and communicating data to practitioners when handling tasks. Indeed, the empirical findings highlight a need to rely on digitalized capabilities for handling contemporary shop floor tasks, but such SFM VBs do not yet exist. The research activities in WP 2 pursue chasing such a development; the following section reveals the related findings and aims to finalize an answer to the research objective of this PhD project.

4.2 Explaining the desired state of the research topic (WP 2)

The findings from WP 1 indicate that the role of VBs as an SFM instrument must change along with their functionalities to keep up with smart manufacturing trends on the manufacturing shop floor. Although the results provide the author with a solid foundation for understanding the research problem, the "how-to" explanation for overcoming this problem remains elusive. The research activities in WP 2 aim to continue exploring whether current VBs are technologically outdated, as the findings in WP 1 assert, by investigating whether the current functionalities of VBs are inadequate to handle shop floor tasks. These findings are expected to guide the author in developing a VB that complies with today's expected functional requirements for an SFM instrument to handle contemporary shop floor tasks.

Based on the author's interaction with the field, this study investigates the SFM VB- shop floor task nexus by operating with three categories of shop floor tasks: performance management, continuous improvement, and takt-time compliance for controlling and monitoring an even production flow. These categories mirror the most frequent types of VBs applied to handle shop floor tasks in the previous 18 studies of manufacturing companies.

The SFM VB- shop floor task nexus – does fit exist?

Both TM and OM researchers have revealed findings that motivate a need for new functionalities of SFM VBs. The challenges that emanate from the functionalities of current VBs (primarily analog VBs) have been examined by a stream of TM researchers (such as Zhang et al., 2017; Dai et al., 2019; Jwo et al., 2021). Their findings indicate that challenges with analog VBs arise because they mainly represent historical data and due to the fact that they are limited in enabling communication that ranges across the shop floor. In addition, OM researchers (like Cagliano et al., 2019; Cimini et al., 2020) indicate that the handling of shop floor tasks is dependent on collaboration across the shop floor.

However, although several advantages of data-driven shop floor approaches exist and digital technologies have largely solved the problem of conveying information across physical locations, technology has not yet succeeded in improving the ineffective transfer of information in close-range environments, such as the different work practices on the shop floor (Tezel et al., 2016). While TM researchers (Zhang et al., 2017; Tao and Zhang, 2017; Dai et al., 2019) prescribe data-driven SFM as a smooth digital transition solely described from a technological viewpoint, OM researchers such as Torres et al. (2019) focus on the usability of VBs (the social components) and disregard the technological development within the digital transition. This indicates that a combined TM/OM (sociotechnical) view on handling a digital transition of analog SFM VBs is lacking.

Against this background, it seems necessary to pursue a combined TM/OM view when studying the prerequisites for a digital transition of analog SFM VBs, although prevalent approaches adopt a fragmented view. For this research project, it is necessary to identify what functionalities of VBs make a fit to handle contemporary shop floor tasks. Once known, it becomes possible to initiate a digital transition of them. RQ4 aims to explore this. The following sections summarize the related findings presented in **PAPER III**.

4.2.1 The prerequisites for achieving fit between VBs and shop floor tasks (RQ4)

Research background

The research activities carried out to investigate RQ4 had a dual purpose. First, we (the authors of **PAPER III)** strived to verify whether our working hypothesis was plausible; prior to the research activities, the empirical and theoretical assertions led us to formulate a working hypothesis claiming, "the current functionality of VBs is inadequate to handle shop floor tasks." Second, we explored the prerequisites for achieving fit between the functionalities of VBS and the shop floor tasks.

To study the usability of current SFM VBs, a TTF framework inspired by the work of Goodhue and Thompson (1995) and Zigurs and Buckland (1998) was developed. The framework served to clarify fit/misfit situations between shop floor tasks and VB functionality. As mentioned earlier, shop floor tasks are divided into performance management, continuous improvement, and takt-time compliance. Based on a literature review, the representational capacity of VBs was identified. VBs function as tools for communicating, structuring, and processing information, which constitutes the VB functionalities to identify fit/misfit. For further elaboration of the TTF framework, please see **PAPER III.**

Qualitative case studies in three large manufacturing companies, Alpha, Bravo, and Charlie, represent the empirical exploration. Alpha, Bravo, and Charlie are referred to in Section 4.1.1 as the three companies that have implemented digitized VBs. A cross-case study was performed in Bravo and Charlie, and an intervention took place in Alpha. While the purpose of the cross-case study was to understand the TTF of current VBs, the purpose of the intervention was to design and evaluate VBs affording TTF. The following sections individually present the findings within the cross-case study and the intervention.

Findings – a cross-case study in Bravo and Charlie

During the time of the study, both companies applied analog and digitized VBs to handle shop floor tasks. Within the last five years, Bravo and Charlie have gradually implemented digitized VBs as they believe that analog VBs no longer possess the necessary functionalities to handle contemporary shop floor tasks. At the outset, both companies wanted a digital VB with digitalized functionalities. However, due to several technical hindrances related to the data lifecycle as described in **Section 4.1.1**, both Bravo and Charlie decided on a stepwise approach to reach the objectives first set out for the digital transition of VBs. Table 21 presents the characteristics of the current VBs applied in Bravo and Charlie.

Bravo	
Analog VB	**Digitized VB**
Performance management VB: A whiteboard that presents data as bar charts and Pareto diagrams. For instance, the data visualized on the Pareto diagram make up a trend analysis that identifies problematic issues (e.g., defects in components). **Continuous improvement VB:** Whiteboards displaying two templates, one for plan-do-check-act and one for root cause analyses.	**Performance management VB**: The building blocks are the use of the Microsoft SQL database, Power BI, and Excel, eliminating several feral IT systems, and sweeping changes in the IT architecture, including software solutions. The VB displays automatically generated data with a delay of 30 minutes due to a complex IT architecture. In total, 80% of the displayed data are automatically generated; the remaining 20% are collected manually. **Continuous improvement VB:** An interactive flat screen; the displayed content is identical to the analog continuous improvement VB.
Charlie	
Analog VB	**Digitized VB**
Performance management VB: A whiteboard with different bar charts and diagrams that provide an overview of the current performance status. **Continuous improvement VB:** Whiteboards displaying templates for handling shop floor tasks over a period of time, such as A3 templates and DMAIC approaches. Furthermore, templates for root cause analyses such as fishbone methods, are also attached.	**Performance management VB:** It draws on a Microsoft VBA solution, where data are converted from Excel documents. The VB mirrors the image of the analog performance management VB, and data is not real-time due to a complex application architecture; however, the accessibility of information is improved. **Continues improvement VB:** An interactive flat screen. Besides offering the same functionalities as the analog version, the continuous improvement VB enables practitioners to save drawings made on the screen.

Table 21. The characteristics of the current VBs in Bravo and Charlie applied to handle shop floor tasks.

The characteristics of the current VBs in Bravo and Charlie share many similarities. While the analog VBs in both companies rely on identical approaches, the digitized VBs have minor differences, as the companies apply different software solutions to represent data and perform data analyses, however, the outcome of the use situations did not indicate any differences. To evaluate the usability of analog and digitized VBs, a cross-case analysis was performed. The focal point of the analysis was to identify whether the communication, structure, and information processing functionalities of the analog and digitized VBs indicate a fit/misfit situation between the functionality of the VBs and shop floor tasks. Based on the objectives of the digital transition of analog VBs listed in **Section 4.1.1**, we were able to identify a list of functional requirements to perform the evaluation. Table 22 presents the results from the cross-case analysis in Bravo and Charlie.

Communication functionalities	**Analog VBs**	**Digitized VBs**
Within shop floor	Fit	Fit
Across shop floors	Misfit	Fit
Structure functionalities	**Analog VBs**	**Digitized VBs**
Ensure compliance with SOP	Fit	Fit
Systematic root-cause analysis	Fit	Fit
Information processing functionalities	**Analog VBs**	**Digitized VBs**
Recall past solutions	Misfit	Fit
Real-time monitoring	Misfit	Misfit
Advanced data analytics	Misfit	Misfit

Table 22. Fit/misfit between the functionalities of the visualization boards and shop floor tasks.

Our findings show that analog VBs allow practitioners to communicate and accomplish shop floor tasks systematically. The VBs depicting analog representations are valuable for social interaction, knowledge sharing, and handling tasks as long as the involved practitioners stand close to the VB and each other; physical proximity is a fundamental requirement for applying analog VBs. In addition, analog VBs lack information processing functionalities, mainly because of one-way updates; representations in the form of graphs, bar charts, and notes are manually posted on the VBs. Analog VBs neither upload data nor download data automatically.

The digital transition adds to the functionalities of VBs, which positively influences the extent of TTF. Digitized VBs afford online involvement in meetings and task handling and enable across-time analyses in that they retrieve and analyze historical data. It seems the structure functionality of the digitized VB equals the analog VB; moreover, our findings indicate that the possibility to tailor the digitally displayed representations to the task being handled positively influences the motivation and proactiveness for participating in handling tasks. Finally, the new information processing functionalities provide practitioners with a two-way update of a large part of the manufacturing data, uploading data to VBs and downloading data to IT systems. Although the current digital transition of VBs allows practitioners to conduct Excel data analytics, our findings reveal some misfits. The displayed representation is not based on real-time data. Data reliability is an issue, as some of the steps in the data lifecycle are manually handled, and advanced analytics is still not possible.

Findings – intervention in Alpha

The findings in Bravo and Charlie allowed us to understand the TTF of current VBs. With this understanding, we were ready to intervene in designing and evaluating VBs' TTF in Alpha. The intervention in Alpha covers a two-year period and makes up an ample amount of empirical material exploring the **current** and **desired state** of applying VBs, including the **design and**

evaluation process of the intervention. Although the intervention in Alpha constitutes the most considerable amount of research carried out during this PhD project, this section only summarizes the main findings. For a more detailed exploration, I refer to **PAPER III**.

Current state of applying analog takt-time VBs

Even though Alpha initiated a digital transition of performance management VBs in 2018, it had not begun a digital transition of its analog takt-time VBs prior to the authors' intervention. The purpose of the intervention in Alpha was to develop digitized takt-time VBs for controlling and monitoring an unpaced synchronous flow line producing blades for wind turbines. The production set-up is highly complex and characterized by a high level of manual labor. The production set-up consists of five workcells, each including several workstations. Given the shop floor layout, collaboration within and across workcells and collaboration with management is essential for handling tasks. Figure 13 illustrates the takt-time meeting structure within and across workcells where the intervention occurred.

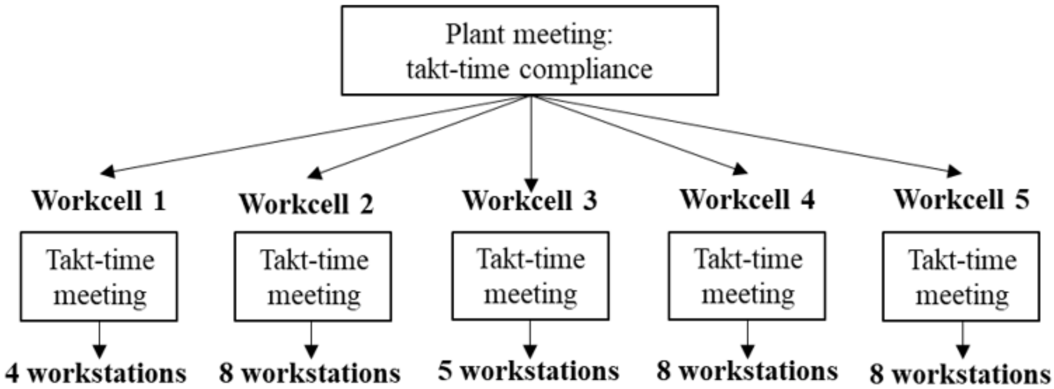


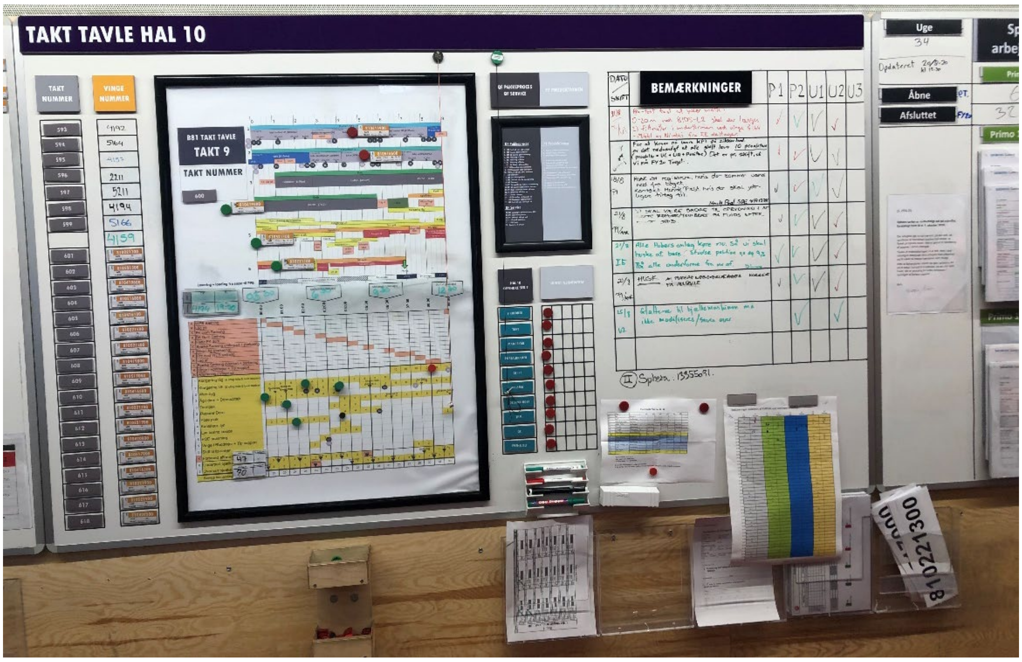
*Figure 13. Takt compliance communication structure in Alpha. Source: (Mathiasen and Clausen, 2022 (**PAPER III**)).*

Takt-time meetings within the workcells occur every third hour on the shop floor and last around five minutes. No standardized communication between the workcells occurs outside the plant meetings, which are held two times a day. At the takt-time meetings, the workcell manager and workstation managers are present. The plant meeting typically includes the plant manager, workcell managers, and specialist/managers from different departments. Table 23 presents the analog takt-time VBs' characteristics applied to facilitate the takt-time meetings. Picture 2 depicts an analog takt-time VB in Alpha.

Analog takt-time VBs in Alpha	
Purpose	**Physical characteristics**
Ensure takt-time compliance in each workcell and thus comply with the takt-time requirements by handling related tasks revolving around monitoring, controlling, and coping with variations.	A whiteboard displaying a comprehensive Gantt chart. The Gantt chart includes the actual progress of the production line, planned progress, and downtime, including the reasons for deviations.

The content displayed on the takt-time VBs and the use of the VBs are identical in all workcells.	Before meetings, the workstation managers update the takt-time VBs with these data.

Table 23. The characteristics of current takt-time VBs in Alpha.



Picture 2. An example of an analog takt-time VB in Alpha. Source: own picture.

The data displayed on the analog takt-time VB derive from the manual clock in/out on job orders in Alpha's manufacturing execution system (MES) PRISMA. Any downtime, including causes of deviations, is registered on sheets or directly on the VB. Much of the data processing occurs manually; for instance, the data written on sheets are picturized, then transcribed to Excel, and downloaded to a SQL database. In general, several IT systems for data acquisition, storage, and visualization are applied; master data such as job order data and material reservations take place via the enterprise resource planning (ERP) system SAP and related feral systems (mainly Excel).

The desired state of applying digital takt-time VBs in Alpha

The functionalities of the analog takt-time VBs restrict the monitoring and control of the progress of the unpaced synchronous flow line, primarily since data is unreliable and not real-time, which is due to the manual data collection. Alpha highlights six functional requirements for the digitalized takt-time VB to reach the desired state. We added two additional functional requirements to that list based on our insights from the cross-case analysis in Bravo and Charlie. Table 24 presents the eight functional requirements.

Functional requirements for a digitalized takt-time VB in Alpha	
Communication functionalities	1. A hybrid model for takt-time meetings (onsite/online) 2. A malleable display for data/information when handling shop floor tasks

	3. Monitoring of variations between planned and actual progress
Structure functionalities	4. Complying with standard operating procedures 5. Accomplishing systematic root cause analyses
Information processing functionalities	6. Access to reliable and real-time data 7. Access to historical data 8. Performance of data analytics

Table 24. Functional requirements for a digitalized takt-time VB in Alpha.

The interventions in Alpha – designing digitalized takt-time VBs

The pursuit of developing a digitized takt-time VB meeting all functional requirements listed in Table 24 triggered two different interventions, as we encountered several constraints when first initiating the digital transition. Intervention 1 was led by a lean manager, and the project team consisted of lean specialists, data specialists, workcell managers, and the authors. For Intervention 2, a data scientist acted as project manager, and the team consisted of data scientists, software specialists, partly lean specialists, and the authors. The following sections first describe Interventions 1 and 2 and then evaluate the interventions based on the test results.

Intervention 1

While Table 25 summarizes the main constraints encountered during Intervention 1, how these were handled/not handled, and describe why the solution failed to meet all eight functional requirements listed in Table 24, Figure 14 illustrates Intervention 1 by presenting the application architecture of the solution.

Intervention 1 in Alpha		
Constraints	*Authors' suggestion*	*Decisions made*
Complex application architecture – data are collected across multiple systems.	We suggested enhancing the interoperability among IT systems by eliminating architectural constraints. Results from the cross-case analyses showed that reducing feral systems and implementing an SQL database as an information hub to ease data retrieval would enhance interoperability.	An SQL database to enhance the accessibility and storage of data from PRISMA, SAP, and feral systems was developed.
PRISMA cannot be substituted with another system (too expensive; a new integration with existing systems (such as SAP) is very comprehensive).	We argued for automating the data treatment throughout the whole data lifecycle of shop floor data to ensure reliable and real-time data.	No new solution for data collection was developed. The project team obeyed the constraint. Microsoft's Power Apps was instrumental in

	Specifically, we suggested that the solution should consist of **automated data collection** of blue-collar workers' clock in/out on job orders, material movement, and downtime, that **data storage and retrieval** happen **directly** in SAP, implementation of **a web-based application programming interface (API)**, and **user-friendly adaptable interfaces** for capturing data.	designing the takt-time VB layout to retrieve data from the SQL database and to visualize data. The hardware for the solution was an industrial interactive screen.
IT policies, cyber security, and data security.	We recommended that the policies be obeyed.	All policies were obeyed.

Table 25. The main constraints encountered when initiating Intervention 1 in Alpha.

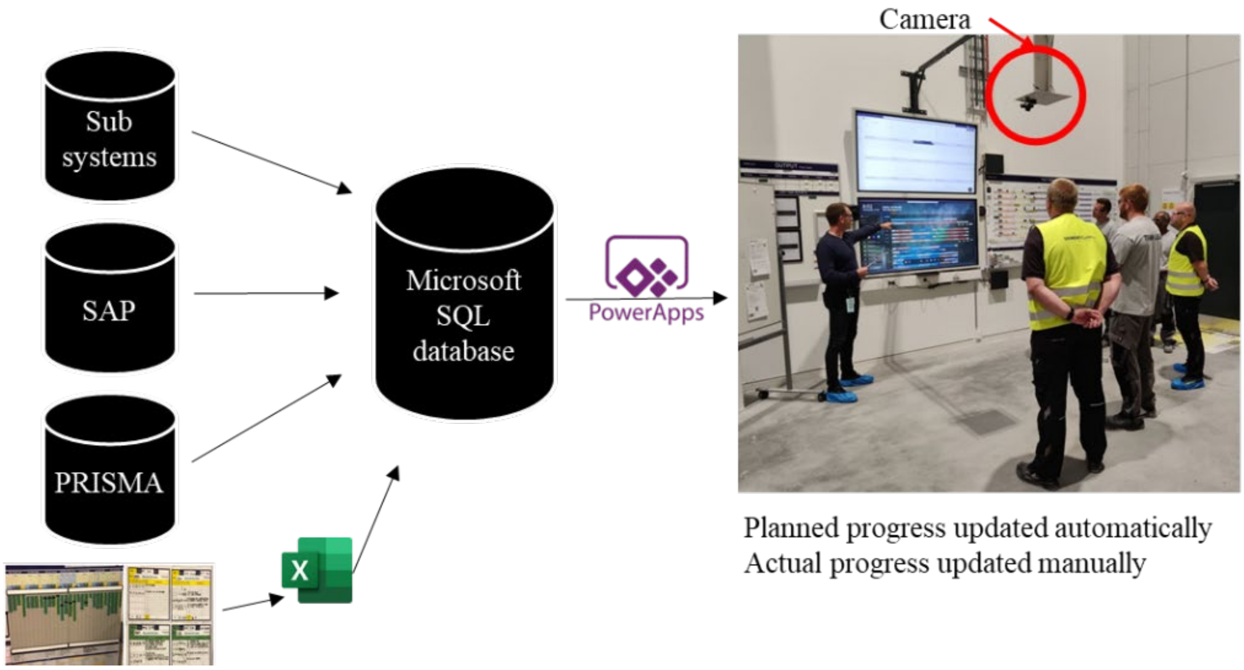


*Figure 14. Intervention 1 – application architecture. Source: (Mathiasen and Clausen, 2022 (**PAPER III**)).*

As shown on the left in Figure 14, an SQL database functioned as an information hub to access and store relevant data collected in various systems. Microsoft Power Apps was the software used to design the layout on the digital screen. From the Power Apps platform, it was possible to retrieve and visualize data from the SQL database. The layout of the takt-time VB on the digital screen was very similar to the analog takt-time VB. A camera (the red circle) provided online access to the takt-time meetings.

Intervention 2
Given that the top management in Alpha was very keen on developing a digital takt-time VB that met all eight functional requirements, the "chase" proceeded in a new project team. The new team, the authors included, brought fresh energy to the pursuit of a new intervention, Intervention 2. However, the practical knowledge gained during Intervention 1 provided crucial means to overcome the experienced constraints that hindered fulfilling all eight functional requirements. Hence, Intervention 2 had to include a solution for automating the data collection of blue-collar workers' clock in/out on job orders, the material movement, downtime, data storage, data retrieval directly into either SAP or an SQL database, and developing a web-based API to ensure interoperability among systems.

While the constraints related to IT policies and cyber/data security were indisputable, the project manager challenged them. For the project manager, PRISMA was not a feasible solution for data collection if Intervention 2 was to fulfill all eight functional requirements. In the end, the project team was allowed to bend the IT policies and design a new application for data collection and storage outside PRISMA. However, top management declared that PRISMA could not be replaced before Intervention 2 had shown successful results and was fully implemented. This meant that production data needed to be registered twice. The project team, except for the two authors, did not consider this an issue, despite the authors warning against this, as experiences from Bravo and Charlie advised against it. Figure 15 illustrates Intervention 2 by presenting the application architecture of the solution.

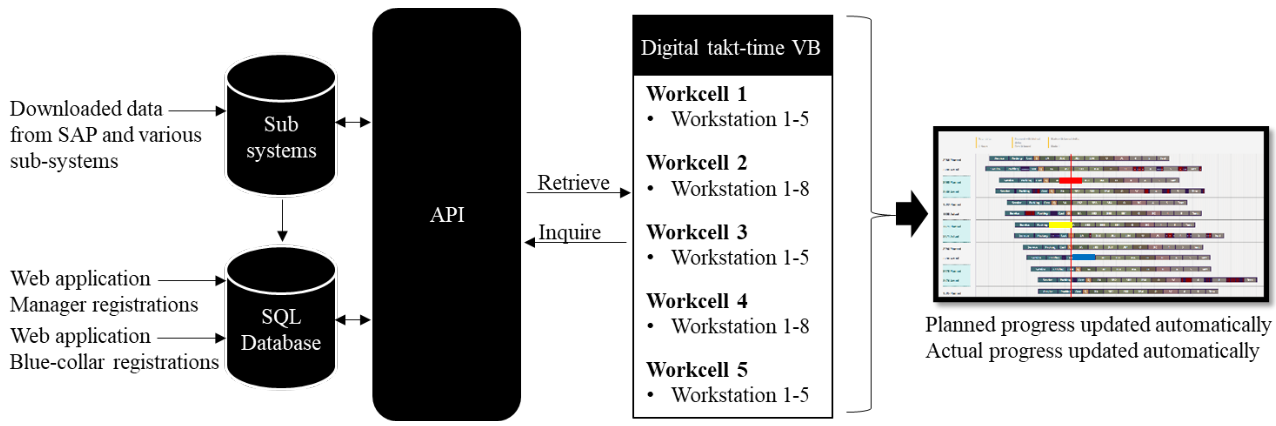


*Figure 15. Intervention 2- application architecture. Source: (Mathiasen and Clausen, 2022 (**PAPER III**)).*

The main difference between Intervention 1 and Intervention 2 is the technical solutions revolving around web applications for automating the data collection. Two web applications (lower left corner in Figure 15) facilitated real-time data (with an acceptable delay of 10 minutes) via interactive screens at the production line. Data were clocked manually every time an operation was finished (the applications increased the data registrations compared to PRISMA). Separate systems for managers and blue-collar workers were needed to capture all relevant production data. Data were stored directly in an SQL database after reporting. To enhance interoperability, the SQL database functioned as an information hub (as in Intervention 1) to store data from other subsystems. A web-based API for data retrieval was implemented and linked to the web-based solution developed for visualizing data on an interactive screen, the digital takt-time VB.

Test and evaluation of Intervention 1 and Intervention 2

Intervention 1 was tested and subsequently implemented during the COVID-19 pandemic. The pandemic resulted in several lockdowns, which significantly influenced how production was carried out. The test took place in the manufacturing environment, and the evaluation was based on the TTF framework. Although the test results revealed that Intervention 1 did not fulfill all eight functional requirements, the intervention seemed useful for Alpha in several ways. Because of the COVID-19 situation, nearly all white-collar workers in Alpha had to work from home for extended periods, which meant that the top management in Alpha urgently needed online access to the takt-time VB.

Intervention 2 demonstrated different results during the test and evaluation. Data scientists conducted the test, which was purely technical and not performed in the manufacturing environment. The results proved that the solution fulfilled all eight requirements. The TFF evaluation drew on a 24-hour test in the manufacturing environment; the evaluation ran over two shifts of 12 hours. Technology-wise, Intervention 2 functioned as carried out in the test, but as for the human-machine use situation, it became apparent that Intervention 2 was developed by a team with insufficient OM capabilities to control unpaced synchronous flow lines. The evaluation failed on several parameters, primarily due to the challenges of registering production data twice and the user interface design that proved inappropriate, as it was not accommodating the needs of the practitioners. The results generated were not sufficient to be evaluated accurately. Table 26 summarizes the test and evaluation results of Intervention 1 and Intervention 2.

	Intervention 1	**Intervention 2**	
	Test and evaluation	**Test**	**Evaluation**
Communication functionalities			
• Accomplish onsite/online takt-time meetings	Fit	Fit	Misfit
• Adapt displayed data/information to shop floor tasks being handled	Fit	Fit	Misfit
• Monitor variations between planned progress and actual progress	Misfit	Fit	Misfit
Structure functionalities			
• Comply with standard operating procedures	Fit	Fit	Misfit
• Accomplish systematic root cause analyses	Fit	Fit	Misfit
Information processing functionalities			
• Gain access to real-time and reliable data	Misfit	Fit	Misfit
• Gain access to historical data	Fit	Fit	Misfit
• Carry out data analytics	Misfit	Fit	Misfit

*Table 26. Task-technology fit in Intervention 1 and Intervention 2. Source: (Mathiasen and Clausen (**PAPER III**)).*

Table 26 presents additional insights regarding the prerequisites for achieving fit between VBs and shop floor tasks. The learning revolves around the imbalance in equally dealing with digital transition's social and technical components (like Van Aken et al., 2016). The findings reveal a tendency to perceive sociotechnical systems as entirely technical or social; for instance, while the project team in Intervention 1 was OM-oriented, focusing on a solution accommodating the social needs, the project team in Intervention 2 was TM-oriented and focused on a solution overcoming the technical needs that took precedence over the social components. As a result, we failed to develop a digitized VB fulfilling all eight functional requirements. The following section summarizes the findings of answering RQ4, and Table 27 shows the specific contribution of the related research activities.

4.2.2 Summary and contributions – RQ4

With the cross-case study of Bravo and Charlie and the intervention in Alpha, it is possible to shed light on the prerequisites for achieving fit between the functionalities of VBs and contemporary shop floor tasks. At the outset, we put forward a working hypothesis claiming that the current functionalities of VBs are inadequate to handle shop floor tasks. The best way to test this draws on the cross-case analysis. The results show that current VBs are not yet outdated, as they are still useful for several purposes when handling shop floor tasks. However, three TFF misfits were identified: current VBs inhibit the use of **real-time data**, **data reliability** is an issue, and **advanced analytics** is still impossible.

Based on the lessons from the intervention in Alpha, we have identified four prerequisites for achieving fit between VBs and contemporary shop floor tasks. They are: 1) automation of the data lifecycle, 2) standardized IT interfaces to enable interoperability, 3) user-friendly interfaces to capture data that possess malleable functionalities (the interface must possess malleable functionalities to adapt the layout), and 4) transcending boundaries between the OM and TM domain – digital developments must be understood as sociotechnical systems.

Aim	Findings	Contribution
WP 2 (research activity 1) – explaining the desired state of the research topic: What are the prerequisites for achieving fit between SFM VBs and contemporary shop floor tasks?	Current VBs are not outdated but have restricted functionalities. The prerequisites for achieving fit between contemporary shop floor tasks and VBs are: 1) automation of the data lifecycle, 2) standardized IT interfaces to enable interoperability, 3) user-friendly interfaces to capture data (the interface must possess malleable functionalities to adapt the layout), and 4) transcending boundaries between the OM	The findings contribute to the theoretical discussion about the interplay between the digital transition of shop floors and the usability of VBs in several ways by demonstrating that current VBs displaying analog representations are still applicable. However, essential functionalities are missing. VBs displaying digital representations provide some of the demanded contemporary functionalities but lack functionalities to display real-time and reliable data

	and TM domain – digital developments must be understood as sociotechnical systems.	and carry out advanced analytics. Moreover, the study reveals the importance of combing OM and TM knowledge with practical knowledge and elaborates that the consequences of dividing OM and TM knowledge are the intervention of a not-yet operational digitalized VB.

Table 27. Overview of the contribution of research activity 1 (WP 2): aim and findings.

4.2.3 The preconditions when considering a digital transformation at SFM level (RQ5)

From the above empirical findings, digital transformation of SFM seize today's manufacturing agenda. In general, the findings indicate that understanding the socio-technical systems that correspond to the digital transformation of SFM VBs is immature, as practitioners seem to have an unbalanced relationship with technology implementations and its users (people). Following some of the researchers that have investigated the technology-use nexus in the context of smart manufacturing (e.g., Westerman, 2018), a company needs to fully understand the organization's adoption process regarding the technological and social factors involved before embarking on a digital transformation. OM/TM researchers, like Schwab (2017) and Frank et al. (2019), suggest that companies perform a digital maturity- or readiness evaluation to identify their current state to clarify possible constraints hindering the transformation.

Although the empirical findings from the cross-case study and the intervention provide valuable learnings of the practical prerequisites for developing emerging digitalized SFM VBs by opening the "black box" of technologies, our attempt to develop such a VB was unsuccessful. We failed because we did not account for the value of the technological and social components equally within the digital transformation when exploring the TTF. Although we tried to transcend OM knowledge within Intervention 2, the team's mindset was too focused on the technological components, which resulted in a fatal situation of underestimating the value of ensuring the stakeholders' contribution regarding the usability of the VB.

The test of Intervention-2 taught us to identify three technical-oriented prerequisites for achieving fit between contemporary shop floor tasks and VBs. However, after completing the test, we identified a fourth prerequisite that revolves around the OM system's social components; the people involved must learn to transcend knowledge across OM and TM boundaries. For the first three prerequisites, we provide examples of how to overcome these given our practical learnings, but we refrain from suggesting how to overcome the fourth prerequisite.

To answer the research objective of this PhD project, it seems necessary to investigate how to transcend knowledge between OM and TM boundaries, as this seems to be the most critical prerequisite to successfully steering digital transformation projects. The exploration of the fifth and final RQ aims to investigate the social preconditions for accomplishing a digital transformation on the SFM level. The study takes place in Alpha, and the related research activities shed light on the identified fourth prerequisite, which is now recognized as a sincere problem to pay attention to in Alpha. The following section presents the related findings published in **PAPER IV.**

Research background

The research represents a single case study. During the intervention in Alpha, the author engaged in another project exploring the understanding and communication of Alpha's generic digitalization strategies targeting the SFM level. The research combines semi-structured interviews with a survey involving 17 managers in ongoing digital transformation projects in Alpha. All involved managers are a part of the organization where the intervention took place.

Findings

During the last five years, Alpha has invested considerable resources in operationalizing digital transformation projects at the SFM level. A broad digitalization strategy has been communicated to the entire organization with the purpose of enabling across-collaboration (e.g., between plants, departments, and units) using highly standardized procedures. However, during the intervention in Alpha, the author frequently observed that "localized" guidelines had been developed to steer projects, making the department or unit vulnerable to across-collaborations, as their approaches to handling the same problem conflicted (e.g., Intervention 1 vs. Intervention 2). This scenario led the author to believe that Alpha's current official digital transformation strategy targeting the SFM level is not operational and might be contributing to the failures during the intervention.

The managers involved in the study were asked whether they understood Alpha's digital transformation strategy. It became clear that most had a limited understanding of the official definitions and the operationalization thereof, as most were used to following "local" developed guidelines, which resulted in turning a blind eye to the official strategy. The distribution of the answers from the survey is shown in Table 28.

Survey questions	**Yes**	**No**
Does the current digital transformation strategy appear to be clear?	10%	90%
Are you aware of the digital maturity level on the SFM level?	20%	80%
Are you feeling equipped to take part in digital transformation initiatives?	50%	50%

*Table 28. The understanding level of the digital transformation strategy. Source: (Clausen and Henriksen, 2022 (**PAPER IV**)).*

The interview data in Table 29 provide insight behind the answers distributed in Table 28. From the distribution in Table 28, it seems the managers have a limited "relationship" to the official strategy and generally possess a limited understanding of the digital maturity level within their SFM environments. With a 50% distribution of managers not feeling equipped to participate in digital transformation projects, it seems obvious why it had to take different project teams in Alpha to pursue the development of a digitalized VBs, and it does not seem shocking why none was successful.

The managers' interpretation of the digital transformation strategy
Lack of clearly defined guidelines (e.g., what to do, how to do it, whom to involve)

Definitions are unclear and confusing (e.g., difficult to derive common understandings)
The guidelines do not accommodate different leadership approaches- and working cultures
The strategy does not reflect the company's current digital maturity stage (this leads to digital transformation projects being run in the dark and "local" guidelines are developed)
The strategy illustrates conflicting performance indicators between the organization and internal departments
The strategy is not communicated properly – it does not reach the practitioners on the shop floor very well, so they often appear uninformed and uncomprehending toward digital initiatives
The strategy does not seem to align the different organizational levels well. It seems that some levels are more prioritized than others, and it is unclear why

*Table 29. Managers' view on why the digital transformation strategy is not operational. Source: (Clausen and Henriksen, 2022 (**PAPER IV**)).*

To identify the preconditions to develop operational digitalization strategies that increase the success rate of digital transformations on the SFM level, the managers were asked to share their opinion about their experience. Table 30 presents their answers.

The identified preconditions for an operational digital transformation strategy
The underlying need for developing a digital transformation strategy must be argued (e.g., why is it necessary, what for, and where?)
A digital maturity evaluation should be performed to ensure that the strategy reflects the company's current technological and people competencies
The strategy must reveal a positive business model covering operational targets that are easily recognized and understood
A visual strategy: where are we right now, digital maturity-wise, and what is the end goal
One generic strategy is not operational. The strategy should be divided and localized to avoid developing a strategy that is too superficial once more
The communication model for disseminating the strategy should accommodate all to ensure commitment and understanding from all employees in the organization
The strategy should be considered a change management process, as its success depends on how well everyone collaborates to make it operational, as it requires many people to evolve into new roles
The strategy should be released with tools and procedures to ensure proper guidance, although no "one-size" fits all approach exists, to enhance collaboration across the organization

*Table 30. The preconditions for an operational digital transformation strategy. Source: (Clausen and Henriksen, 2022 (**PAPER IV**)).*

Having a generic "one-strategy-fits-all" does not seem to be sufficient, as no strategy never will be "wide" enough to embrace all work environments in the organization (having individual cultures and leadership approaches). This does not mean discarding a company-wide strategy; the company-wide strategy is essential for informing about the vision, elaborating on the common goal, and what we are chasing as one company; however, the operationalization hereof should be scaled down to the individual projects.

Based on the findings in Table 30, it is possible to propose a conceptual framework reflecting the preconditions for developing a strategy to guide the digitalization project on the SFM level. In collaboration with the involved managers, the findings were divided into three stages, in which each stage proposes a general direction of what to consider when setting out a strategy for a digital transformation on the SFM level, see Figure 16.

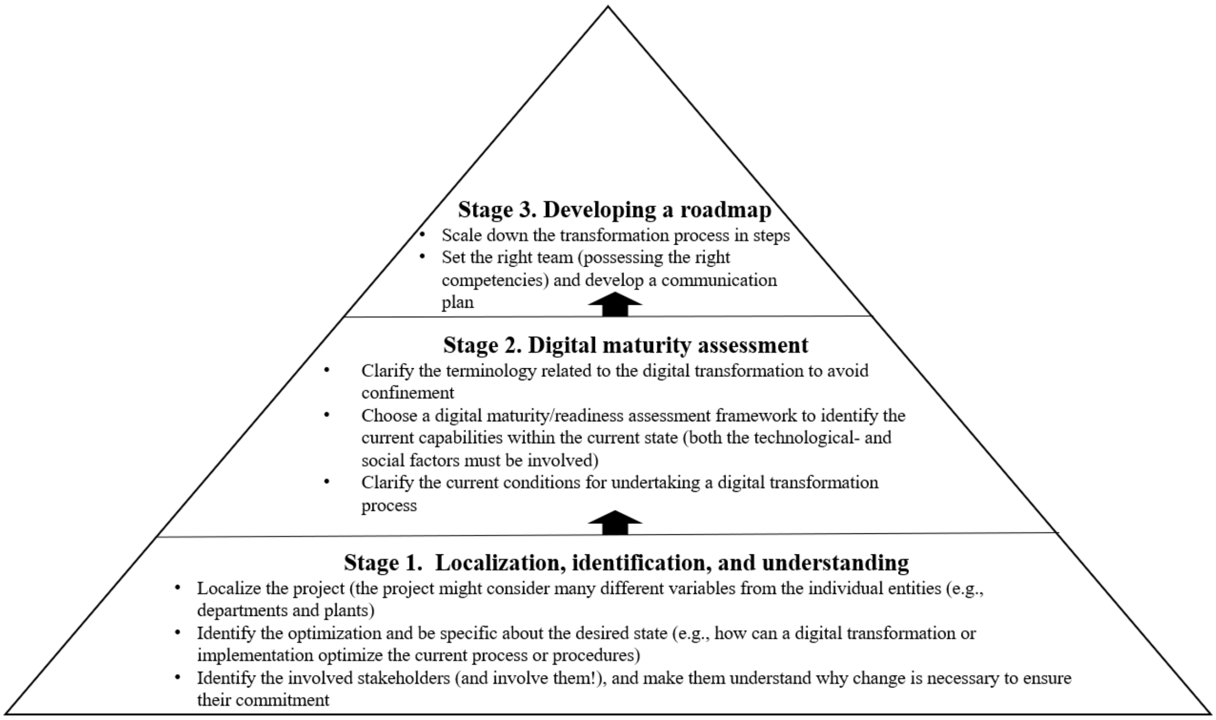


*Figure 16. The preconditions for a developing an operational digitalization strategy. Source: (Clausen and Henriksen, 2022 (**PAPER IV**)).*

4.2.4 Summary and contributions – RQ5

To summarize the conceptual framework illustrated in Figure 16, the preconditions for a digital transformation strategy all seem to depend on how well the strategy reflects a realistic end-target and how well it incorporates the right stakeholders. The framework consists of several stages, as both the theoretical and empirical findings claim that digital transformations equal a change management process, where the technology itself does not play the focal role, as it comes down to people and values, as stated by Westerman (2018, p. 2). "…when it comes to digital transformation, digital is not the answer. Transformation is."

To summarize the findings in answering RQ5, Table 31 presents the contributions of the related research activities.

Aim	Findings	Contribution
WP 2 (research activity 2) – Explaining the desired state of the research problem: What are the preconditions when considering a digital transformation at the SFM level?	The preconditions revolve around the managerial capabilities of developing a strategy that indicates proper planning of getting the right people involved and making them truly understand why a digital transformation is required. Without proper	The findings contribute to the discussion of overcoming the key OM challenge of combining OM and TM when dealing with socio-technical systems by suggesting practical guidelines being the preconditions for

	understanding and involvement, the involved people will not be able to transcend knowledge across different boundaries Our findings suggest a three-stage framework for developing an operational strategy: **1.** *localizing* the project, *identifying* the objective, and *involving* the related stakeholders. **2.** perform a *digital maturity assessment* to understand project boundaries (identify the necessary capabilities). **3.** develop *a* set of *roadmap tasks.* The transformation reflects a change management process, affording new technological and social interactions involving evolving new roles with new capabilities.	developing an operational strategy for accomplishing digital transformations on the SFM level.

Table 31. Overview of the contribution of research activity 2 (WP 2): aim and findings.

5 Chapter – Discussion

This PhD dissertation aims to understand the research objective **of how to develop VBs providing functionality to handle contemporary tasks on a smart manufacturing shop floor.** The project has a threshold in the OM and TM literature, as the study conceptualizes a technological tool and the sociotechnical system it operates within. The ambition has been to extend the current body of knowledge within the OM research domain, as the current knowledge of smart manufacturing shop floor implementations is heavily fragmented (Van Aken et al., 2016). Furthermore, the author desires to provide practical guidelines for manufacturing to follow as the research topic addresses a timely topic receiving high interest.

Given this, this chapter aims to elaborate on the relevance of the research related to answering the research findings disseminated in the appended papers, **PAPER I-IV**, by presenting the related theoretical and practical implications. Although this dissertation has followed a bipartite WP structure to illustrate the nature of the research project, this chapter addresses the implications from a combined perspective to highlight how well the research results generated in the two WPs are connected in answering the research objective. In the end, the limitations and related future research thoughts are presented.

5.1 Theoretical implications

The gaps in the literature make it difficult to establish whether a digital transition of SFM VBs is something practitioners are truly chasing (Meissner et al., 2018; Meissner et al., 2020). At the outset of this project, the theoretical assertions led the author to formulate a working hypothesis claiming that "the current adaptation level of digital SFM VBs is nearly non-existent." This study reveals an adaptation level of digital SFM VBs on 21%, which aligns with a similar study performed by Pötters et al. (2018); they revealed that 17.5% of manufacturing companies rely on digital systems to facilitate SFM. Although the adaptation level might indicate low interest in applying digital SFM VBs, the case study research findings in WP 1 convince us differently. In total, 79% of the case companies attribute digital VBs as a means to facilitate SFM in today's smart manufacturing environment and claim that a digital transition of SFM VBs is warranted.

A study performed by Kandler et al. (2020) explains that the low adaptation level of digital support systems on the shop floor might be due a limited access to shop floor data. Our results extend these findings by claiming that the hindering forces connected to a digital transition of SFM VBs are related to both technical and social issues. While the t*echnical issues* are related to automating the data life cycle (see Dai et al., 2019) and immature IT architectures, the *social issues* are related to the managerial capabilities, such as the company lacking practical experience with smart manufacturing shop floor implementations. However, it might appear puzzling that the companies provide such a decisive answer favoring a digital transition of SFM VBs, while their awareness of the opportunities within is low. Although several TM researchers (Kusiak, 2018; Zhuang et al., 2018; Dai et al., 2019) praise that manufacturing is keeping up with I4.0 trends, it does not seem to be the case on the shop floor. Moreover, shop floor practitioners seem to have difficulty moving forward from Industry 2.0 principles, like indicated by Yin et al. (2018).

The OM researchers that have examined the usability of digital VBs, such as Hultin and Mähring (2014), Steenkamp et al. (2017), Li et al. (2017), and Østerlie and Monteiro (2020), have not touched upon the “black box” of technologies in their studies, namely describing the technological functionalities of the VB. Without clear notions of the term “digital,” “digitized,” or “digitalized,” confusion of concepts might arise, which for example, was the case while studying the adaptation level of “digital” VBs in WP 1 (see **Section 4.1.2**) and during the intervention in Alpha in WP 2. This confusion resulted in problematic issues of not turning research findings into common knowledge. To avoid this confusion, this project suggests adopting the concepts of digitization and digitalization (such as Holmström et al., 2019) when describing the technological functionalities of VBs.

Moreover, this project asserts that prevalent literature on smart manufacturing implementations on the shop floor does not reflect the practical realities, which indicates a need for reconciling theory and practice. It seems the solid phrase provided by Lewin (1945), “there is nothing as practical as good theory,” not seems to reach through in current studies of digital implementations on the shop floor. For example, TM researchers (Zhang et al., 2017; Dai et al., 2019) describe a digital transformation of the manufacturing shop floor as a straightforward journey in which technological determinism “easily” is achieved. However, this was not proven to be the case during the intervention in Alpha (WP 2), when we discovered how few similarities of reaching Alpha’s desired state (being “providing practitioners with real-time data to manage the production line”) had in common by Zhang et al.’s (2017) mirror image statement. We did not identify pursuing the desired state as being a straight road. Instead, we learned those prevalent theories help define and clarify the desired state, but the advice on reaching the desired state seems to be decoupled from the practical setting regarding the interventions of digitalized VBs.

As put forward by several OM researchers (Van Aken et al., 2016; Moghaddam et al., 2018; Cimini et al., 2020), combining OM and TM knowledge when dealing with socio-technical systems has been addressed as a critical challenge, mainly how to deal with the social components is highlighted as a key challenge (Van Aken et al., 2016). During the intervention in Alpha, we experienced issues dealing with the technological components in intervention 1 and the social components in Intervention 2. Problems occurred with transferring OM and TM knowledge in the different interventions. This situation triggered reflections upon Van Aken et al.’s (2016) engineering-OM transfer, which suggests a “knowledge-transfer” approach to transcend boundaries between OM and TM knowledge when dealing with OM systems that lie between the social and technical components. We assert that digital implementations on the shop floor cannot be treated with a smooth engineering OM-transfer and necessities transcending OM knowledge and TM knowledge equally.

5.2 Practical implications

This empirically driven study illustrates a low adaptation level of digital SFM VBs, although the findings in both WP 1 and WP 2 indicate a need for VBs with digitalized functionalities to enable fit for handling contemporary shop floor tasks. Given this, only a few companies have commenced a digital transition of SFM VBs, all reporting results of digital VBs with digitized functionalities. The findings illustrate that technical issues related to automating the data life cycle (Dai et al., 2019) and immature IT architectures and IT systems seem to hinder a digital transformation, along with social issues related to lack of practical experience in managing such implementation. Based on the results emerging from WP 1, the author constructed a working hypothesis to guide the research activities in WP 2, claiming that the current functionality of VBs is inadequate to handle shop floor tasks. However, the research results in WP 2 indicate that current VBs are still valuable; however, VBs with analog functionalities induce information islands and necessitate physical proximity. VBs with digitized functionalities allow practitioners to transcend information across organizational boundaries and to recall and rely on past solutions through their digital capabilities. However, given that the research results in WP 1 illustrate a confusion of concepts of the term "digital," this project asserts that managers standing ahead of a digital transition of SFM VBs pay attention to the fact that "what you think you see is not necessarily what you get." During the studies in WP 1 and the intervention in WP 2, digital SFM VBs were mainly a result of pure frontend development via Microsoft PowerBI, Trello, or Microsoft Office (e.g., Excel) software solutions. These digitized SFM VBs do not provide the necessary functionalities to enable fit to handle shop floor tasks in a smart manufacturing context.

The research findings illustrate that manufacturing still struggles with several constraints in their IT architecture related to the shop floor. Unconstrained access to data is a central requirement for tailoring SFM VBs to the context of smart manufacturing, but current IT architectures constrain access to shop floor data and information. According to the research results, digitalized SFM VBs require frontend and backend development to go hand in hand to ensure that *i)* the frontend development provides a user-friendly interface to capture data, *ii)* backend development reflects automation of the whole data life cycle to eliminate information islands and to enable interoperability, and *iii)* the VB interface enable an adaptable layout.

Adopting an IBR approach to initiate a digital transition of analog SFM VBs to digitalized SFM VBs in Alpha proves that the means to go from the current state to the desired state depends on the mindset of the involved people. For intervention 1 in Alpha, the project team possessed a heavy lean mindset, while the team for Intervention 2 possessed a data science mindset. However, we identified this to be a problem, as having such divided mindsets in each project team might result in an unbalance of transcending OM and TM knowledge within the interventions (Van Aken et al. 2016), as people are influenced by their mindsets, which guide their knowledge creation, social interaction, and actions (Paiva et al., 2008). To transcend the OM and TM knowledge boundaries, we (the authors of **PAPER III**) tried to push knowledge towards technical means within Intervention 1 to dare the lean mindset, and for Intervention 2, we pushed knowledge towards operational means to challenge the data science mindset. Unfortunately, our effort was insignificant. This project asserts that the managerial roles on the shop floor which are incorporated to manage digital transformation projects should evolve capabilities to combine OM and TM knowledge. Several OM researchers, such as Holm (2018) and Li et al. (2019), have already demonstrated that the shop floor workers' role must evolve along with the digital transformations of shop floors. This project extent these findings and requires that the managerial roles gain new knowledge; otherwise, they lose behind.

Transcending OM and TM knowledge across boundaries when developing an SFM VB enabling fit was identified as the fourth prerequisite after terminating Intervention 2 in Alpha.

Although the first three identified prerequisites reflect how to deal with the technological components and indicate practical suggestions based on the intervention uses-cases, this project suggests that the fourth prerequisite should be valued above these within a future intervention. Intervention 2 failed because we could not balance the technological and social components equally when chasing the digitalized VBs. Findings from the single-case study performed in Alpha (the findings related to exploring RQ5) suggest a conceptual framework reflecting the managerial guidelines, which encompass that a project team ensures they possess the right capabilities to go through with the project before embarking on a digital transition. The framework suggests that a digital transition should revolve around a **transformation** that includes a corporation culture and mindset, as it will impact all levels of the company. Hence, a digital transformation affords new technological and social interactions demanding practitioners evolve new roles possessing new capabilities. Indeed, the findings repeat the wise words of Jeanne W. Ross, "Clearly, the thing that is transforming is not the technology, and it is the technology that is transforming you."

5.3 Limitations

Although this project has identified several prerequisites to answer the research objective and thereby provided several contributions to theoretical and practical understandings, the methods employed during this three-year research study provide several limitations.

First, this project limited its industrial horizon to three manufacturing companies (Alpha, Beta, and Charlie) when studying the usability of current and emerging VBs. To discuss the generalizability of the related findings, it is important to highlight their characteristics (see **Section 4.2.1**), as these conditioned the outcome of finalizing an answer to the research objective. Alpha, Beta, and Charlie were selected as case companies among 18 companies (see **Table 7**), as these three companies apply both analog and digital VBs. In contrast, the remaining companies only apply analog SFM VBs. Going with Alpha, Beta, and Charlie might bias the findings, favoring the use and advantages of VBs providing digital functionalities. Furthermore, Alpha, Bravo, and Charlie are large global manufacturers based in a high-labor country (Denmark), which might also reflect limitations on the generalizability. Due to the latter limitation, a suggestion for future work is to study to what extent the identified four prerequisites enable the development of digitalized VBs in various industries (with different global locations) and manufacturing setups (and manufacturing sizes).

Second, regarding the project's robustness, the outcomes derive from different research activities, representing extreme differences in the extent of data collection. However, all research activities have been empirically driven. While the data collection carried out in WP 1 range "broad", clarifying the research topic from a "zoom out view", WP 2 present a "zoom-in" view by presenting a longitudinal study which represents a much more thorough study than the other research activities conducted. Because the exploration in Alpha has contributed heavily to the author's empirical understanding of the research topic, this might have negatively influenced the study's trustworthiness. However, all conducted research activities are considered to have originated the research outcomes.

Third, as this research project is considered a "pioneer" work, the four prerequisites proposed to enable the development of digitalized SFM VBs providing functionality to handle contemporary shop floor tasks should be viewed as an initial attempt to answer the PhD research objective. Future research is needed to validate the intervention findings to refine the development process of an operational digitalized SFM VB, which this research project failed to accomplish.

6 Chapter - Conclusions

With this research project, the author was allowed to empirically investigate smart manufacturing implementations on the shop floor by chasing the development of VBs providing functionality to handle contemporary shop floor tasks. Through this three-year study, several research activities have been conducted to formulate an answer to the research objective. In synthesis, the research outcomes have outlined the challenges and enablers related to accomplishing a digital transition of SFM VBs and provide a normative theory for understanding the prerequisites for developing digitalized VBs. Clearly, a digital transition/transformation in this context is a complex agenda.

Given that the explored research topic receives significant interest from academia and industry, the author has participated in several knowledge dissemination activities, where the project findings have been presented and discussed. On the industrial side, the author has been invited to provide industrial presentations at seminars, workshops, company events, and fairs. On the academic side, the author has held several lectures and supervised several projects dealing with the research topic. Moreover, the author has published scientific articles targeting OM and TM outlets and presented at conferences (e.g., *European Operations Management Association (EurOMA)*, Portland International Center for Management of Engineering and Technology (PICMET), and Transdisciplinary Engineering (TE)).

The author's involvement in the abovementioned activities might contribute to the project's robustness. Through these activities, the author received many excellent comments, which have helped to deal with biases by having others' constructive opinions about the research results. For that reason, dissemination has sometimes functioned as "third party testing."

Concluding this dissertation, it is worth reflecting upon what has been achieved with this research project. Although the PhD project did not fulfill the author's ambition of developing an operational VB serving its attended purpose, the lessons learned during this three-year research project are valuable. With the wise words of Albert Einstein in mind "failure is a success in progress", the "failure learnings" have contributed to answering the research objective with both generating theoretical and practical contributions.

The research results put forward four prerequisites, which the fourth directly derives from the failure attempt when evaluating Intervention 2 within the physical shop floor setting in Alpha. In **Section 5**, the author suggests that the fourth prerequisite should be valued above the three others, given that the research results reveal that the digital transition of the shop floor VBs ceases because OM knowledge and TM knowledge are poles apart. Hence, a digital transition of SFM VBs revolves around the ability to transcend knowledge across OM and TM.

References

Barratt, M., Choi, T. Y., & Li, M. (2011). Qualitative case studies in operations management: Trends, research outcomes, and future research implications. *Journal of Operations Management*, 29(4), 329-342. https://doi.org/10.1016/j.jom.2010.06.002

Bateman, N., Philip, L., & Warrander, H. (2016). Visual management and shop floor teams – development, implementation and use. *International Journal of Production Research*, 54(24), 7345-7358. https://doi.org/10.1080/00207543.2016.1184349

Baumeister, R. F., & Leary, M. R. (1997). Writing narrative literature reviews. *Review of general psychology*, 1(3), 311-320. https://doi.org/10.1037%2F1089-2680.1.3.311

Bendoly, E., & Cotteleer, M. J. (2008). Understanding behavioral sources of process variation following enterprise system deployment. *Journal of Operations Management*, 26(1), 23-44. https://doi.org/10.1016/j.jom.2007.03.002

Beynon-Davies, P., & Lederman, R. (2017). Making sense of visual management through affordance theory. *Production Planning & Control*, 2, 142–157. https://doi.org/10.1080/09537287.2016.1243267

Blumer, H. (1969). *Symbolic interactionism: Perspective and method*, University of California Press.

Browning, T. R. (2010). On the alignment of the purposes and views of process models in project management. *Journal of Operations Management*, 28(4), 316-332. https://doi.org/10.1016/j.jom.2009.11.007

Bryman, A., & Bell, E. (2007). *Business Research Methods*, Oxford University Press.

Bryman, A., Becker, S., & Sempik, J. (2008). Quality criteria for quantitative, qualitative and mixed methods research: A view from social policy. *International journal of social research methodology*, 11(4), 261-276. https://doi.org/10.1080/13645570701401644

Buer, S.-V., Strandhagen, J.W., Semini, M. and Strandhagen, J.O. (2021), The digitalization of manufacturing: investigating the impact of production environment and company size, *Journal of Manufacturing Technology Management*, 32(3), 621-645. https://doi.org/10.1108/JMTM-05-2019-0174

Cagliano, R., Canterino, F., Longoni, A., & Bartezzaghi, E. (2019). The interplay between smart manufacturing technologies and work organization. *International Journal of Operations & Production Management*, 39(6-8), 913-934. https://doi.org/10.1108/IJOPM-01-2019-00933

Caniato, F., Doran, D., Sousa, R., & Boer, H. (2018). Designing and developing OM research – from concept to publication, *International Journal of Operations & Production Management*, 38(9), 1836-1856. http://doi.org/10.1108/IJOPM-01-2017-0038

Chandrasekaran, A., de Treville, S., & Browning, T. (2020). Intervention-based research (IBR)—What, where, and how to use it in operations management. *Journal of Operations Management*, *66*(4), 370-378. https://doi.org/10.1002/joom.1093

Charmaz, K. (2020) Grounded Theory – main characteristics in Järvinen, M. & Mik-Meyer, N. (eds) *Qualitative Analysis: Eight approaches for the social sciences. London: Sage.*

Cimini, C., Pirola, F., Pinto, R., & Cavalieri, S. (2020). A human-in-the-loop manufacturing control architecture for the next generation of production systems. *Journal of manufacturing systems*, (54), 258-271. https://doi.org/10.1016/j.jmsy.2020.01.002

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Dai, H.N., Wang, H., Guangquan, X., Wan, J., & Imran, M. (2019). Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies. *Enterprise Information Systems*, 1–25. https://doi.org/10.1080/17517575.2019.1633689

de Treville, S., Edelson, N. M., Kharkar, A. N., & Avanzi, B. (2008). Constructing useful theory: The case of Six Sigma. *Operations management research*, 1(1), 15-23. https://doi.org/10.1007/s12063-008-0005-z

Dewey, J. (1933). *Essays and How We Think*, Carbondale, Southern Illinois University Press.

Dewey, J. (1938). *Logic: The Theory of Inquiry*, (12), Carbondale, Southern Illinois University Press.

Dubois, A., and Gadde, L.-E., (2002). Systematic combining: An abductive approach to case research. *Journal of Business Research*, 2, 553-560.

Eaidgah, Y., Maki, A. A., Kurczewski, K., & Abdekhodaee, A. (2016). Visual management, performance management and continuous improvement: a lean manufacturing approach. *International Journal of Lean Six Sigma*, 7(2), 187-210. https://doi.org/10.1108/IJLSS-09-2014-0028

Fast-Berglund, Å., Harlin, U., & Åkerman, M. (2016). Digitalisation of meetings–from white-boards to smart-boards. *Procedia CIRP*, 41, 1125-1130. https://doi.org/10.1016/j.procir.2015.12.120

Flores, E., Xu, X., & Lu, Y. (2020). Human Capital 4.0: a workforce competence typology for Industry 4.0. *Journal of Manufacturing Technology Management*, 31(4), 687-703. https://doi.org/10.1108/JMTM-08-2019-0309

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15-26. https://doi.org/10.1016/j.ijpe.2019.01.004

Fullerton, R. R., Kennedy, F. A., & Widener, S. K. (2014). Lean manufacturing and firm performance: The incremental contribution of Lean management accounting practices. *Journal of Operations Management*, 32(7-8), 414-428. https://doi.org/10.1016/j.jom.2014.09.002

Ganev, D. (2017). *Build applications with Meteor: full stack development*, Birmingham, Packt Publishing.

Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS Quarterly*, 19(2), 213-236. https://doi.org/10.2307/249689

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Ectj*, 29(2), 75-91. https://doi.org/10.1007/BF02766777

Hanenkamp, N. (2013). The process model for shop floor management implementation. *Advances in Industrial Engineering and Management*, 2(1), 40-46.

Heim, G. R., Nair, A., & Bendoly, E. (2021). Aims and criteria for advancing technology management research at the Journal of Operations Management. *Journal of Operations Management*, *67*(8), 920-925. https://doi.org/10.1002/joom.1164

Helu, M., Libes, D., Lubell, J., Lyons, K., & Morris, K. C. (2016). Enabling smart manufacturing technologies for decision-making support. In *International Design*

Engineering Technical Conferences and Computers and Information in Engineering Conference, 50084, https://doi.org/10.1115/DETC2016-59721

Hertle, C., Siedelhofer, C., Metternich, J., & Abele, E. (2015). The next generation shop floor management–how to continuously develop competencies in manufacturing environments. In the consortium of *The 23rd International Conference on Production Research.*

Hertle, C., Tisch, M., Kläs, H., Metternich, J., & Abele, E. (2016). Recording shop floor management competencies–a guideline for a systematic competency gap analysis. *Procedia Cirp*, 57, 625-630. https://doi.org/10.1016/j.procir.2016.11.108

Hertle, C., Tisch, M., Metternich, J., & Abele, E. (2017). Das Darmstädter Shopfloor Management-Modell. *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 112(3), 118-121.

Holm, M. (2018). The future shop-floor operators, demands, requirements and interpretations. *Journal of Manufacturing Systems*, (47), 35–42. https://doi.org/10.1016/j.jmsy.2018.03.004

Holmström, J., Ketokivi. M., & Hameri. A.P. (2009). Bridging practice and theory: A design science approach. *Decision sciences*, 40(1), 65-87. https://doi.org/10.1111/j.1540-5915.2008.00221.x

Holmström, J., Holweg, M., Lawson, B., Pil, F. K., & Wagner, S. M. (2019). The digitalization of operations and supply chain management: Theoretical and methodological implications. *Journal of Operations Management*, 65(8), 728-734. https://doi.org/10.1002/joom.1073

Hultin, L., & Mähring, M. (2014). Visualizing institutional logics in sociomaterial practices. *Information and Organization*, 24(3), 129-155. https://doi.org/10.1016/j.infoandorg.2014.05.002

Humphlett, M. (2016). Operations how will digitalization impact personnel on the manufacturing shop floor? *Industry Week.*

Illing, H. (2012). Shopfloor-Management. Besser führen in der Fabrik. *Management und Qualität,* 47(9), 23-24.

Ji, W., & Wang, L. (2017). Big data analytics-based fault prediction for shop floor scheduling. *Journal of Manufacturing Systems*, (43), 187-194.
https://doi.org/10.1016/j.jmsy.2017.03.008

Johnson, G., Whittington, R., Regnér, P., Angwin, D., & Scholes, K. (2014). *Exploring strategy*. Pearson UK.

Jwo, J. S., Lin, C. S., & Lee, C. H. (2021). Smart technology–driven aspects for human-in-the-loop smart manufacturing. *The International Journal of Advanced Manufacturing Technology*, 114(5), 1741-1752. https://doi.org/10.1007/s00170-021-06977-9

Kandler, M., Kurtz, J. J., Stricker, N., & Lanza, G. (2020). Digitales, agiles Management auf dem Shopfloor. *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 115(1-2), 23-26. https://doi.org/10.3139/104.112241

Kim, B. (2001). Social constructivism. *Emerging perspectives on learning, teaching, and technology*, 1(1).

Koh, L., Orzes, G. and Jia, F.(J). (2019). The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management, *International Journal of Operations & Production Management*, 39 (6-8), 817-828. https://doi.org/10.1108/IJOPM-08-2019-788

Kumar, S., Mookerjee, V., & Shubham, A. (2018). Research in operations management and information systems interface. *Production and Operations Management*, 27(11), 1893-1905. https://doi.org/10.1111/poms.12961

Kumari, M., & Kulkarni, M. S. (2016). A complexity based look-ahead mechanism for shop floor decision making. *Procedia CIRP*, 41, 63-68. https://doi.org/10.1016/j.procir.2015.12.032

Kusiak, A. (2018). Smart manufacturing. *International Journal of Production Research*, 56(1-2), 508-517. https://doi.org/10.1080/00207543.2017.1351644

Larteb, L., Benhadou, M., Haddout, A., & Nahla, H. (2016). The key to lean performance: Implementing a daily shop-floor control system using standardization and visual management. *Journal of Advanced Research in Management (IJARM)*, *7*(1), 34-43.

Lewin, K. (1945). The research centre for group dynamics at Massachusetts Institute of Technology. *Sociometrics*, 8, 128-135. https://doi.org/10.2307/2785233

Li, D., Fast-Berglund, Å., Dean, A., & Ruud, L. (2017). Digitalization of whiteboard for work task allocation to support information sharing between operators and supervisor. *IFAC-PapersOnLine*, 50(1), 13044-13051. http://dx.doi.org/10.1016/j.ifacol.2017.08.2003

Li, D., Fast-Berglund, Å., & Paulin, D. (2019). Current and future Industry 4.0 capabilities for information and knowledge sharing. *The International Journal of Advanced Manufacturing Technology*, *105*(9), 3951-3963. https://doi.org/10.1007/s00170-019-03942-5

Liker, J.K., & Meier, D. (2006). *The Toyota Way Fieldbook*. New York, McGraw-Hill.

Lorenz, R., Powell, D., & Netland, T. H. (2019). Exploring the effect of digitalizing shop floor management. In *26th Annual EurOMA Conference: Operations adding value to society (EurOMA 2019)*.

Lowe, J. (1993). Manufacturing reform and the changing role of the production supervisor: the case of the automobile industry. *Journal of Management Studies*, 30(5), 739-758. https://doi.org/10.1111/j.1467-6486.1993.tb00324.x

Luthra, S., Kumar, A., Zavadskas, E. K., Mangla, S. K., & Garza-Reyes, J. A. (2020). Industry 4.0 as an enabler of sustainability diffusion in supply chain: an analysis of influential strength of drivers in an emerging economy. *International Journal of Production Research*, *58*(5), 1505-1521. https://doi.org/10.1080/00207543.2019.1660828

Mathiasen, J.B. (2017). Doing product development activities: The role of experience and ends-in-view. *International Journal of Innovation and Learning*, 22(4), 524-543. https://doi.org/10.1504/IJIL.2017.087494

Mathiasen, J. B., & Clausen, P. (2019). Digitising shop floor visualisation boards: A missing link in the Industry 4.0 Era. In *Transdisciplinary Engineering for Complex Socio-technical Systems* IOS PRESS, 10, 189-198. https://doi.org/10.3233/ATDE190123

Mathiassen, L. (2002). Collaborative practice research. *Information Technology & People,* 15 (4), 321-345. https://doi.org/10.1108/09593840210453115

McNiff, J. (2016). *You and your action research project / Jean McNiff and Jack Whitehead. – 3rd ed.* Routledge.

McNiff, J. (2013). *Action research: Principles and practice*. Routledge.

Meissner, A., Grunert, F., & Metternich, J. (2020). Digital shop floor management: A target state. *Procedia CIRP*, 93, 11-315. https://doi.org/10.1016/j.procir.2020.04.083

Meissner, A., Müller, M., Hermann, A., & Metternich, J. (2018). Digitalization as a catalyst for lean production: A learning factory approach for digital shop floor management. *Procedia Manufacturing*, 23, 81-86. https://doi.org/10.1016/j.promfg.2018.03.165

Meredith, J. R. (2001). Hopes for the future of operations management. *Journal of Operations Management*, *19*(4), 397-402. https://doi.org/10.1016/S0272-6963(01)00056-0

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2019). Smart manufacturing: Characteristics, technologies and enabling factors. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 233(5), 1342-1361. https://doi.org/10.1177%2F0954405417736547

Moghaddam, M., Cadavid, M. N., Kenley, C. R., & Deshmukh, A. V. (2018). Reference architectures for smart manufacturing: A critical review. *Journal of manufacturing systems*, *49*, 215-225. https://doi.org/10.1016/j.jmsy.2018.10.006

Nicolini, D. (2012). Practice theory, work, and organization: An introduction. *OUP Oxford.*

Oliva, R. (2019). Intervention as a research strategy. *Journal of Operations Management*, *65*(7), 710-724. https://doi.org/10.1002/joom.1065

Orlikowski, W. J., & Baroudi, J. J. (1991). Studying information technology in organizations: Research approaches and assumptions. *Information systems research*, 2(1), 1-28. https://doi.org/10.1287/isre.2.1.1

Paiva, E. L., Roth, A. V., & Fensterseifer, J. E. (2008). Organizational knowledge and the manufacturing strategy process: a resource-based view analysis. *Journal of Operations Management*, 26(1), 115-132. https://doi.org/10.1016/j.jom.2007.05.003

Parry, G.C., & Turner, C.E. (2006). Application of lean visual process management tools. *Production Planning & Control*, 17(1), 77–86. https://doi.org/10.1080/09537280500414991

Peters, R. (2009), *Shopfloor Management: Führen am Ort der Wertschöpfung*, Stuttgart: LOG_X Verlag.

Pötters, P., Schindler, P., & Leyendecker, B. (2018). Status quo Shopfloor Management. *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 113(7-8), 522-525. https://doi.org/10.3139/104.111948

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., ... & Nee, A. Y. C. (2021). Enabling technologies and tools for digital twin. *Journal of Manufacturing Systems*, *58*, 3-21

Rajan, K., & Safiotti, A. (2017). Towards a science of integrated AI and Robotics. *Artificial Intelligence*, 247, 1–9. https://doi.org/10.1016/j.artint.2017.03.003

Roscoe, S., Cousins, P. D., & Handfield, R. (2019). The microfoundations of an operational capability in digital manufacturing. *Journal of Operations Management*, *65*(8), 774-793. https://doi.org/10.1002/joom.1044

Schmenner, R. W., & Swink, M. L. (1998). On theory in operations management. *Journal of Operations Management*, 17(1), 97-113. https://doi.org/10.1016/S0272-6963(98)00028-X

Schön, D.A. (1983). The Reflective Practitioner, New York, Basic Books, Inc., Publishers.

Schwab, K. (2017). *The fourth industrial revolution*. Currency.

Simon, H. A. (1973). Does scientific discovery have a logic? *Philosophy of Science,* 40(4), 471–480. https://doi.org/10.1086/288559

Simon, H. A. (1988). The science of design: Creating the artificial. *Design Issues*, 4(1-2), 67–82. https://doi.org/10.2307/1511391

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). Cambridge, MA: MIT Press.

Stake, R.E. (2000). *The case study method in social inquiry*, in R. Gomm, M. Hammersley, P. Foster (Eds.), Case Study Method: Key Issues, Key Texts, London, SAGE Publications.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology,translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social studies of science*, 19(3), 387-420. https://doi.org/10.1177%2F030631289019003001

Steenkamp, L. P., Hagedorn-Hansen, D., & Oosthuizen, G. A. (2017). Visual management system to manage manufacturing resources. *Procedia Manufacturing*, *8*, 455-462. https://doi.org/10.1016/j.promfg.2017.02.058

Stoop, P. P., & Wiers, V. C. (1996). The complexity of scheduling in practice. *International Journal of Operations & Production Management*, 16(10), 37-53. https://doi.org/10.1108/01443579610130682

Subramaniam, S. K., Husin, S. H., Singh, R. S. S., Hamidon, A. H. (2009). Production monitoring system for monitoring the industrial shop floor performance. *International Journal of Systems Applications, Engineering & Development*, 3(1), 28-35.

Subramaniam, V., Raheja, A. S., Rama Bhupal Reddy, K. (2005). Reactive repair tool for job shop schedules. *International Journal of Production Research*, 43(1), 1-23. https://doi.org/10.1080/0020754042000270412

Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of Manufacturing Systems*, 48, 157–169. https://doi.org/10.1016/j.jmsy.2018.01.006

Tezel, A., Koskela, L., & Tzortzopoulos, P. (2009). The functions of visual management. In: *International Research Symposium, Salford, UK*, 201-209.

Tezel, A., Koskela, L., & Tzortzopoulos, P. (2016). Visual management in production management: a literature synthesis. *Journal of manufacturing technology management*, 27(6), 766-799. https://doi.org/10.1108/JMTM-08-2015-0071

Torres, D., Pimentel, C., & Duarte, S. (2019). Shop floor management system in the context of smart manufacturing: a case study. *International Journal of Lean Six Sigma*, 11(5), 837-862. http://dx.doi.org/10.1108/IJLSS-12-2017-0151

Van Aken, J., Chandrasekaran A., & Halman, J. (2016). Conducting and publishing design science research. *Journal of Operations Management*, 47, 1-8. https://doi.org/10.1016/j.jom.2016.06.004

Van de Ven, A. H. (2007). *Engaged scholarship: A guide for organizational and social research*. Oxford University Press on Demand.

Vidgen, R., & Braa, K. (1997). Balancing interpretation and intervention in information system research: the action case approach. In *Information systems and qualitative research* (pp. 524-541). Springer, Boston, MA.

Wang, X., Yew, A. W. W., Ong, S. K., & Nee, A. Y. C. (2020a). Enhancing smart shop floor management with ubiquitous augmented reality. *International Journal of Production Research*, 58(8), 2352-2367. https://doi.org/10.1080/00207543.2019.1629667

Wang, W., Zhang, Y., Zhong, R. Y. (2020b). A proactive material handling method for CPS enabled shop-floor. *Robotics and Computer-Integrated Manufacturing*, 61, 101849.

Westerman, G. (2018). Your company doesn’t need a digital strategy. *MIT Sloan Management Review*, 59(3), 1-5.

Womack, J.P., Jones, D. T, and Roos, D. (1990). *The Machine That Changed the World,* New York: Rawson Associates.

Xu, M., David, J. M., & Kim, S. H. (2018). The fourth industrial revolution: Opportunities and challenges. *International journal of financial research*, *9*(2), 90-95. https://doi:10.5430/ijfr.v9n2p90

Yin, Y., Stecke, K. E., & Li, D. (2018). The evolution of production systems from Industry 2.0 through Industry 4.0. *International Journal of Production Research*, 56(1-2), 848-861. https://doi.org/10.1080/00207543.2017.1403664

Zeng, J., Anh, P. C., Matsui, Y. (2013). Shop-floor communication and process management for quality performance: An empirical analysis of quality management. *Management Research Review*, 36(5), 454-477. https://doi.org/10.1108/01409171311327235

Zhang, Y., Wang, J., Liu, S., & Qian, C. (2017). Game theory based on real-time shop floor scheduling strategy and method for cloud manufacturing. *International Journal of Intelligent Systems*, 32(4), 437-463. https://doi.org/10.1002/int.21868

Zhuang, C., Liu, J., Xiong, H. (2018). Digital twin-based smart production management and control framework for the complex product assembly shop-floor. *The International Journal of Advanced Manufacturing Technology*, 96(1), 1149-1163. https://doi.org/10.1007/s00170-018-1617-6

Zigurs, I., &Buckland, B. K. (1998). A theory of task/technology fit and group support systems effectiveness. *MIS Quarterly*, 22 (3), 313-334. https://www.jstor.org/stable/249668

Østerlie, T., & Monteiro, E. (2020). Digital sand: The becoming of digital representations. *Information and Organization*, 30(1), 100275. https://doi.org/10.1016/j.infoandorg.2019.100275

References

Appended papers

PAPER I:

Clausen, P., Mathiasen, J. B., & Nielsen, J. S. (2020). Smart manufacturing through digital shop floor management boards. *Wireless Personal Communications Springer*, *115 (4),* 3261-3274. https://doi.org/10.1007/s11277-020-07379-y

PAPER II:

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PAPER III:

Mathiasen, J. B., Clausen, P. (**resubmitted August 2022, 3rd revision**) Chasing digitalized visualization boards: Achieving fit between visualization boards and shop floor tasks. In 3rd review in *Journal of Operations Management*. **First submitted September 2020**.

PAPER IV:

Clausen, P., Henriksen, B. (2022). Teaching Old Dogs New Tricks - Towards a Digital Transformation Strategy at the Shop Floor Management Level: A Case Study from the Renewable Energy Industry. *Lecture Notes in Mechanical Engineering* Springer, Cham. 746-753 https://doi.org/10.1007/978-3-030-90700-6_85

PAPER I

Smart manufacturing through digital shop floor management boards

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Smart Manufacturing through Digital Shop Floor Management Boards

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Abstract

Smart manufacturing, an offspring from Industry 4.0 (I4.0), defines the future for the manufacturing industry. Smart manufacturing leads to digitalization of the shop floor, which is automated, computerized and complex. To stay competitive, digitalization of the shop floor management (SFM) boards will be instrumental in improving performance management and continuous improvement. The purpose of this paper is to improve the understanding of SFM board meetings in the era of I4.0. The paper explores the current adaptation level of digital SFM boards, and identifies influencing *forces for* and *forces against* a further transition from analogue to digital SFM boards. Based on a survey and a subsequent workshop with practitioners, this paper reveals that digital SFM boards have not yet been adapted at shop floor level, and currently, practitioners are stuck to the standardized procedures and manual processes. The *forces against* a further adaptation are a managerial mindset stuck in an Industry 2.0 era and immature technologies to digitize the visualization of real-time data. The *forces for* are the need of enhancing data transparency within and across teams, which means elimination of information silos and time-consuming manual updates of SFM boards.

Keywords Shop Floor Management • Industry 4.0 • Smart Manufacturing •Digital SFM boards

1 Introduction

In the digital era of Industry 4.0 (I4.0), the concept of smart manufacturing highlights the importance of big data and the use of these data in a smarter way through digital technologies [1, 2]. This evolution influences shop floor management (SFM) activities, as many characteristics of smart manufacturing aim to utilize the analytical power of real-time data by using more technological equipment as computing platforms and communication technologies [3, 4]. In a smart manufacturing practice, SFM is digitalized [5]. Digital SFM provides an effective way to monitor, diagnose and prognosticate activities at shop floors [5, 6] entailing that digital SFM visualization boards offer new ways of working with real-time data, big data, and artificial intelligence [7, 8]. However, at present, the application of digital SFM visualization boards is still incipient [3] and full adaptations are rare to be found [5, 9].

In line with Mathiasen and Clausen [10], the fourth industrial revolution has skipped a digitalization of SFM boards; thus leaving the practitioners stuck in the Industry 2.0 (I2.0) era. Likewise, Holm [11] state that the interfaces of the shop floor information systems and communicating platforms look as they did 20–30 years ago. Hence, we lack understanding of what opportunities a digital board offers in terms of doing SFM, as the rapid development of intelligent communication technologies has only marginally reached the shop-floor.

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This paper defines a digital SFM board as a digital physical object like a dashboard that has computing capabilities including analytical tools. Digital SFM boards makes it possible to improve the quality of and reduce the cost of processing, monitoring, and analyzing performance management (PM) and continues improvement (CI) data, thus reducing decision-making response-time.

Accordingly, this paper aims to identify the current adaptation level of digital SFM boards as well as investigating the *forces for* and *forces against* a further adaptation of digital boards to aid in decision-making at SFM meetings. To guide the research, we ask, "*what is the current adaptation level of digital SFM board?"* and *"what forces influence a further adaptation of digital SFM boards?"*

Methodologically, a mixed method is applied [12]. First, a quantitative study is accomplished to gain an overview of the current application of digital SFM boards, including *forces for* and *forces against* enhancing the adaptation rate; secondly, a qualitative study is conducted to gain a deeper understanding of the quantitative findings, especially the forces influencing the future adaptation of digital SFM boards.

The findings show that practitioners in the companies we have studied, lack understanding of the possibilities of applying digital SFM boards and they do only have limited experience with smart digital technologies at the SFM level; indeed, digitalization of SFM meetings is nearly non-existent. The *forces for* applying digital SFM boards are: elimination of information silos and elimination of time-consuming manual updates of analogue SFM boards. The *forces against* are: immature data foundations, unsuitable IT architectures and organizational procedures being stuck in the habitual ways of facilitating SFM. This paper opens new ways to improve our understandings of forces influencing the transition into a smart manufacturing SFM board meeting practice. Companies, which are capable of automating the data treatment and information handling at the SFM level and eliminating information silos, will operate in a smart manufacturing practice, in which data and information flow easily across boundaries, enhancing both intra- and interorganizational communication and collaboration.

The following sections are structured as follows: the first section explains the theoretical background of the study and presents theoretical findings regarding forces influencing the digital transition at the SFM level. The second section presents the methodological considerations. In the third section the analysis of the current adaptation level and forces influencing a further adaptation of digital SFM boards are presented followed by a discussion and the conclusion.

2 Theoretical background

The term "shop floor" origins from the Japanese word "Genba" and it addresses the place where value is created [13]. The shop floor is the point of convergence between information flows, material flows, and flows of following up activities [4]. Despite a common definition of the constituents of a shop floor does not exist, this paper considers SFM board meetings as a managerial system that facilitates the communication and control of the PM and CI activities at the shop floor level [3, 9].

I4.0 has a strong impact on the manufacturing set-up [3], and has thus attracted attention from governments, industries, and researchers, but still many aspect of the new digital opportunities are unknown and uncertain [14]. I4.0 can be understood as a digital transformation of the business foundation, where smart manufacturing is on the forefront, but the question is, to what extent companies at the manufacturing level has adapted this type of industrial transformation? Because of smart manufacturing enables companies to achieve a high performance level and thereby competitive advantages [15, 16, 17, 18], the level of adapting digital technologies is of great interest.

In smart manufacturing practices, practitioners witness new technological equipment and IT-systems as for instance digital technologies [4], big data equipment [6], and artificial intelligence [19]; manufacturing has evolved and thus automated, computerized and complex [20]. The smart manufacturing and digital technologies go hand-in-hand and highlights the importance of big data and the use of data in a smarter way [1, 2]. In other words, these digital technologies have a huge impact on managing PM and CI activities at the SFM level [21].

The prevalent academia understanding of smart manufacturing illustrates a future state of manufacturing in which machines, products, and practitioners act digitally and intelligently together; everything including the practitioners are digitally connected via the internet [7]. The aim of this connectivity is to form connected platforms for sharing information and knowledge and to exploit data in a smarter ways through more advanced data analytics [4, 22]. In general, however companies lack capabilities to share information and knowledge, meaning that they have loads of unutilized data. Likewise, only few companies have yet explored the benefits of working with such digital opportunities at SFM level [3, 7, 8], and the companies do only show a slow progress in their adaptation and use of this kind of technological systems [14, 23].

SFM board meetings are often accomplished in open locations and managed by a foreman [3, 13]. At present, the prevalent understanding is that SFM meetings are accomplished by using analog visualization boards [9]; i.e., analog communication approaches are mostly applied at shop floor level. Iuga et al. [24] state that analogue communication results in lots of waste time at SFM levels. This, combined with the fact that shop floor practitioners are accomplishing PM and CI activities by following standard operating procedures and manual processes without any supportive technologies to support decision-making [9, 11, 14] results in ineffective SFM board meetings.

However, the focal point for the practitioners is to achieve high manufacturing efficiency, low manufacturing cost, high product quality, and high employee satisfaction [7]. Likewise, because of intensive competition in the market, it is crucial that shop floor practitioners are continuously capable of being responsive, reliable, resilient, and relational to enhance the competitive position of the company [15]. In addition, the practical realities illustrate that the accomplishment of SFM activities are becoming more complex and uncertain, for which it is important that the information is up-to-date and communicated properly [25] within and across shop floor teams. Hence, the executions of SFM activities require the right amount of information as well as reliable and up-to-date information, which calls for the use of digital technologies [10].

To recap, SFM draws on analog systems, but manufacturing faces new advances in information technologies as cloud computing, Internet of Things, Big Data and artificial intelligence that leads to a smart manufacturing era [6, 26]. To adapt these digital opportunities there is a need to converge the manufacturing physical world and virtual world [6]. Based on the above, next section addresses the forces influencing the digital transition of the SFM level.

Forces influencing the digital transition of the SFM level

The paper interprets and defines the influencing *forces for* and *forces against* the digital transition as follows:

- The influencing *forces for* the digital transition are defined as the opportunities for achieving full data transparency and to enhance the competitive situation both in a short and long term; i.e., through the new ways of working with real-time data, big data, and artificial intelligence.
- The *forces against* the digital transition are disadvantages in terms of immature data foundation and of practitioners' capabilities to use digital technologies in SFM board meetings; as for the latter, practitioners are incapable of utilizing data through the digitized technologies.

The literature addressing the digital transition at the SFM level is very limited and only few researchers have attempted to systematize the practical realities [3]. Torres et al. [5] state that the impact of digitalization is going to be more evident at shop floor level as it is the focal point in manufacturing companies. The new way of working will require that practitioners have useful support systems that can aid in the decision-making; needed information should always be available at the right time and space [5, 7].

Holm [11] suggests that SFM practitioners should form self-controlled teams and apply a holistic approach in their work with digital technologies. This paves the way for achieving a high degree of flexibility, adaptability, and initiative in terms of further adaptations of digitalized technologies. Zhuang et al. [4] propose addressing the planning and following up activities related to PM and CI activities with the aim to evolve SFM from a single point and isolated decision-making system characterized by "information silos in the business," to a smart intelligent and digital SFM systems. Torres et al. [5], Hertle et al. [13] and Winby and Mohrman [16] agree that the digital transition creates many new opportunities to enhance the performance at the SFM level, but these authors do also highlight that a successful transition requires huge managerial attention on both technical and social issues. Hence, the digital transition of the SFM level is resource demanding and time consuming, which requires full managerial support related to technological and organizational changes. Hence it is a necessity that the company invests resources in developing and supporting their competences both technological- and organizational wise.

Meissner et al. [3] and Torres et al. [5] state that digitalization is a catalyst for following up on and enhancing performance at the SFM level; they argue that PM, CI (problem solving management), and leadership are the main activities to be conducted at the SFM level. In a conceptual paper, Meissner et al. [3] have mapped the influencing *forces for* and *forces against* of digitalizing PM-, CI- and leadership activities at the SFM level. The influencing *forces for* are; *i*) opportunities of using real-time data and enhancing data transparency; *ii)* digital information network among practitioners; *iii*) accessibility of information increases and is straightforward; *iiii*) digital technologies to support solving PM and CI activities within and across teams. The influencing *forces against* are related to the application of digital technologies including Big Data, because it requires changes in both managers' and practitioners' capabilities and it requires a huge technological transformation. More specifically, disadvantages are; *i*) practitioners and managers lack of capabilities; *ii*) "data blindness syndrome, meaning practitioners may become incapable of understanding applicable data, as they rely too much on the technological capabilities"; *iii*) cultural barriers against new working procedures and technologies. Meissner et al.'s [3] findings in regard of the influencing *forces for*- and *against* a digital transition at SFM level, do not reflect upon the negative side effects of applying digital SFM, beside mentioning the risk of achieving the "data blindness syndrome". Hence, the academic understanding provide a limited view on the practical gains from applying digital SFM boards.

To recap, *forces for* and *forces against* the digital transition of the SFM level are categorized into a Force Field Analysis [27], see Table 1.

Table 1. *Forces for* and *forces against* a digital transition of the SFM level

Influencing forces in the digital transition of SFM	
Influencing *forces for*	Influencing *forces against*
• Real-time and reliable data • Improved data accessibility • Improved data transparency • Early problem detection • Data-driven decision making • Enabling communication via network • Improved data foundation • Improved competitiveness	• Cultural barriers • Low competence level • Data blindness • Resource demanding • Time-consuming • Unstructured data storage • Limited organizational support • Low utilization of data

The next section accounts for the applied methodology.

3 Methodology

The research is an empirical study based on the retroductive approach [28]. Accordingly, the knowledge generation has ran in iterative loops between empirical- and literature analyses. The empirical data have been collected through a mixed methods study [12], starting with a quantitative study based on a survey, and then a qualitative study based on the accomplishment of a workshop with practitioners. Furthermore, the authors have implemented analog SFM boards in more than 40 companies.

Based on the authors' knowledge achieved through many years of experience in the field, we put forward a hypothesis claiming that the current adaptation of digital SFM boards is close to be non-existent. Hence, the purpose of the quantitative study was to gain a broad understanding of the current adaptation level of digital SFM boards. Thus, the survey did not have the purpose of providing a detailed understanding of the phenomenon being studied; it was more important for the authors to gain a sufficient understanding before accomplishing the qualitative data collection.

The preparation of the questions in the survey reflects the authors' practical experience and empirical knowledge gained within this area and a conducted literature review. The survey was constructed digitally and sent to around 900 companies in Denmark. The survey was available for the companies in a period of three months, 97 companies answered the survey. All companies involved in the survey were informed about the purpose of collecting the data and have given their consent for applying the received answers in scientific work and publication.

The data from the survey provided interesting patterns, but obviously some of these needed further investigation. Indeed, some of the findings from the survey raised new questions to investigate, which the authors addressed at the workshop.

The workshop was conducted at Aarhus University. Both private and public companies were invited, including all companies, which had answered the survey. 38 companies participated in the workshop. All participating companies have accepted that all kinds of data collected during the workshop would be applied in scientific work and publication; all 38 companies have given their consent.

As illustrated in table 2, the workshop consisted of three steps.

Table 2. The three steps discussed in the workshop

Workshop program	**Step 1**: Presentation of theoretical perspectives of digital boards in operational environments at the SFM level, including a presentation of the digital bord solutions available.
	Step 2: Presentation of the data generated from the survey, including our findings. The results were discussed in plenum with the participating companies.
	Step 3: Practical workshop - the companies were divived into groups and should answer and discuss different questions developed by the authors.

The data collection followed the Café Seminar method [29]. The purpose of using the Café Seminar approach was to achieve a common understanding among the three authors of this paper, in terms of both the underlying causes to the current adaptation of digital SFM boards and the forces influencing the digital transition of SFM visualization boards. Throughout the workshop, the data collection was based on an exchange of experience among all participating companies, which paved the way for the authors to gain new understanding of the phenomenon being studied.

As mentioned elsewhere, the authors' interpretation of the results from the survey indicated that the companies did not have the same prerequisites for answering the questions in the survey. Accordingly, at the outset of the workshop a presentation was conducted with the purpose of forming a common understanding of digital SFM visualization boards among all the participants; thus, the companies participating in the workshop had the same prerequisites when doing the Café Seminar.

The five questions discussed at the Café Seminar were developed by two of the authors, which were used to form five question-stations. Each of the five question-station was facilitated differently, but in general, the focal point was to encourage open dialogues from several perspectives. The companies were divided into five groups, and each of the group discussions at the five Café Seminars was managed by a station-manager who had to facilitate the process, observe, and take notes. The Café Seminar was divided into four steps (Table 3).

Table 3. The four steps of the Café seminar

Structure of the Café Seminar method workshop	**Step 1**: Open dialogue. Every participant in each group shares their viewpoint in terms of the question. A common answer for the group was developed (15 minutes rotation period).
	Step 2: Rotation to the next question-station. There were in total five question-stations, thereby four rotations. The process in each question-station followed step 1.
	Step 3: Return to the first question-station. Joint discussion about all answers from the five groups. A common generic answer at each question-station was developed.
	Step 4: Joint presentations. Each facilitator presented the answers from the question-stations.

The next section presents the empirical findings in the survey and in the workshop.

4 Empirical findings and analyzing the data

First, the findings from the survey are presented; secondly, the workshop data is analyzed.

The survey provides an overview of the current application of board meetings in companies and the adaptation level of digital SFM boards. Table 4 summarizes these findings.

Table 4. Application of board meetings and adaptation level of digital SFM board

Question	***Percentage***
Number of companies that conducts board meetings on a daily or weekly basis	81.70%
Number of companies that has heard about digital SFM boards	75.30%
Number of companies that uses both digital and analog SFM boards	21.00%
Number of companies that only uses digital SFM boards	7.00%

The findings in Table 4 indicate that board meetings are an activity that are often used. Roughly, 75% of the companies are aware of digital SFM boards and 21% of the companies state that they apply both digital and analogue SFM board to manage meetings. However, less than 10% of the companies do only apply digital SFM boards to manage board meetings. Hence, these findings show high application of SFM board meetings, but low use digital SFM boards.

Companies were requested to specify their answers if they used digital SFM boards. The answers clearly illustrate that companies do not yet have a common understanding of SFM digital boards and the fundamental technological features to enable that. The majority of companies answer that their digital SFM boards consist of a computer- or a flat-screen, and that the embedded software in the digital board consists of standard Microsoft Office package programs. Likewise, none of the companies mentions any kind of smart technological features or any kind of advanced analytical tools to support decision-making processes. However, few companies answer that they have acquired new software applications, for instance “PowerBi” and “Trello,” to enhance the visualization features. Apparently, the current adaptation level of digital SFM boards is lower than 7%, which our survey indicates. More importantly, it seems the practitioners have not yet initiated a clarification of technical requirements and features in terms of developing a suitable information architecture platform for digitalizing SFM board meetings.

As for the data collected during the *workshop,* an initiating plenum discussion involving all participating companies supports the above statement, which indicates a much lower adaptation of digital SFM boards than depicted in Table 4. Indeed, during this discussion, it gradually became apparent that only one of the participating companies has practical experience in using digital SFM boards. The discussion also revealed that the practical experience with digital technologies to facilitate board meetings is nearly non-existent in the companies.

In the same way, the dialogues clearly showed a lack of common understanding among the participating companies regarding technical requirements and features to digitalize SFM boards. Most companies categorized TV-screens with simple visualization features as digital SFM boards, even though it did neither provide any positive influence on the response-time nor at the processes of monitoring and discussing PM and CI activities. These findings indicate that the practitioners do not yet have a sufficient understanding of what a digital SFM board is, and what opportunities it brings. It seems that practitioners lack understanding of digital SFM boards, and more importantly, what kind of possibilities for action such a digital board offers and the technical prerequisites for facilitating that.

Based on the discussions and notes taken during the Café Seminar, a number of *forces for* and *forces against* the transition from analog to digital SFM boards are identified. Table 5 summarizes these findings.

Table 5. Categorization of *forces for* and *forces against* for adapting digital SFM boards.

Influencing forces for adapting digital SFM boards	
Influencing *forces for*	Influencing *forces against*
• Data transparency (no "hidden factory" syndrome) • Data and information sharing via digital network • Elimination of information silos • Less time spent on updating VBs • Real-time/big data enabling efficient decision making • Synchronization of data • Intelligent technologies for decision making • Enhancing human capabilities for decision making • Digitization is a prerequisite for competitiveness	• High investment • Habitual mindset/procedures • Too inconsistent IT systems • Unsuitable IT architectures • Immature technologies • Greater vulnerability if IT systems fail • Poor data quality in the company • Data blindness • Low commitment to change at SFM level • Managers deprioritizing a digital transition • Low awareness of the opportunities

Table 5 shows that the key influencing *forces for* adapting digital SFM boards are the multiple opportunities, which are not just related to managing the activities at shop floor, but also to optimize various business processes across the company to improve the competitive situation in the future. The key influencing *forces against* the adaptation of digital SFM boards are immature IT architecture and systems, low utilization of data and the cultural challenges related to managing the transition processes of both technical and organizational issues. This transition processes calls for changing the habitual way of working in companies, which will be resource demanding and time consuming, mainly due to the companies' current technical and managerial competence levels.

5 Discussion

The analysis demonstrates a low adaptation level of digital SFM boards, and that the practical experience with digital technologies to accomplish SFM board meetings is nearly non-existent in the companies.

Zhuang et al. [4] state that today's data and information assessment are defined as a single point manual and analogue decision-making system with low accessibility of information across functional boundaries and information silos in the company. The same authors suggest that the planning and following up activities related to PM and CI activities should evolve to smart manufacturing SFM in which the digital technologies enable communication and information sharing within and across both functional and organizational boundaries [4].

Mathiasen and Clausen [10] state that the fourth industrial revolution has skipped a digitalization of SFM boards; thus leaving the practitioners stuck in the I2.0 era meaning, that practitioners are accomplishing the PM and CI activities by following standard operating procedures and manual processes. Likewise, Holm [11] state that the interfaces of the shop floor information systems and communicating platforms are far behind as they look as they did 20–30 years ago. Hence, practitioners er without any supportive digital technologies to support decision-making at the SFM board meetings. Based on these findings, Fig. 1 depict the forces influencing the digital transition of the SFM level in regard of the technological maturity level and the accessibility of data and information.

The *vertical axis on Fig 1.* shows the opportunities—from single point SFM in which information silos constrain the accessibility of information, to smart manufacturing SFM in which digital technologies enable communication and information sharing within and across both functional and organizational boundaries. The *horizontal axis* in Fig. 1 addresses the technological maturity ranging from the I2.0 era characterized by analogue manufacturing methods and operations to the I4.0 era in which digital technologies are embedded in all manufacturing processes and operations including suitable IT-architecture and data foundation.

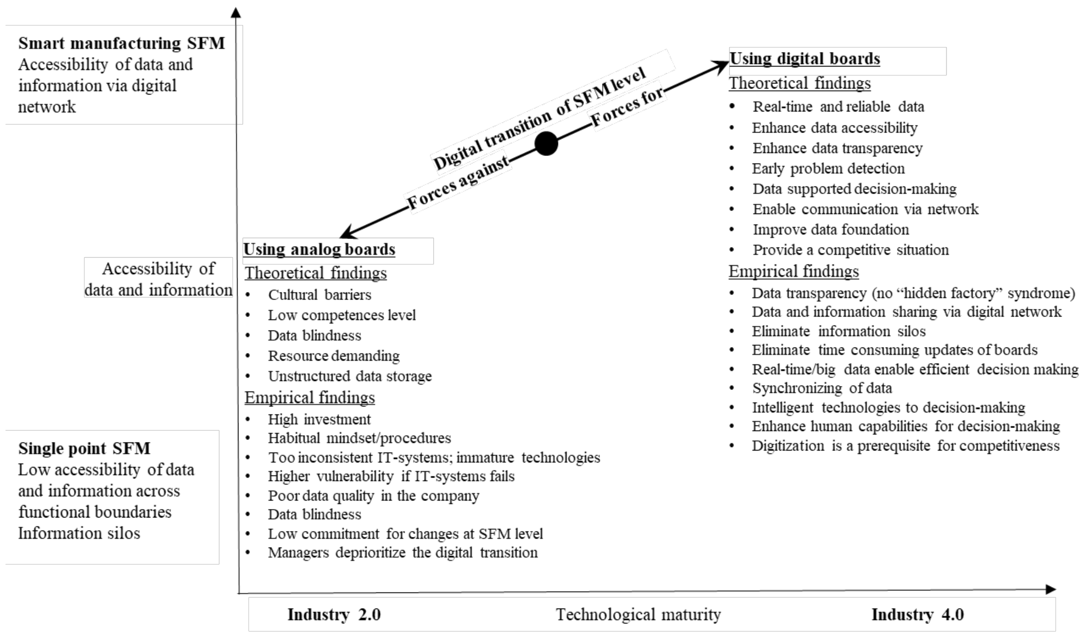

Fig. 1 Forces influencing the digital transition of the SFM level

In the middle of Fig. 1, the *forces for* using digital boards are listed in the right side, while *forces against* the digital transition of the SFM level appears at the left. The *forces against* results in the practitioners remaining in the I2.0 era and thus using analogue boards and the *forces for* result in a transition towards applying digital boards at SFM meetings. The *forces against* our findings stand out on two issues. First, the immature digital technology and minimal attention on the required data foundation if a company wants to go digital; i.e., too inconsistent IT systems and architectures, high vulnerability if IT systems fail, and poor data quality in the company. Second, the managerial approach characterized by the habitual way of doing SFM meetings; i.e., the managers deprioritize the digital transition of the SFM level, and in general, the practitioners seem to have a low commitment for changes.

The researchers addressing the technological progress claim that the practitioners witness an exponential development of digitized technologies [4], Big Data [6], and artificial intelligence [18]. If these researchers are right in their viewpoints, the necessary technologies are available to a successful transition from the analogue to digital boards at the SFM level. Accordingly, it might be reasonable to suggest that the key *forces against* the adaptation of digital boards are managerial challenges related to managing the transition process; i.e., changing the habitual way of doing SFM meeting, enhancing the practitioners' capabilities, and facilitating a higher degree of commitments among the involved practitioners. The analysis in this paper illustrates that the practitioners' capabilities, procedures, and methods used today are incapable of handling the digital transition process, mainly because the current managerial mindset is stuck to the manual processes developed in the I2.0 era, and thus not yet has been adapted to the I4.0 era.

The analysis in this paper echoes the prevalent theoretical understanding [3, 20], emphasizing that digital technologies are a prerequisite for enhancing the performance at SFM level and for being competitive in the context of smart manufacturing. Holm [11] and Yin et al. [14] highlighted that the ongoing digitalization of operations in general will result in an increasing complexity and uncertainties at the SFM level. If managers do not realize that the SFM level is stuck in a managerial mindset formed at the Toyota Production Systems around 1950, the gap between the digitalization of business and the SFM level will increase to an unmanageable level. However, to discard this habit of applying analogue boards, the practitioners at SFM face several challenges. Our findings indicate that the current managerial approach at the SFM level is characterized by the habitual attitude of mind, in terms of performing PM and CI activities. Another challenge is the immature technologies at the SFM level to enable ongoing processing, monitoring, and analyzing PM and CI data and information. This paper suggests a more reflective mindset in terms of digitalization and managerial approach at the SFM board meetings; thus, gradually bringing the smart manufacturing opportunities to the force, if not, the managers will intentionally hinder the digital transformation at the SFM level. Holm [11] agrees upon this and suggests that the practitioners at the SFM level should form self-controlled teams, and thus take a holistic approach in their work with digital technologies, with the aims of achieving a high degree of flexibility, adaptability, and initiative.

Based on the empirical findings it was identified that only one of the participating companies in the workshop had experienced some of the advantages of applying a digital SFM board. As the information about the actual experienced advantages of the digital SFM was limited (the digital board was newly implemented in the company), it is hard to establish whether the company have experienced remarkable differences in applying a digital SFM board instead of an analogue board to conduct SFM board meetings.

A prerequisite for being competitive in the future is the digital transition of shop floors [3, 19]. Accordingly, it causes wonder why the digital transition of SFM board meetings is rather slow-paced as demonstrated in our findings when the necessary technology is available. To gain an understanding of this paradox future research could address; *i*) technical prerequisites for the digital transition of SFM board meetings; *ii*) managerial prerequisites for the digital transition of SFM board meetings. In addition, our empirical findings illustrate that the practical realities at shop floor levels in companies are characterized by an I2.0 habitual way of working and the use of non-digitized SFM systems. These findings pave the way for future research to clarify; *i*) why companies are stuck in manual procedures and are still using immature technologies; *ii*) the technological readiness in companies including the necessary capabilities to enable a transition towards more advanced data analytics – i.e. descriptive-, diagnostic-, predictive- or prescriptive analytics (see Dai et al., [22]).

6 Conclusion

At the outset, this paper aimed at exploring the current and future adaptation of digital SFM boards, and the research was guided by the following research questions "*what is the current adaptation level of digital SFM board?*" and "*what forces influence a further adaptation of digital SFM boards?*".

Based on the authors' experience with implementing SFM boards, a survey was sent to 900 companies, and a Café Seminar in which 38 companies participated. We conclude the followings:

- Only very few companies has successfully accomplished a transition from analogue to digital SFM boards. In the same way, the companies lack understanding of and practical experience with digital technologies at the SFM level. Currently, the digital SFM board meetings are nearly non-existent in the companies we have analyzed.
- This study contributes to two new findings in terms of *forces for* the digital transition, which are elimination of information silos as well as elimination of time-consuming manual updates of the SFM boards. Automating the data treatment and information handling at the SFM level—collection, processing, and visualization—and eliminating information silos will enable data and information to flow easily across the boundaries, enhancing intra- and inter-organizational communication and collaboration.
- The analysis of the *forces against* a digital transition contributes to two new findings. First, the immature digital technology and unsuitable data foundation, i.e., too inconsistent IT systems, high vulnerability if IT systems fail, and poor data quality. Second, a habitual way of managing the SFM level, i.e., deprioritization of the digital transition of the SFM level and a low commitment for changes.

References

[1] Liao, Y., Deschamps, F., Loures, E. d. F. R. & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0—A systematic literature review and research agenda proposal. *International Journal of Production Research*, 3609–3629.

[2] Buer, S.-V., Strandhagen, J. O. & Chan, F. (2018). The link between Industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda. *International journal of Production Research*, (8), 1–18.

[3] Meissner, A., Müller, M., Herman, A., & Metternich, J. (2018). Digitalization as a catalyst for lean production: A learning factory approach for digital shop floor management. *Procedia Manufacturing*, pp. 81–86.

[4] Zhuang, C., Liu, J., & Xiong, H., 2018. Digital twin-based smart production management and control framework for the complex product assembly shop-floor. *The International Journal of Advanced Manufacturing Technology*, 7(2), 1149–1163.

[5] Torres, D., Pimentel, C., & Duarte, S. (2019). Shop floor management system in the context of smart manufacturing: a case study. *International Journal of Lean Six Sigma*.

[6] Zhuang, C., Liu, J., & Xiong, H. (2018). Digital twin-based smart production management and control framework for the complex product assembly shop-floor. *The International Journal of Advanced Manufacturing Technology*, *96*(1-4), 1149-1163.

[7] Syberfeldt, A., Holm, M., Danielsson, O., Wang, L., & Brewster, R. L. (2016). Support systems on the industrial shop-floors of the future–operators' perspective on augmented reality. *Procedia CIRP*, *44*, 108-113.

[8] Iuga, M. V., & Rosca, L. I. (2017). Comparison of problem solving tools in lean organizations. In *MATEC Web of Conferences* (Vol. 121, p. 02004). EDP Sciences.

[9] Fast-Berglund, Å., Harling, U., & Åkerman, M. (2016). Digitalization of meetings—from whiteboards to smart-boards. *Procedia CIRP*, 1125–1130.

[10] Mathiasen, J. B., & Clausen, P. (2019). Digitising Shop Floor Visualisation Boards: A Missing Link in the Industry 4.0 Era. In *26th ISTE International Conference on Transdisciplinary Engineering* (pp. 189-198). IOS Press.

[11] Holm, M. (2018). The future shop-floor operators, demands, requirements andinterpretations. *Journal of Manufacturing Systems*, 35–42.

[12] Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches.* s.l.:SAGE.

[13] Hertle, C., Siedelhofer, C., Metternich, J., & Eberhard, A. (2015). The next generation shop floor management—how to continuously develop competencies in manufacturing environments. *The 23rd International Conference on Production Research 2015*, pp. 1–8.

[14] Yin, Y., Stecke, K., & Li, D. (2018). The evolutionn of production systems from Industry 2.0 through Industry 4.0. *International Journal of Production Research*, 24(11), 848–861.

[15] Christopher, M. (2016). *Logistics & supply chain management*. Pearson UK

[16] Mohrman, S. A., & Winby, S. (2018). Working toward sustainable development: Consulting to the eco-system. *Research in Organizational Change and Development*, (26), 1–45.

[17] Chen, Y., & Zhu, J. (2004). Measuring Information Technology's Indirect Impact. *Information Technology and Management*, (5), 9–22.

[18] Kumari, M., & Kulkarni, M. S. (2015). A complexity based look-ahead mechanism for shop floor decision making. *Procedia CIRP 41*, 63–68.

[19] Rajan, K., & Safiotti, A. (2017). Towards a science integrated of AI and Robotics. *Artificial Intelligence* , 247.

[20] Kusiak, A. (2018). Smart manufacturing. *International Journal of Production Research*, *56*(1-2), 508-517.

[21] Kagerman, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). Securing the future german manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Final report of the Industrie 4.0 Henderson, K. (1999). *Visual Representations, Visual Culture and Computer Graphics in Design Engineering*.

[22] Dai, H. N., Wang, H., Xu, G., Wan, J., & Imran, M. (2019). Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies. *Enterprise Information Systems*, 1-25.

[23] Eaidgah, Y., Maki, A. A., Kurczewski, K., & Abdekhodaee, A. (2015). Visual management, performaance management and continuous improvement: A lean manufacturing approach. *International Journal of Six Sigma*, 6(6), 187–210.

[24] Iuga, M. V. (2017). Visual communication in lean organizations. In *MATEC Web of Conferences* (Vol. 121, p. 02005). EDP Sciences.

[25] Bateman, N., Philip, L., & Warren, H. (2009). Visual Management and Shopfloor Teams—Utilising Shopfloor Knowledge. *EUROMA*, 11.

[26] Qi, Q., Zhao, D., Liao, T. W., & Tao, F. (2018, June). Modeling of cyber-physical systems and digital twin based on edge computing, fog computing and cloud computing towards smart manufacturing. In *ASME 2018 13th International Manufacturing Science and Engineering Conference*. American Society of Mechanical Engineers Digital Collection.

[27] Johnson, G. et al. (2014). *Exploring Strategy.* 10 ed. s.l.:Pearson.

[28] Blaikie, N. (2010). *Designing Social Research.* 2 ed. s.l.:Polity Press.

[29] Consulting, H. B. (2018). *CAFÉ metoden—Resultater igennem bred involvering.* s.l.: How Biz Consulting.

Co-author statement – PAPER I

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Pernille Clausen

This declaration concerns the following article/manuscript:

Title:	Smart manufacturing through digital shop floor management boards
Authors:	Pernille Clausen, John Bang Mathiasen, Jacob Steendahl Nielsen

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: Clausen, P., Mathiasen, J. B., & Nielsen, J. S. (2020). Smart manufacturing through digital shop floor management boards. Wireless Personal Communications, 115(4), 3261-3274.

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

- A. Has essentially done all the work
- B. Major contribution
- C. Equal contribution
- D. Minor contribution
- E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	C
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	B

Signatures of the co-authors

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In case of further co-authors please attach appendix

Date: 16.08.22

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Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

PAPER II

Ready, Steady, Go! Digital Shop Floor Management Visualization Boards as a means for survival in Industry 4.0

Clausen, P.

(2022)

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Ready, Steady, Go! Digital Shop Floor Management Visualization Boards as a means for survival in Industry 4.0

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Abstract:
Purpose of the article: Under the umbrella of Industry 4.0 (I4.0), manufacturing companies have implemented various digital solutions, which have improved productivity. Shop floor management (SFM) is the core management instrument in manufacturing and is a precondition for implementing new systems. In recent decades, visual management solutions have played a significant role in handling shop floor tasks. This paper investigates the attributed role of visualization boards (VBs) to facilitate SFM in the manufacturing context of I4.0.
Design/methodology/approach: This research follows a case study approach. The research draws upon 14 cases that illustrate the use of SFM VBs in 14 international companies. The empirical material consists of observations and interviews.
Findings/results: The findings show that VBs are indispensable tools to facilitate SFM. Given the increasing amount of smart machinery on the shop floor, analog VBs provide limited functionality to communicate this information properly to the shop floor which indicate that the analog VBs are outdated.
Originality/contribution/conclusions: This study contributes to the existing literature on SFM by adding to the discussion on how the role of VBs as an SFM instrument is changing and why an increased focus on the digital transition of SFM VBs should be emphasized. Current limited prescriptive knowledge of how to implement digital SFM VB exists. Moreover, the findings reveal that manufacturing is concerned about this, as they need digital functionalities to handle shop floor tasks.
Keywords: Industry 4.0, Smart Manufacturing, Shop Floor Management, Visualization Boards, Digital Transition/Transformation
Paper type: Research paper

1.0 Introduction

"*The Fourth Industrial Revolution is still in its nascent state. But with the swift pace of change and disruption to business and society, the time to join in is now*" – *Gary Coleman*

At present, terms such as "digital factory," "Factory 4.0," and "smart manufacturing" are defining the future paradigm of the manufacturing industry, which is also known as Industry 4.0 (I4.0) (Ghobakhloo, 2018; Dai *et al.,* 2019; Flores *et al.,* 2020). With the advent of a new paradigm shift, new technologies are about to boost industrialization on all scales, which will significantly change the way production is undertaken (Torres *et al.,* 2019; Flores *et al.,* 2020; Buer *et al.,* 2021). Hence, manufacturing will become more automated, computerized, and complex to stay competitive when growing volumes, reliance on data, and predictive analytics are the focus (Kusiak, 2018).

According to Humphlett (2016) and Wang *et al.* (2020), the impact of I4.0 will be more evident at the heart of the manufacturing enterprise: the shop floor level. The shop floor level addresses where value is created and symbolizes the operational level in manufacturing (Hertle *et al.,* 2015). The implementation of intelligent shop floors is an active research topic aimed at making use of I4.0 technologies to enhance the productivity, flexibility and ergonomics of manufacturing systems (Wang *et al.*, 2020). With shop floor management (SFM) being the core management instrument in manufacturing (Pohl, 2017), it is considered a precondition for implementing new systems, processes, or procedures (Wickramasinghe and Wickramasinghe, 2017; Pohl, 2017; Torres *et al.*, 2019).

Visualization boards (VB) are fundamental technology enabled resources used to facilitate SFM in many manufacturing companies. SFM VBs contain data to make operations visible (Beynon-Davis and Lederman, 2017) with the purpose to provide shop floor practitioners the information they need to handle tasks. For that reason, one would expect that such focal tool, should adapt to the context it operates within. Hence, considering the increase in the complexity of modern production systems put forward by I4.0, VBs are likely to assume even more impact due to the contemporary digital transformation of shop floor (Torres *et al.,* 2019; Meissner et al., 2020).

However, currently it does not seem that SFM VBs has been undergoing a digital transition, given a low adaptation rate on approximately 20% (Pötters, 2018; Clausen et al., 2020), the digital transition seems nascent. It appears that practitioners are stuck with analog VBs, as they keep these analog functionalities close to heart; upon taking a walk along the shop floor, you will notice how well analog VBs are applied to facilitate SFM (Mathiasen and Clausen, 2019). However, the literature emphasizing the digital transitions on the shop floor is rather scarce concerning how the role of SFM should evolve around the smart manufacturing context. The literature does not provide practical evidence as to why digital SFM VBs is a necessity, nor prove why the current ones should be technologically outdated.

However, several conceptual papers suggest improvement for optimization via digitalization (e.g., Meissner et al., 2018), but they refrain from clarifying what functionality such digital SFM VB should provide, and how to accomplish a digital transition. For that reason, it seems relevant to seek answers of what role practitioners attribute to digital SFM VBs, to identify whether digital SFM VBs are a real need, or just a “nice illusion” enabled by I4.0 trends. Motivated by this need, this paper aims to investigate the attributed role of digital VBs to facilitate SFM in context of I4.0.

The research draws upon 14 cases that illustrate SFM VBs in 14 different manufacturing units in Denmark, all owned by international companies. With the unit of analysis on the shop floor, the cases explicate the SFM practices of applying analog and digital VBs when handling shop floor tasks. Furthermore, the cases clarify the considerations of applying digital VBs in the future. The following research question guides the study: “*What role do shop floor practitioners attribute to digital VBs in facilitating SFM?*"

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

2.0 Theoretical background

"Shop floor" is a well-used term in manufacturing, and it refers to the operational level where physical actions as producing and packing products occur (Fairris, 2002; Bauer *et al.,* 2012; Materna *et al.,* 2019). The practitioners operating on a shop floor are primarily blue-collar workers, and the tasks are accomplished by standard procedures, manual processes, and monatomic task control with limited technical support to aid in decision making (Holm, 2018; Wang *et al.*, 2020).

Following Hertle *et al*. (2015) the term SFM and its specific objectives are not clearly defined. However, it appears that the pursued goals of SFM are associated with lean manufacturing (Torres *et al*., 2019), where the underlying objectives are recognized as having an increased focus on the utilization of the full potentials of the practitioners and optimization of various performance metrics to support a swift and even production flow. The researchers that link SFM to lean manufacturing principles argue that visual management is the base of SFM (Hertle *et al*., 2015).

At the shop floor, visual tools that typically include VBs (Fast-Berglund *et al.*, 2016; Beynon-Davis and Lederman, 2017) are perceived as the fundamental tool for facilitating SFM at daily meetings (Torres *et al*., 2019). It seems that VBs (also referred to as communication boards by Bateman *et al.* (2016)), a material thing (Ewenstein and Whyte, 2009), guide the actions and social interactions of practitioners through their functionalities when conducting SFM (Bechky, 2003; Germonprez and Zigurs, 2009; Hertle *et al.*, 2015 Galsworth, 2017).

A walk around manufacturing companies reveals widespread use of VBs to facilitate everyday management and communication (Torres *et al*., 2019; Clausen *et al*., 2020). Providing the right information to the right people and in the right way in an efficient manner so that correct decisions can be made is difficult (Eaidgah *et al.,* 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 (Eaidgah *et al*., 2016; Beynon-Davis and Lederman, 2017) by exposing problems and enabling improvement when making decisions (Leseure *et al.,* 2010; 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 decision making is highly influenced by the functionalities of VBs. 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 practitioners. 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 visualization board 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 (Bell *et al.*, 2013; Bateman *et al.*, 2016; 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 (Imai, 1997; Liker and Meier, 2006; Parry and Turner, 2006; Bateman *et al.*, 2016).

The VB has been developed by lean practitioners and applied as communication tools to assess management effectiveness for many years (Parry and 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 (e.g., performance management boards (*KPI boards*), planning 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 and 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 *et al.*, 2009; Hertle *et al.*, 2015: Eaidgah *et al.,* 2016). However, following 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 frame SFM meetings in production (Eaidgah *et al.*, 2016; Meissner *et al.*, 2018). In other words, the role of SFM VBs is to serve as a communication tool, as they link the constituents of the SFM practice (Hertle *et al.,* 2015).

An urgent SFM task is to deal with unplanned events before they gradually spread and exacerbate a situation (Zhang *et al.*, 2011; Torres *et al.,* 2019). For instance, having access to performance 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. For that reason, ideally, VBs should enable a fast, responsive SFM practice where data is visualized in real time across the manufacturing floor. The VBs should also provide an opportunity to conduct advanced analytics to support the decision-making process.

The ability to solve 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 information at the shop floor seems to be a demand for the future. 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 (Wickramasinghe and Wickramasinghe, 2016; Iuga and Rosca, 2017; Li *et al.,* 2019). Thus, it is important to provide the information they need and in real time (Flores *et al*., 2020).

2.1 Digital SFM visualization boards

The increase in the complexity of modern production systems put forward by I4.0 has put new demands on the SFM practice (Wang *et al.*, 2020) and led to the need for proper communication of information to support practitioner cognition at the shop floor (Li *et al.*, 2017). 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 at team practices on the shop floor (Tezel *et al*., 2016).

Considering that there is an abundance of new information technologies, manufacturing should embrace these opportunities to simplify information sharing among the shop floor practitioners (Li *et al.,* 2019). Hence, from an evolutionary perspective, convergence is inevitable for SFM (Torres *et al.,* 2019), as the shop floor is the basic manufacturing unit. For that reason, it becomes imperative (Tao and Zhang, 2017).

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 SFM VBs consist of hardware, such as a computer or TV screen, that visualizes BI software that illustrates various performance measures (Fast-Berglund *et al.*, 2016). Due to the rapid development within this area, the customization within these products increases, making the solutions appealing for more companies. Some of the most applied BI tools applied for data visualization to support SFM are Looker, InetSoft, Microsoft Power BI, Tableau, Datapine, Oracle BW, and SAP HANA (Haije, 2019; Aston, 2021). The use of digital solutions provides opportunities to conduct advanced analytics of production data to enhance operational decision making (Buer *et al.,* 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 (Zhuang *et al.*, 2018; Meissner *et al.*, 2020; Buer *et al.,* 2021). Nevertheless, currently, the application of digital VBs does not seem to be widespread on the shop floor (Li *et al.*, 2017; Clausen *et al.*, 2020). In general, the digital transformation in manufacturing companies 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 of handling information technologies at the SFM level.

A study performed by Clausen *et al.* (2020) reveals some of the forces *agains*t 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 contributes to leaving practitioners behind digital development. 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 amount of manual procedures by a digital transformation of their equipment. In other words, the traditional analog VBs used for SFM are considered potential targets for digitization and digitalization (Lorenz *et al.*, 2019; Meissner *et al.*, 2020).

3.0 Research design and setting

The research herein draws on a case study approach. The study follows the Dubois and Gaddes (2002) abductive approach to case studies, where an empirical understanding is developed while exploring the theoretical concepts of the subject through a narrative literature review. This ongoing iteration between theory and empirical data seems appropriate, as it paves the way to move between the data collected from the case study 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.

3.1 Narrative literature review

The narrative literature review follows the third type of narrative literature review by Baumeister and Leary (1997) and has the goal of shedding light on the background, functionalities and role of SFM VBs. The review findings provide insights into what is currently known about this phenomenon to support the knowledge base of the author when investigating the topic in the case study companies. However, the intention of the review is not to offer novel ideas, new interpretations, or sweeping conclusions; thus, the theoretical contribution by conducting the review is minimal (Baumeister and Leary, 1997).

The following four steps guided the literature review. First, *a preliminary search* was performed. This search was driven by grounded theory principles (Charmaz, 2020), where the theoretical explanation of the SFM practice was derived from an empirical exploration (Ketokevi and Choi, 2014). The search was guided by the current understanding of SFM of the author, and the topic and objective of the overview being written were refined. The preliminary investigation includes unstructured interviews and observations of SFM meetings in four companies conducted in Fall 2018 and Spring 2019. Second, *a keyword selection* was made*;* the keywords to guide the literature search were chosen based on the terms related to the investigated topic discovered through the preliminary search. Third *a database search* was carried out. All databases for peer-reviewed articles connected to the University subscriptions to scientific search databases were applied. The following keywords (both in individual and combined searches) guided the main search: *Industry 4.0, shop floor management, visualization boards, digital visualization boards, shop floor decision making, performance management,* and *continuous improvement.* Fourth, *a sorting* of unrelated or irrelevant articles was done. Two processes structured the sorting process: *i)* title and abstract skimming and *ii)* a review of the introduction. If the title and abstract appeared relevant for the topic, the introduction section was reviewed; if not, the article was eliminated. In total, approximately 40 out of 100+ articles were included and applied to develop the theory section in this paper.

3.2 Case studies

The research question was studied in 14 global manufacturing companies, all with a location in Denmark. The criterion developed by Stake (2000) for selecting cases through a formal sampling was applied as an attempt 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 14 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.* 2020). 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, 14 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 *et al.,* 1994). It did not seem necessary to expand the data collection after finishing the data collection for the 14 case study companies, as no new data was being unearthed; it is believed that theoretical saturation was achieved (Strauss and Corbin, 1998).

The empirical data collection consisted of semi-structured interviews (Bryman and Bell, 2011) and observations of SFM meetings that included various types of VBs, and the data was collected in Fall 2019 and in Spring 2020. 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 the narrative literature review. To refine the data collection, a pilot case study was conducted (Yin, 2014). The pilot case was selected to be run in a company where it was possible to observe different SFM meetings applying different types of VBs. The pilot case strived for strong conditions to understand the SFM practice of applying VBs to handle shop floor tasks.

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, continues 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. To ensure a trustworthy and an ethical approach, all the notes were discussed with the informants being interviewed. These aligned notes were used to draw up the minutes.

Table I shows the industries, company sizes, number of SFM meetings observed, and number of conducted interviews in each of the 14 manufacturing companies. To ensure anonymity, the companies are designated as Company 1, Company 2, Company 3, and so on.

Company	Industry	Size (employees in total)	SFM meetings observed	Interviews
1	Industrial chemistry	32000	3	3
2	Meat processing	26000	3	2
3	Renewable Energy	23000	4	3
4	Pump solutions	19300	3	3
5	Skylights	10000	2	2
6	Tobacco	7600	1	1
7	Plastic pipe systems and solutions	5000	3	1
8	Smart metering solutions for energy and water	1300	1	2
9	Advanced mission critical solutions	1250	1	1
10	Iron casting	1100	2	2
11	Cutting tools	700	1	1
12	Bolts	200	2	1
13	Fish processing	140	1	1
14	Acoustic panels	100	1	1

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

3.3 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 narrative literature review (Merriam, 1998). The process of making meaning follows a pattern-matching analysis (Sinkovics, 2018), in which the empirical data from the 14 manufacturing companies was analyzed through comparable patterns. The analysis was divided into two stages. *In the first stage*, analog VBs were applied to highlight their role in facilitating SFM. *In the second stage*, a display for structuring the collected data was drawn up. The display identified different experiences in applying analog and digital VBs to facilitate SFM. Juxtaposing the empirical data with the theoretical conceptualization of applying VBs made it possible to develop a deeper understanding of the role of SFM VBs in the context of I4.0.

4.0 Empirical findings and analysis

4.1 Application of visualization boards to facilitate SFM

Observations of SFM meetings and semi-structured interviews were conducted in 14 manufacturing companies, which made up the empirical foundation for the inquiring logic applied in this study. In general, each SFM meeting took 10-20 minutes on average. If practitioners took notes, they were either recorded on A4 paper or written directly on the analog whiteboard by hand. Table II presents an overview of whether analog or digital SFM VBs were applied in the 14 companies and whether the companies consider applying digital VBs in the future.

Company	Analog VBs	Digital VBs	Consider applying digital VBs
1	Yes	Yes	Yes
2	Yes	No	Yes
3	Yes	Yes	Yes
4	Yes	Yes	Yes

5	Yes	No	Yes
6	Yes	No	Yes
7	Yes	No	Yes
8	Yes	No	Yes
9	Yes	No	Yes
10	Yes	No	Yes
11	Yes	No	No
12	Yes	No	Yes
13	Yes	No	No
14	Yes	No	No

Table II. Overview of the application of analog and/or digital SFM VBs at the 14 case study companies.

4.1.1 Application of analog SFM visualization boards

As shown in Table II, all 14 companies applied analog VBs to manage SFM meetings and handle related tasks, including a discussion of key performance indicators, coordination, and 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 some companies, the boards were applied more than once per day (e.g., having team shifts or the production set-up requires frequent performance monitoring and controlling).

The role of analog SFM VBs to facilitate SFM in the 14 companies shared many similarities. For that reason, it was possible to create a generalized picture that illustrates the role of analog VBs based on the conducted observations and interviews, as shown in Figure 1.

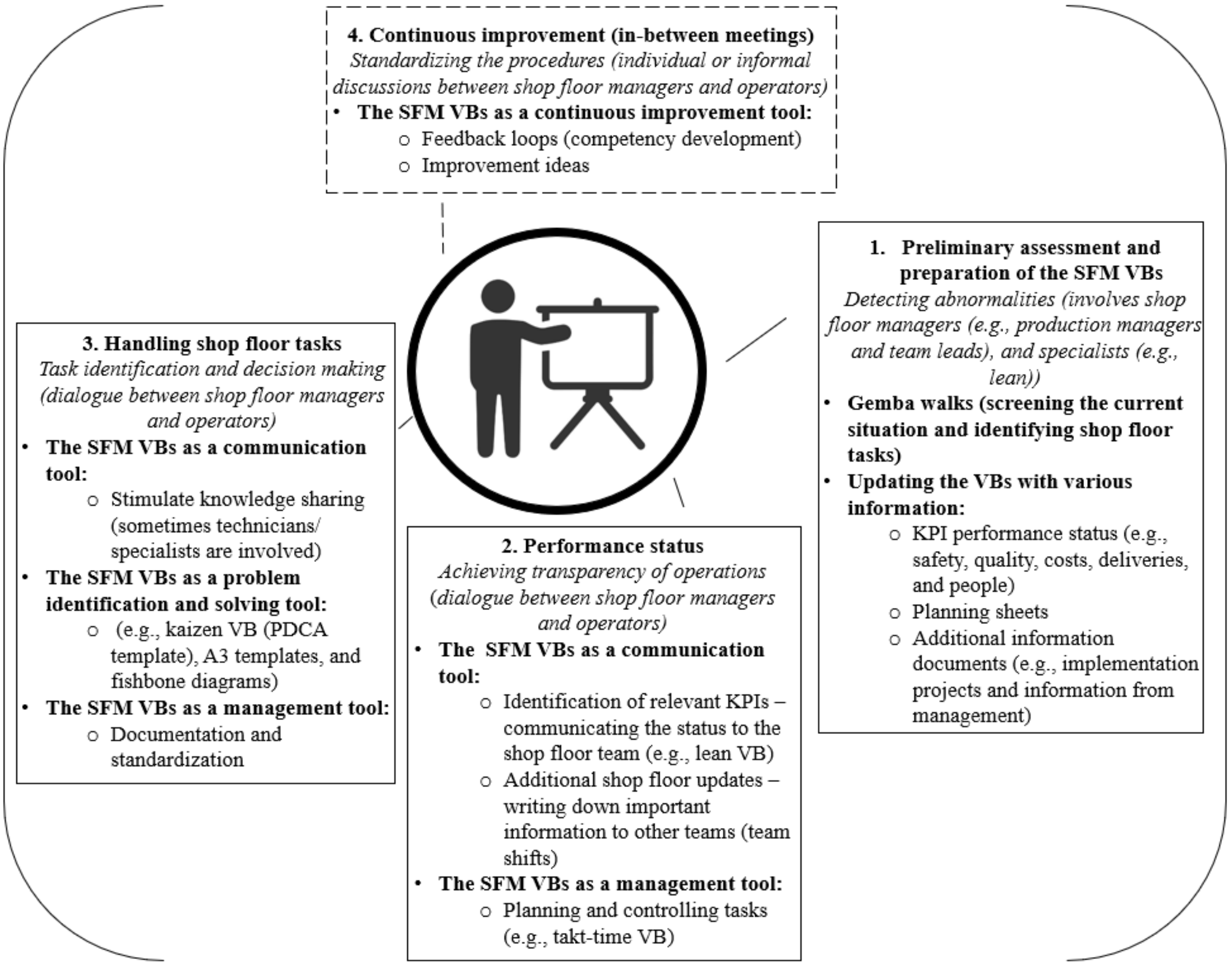

Figure 1. *The role of analog VBs to support SFM based on observations and interview data.*

As illustrated in Figure 1, analog VBs played a central role in facilitating SFM. The VBs were involved in the pre-planning of SFM meetings, as shown in stage 1; communicating the performance status, as shown in stage 2; handling shop floor tasks, as shown in stage 3; and being a part of the non-formal space enabling continuous improvement, as shown in stage 4. To complete all stages, more than one kind of SFM VB was typically applied. Some companies went through stages 2-4 as a standardized routine for completing the SFM meeting. In contrast, others applied the additional VBs (problem-solving VBs and continuous improvement VBs) when needed. For that reason, they were not necessarily a part of the standardized routine of completing SFM meetings. Many companies had the applied VBs located in the same area, called a war room by many companies. 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).

The type of SFM meeting and VB applied to support the meeting depended on the production set-up of each company. SFM meetings were held for several reasons in the case study companies. For instance, all case study companies applied performance management VBs (lean VBs) to conduct "a general" performance status of the main KPIs, as illustrated in stage 2. However, some companies supplemented the performance status meeting by having additional SFM meetings and applying takt time VBs to go through other performance parameters than the KPIs. These meetings were held on premises other than those for the lean

VB performance status meeting because they might involve different shop floor practitioners, and the time duration may differ as well.

In general, conducting SFM meetings and having the right tools available (e.g., VBs) to support the practice is very important to monitor and control the shop floor and support the managerial tasks related to the shop floor at a higher organizational level. Hence, the outcome from the SFM meetings is communicated across shop floor units and at the top plant level on additional daily or weekly held meetings.

In general, all 14 companies expressed that having physical meetings stimulates a good social working environment, as the meetings constitute a social event where it is possible to meet colleagues across the shop floor. Based on the observations, applying analog VBs enables flexibility during meetings, as quick drawings and visual illustrations made by hand often seem to ease the communication among the involved practitioners and provide a structure through the “power of the pen” syndrome.

However, the use of analog VBs can present several limitations. Based on interviews with shop floor practitioners involved in the SFM meetings, Table III present the view of applying analog VB to facilitate SFM.

The view of applying analog VBs to facilitate SFM
• The physical meeting around the VB stimulates a good working environment. • It is labor-intensive to ensure that analog “paper-based” VBs are updated. • Retrieving data for manual printouts to attach to the analog boards requires access to several different IT systems. • Information is only available for a limited time, as printouts and handwritten notes on boards are discarded when the board is updated for the next meeting. • There is limited information sharing across the production shop floor, as people need to physically attend the meeting to receive the update. • There is low reliability of the data, as manually updated data and data not collected in real time negatively affect the decision-making process (decisions are made on the basis of outdated data). • It is a waste of time, because evaluating outdated performance data is not effective. • It provides flexibility during meetings (quick drawings made by hand ease the communication (“the power of the pen” syndrome).

Table III. *The view of applying analog VBs to facilitate SFM*

4.1.2 Application of digital SFM visualization boards

Table II reveals that only companies 1, 3, and 4 applied digital VBs to facilitate SFM. The digital VBs, technically, drew on Microsoft Power BI and VBA software. The physical appearance of the digital VBs in these three companies were a mirror image of the analog VBs, but the accessibility of the information was improved. Companies 1 and 3 invested substantial resources in SFM digitalization by developing solutions that interfaced with their SAP ERP systems by implementing Microsoft Azure SQL databases and allowed accessibility of data across the shop floor. All three companies are 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 applied analog VBs, as they, from a technological perspective, were not ready to deal with all types of decision-making situations based solely on the digital VBs. However, the target is to replace all analog boards within a five-year timeframe.

The three companies implemented digital VBs in 2017, 2018, and 2019. At the outset, the objectives were to:

- 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).

The use of digital VBs in companies 1, 3, and 4 did not fulfill the objectives mentioned above. All three companies reduced the time spent on preparing for SFM meetings. Furthermore, the digital boards created awareness among the shop floor practitioners, which resulted in a welcoming of the new boards. Increased curiosity made several practitioners explore the new opportunities by applying Power BI or VBA software to conduct SFM.

All three companies were able to facilitate decision making across the shop floor via the digital VBs. However, they only experienced a limited increase in performing decision making, as they did not have full access to data. Applying digital VBs seems 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 need to be in real time for solving resource allocation problems, the digital VBs do not seem sufficient in their current state.

Nevertheless, companies 1, 3, and 4 were confident that they will accomplish the above-listed objectives, as the functionalities a digital SFM VB can provide are necessary to gain full control of shop floor operations. Practically, all three companies mentioned that they felt limited by their immature and inconsistent IT infrastructure to move forward, which should be placed in order first.

4.1.3 Application of digital SFM visualization boards in the future

Although digital SFM VBs are only applied in companies 1, 3, and 4, all companies, besides 11, 13, and 14, 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. Table IV summarize the empirical findings of the drivers of transitioning towards 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. • 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 decision making and problem solving through real-time data and more advanced analytics. • Participate in SFM VB meetings remotely. • Develop skills (more responsibility on the shop floor). • Become proactive to minimize disturbances (variation) using data and analytics.

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

4.2 The role of SFM visualization boards

Following the empirical material, the role of SFM VBs is expressed through the functionalities of the VB. As shown in Figure I, the overall role of a VB is to be a communication tool that can release different functionalities, depending on its form (e.g., a lean board, takt time board, or Kaizen board). Hence, the limitations of the VB functionalities depend on its analog or digital functionalities.

Most of the companies applied analog VBs to facilitate SFM. Despite analog VBs being prone to several disadvantages (e.g., it is labor intensive to update the boards, data and information is outdated, and there is limited information- and knowledge-sharing across the shop floor), the VBs are essential for the social aspect of conducting SFM. It seems the physical presence of the boards 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 trust in the meeting technique, such as the "power of the pen," to provide structure and communication.

Approximately 79% of the case study companies expressed that the current functionalities within the analog SFM VBs are insufficient to support the decision making when handling shop floor tasks. For that reason, they all have a digital transition of their SFM practice on their agenda. Not having access to data in real time via the analog VBs does not provide the practitioners the necessary insight when handling shop floor tasks, as they rely on outdated data. Hence, a digital VB is expected to release more functionalities.

However, although the analog 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 boards have gained high material value and symbolize the SFM practice. Besides being a material object, it seems that VBs play a central role in facilitating SFM when guiding the social interactions; hence, VBs are considered an indispensable tool. A shop floor manager from company 1 declare: "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 the above statement, it appears that the analog VB functionalities will not remain sufficient due to the increasing complexity on the shop floor. 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. 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, 21% of the case study companies already initiated a digital transition of the analog VB. The digital SFM VBs for these companies are characterized by a 1:1 conversion of the analog VB. The digital version did not provide any intelligent functionalities, such as visualizing data in real time or offering advanced analytical capabilities. However, they were beneficial in reducing the preparation time and making information available across the shop floor. Furthermore, the digital VBs proved efficient when dealing with simple tasks, such as identifying failure trends through enhanced visualization features and direct access to data files.

The current state of the digital transition of the VBs does not mirror the expectations set out by the companies. Due to several barriers, the companies could not develop a solution that met their requirements. Several managers claimed that they had participated in various seminars, workshops, and fairs regarding the topic, but not sufficient guidelines were available. This seemed to be a concern for several companies. Those three companies taking part in the digital transition mention that they are still focused on taking the digital transition of SFM VBs further; first, they need to get their foundation right. Despite the challenges, completing the digital transition of the VBs is still an urgent goal for the companies, as they label the transition necessary to stay competitive.

5.0 Discussion

The empirical findings state that a digital transformation of SFM is a precondition for staying competitive in the future; this viewpoint aligns with those in academia (Mrugalska and Wyrwicka, 2017; Kusiak, 2018, Buer *et al.,* 2021). However, currently, SFM is facilitated through manual means, meaning that shop floor tasks, such as conducting performance updates, eliminating problems, and identifying root causes (Liker and Meier, 2006; Leseure *et al.,* 2010; Wickramasinghe and Wickramasinghe, 2016), are handled by applying analog VBs. Both the empirical and theoretical findings claim that the digital transition of SFM VBs is somewhat limited, as it only has been initiated by a few companies (Li *et al.*, 2017; Clausen *et al.*, 2020; Meissner *et al.*, 2020).

VBs are considered a potential target for a digital transition (Meissner *et al.*, 2020), as several technological possibilities for connectivity and visualization are available to support its development (Lorenz *et al.*, 2019). Moreover, following Fast-Berglund *et al.* (2016), a digital transition of VBs paves the way for filtering the vast amount of production data and thereby gaining the full benefit of the exponential development of digital technologies (see Tao *et al.* (2018)). Based on technology management literature, digital transformation initiatives on the shop floor seem to be straightforward, particularly if companies solely lean on the technological aspects (Tao *et al.*, 2018; Zhuang *et al.*, 2018; Dai *et al.*, 2019).

However, completing a digital transition of SFM VBs does not seem to be an easy task to accomplish. Following the empirical material, several practicalities have challenged the companies based on immature and inconsistent IT infrastructures. Neither of the companies gained the desired outcome from the results of converting their analog SFM VBs to a digital version. Despite the challenges, the companies plan to move forward with their desire to complete a total digital transition of the VBs. The potential of doing so seems to be necessary if the shop floor must comply with increasing complexity (Wang *et al.*, 2020). Given the industrial rethinking represented by I4.0, manufacturing needs to recognize that the shop floor is an information-intensive environment facing dynamically changing demands (Holm, 2018). In an I4.0 SFM practice, all kinds of decision making are purely handled by technologies, as implicitly proposed by Dai *et al.* (2019). Manufacturing is expected to comply with the "life-cycle of big data," as suggested by Dai *et al.* (2019), as access to reliable data will enable the development of digital VBs.

However, it appears clear that manufacturing recognizes the need to apply real-time and reliable data to support the SFM practice. For that reason, they are not giving up the digital transition of the SFM VBs, as they are expected to release new and necessary functionalities. Having data available and in real time makes it possible to conduct advanced analytics (Wang *et al.*, 2020). Hence, advanced information technologies will allow the practitioners to process data intelligently, providing the opportunity to react to unpredictable events rapidly with minimal resource costs (Lorenz *et al.*, 2019; Buer *et al.*, 2021), when handling tasks.

6.0 Limitations

Although this study addressed the role of digital VBs to facilitate SFM in the context of I4.0 and contributes to the theoretical and practical understanding to this topic, the employed method has limitations. Interviews and observations were accomplished at 14 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 many observations of shop floor activities and interviews from the case descriptions might negatively influence the credibility of the study. The proportion of companies that adopted digital VBs in the case selection might seem somewhat limited. To enhance reliability, more cases applying digital VBs could have been included in the study.

7.0 Conclusions

At the outset, this paper aimed to investigate the role of VBs to facilitate 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 digital VBs in facilitating SFM*?"

Based on a narrative literature review followed by a case study with 14 manufacturing companies, the following can be concluded: SFM VBs seem to be an indispensable tool with multiple functionalities. VBs play a central role in facilitating operations on the shop floor through various visual means. VBs are a communication tool, releasing different functionalities depending on their form and purpose on the shop floor. Hence, limitations of VB functionalities depend on their analog or digital capabilities.

The findings illustrate that a digital transition of the SFM VBs is on the manufacturing agenda despite low technological capabilities characterized by immature data foundations and complex IT infrastructures. Currently, few companies have accomplished a transition from analog to digital SFM VBs. However, digital VBs are considered to play a more significant role in the context of the I4.0 agenda on the shop floor, as it is believed that they will release functionalities that make it possible to comply with increasing complexity.

However, a digital transition of SFM was not prioritized by all companies enrolled in the study. A minority were not pursuing a digital transition of SFM VBs in any regard, as they did not see the potential. Hence, these companies were satisfied with the current functionalities of analog VBs.

Although most companies were considering a digital transition of SFM VBs, the objectives within this transition fluctuated. Some target a simple digital transition (e.g., a 1:1 conversion of the analog to a digital version). In contrast, others targeted a complete digital **transformation** followed by the functionalities "the lifecycle of big data" can release. Although the findings indicate that analog VBs seem to be part of the future shop floor, a digital transition seems inevitable.

References

Abercrombie, N. (1984). Hill, s.-turner, bs. *The Dictionary of Sociology*., R. K., (2014). “Case study research: Design and methods”, 5th ed. *SAGE Publications, Inc.*

Aston, B. (2021), “10 Best Business Intelligence Tools (BI Tools) of 2021”, available at: https://thedigitalprojectmanager.com/business-intelligence-tools/ (accessed 10 April 2021).

Bateman, N., Philp, L., & Warrender, H. (2016). “Visual management and shop floor teams–development, implementation and use”. *International Journal of Production Research*, Vol. 54, No. 24, pp. 7345-7358.

Baumeister, R. F., & Leary, M. R. (1997). “Writing narrative literature reviews”. *Review of general psychology*, Vol. 1, No. 3, pp. 311-320.

Bauer, A., Browne, J., Bowden, R., & Duggan, J. (2012). “Shop floor control systems: from design to implementation*”. Springer Science & Business Media*.

Bechky, B.A. (2003), “Sharing meaning across occupational communities: the transformation of understanding on a production floor”. Organization Science, Vol, 3, pp. 312–330.

Bell, E., J. Schroeder, and S. Warren, ed. 2013. “The Routledge Companion to Visual Organization”. *London and New York: Routledge.*

Beynon-Davies, P., & Lederman, R. (2017). “Making sense of visual management through affordance theory”. *Production Planning & Control*, Vol. 28, No.2, pp. 142-157.

Bryman, A., and Bell, E., (2011). “Ethics in business research”. *Business Research Methods*, Vol 2, pp. 23-56.

Buer, S.-V., Strandhagen, J.W., Semini, M. and Strandhagen, J.O. (2021), "The digitalization of manufacturing: investigating the impact of production environment and company size", *Journal of Manufacturing Technology Management*, Vol. 32 No. 3, pp. 621-645.

Charmaz, K. (2020) Grounded Theory – main characteristics in Järvinen, M. & Mik-Meyer, N. (eds) *Qualitative Analysis: Eight approaches for the social sciences. London: Sage.*

Clausen, P., Mathiasen, J. B., & Nielsen, J. S. (2020). „Smart Manufacturing Through Digital Shop Floor Management Boards”. *Wireless Personal Communications*, Vol. 115, pp. 3261-3274.

Dai, H. N., Wang, H., Xu, G., Wan, J., & Imran, M. (2020). “Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies”. *Enterprise Information Systems*, Vol. 14, No. 9-10, pp. 1279-1303.

Dubois, A., and Gadde, L.-E., (2002).” Systematic combining: An abductive approach to case research”. *Journal of Business Research*, Vol. 2, pp. 553-560.

Eaidgah, Y., Maki, A. A., Kurczewski, K., & Abdekhodaee, A. (2016). “Visual management, performance management and continuous improvement: a lean manufacturing approach”. *International Journal of Lean Six Sigma*, Vol 7, No 2, pp. 187-210.

Ewenstein, B., Whyte, J. (2009), “Knowledge practices in design: the role of visual representations as ‘epistemic objects’”, *Organization Studies*, Vol. 30, No. 1, pp. 7–30.

Fairris, D. (2002). “Shopfloor Matters: Labor-Management Relations in 20th Century American Manufacturing*”,Routledge*, Vol 5.

Fast-Berglund, Å., Harlin, U., & Åkerman, M. (2016). “Digitalisation of meetings–from white-boards to smart-boards”. *Procedia CIRP*, Vol. 41, pp. 1125-1130.

Flores, E., Xu, X., & Lu, Y. (2020). “Human Capital 4.0: a workforce competence typology for Industry 4.0”. *Journal of Manufacturing Technology Management*, Vol. *31*, No. 4, pp. 687-703.

Galsworth, G. D. (2017). “Visual Workplace Visual Thinking: Creating Enterprise Excellence Through the Technologies of the Visual Workplace”. *Productivity Press.*

Gary Coleman**,** *Global Industry and Senior Client Advisor*, Deloitte Consulting, 202, available at: https://www.automationalley.com/articles/7-inspirational-quotes-on-industry-4-0 (accessed 10 August 2021).

Germonprez, M., & Zigurs, I. (2009). “Task, technology, and tailoring in communicative action: An in depth analysis of group communication”. *Information and organization*, Vol. 19, No. 1, pp. 22-46.

Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", *Journal of Manufacturing Technology Management*, Vol. 29 No. 6, pp. 910-936.

Haije, E. G. (2019), “Top 15 Business Intelligence Tools: An Overwiev”, available at: https://mopinion.com/business-intelligence-bi-tools-overview/ (accessed 10 April 2021).

Hertle, C., Siedelhofer, C., Metternich, J., & Abele, E. (2015). “The next generation shop floor management–how to continuously develop competencies in manufacturing environments”. *The 23rd International Conference on Production Research.*

Holm, M. (2018). “The future shop-floor operators, demands, requirements and interpretations”. *Journal of manufacturing systems*, Vol. 47, pp. 35-42.

Holmström, J., Holweg, M., Lawson, B., Pil, F. K., Wagner, S. M. (2019). The digitalization of operations and supply chain management: Theoretical and methodological implications. *Journal of Operations Management*, Vol. 65, No. 8, pp. 728-734.

Humphlett, M. (2016), “Operations how will digitalization impact personnel on the manufacturing shop floor?”, *Industry Week.*

Imai, M. 1997. “Gemba Kaizen. A Commonsense, Low-cost Approach to Management”. *London: McGraw Hill.*

Iuga, M. V. (2017). “Visual communication in lean organizations”. In *MATEC web of conferences*, Vol. 121, p. 02005. *EDP Sciences*.

Iuga, M. V., & Rosca, L. I. (2017). “Comparison of problem solving tools in lean organizations”. In *MATEC Web of Conferences*, Vol. 121, *EDP Sciences*.

Jwo, J. S., Lin, C. S., Lee, C. H. (2021) Smart technology–driven aspects for human-in-the-loop smart manufacturing. *The International Journal of Advanced Manufacturing Technology*, Vol. 114, No. 5, pp. 1741-1752.

Ketokivi, M., & Choi, T. (2014). “Renaissance of case research as a scientific method”. *Journal of Operations Management*, Vol. 32, No. 5, pp. 232-240.

Kumari, M., & Kulkarni, M. S. (2016). ”A complexity based look-ahead mechanism for shop floor decision making”. *Procedia CIRP*, Vol. 41, pp. 63-68.

Kusiak, A. (2018). “Smart manufacturing”. *International Journal of Production Research*, Vol. 56, No.1-2, pp. 508-517.

Leseure, M., Hudson-Smith, M., & Radnor, Z. (2010). “Transferring Lean into government”. *Journal of Manufacturing Technology Management*.

Li, D., Fast-Berglund, Å., & Paulin, D. (2019). „Current and future Industry 4.0 capabilities for information and knowledge sharing.” *The International Journal of Advanced Manufacturing Technology,* Vol. 105, No 9, pp. 3951-3963.

Li, D., Fast-Berglund, Å., Dean, A., & Ruud, L. (2017). “Digitalization of whiteboard for work task allocation to support information sharing between operators and supervisor”. *IFAC-PapersOnLine*, Vol. 50, No. 1, pp. 13044-13051.

Liker, J. K., & Meier, D. (2006), “The Toyota Way Fieldbook; A Practical Guide for Implementing Toyota's 4P's”. *Bok-McGraw-Hill Professional*.

Lorenz, R., Powell, D., & Netland, T. H. (2019). “Exploring the effect of digitalizing shop floor management”. In *26th Annual EurOMA Conference: Operations adding value to society (EurOMA 2019)*.

Materna, L., Hinrichsen, S., Adrian, B., & Schulz, A. “HOW TO IMPROVE SHOP FLOOR MANAGEMENT”. *Direct Digital Manufacturing in the Context of Industry 4,* pp. 179-188.

Mathiasen, J. B., & Clausen, P. (2019). “Digitising Shop Floor Visualisation Boards: A Missing Link in the Industry 4.0 Era”. In *26th ISTE International Conference on Transdisciplinary Engineering*, pp. 189-198. *IOS Press.*

Meissner, A., Grunert, F., & Metternich, J. (2020). „Digital shop floor management: A target state”. *Procedia CIRP*, Vol. *93*, pp. 311-315.

Meissner, A., Müller, M., Hermann, A., & Metternich, J. (2018). “Digitalization as a catalyst for lean production: A learning factory approach for digital shop floor management”. *Procedia Manufacturing*, Vol.*23*, pp. 81-86.

Merriam, S. B. (1998). "Qualitative Research and Case Study Applications in Education". Revised and Expanded from" Case Study Research in Education". Jossey-Bass Publishers, 350 Sansome St, San Francisco, CA 94104.

Mortenson, M. J., Doherty, N. F., & Robinson, S. (2015). "Operational research from Taylorism to Terabytes: A research agenda for the analytics age". *European Journal of Operational Research*, Vol. 241, No.3, pp. 583-595.

Mrugalska, B., & Wyrwicka, M. K. (2017). "Towards lean production in industry 4.0". *Procedia Engineering*, Vol. 182, pp. 466-473.

Parry, G. C., & Turner, C. E. (2006). Application of lean visual process management tools. *Production planning & control*, Vol. 17, No. 1, pp. 77-86.

Nicolini, D. (2012). "Practice theory, work, and organization: An introduction". *OUP Oxford.*

Pohl, J. (2017), "Digital shop floor management the backbone of the smart factory", Inside the Smart Factory: How the Internet of Things Is Transforming Manufacturing, ROI Management Consultants, p. 8.

Pötters, P., Schindler, P., & Leyendecker, B. (2018). Status quo Shopfloor Management. *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, 113(7-8), 522-525.

Sinkovics, N. (2018). "Pattern matching in qualitative analysis". *The sage handbook of qualitative business and management research methods*, pp. 468-485.

Stake, R. E., (2000). "The case study method in social inquiry". In R. Gomm, M. Hammersley, and P. Foster (eds.), *Case Study Method: Key Issues, Key Texts*, pp. 19-26. *London, SAGE Publications.*

Strauss, A., & Corbin, J. (1998). "Basics of qualitative research techniques". *Thousand oaks, CA: Sage publications.*

Tao, F., & Zhang, M. (2017). "Digital twin shop-floor: a new shop-floor paradigm towards smart manufacturing". *Ieee Access*, Vol. *5*, pp. 20418-20427.

Tezel, A., Koskela, L., & Tzortzopoulos, P. (2009). The functions of visual management.

Tezel, A., Koskela, L., & Tzortzopoulos, P. (2016). Visual management in production management: a literature synthesis. *Journal of manufacturing technology management*, 27(6), 766-799.

Torres, D., Pimentel, C., & Duarte, S. (2019). "Shop floor management system in the context of smart manufacturing: a case study". *International Journal of Lean Six Sigma.* Vol. 11, No. 5, pp. 837-862.

Zhang, Y., Xu, J., Sun, S., & Yang, T. (2015). "Real-time information driven intelligent navigation method of assembly station in unpaced lines". *Computers & Industrial Engineering*, Vol. 84, pp. 91-100.

Zhuang, C., Liu, J., & Xiong, H. (2018). "Digital twin-based smart production management and control framework for the complex product assembly shop-floor". *The International Journal of Advanced Manufacturing Technology*, Vol. 96, No. 1-4, pp. 1149-1163.

Yin, R.K., (2014). "Case Study Research Design and Methods (5th ed.)" .*Thousand Oaks, CA: Sage.*

Wang, X., Yew, A. W. W., Ong, S. K., & Nee, A. Y. (2020). "Enhancing smart shop floor management with ubiquitous augmented reality". *International Journal of Production Research*, Vol. 58 No.8, pp. 2352-2367.

Wickramasinghe, G.L.D. and Wickramasinghe, V. (2017), "Implementation of lean production practices and manufacturing performance: The role of lean duration", *Journal of Manufacturing Technology Management*, Vol. 28 No. 4, pp. 531-550.

Wickramasinghe, V. and Wickramasinghe, G.L.D. (2016), "Variable pay and job performance of shop-floor workers in lean production", *Journal of Manufacturing Technology Management*, Vol. 27 No. 2, pp. 287-311.

PAPER II

PAPER III

Chasing digitalized visualization boards: Achieving fit between visualization boards and shop floor tasks

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Chasing digitalized visualization boards: Achieving fit between visualization boards and shop floor tasks

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Abstract
Visualization boards (VB), essential technology-enabled operations management resources, are used in many manufacturing companies. VBs are likely to gain even more impact due to the contemporary digital transformation of shop floors. Automated and computerized equipment combined with sensors and artificial intelligence systems create tons of data and facilitate new functionalities for VBs. With data increasingly becoming pivotal, an empirical study of the functionalities of current and emerging VBs for handling shop floor tasks is warranted. This intervention-based research consists of two exploratory phases: a cross-case study of two companies followed by a longitudinal study within a third company. Both phases use Task-Technology-Fit theory, first to explore the fit/misfit between current VB-shop floor tasks and second to explore prerequisites for tailoring shop floor VBs to the context of smart manufacturing. By combining operations management (OM) research dealing with the usability of VBs with technology management (TM) research on the digitalization of shop floors, the paper asserts the following. Although current VBs afford valuable functionalities, some are still lacking. Four prerequisites for providing all of the needed functionalities are frontend development of user-friendly interfaces, backend development to enhance interoperability, backend development to enable automation of data life cycles, and the ability to transcend OM and TM knowledge boundaries.
Keywords: Intervention-based research, Functionality of visualization boards, Shop floor tasks, Smart manufacturing, Task-Technology-Fit.

1.0 Introduction

This intervention-based research (IBR) addresses the field problem of tailoring shop floor visualization boards (VB) to the context of smart manufacturing. Shop floor VBs contain data to make work actions visible (Beynon-Davis and Lederman, 2017). The functionalities of VBs are to provide a visual abstraction about the physical reality on the shop floor that have sufficient representational capacity to fit the practitioners' handling of day-to-day shop floor tasks (Bateman et al., 2016). Automation and computerization of manufacturing equipment and information technologies (Kusiak, 2018) enhance the acquisition and storage of data (Dai et al., 2019). With data increasingly becoming the focal point in handling tasks (Jwo et al., 2021), an empirical study of the functionalities of current and emerging VBs for handling shop floor tasks is warranted.

When embarking on this IBR study, we realized that the prevalent operations management (OM) research and technology management (TM) research of smart manufacturing shop floors is both fragmented and a world apart from physical reality. We, the authors, noticed that some companies still attach printouts such as Excel/Word documents manually on whiteboards. Such VBs depict analog representations. OM researchers are advocating for the functionalities of

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such analog VBs to highlight the power of the pen (Bateman et al., 2016), that is, to use non-digitized VBs rather than software-based systems (Fullerton et al., 2014), provide easy-to-understand information (Parry and Turner, 2006), and recognize the importance of having brief meetings (Liker and Meier, 2006).

A stream of TM researchers has examined challenges due to the functionalities of analog VBs (Zhang et al., 2017; Dai et al., 2019; Jwo et al., 2021). The challenges with analog VBs arise mainly because these VBs only depict historical data, and they do not enable cross-boundary worker interaction. Indeed, Cagliano et al. (2019) and Cimini et al. (2020) indicated that handling tasks in smart manufacturing often necessitates cross-boundary worker interaction, which motivates a need for the new functionalities in emerging shop floor VBs. In our involvement with practitioners, we noticed that the few VBs which displayed digital representations on an interactive screen, via the use of PowerBI and Microsoft Azure SQL database, afforded cross-boundary worker interaction. However, the functionalities provided by such VBs seem problematic because automated and computerized manufacturing equipment generates big, reliable, and real-time data (Kusiak, 2018). This, in combination with emerging machine learning and artificial intelligence systems (Rajan and Safiotti, 2017), will open up new possibilities for visualizing digital representations to practitioners involved in handling tasks (Jwo et al., 2021).

Our IBR commences with a few assertions. TM researchers (Zhang et al., 2017; Dai et al., 2019) contribute valuable knowledge about the advantages of data-driven analytics and prescribe a smooth digital transition. By contrast, OM researchers (Torres et al., 2019) concentrate on the usability of VBs, but they refrain from explicating the extent of the digital transition. Thus, are the current VBs technologically outdated systems, as asserted above? Or do the current VBs displaying digital representations via PowerBI and Microsoft Azure SQL databases offer adequate functionality to handle tasks in a smart manufacturing context (Dai et al., 2019)? These questions lead us to form a working hypothesis (Peirce, 1878; Dewey, 1938), stating that "*the current functionality of VBs is inadequate to handle shop floor tasks*."

The study has a dual purpose: first, we hope to verify whether our working hypothesis is plausible, and second, we hope to explore prerequisites for achieving a fit between the functionalities of VBs and contemporary shop floor tasks. To fulfill this dual purpose, we draw on Task-Technology-Fit (TTF) theory (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998). Fit is equivalent to the functionality of VBs that allows practitioners to handle tasks. This study verifies the working hypothesis and explores the research question "*what are the prerequisites for achieving fit between VBs and contemporary shop floor tasks?*" in three manufacturing companies, designated Alpha, Bravo, and Charlie in this paper. The study consists of exploratory research to transform the functionalities of current VBs into the desired state, fulfilling Alpha's managerial requirements, followed by explanatory research to elaborate theories (Holmström et al., 2009). Before the exploratory IBR within Alpha, we conducted an exploratory case study within Bravo and Charlie to verify our working hypothesis, gain valuable knowledge supporting our involvement in the IBR within Alpha, and enhance the generalizability of our findings.

Our study subscribes to the stream of OM researchers who conceptualizes smart manufacturing as a sociotechnical configuration (Van Aken et al., 2016; Cagliano et al., 2019). Hence, in such a context, fit depends on whether a VB has sufficient representational capacity to guide practitioners' task handling. Yet, the digital representations displayed on VBs are only the tip of the iceberg; what is below the tip has a pivotal influence on the functionalities of VBs. To cope with that, this study suggests drawing on Holmström et al. (2019) to distinguish between digitized VBs and digitalized VBs. Only digitalized VBs operate with a profound encapsulation of digital technologies in the data treatment process (Dai et al., 2019) and enable interoperability (Golzarpoor et al., 2018) to provide functionalities to visualize and utilize the real-time nature and predictive power of data (Qi et al., 2021).

This paper contributes in several ways to the theoretical discussion about the interplay between the digital transformation of shop floors and the usability of VBs. First, we demonstrate that current VBs displaying analog representations are still applicable, but essential functionalities are missing, and VBs displaying digital representations provide some of the demanded contemporary functionalities. Second, we explain that current VBs lack functionalities to display real-time and reliable data and carry out advanced analytics. Third, the paper illustrates the importance of combing OM knowledge and TM knowledge with practical knowledge and elaborates that the consequences of keeping OM knowledge apart from TM knowledge are the intervention of a not yet operational digitalized VB. Fourth, we suggest four prerequisites for digitalizing VBs: (i) frontend development of an adaptable layout on interactive VB screens and user-friendly interfaces ensuring data capture, (ii) backend development enhancing interoperability, (iii) backend development enabling automation of the data life cycle, and (iv) engineering-OM transfer necessitates the ability to transcend knowledge boundaries; to transfer is either to translate knowledge or transform knowledge.

In the following, we present the theoretical background, including our conceptualization of the applied TTF approach, followed by methodological considerations. Then, we present an explorative case study within Bravo and Charlie to verify the working hypothesis and an account of the explorative IBR within Alpha to clarify the prerequisites for achieving fit, including a field test and evaluation. Lastly, the explanatory part of the study and conclusions are presented.

2.0 Tailoring shop floor VB to the context of smart manufacturing and task-technology-fit

The digital turn of the manufacturing shop floor is prompting OM researchers (cf. Torres et al., 2019) and TM researchers (cf. Zhang et al., 2017) to explore the functionalities of current and emerging VBs. However, we did not find any empirical research that describes how to tailor shop floor VBs to the context of smart manufacturing. Accordingly, in our theoretical positioning and conceptualization of smart manufacturing shop floor VBs, we appreciate Van Aken et al.'s (2016) work on engineering-OM transfer to handle field problems, which involves both OM knowledge and TM knowledge.

2.1. Definitions and current VBs

A VB is a technological device to display data, which provides functionalities to guide handling tasks at the shop floor level (Fullerton et al., 2014). A shop floor is a constellation of resources such as manufacturing equipment, materials, practitioners, and flows of data and information (Holm, 2018). In automated and computerized shop floors, data exists at manufacturing equipment and material levels, and relevant data and information are exchanged with the surroundings (Kusiak, 2018). This data, in the form of representations displayed on VBs, supports practitioners in maintaining an uninterrupted flow of materials (Schmenner and Swink, 1998). VBs provide functionalities to accomplish various shop floor tasks such as performance management (PM), continuous improvement (CI), and takt-time compliance tasks (Wang et al., 2020).

A study of aerospace companies shows that analog VBs are instrumental in coordinating and prioritizing daily shop floor tasks (Parry and Turner, 2006). In a study of 244 U.S. manufacturing companies, Fullerton et al. (2014) showed that analog VBs are valuable for achieving shared understanding across professional disciplines, in particular, for identifying and responding to performance-related tasks. Bateman et al. (2016) illustrated that analog VBs enhance team communication and problem-solving tasks in a British manufacturing company. The work of Beynon-Davis and Lederman (2017), studying the accomplishment of operational tasks within healthcare, clothing, and software creation, reminds us that VBs may inform practitioners differently. In a conceptual paper, Zhang et al. (2015) designed a digital system to visualize real-time information to control and navigate an unpaced asynchronous assembly line. A case study performed by Torres et al. (2019), demonstrated the benefits of applying real-time digital visualization tools to handle tasks.

However, according to Meissner et al. (2020), around 82 % of manufacturing companies use analog VBs, indicating that the application of digitized VBs is still nascent. Digitized VBs are available. These digitized VBs help mirror the operational reality and handle tasks across professional boundaries. In a study of a university hospital implementing Lean principles of workflow visualization, Hultin and Mähring (2014) illustrated the benefits of applying digitized VBs, first for handling planning tasks and later on for handling PM tasks. Østerlie and Monteiro (2020) study the application of digitized VBs to detect sand in the offshore oil and gas sector. They show that useful representations to accomplish PM tasks combine real data and algorithmic data manipulation. Clausen et al. (2020) studied shop floor management in Danish manufacturing companies and revealed that only a few companies applied digitized VBs (as Meissner et al., 2020). Their usefulness is mainly in handling tasks related to daily manufacturing and coordination across shop floor teams.

The provided functionality of VBs depends on physical and technological characteristics, interfaces (Fichman and Kemerer, 1993), and the extent of digital encapsulation (Holmström et al., 2019). Improving functionality requires engineers to accomplish both frontend and backend development (Ganev, 2017). Frontend development involves what users can see, i.e., the graphic interface(s) displaying digital representations. Backend development entails hardware and software engineers working on databases, backend logic, application programming interfaces (API), servers, and sensors for automated data treatment (Dai et al., 2019) and interoperability (Golzarpoor et al., 2018).

This study draws on TTF theory to study the usability of current and emerging VBs (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998). Other OM studies have applied the TTF theory to examine the fit between technological systems and specific tasks (Bendoly and Cotteleer, 2008; Browning, 2010; Cagliano et al., 2019). Following clarification of shop floor tasks and the functionalities of VBs, the applied TTF framework is elaborated.

2.2. Shop floor tasks

The OM literature (e.g., Graves, 1981; Stoop and Wiers, 1996) distinguishes between scheduling tasks, such as planning activities before releasing orders for production, and rescheduling tasks, such as controlling and coping with variations and unplanned events. As our study focuses on shop floor tasks after releasing orders for manufacturing, our narrative literature review (Bryman and Bell, 2007) of OM papers addresses the controlling activities (Slack and Brandon-Jones, 2019).

A precise definition of shop floor tasks does not exist (Wang et al., 2020). In smart manufacturing, shop floor tasks revolve around ensuring fast deliveries, safe workplaces, high quality, and high-performance levels, including low-process variation (Ji and Wang, 2017). This categorization of shop floor tasks has much in common with the work of Schmenner and Swink, (1998), who highlighted the importance of maintaining an uninterrupted, swift, and even flow of materials. Based on Schmenner and Swink (1998), Ji and Wang (2017), and our interaction with the field, this study operates with three categories of shop floor tasks, which are PM tasks, CI tasks, and takt-time compliance tasks.

2.3. Functionality of Visualization Boards

Some TTF researchers focus on technology as a tool for the individual (Goodhue and Thompson, 1995; Browning, 2010), while others address technology as a tool for social interaction (Zigurs and Buckland, 1998; Cagliano et al., 2019). Drawing on Paiva et al. (2008), knowledge is individualized, but a practitioner's embodiment of knowledge also involves social interactions (Blumer, 1969). Knowledge sharing unfolds as a process of social interactions in which practitioners have "reflective conversations" (Schön, 1983) with the visualized data provided by the functionality of the VB.

Several professional disciplines are often involved in the "reflective conversation". This entails that the conversations when handling tasks are anchored in the belief and commitment of each practitioner (Paiva et al., 2008). For that reason, each practitioner can have a different understanding of the visualized data (Beynon-Davis and Lederman, 2017), and they might have different intentions (Mathiasen, 2017). Generally, in the context of automated and computerized manufacturing, the handling of shop floor tasks involves a team of practitioners having different disciplinary affiliations and knowledge (Cimini et al., 2020), for instance, blue-collar workers, technicians, engineers, software-/hardware specialists, and managers. By acknowledging the interdisciplinary nature of handling tasks and the embodiment of knowledge, an applicable VB provides functionalities that enable social interaction and knowledge sharing.

Zigurs and Buckland's (1998) taxonomy of the different types of fit consists of three functionalities: a communication tool, a structuring tool, and an information processing tool, which in a combined way enables a group to accomplish tasks. In a study of TTF in complex projects, Browning (2010) argued that a manager's handling of tasks depends on what he/she can see and understand. The substance (technological characteristics) of the functionalities are different process models. A process model contains information about a process, and thus it is defined as an abstract representation of reality. Our study draws on the prior work of Zigurs and Buckland (1998) and Browning (2010) to define the functionality of VBs as a tool having sufficient representational capacity to facilitate: (i) communication within and/or across shop floor boundaries, (ii) structure in terms of accomplishing shop floor tasks, and (iii) information processing related to accessing and manipulating information.

2.4. The examination of fit – TTF framework

TTF theory (Goodhue and Thompson, 1995; Zigurs and Buckland, 1998; Browning, 2010) assumes that the achievement of fit affects practitioners' performance. Visualization of data affects both practitioners' performance (Fullerton et al., 2014) and knowledge creation (Bateman et al., 2016). While data are facts, information is generated via processed data, whereas knowledge is personalized information and related to actions (Paiva et al., 2008). Action (here, handling of shop floor tasks), knowledge creation, and social interactions go hand in hand (Blumer, 1969; Schön, 1983). Regardless of whether data are big, reliable, or real-time, data depicted on VBs only fit task handling if data are converted into information, information into visual meaning, and visual meaning into common knowledge among involved practitioners. Thus, this study links performance to the ability to handle tasks knowledgeably.

The applied TTF framework appears in Figure 1. The left part of Figure 1 divides shop floor tasks into PM, CI, and takt-time compliance. Likewise, VBs provide communication-, structure-, and information processing functionality. The rhombus in the middle of Figure 1 illustrates how the study conceptualizes the functionality of a VB as a tool to enable embodiment of knowledge, social interaction, and knowledge sharing when handling tasks. To clarify fit/misfit situations, we follow the principles of pragmatism (Dewey, 1938) which entail a focus on actions and the outcome of actions.

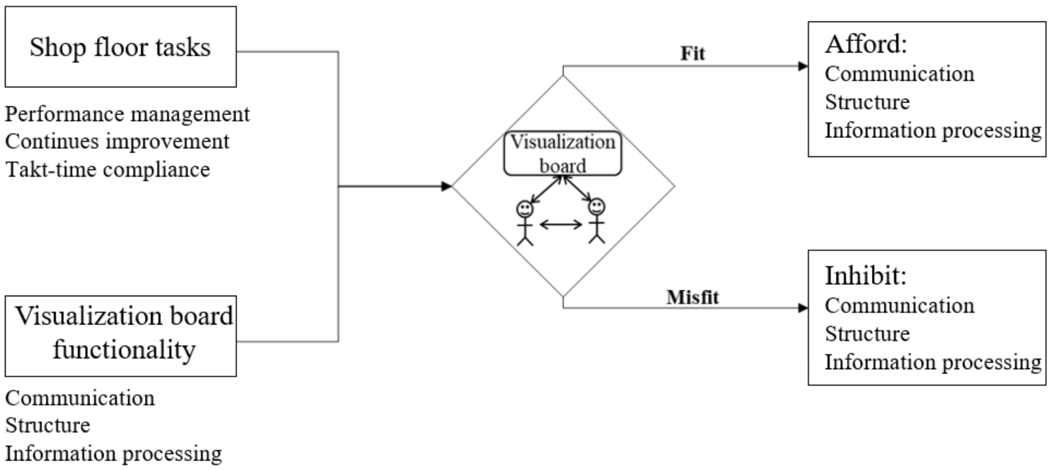

Figure 1 Task-Technology-Fit Framework.

For example, fit equals the following: (i) communication functionality provides cross-boundary interaction, (ii) structure functionality helps practitioners to comply with standard operating procedures, and (iii) information processing functionality allows practitioners to conduct trend analyses. For example, a misfit occurs if (i) communication functionality inhibits practitioners from monitoring variations between planned progress and actual progress, (ii) structure functionality inhibits practitioners from tailoring the displayed content to handle a situational problem, and (iii) information processing functionality inhibits practitioners from accessing real-time data.

3.0. Methodological considerations

Before embarking on this study, we visited 16 manufacturing companies. All 16 companies used analog VBs to facilitate the handling of shop floor tasks. Only Alpha, Bravo, and Charlie also used digitized VBs. Alpha had decided to design and implement a digitalized takt-time VB.

Alpha involved us in the intervention of digitalized takt-time VBs in April 2020. We both struggled with implementing solution proposals from OM theories and TM theories and faced an ill-structured problem in relation to the transition from analog visualization to digital visualization. IBR is a useful OM research approach (Chandrasekaran et al., 2020) to handle ill-structured problems in a systematic manner (Van Aken et al., 2016) when solution proposals emerging from prevalent theories contradict the practitioners' understanding of the problem and potential solutions (Oliva, 2019).

3.1. Research design and settings

In compliance with IBR (cf. Oliva, 2019) and our desire to elaborate theories (Ketokivi and Choi, 2014), this study draws on abduction (Peirce, 1878; Dewey, 1938; Niiniluoto, 1993). Abduction involved an ongoing process of empirical observations within the aforementioned three companies and theoretical reflections on OM theories and TM theories. Subscribing to abduction entails that empirical data are never given, but they are taken, and theoretical reflections are not directly derived from data (Ketokivi and Choi, 2014). Hence, just like other OM researchers, our observations and reflections are influenced by a priori constructs (Barratt et al., 2011; Caniato et al. 2018).

This study operates with three a priori constructs: (i) a working hypothesis "*The current functionality of VBs is inadequate to handle shop floor tasks*", (ii) the representational capacity of VB functions as a tool for communicating, structuring, and information processing, and (iii) fit means that the provided functionality affords actions, misfit means that the provided functionality inhibits actions. We are conscious that these prior constructs influence both our observations of empirical data and theoretical reflections.

To take heed of the duality criterion (Ketokivi and Choi, 2014) and thus reduce the likelihood of idiosyncratic findings, we "*carry [our] hypotheses lightly and [we are] willing to drop heavy tools in order to become more agile theorist…*" (Weick, 2002:15). Thus, throughout the study, our constructs are malleable, revised, rejected, or accepted as the "*best explanation*" to observed facts (Niiniluoto, 1999:442). This study seeks the best explanation by drawing on abductive logic involving theoretical reflections on our constructs and empirical observations and analyses.

The study explores the working hypothesis and the research question in Alpha, Bravo, and Charlie. While the intervention of the digitalized takt-time VB took place within Alpha, operating with unpaced manufacturing lines (see Maccarthy and Fernandes, 2000), we accomplished a cross-case study of Bravo and Charlie. The purpose of the cross-case study was to gain a profound knowledge base from companies with similar problem settings (as Kaipia et al., 2017) before the IBR within Alpha and to enhance the generalizability of the findings. The criteria for selecting Bravo and Charlie draw on Stake's (2000) opportunity to learn from instrumental cases rather than conducting a comparative study: (i) as aforementioned, only Bravo and Charlie use digital visualization of shop floor data, (ii) they operate within similar problem settings, (iii) the manufacturing setup differs, which has a positive effect on reinforcing the generalizability of our findings; Bravo applies paced manufacturing lines and Charlie operates with process manufacturing (see Maccarthy and Fernandes, 2000), and (iv) Bravo and Charlie represent large corporations like Alpha, and they have shown interest and proactiveness in terms of digitizing shop floor VBs. We expect these criteria to give a broader base of observations and thus reduce the risk of contextual idiosyncrasies (Ketokivi and Choi, 2014).

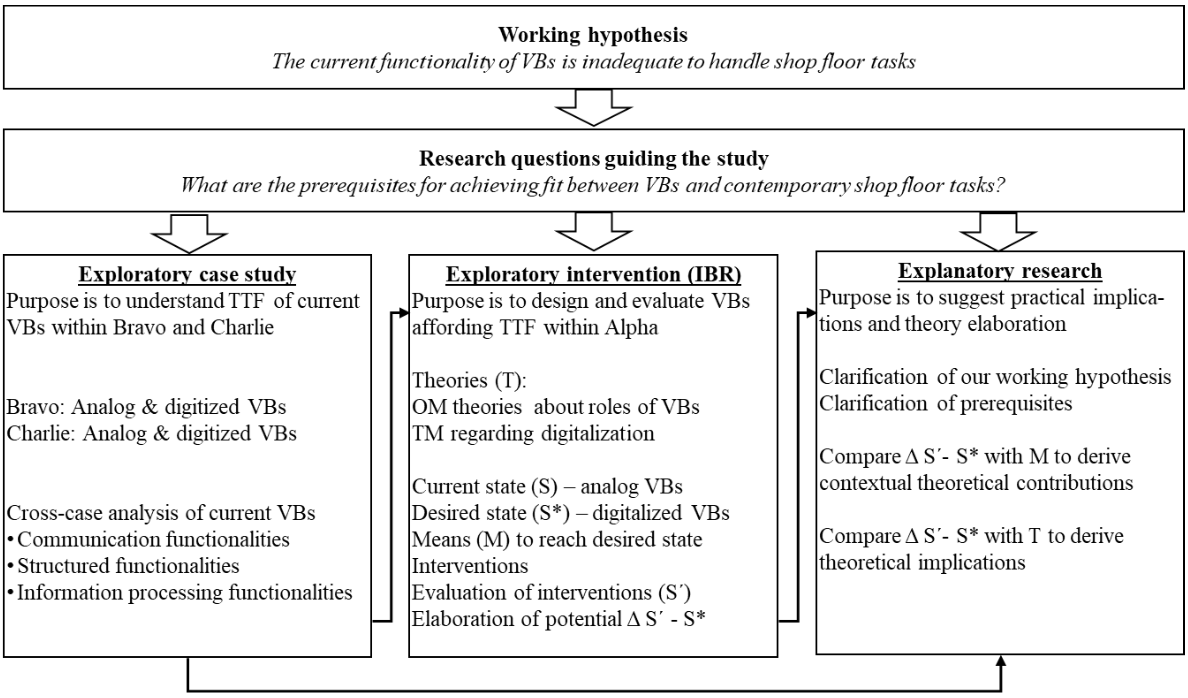

Figure 2. Research design in this study.

Figure 2 divides the study into exploratory research, to transform the current state into the desired state, and explanatory research, with the purpose of elaborating theories (Holmström et al., 2009). The exploratory research focuses on exploring the fit and misfit between shop floor tasks and the functionalities of VBs. An appropriate methodology to explore an empirical phenomenon within its natural context, and, in particular, to inquire about a phenomenon that is still in its infancy in companies (Ketokivi and Choi, 2014) is an explorative case study (Sousa and Voss, 2002; Caniato et al., 2018). Hence, prior to the exploratory IBR within Alpha, we conducted an exploratory case study to understand the current TTF within Bravo and Charlie. We expected that the knowledge gained would be valuable for active involvement in the exploratory IBR phase, and we also hoped that the findings from the exploratory case study would fuel the explanatory research. In the following, the paper elaborates the exploratory case study, then the exploratory IBR, and finally the explanatory research.

3.2. Exploratory case study within Bravo and Charlie

The data collection consisted of three observations of shop floor meetings in both Bravo and Charlie, a complete observer, and three semi-structured interviews in both companies (Bryman and Bell, 2007). The unit of observation was shop floor meetings, and on average, the observations lasted an hour and a half. We took notes simultaneously because there was not an opportunity to record meetings. Each semi-structured interview lasted an average of 30 minutes and involved managers, coordinators, and specialists/technicians because we assumed their experience of shop floor tasks differed. Notes were taken simultaneously by all authors since we were not allowed to record the interviews. Notes were compared immediately after each observation and interview, and these aligned notes were later used to draw up minutes.

The aforementioned a priori constructs facilitated the preparation of an observation scheme and an interview guide. In line with the notion of being empirically disciplined (Ketokivi and Choi, 2014), the observation scheme and interview guide were gradually modified. We commenced the data collection by observing shop floor meetings and noted the number of participants, their dialog and body language, the managerial approach, the use of and role of analog and/or digitized VBs to handle tasks, including the extent of cross-discipline interaction, characteristics of the meeting including physical settings and level of engagement, issues being discussed, and other meeting details. Immediately after the observations, the semi-structured interviews were accomplished. These interviews drew on the interview guide and the authors' observations during the meetings. All observations, interview notes, and applied quotes were discussed with the informant in question to enhance trustworthiness. Please note that, in general, the informants spoke Danish during observations/interviews, meaning that empirical quotes are the authors' word-to-word translations.

The analysis is qualitative in nature, rather than analyzing TTF in terms of amount, intensity, or frequency (Ketokivi and Choi, 2014). The unit of analysis is the extent to which the functionality of VBs helps or inhibits practitioners in converting representations into meaning and action. As we, OM researchers, are incapable of studying embodied mental processes, for instance, practitioners' cognition, the analysis focuses on the consequences of practitioners' actions (cf. Dewey, 1938).

First, the TTF framework (see Figure 1) guided axial coding. A line-by-line coding of observations and interviews combined with our literature review established an overview of the nexus between the use of analog VBs and digitized VBs to handle shop floor tasks. Second, selective coding formed the basis for a thematic cross-case analysis which revolved around the extent to which communication, structure, and information processing functionalities of analog VBs and digitized VBs caused fit/misfit situations. To clarify fit/misfit situations, we did a line-by-line coding: fit if the VB provides the needed functionality, misfit if the VB does not provide the needed functionality. In addition to exposing functional differences between analog VBs and digitized VBs, the cross-case analysis enhanced our understanding of the functionalities lacking in the current VBs. We used the knowledge gained from the cross-case analysis to enhance our and Alpha's awareness of prerequisites for designing takt-time VBs affording real-time monitoring of an unpaced manufacturing line. The following section elaborates on the IBR approach within Alpha.

3.3. Exploratory intervention-based research within Alpha

IBR is neither an isolated event nor a single action. Our involvement in this longitudinal intervention study should therefore be considered to be a series of actions. Past actions and the future dimension of actions influence our present actions (see Hernes and Schultz, 2020). Past actions take form as our conceptualization of OM theories and TM theories, our contextual embeddedness within Alpha, and the actual progress of the intervention. The future dimension embraces Alpha´s desire to design and implement takt-time VBs and our desire to elaborate theories by combining OM research dealing with usability of VBs with TM research on digitalizing shop floors.

Drawing on Oliva (2019) and Chandrasekaran et al. (2020), the series of actions accomplished during the IBR enable a gradual transformation from analog VBs, the current state (**S**), to digitalized VBs, the desired state (**S***). To explore the gradual transformation from **S** to **S*,** this study draws on the "means-end relation" (Simon, 1988; Holmström et al., 2009). Every time we accomplish IBR actions, the means '*enter into the means-consequence relationship and in doing so take on added meaning*' (Dewey 1933, 233). Means acquire meaning when we are using them to enable the gradual transformation towards the "end", the desired state **S***. The means (**M**) to transform **S** into **S*** are the individuals' interpretation of the desired state, the reciprocity between contextual knowledge gained from our ongoing collaboration with Alpha, and the applied basket of OM theories and TM theories (**T**). OM theories address the functionalities of VBs and shop floor tasks, and TM theories deal with the digital transformation of manufacturing. As it will appear from the evaluation of the field tests, the invention did not successfully transform the current state (**S**) into the desired state (**S***), but the intervention arrived at the actual state ($\mathbf{S}^{\prime\mathbf{Int}}$).

The engagement with Alpha appears in Table 1. It shows our involvement in exploration of the current state, the desired state, the transition towards the desired state, and finally, evaluation of the actual state. Alpha allowed one of the authors to sit in the open plan office and have 24/7 access to manufacturing facilities. This provided us with an outstanding opportunity to follow and be proactive in the intervention. Please notice that the international composition of the project team combined with the Covid-19 pandemic necessitated some online activities.

Exploration of current state **S**	Exploration of desired state **S*** and transition towards **S***	Exploration of actual state **S'**
Observations of takt-time shop floor meetings: •14 online •10 on-site **Informal unstructured interviews:** •10+ face-to-face **Semi-structured interviews:** • 5 online • 6 face-to-face **Presentations:** •2 online presentations with the purpose of agreeing upon current state **Current state report:** •Draw up a current state report •Hand in the report May 2020	**Informal unstructured interviews:** •20+ face-to-face **Semi-structured interviews:** •15 online •7 face-to-face **Active participations in workshops:** •4 online; inputs to solutions •1 on-site; inputs to solutions **Project meetings- international:** •30+ online; status and coordination •3 online; presenting solution proposals **Report** •Proposed framework for solution •Technical web-based solution enabling interoperability	**Observations of takt-time shop floor meetings:** •2 online •4 on-site **Semi-structured interviews:** •3 online •4 face-to-face **Project meetings - international:** •2 online; planning field test and minor redesign of implemented solution **Actual state report and presentation** •Draw up evaluation report, June 2021 •Draw up evaluation report, January 2022 •1 on-site presentation of field test evaluation •1 online presentation of field test evaluation

Table 1. Timeline for involvement in the IBR, from April 2020 to January 2022.

3.4. Explanatory research

The foundation of the explanatory phase was the intervention journey within Alpha, yet the cross-case study of Bravo and Charlie was instrumental in supporting a generalization of these findings. The intention was to learn from the two explorative phases rather than searching for similarities and differences. The evaluation of the designed takt-time VBs showed that the actual state of the first intervention (S'^{Int-1}) was workable, and thus it is still in use within Alpha. The actual state (S'^{Int-2}) for the second intervention proved to be unmanageable for the shop floor workers. This unexpected outcome triggered us to reopen the *means-end relation* and thus put a laser-like focus on the gap between the actual and desired state (Oliva, 2019; Chandrasekaran et al., 2020).

This gap caused two different *means-end analyses* even though insights from the two analyses might overlap (Oliva, 2019). The first *means-end analysis* deals with the use of and ongoing contextual adaptations of means (M) to elaborate generalizable context-dependent theories. More specifically, we reflected upon the consequences and the extent to which the practitioners' understanding of the problem and potential solutions contradicted prevalent theories. The second means-end analysis forefronts the use of theories (T) that support elaboration of the generalizable cross-context theory. Our reflections address why we as researchers (and practitioners) struggle with combining theories about the usability of VBs to handle shop floor tasks and theories concerning the digital transformation of manufacturing companies.

4.0. Exploratory phase 1: case study

This section presents the current use of VBs in Bravo and Charlie and a cross-case analysis.

4.1 The current use of VBs within Bravo and Charlie

Bravo and Charlie have many years of experience in applying analog VBs. Recently, the companies implemented digitized VBs. Table 2 present an overview of Bravo and Charlie.

Company	Manufacturing	Shop floor meeting	Participants
Bravo produces pump solutions	Paced product-line layout	Daily, last around 10 minutes	Blue-collar workers, departmental & team managers, specialists, & technicians
Charlie produces industrial chemicals	Process layout	Daily, last around 15 minutes	Blue-collar workers, lean manager, team managers, & different specialists/technicians.

Table 2. Overview of Bravo and Charlie.

<u>Bravo's</u> daily shop floor meetings were standardized. They took place within the production area, and the team manager leading the meeting used both PM and CI VBs. Bravo's PM VBs displayed bar charts, Pareto diagrams, and data related to safety, quality, delivery, employees, and production equipment. These were used to identify trends, conduct quick and dirty analyses, and handle simple issues. Shop floor tasks requiring either the involvement of specialists/technicians or root-cause analyses were added to the CI VBs and labeled with a yellow or red color depending on the consequence of the issue. Bravo's CI VB consisted of several whiteboards and displayed two templates, one for Plan-Do-Check-Act and one for root-cause analyses. Yellow issues were handled by the shop floor team afterward, often by involving other specialists/technicians. Red issues required prompt action and were often handed over to another department.

Bravo's transition from analog to digitized VBs started in 2019. The managers involved declared "*an urgent need for accomplishing more detailed root-cause analyses …. both internal and external managers/specialists/technicians should have online access to performance data…. around six to eight hours are spent daily on updating analog VBs ….*

several VBs are used to display a great many physical printouts, resulting in too many back-and-forth discussions".

The building blocks for Bravo's digitized PM VBs used the Microsoft SQL database, Power BI, and Excel, eliminated several feral IT systems, and made sweeping changes to the IT architecture, including software solutions. The CI VB was an interactive screen. The content displayed was identical to the analog CI VB. Digitized PM VBs displayed real-time data, but with a delay of 30 minutes. At Bravo, 80 % of the displayed data was automatically generated. Manual updates of the remaining 20 % of the data and a 30-minute delay were due to the complex application architecture.

Charlie accomplished daily shop floor meetings and used both PM VBs and CI VBs. The PM VBs displayed bar charts and diagrams, which provided an overview of the current performance status in terms of quality, environment (people), safety, cost, and delivery. Charlie added all identified issues to the CI VBs to create awareness of the problem(s) and document how the problem was solved. Tasks handled immediately were also added to document problem-solution relations. Tasks not handled right away were put on standby for a while. These tasks were afterward handled via the use of the A3 approach; others required the involvement of internal/external specialists/ technicians and more detailed analysis. Furthermore, the VBs displayed the fishbone method and different Pareto diagrams.

Charlie started the digitization of both types of VBs in 2017. According to the Lean manager, the motivation for digitizing the VBs was "*to improve the documentation such as "what was the problem and how did we solve the problem".... we spend much time on discussing this, and often we are incapable of finding this information …updating the analog VBs is resource-demanding*".

The digitized PM VBs drew on a Microsoft VBA solution and Excel. The displayed representations were equivalent to the analog PM VB. Because Charlie has a complex application architecture, the digitized PM VBs did not display real-time data. The digitized CI VBs were basically an interactive screen. Besides offering the same functionalities as analog VBs, the digitized CI VBs enabled practitioners to save all kinds of notes and drawings made on the interactive screen. According to the Lean manager, digitized VBs improved practitioners' access to data, flexibility in terms of accomplishing meetings (online participation), documentation of problems and solutions, and reduced time spent on preparing shop floor meetings.

The focal point for the following cross-case analysis is communication functionalities, structure functionalities, and the information processing functionalities of analog VBs and digitized VBs.

4.2 Cross-case analysis: functionalities of current VBs

The communication functionalities of analog VBs and digitized VBs allowed practitioners to convert displayed representations into information, into knowledge, and into handling shop floor tasks. The representations displayed on digitized VBs and analog VBs had much in common. Yet, the analog VBs were particularly applicable in giving a brief account of PM and thereby "*provide the team overall information about our performance*" (Manager, Charlie). According to Bravo and Charlie, the vital functionality of analog VBs was indeed to facilitate reflections and communication when accomplishing root cause analyses: "*Being able to write* *and draw anything on the board when discussing problems is paramount*" (Lean manager, Charlie). However, physical proximity remained a fundamental requirement for using analog VBs: *"when facing a problem, we have to call a technician, and it takes a while before he shows up"* (Manager, Bravo). In some situations, analog VBs caused a misfit on the shop floor, mainly because "*our VBs are crowded with printouts, graphs, Word, and Excel documents* (Manager, Bravo), and "*these VBs take up much space, and often we shift between the VBs*" (Manager, Charlie). Digitized VBs provided functionality affording across shop floor communication. Likewise, by digitizing the display, it was possible to gain remote access to the VBs.

The structure functionalities of both analog VBs and digitized VBs allowed practitioners within Bravo and Charlie to accomplish well-structured shop floor meetings and to conduct systematic root-cause analyses. The content of the analog VBs was tailored to comply with standard operating procedures for accomplishing shop floor meetings. For instance, PM meetings were brief accounts of the situations. Indeed, the team managers within Charlie ticked off checklists displayed on the VB. Even though the data displayed on the analog VB afforded actions, it seemed that the structure functionalities resulted in habitual thinking, thus they had a negative influence on sharing knowledge "*we experience a problem in that the workers are rather passive during meetings….I guess it is the result of following a too rigid approach….*" (Manager, Bravo). The use of digitized VBs afforded a more proactive approach, apparently because the digitized VB was adaptable. The adaptability enabled the practitioners to tailor the displayed content to fit a specific situation rather than being "*a VB overcrowded with unnecessary data and information*" (Manager, Bravo). Increasing adaptability positively influenced the practitioners in converting information into shared knowledge and handling tasks, especially within Bravo. "*The participants are more curious and motivated in our meetings, they are more proactive when we have problems*" (Manager, Bravo).

The information processing functionalities of analog VBs were problematic. Before displaying representations on analog VBs, data must pass through a chain of steps: collection, coding, storage, retrieval, manipulation, analysis, and visualization. Bravo and Charlie conducted a great many of these steps manually. The manual retrieval of data, often from various IT systems, including feral systems, led a senior manager from Bravo to consider the manual updates as "*waste activity*".

The analog VBs resulted in several misfit situations: (i) the practitioners were often incapable of retrieving needed information to solve reoccurring tasks, (ii) updating the VBs was time-consuming, (iii) practitioners claimed that the information was not up-to-date to handle a specific task, and (iv) practitioners were incapable of doing ad hoc analyses "*we cannot accomplish advanced data analytics*" (Manager, Bravo).

The digitized data displayed via Power Bi allowed practitioners to access historical data and accomplish simple Excel data analyses during meetings. Charlie emphasized the benefits of "*analyzing trends in our performance ….* [and in] *retrieving information about how previous problems had been solved*". In particular, the digitized VBs had a positive influence on achieving fit when handling CI tasks in both Bravo and Charlie "*Now we do not need to spend unnecessary time on recalling solutions to previous problems….more tasks are handled immediately with no need for external support*" (Manager, Charlie). Despite the fact that digitized VBs did have a positive influence on achieving fit when handling PM tasks, some functionalities were still missing; "*....we have reached a great milestone, but we still lack full data accessibility when facing unforeseen events*" (Manager, Bravo).

To recap, although current VBs afforded online involvement in meetings and in handling task, afforded practitioners to tailor displayed representations to tasks being handled, afforded retrieval and analyses of historical data, current VBs did not display real-time data, did not afford advanced data analytics, and displayed data had low reliability as some steps in the data lifecycle were manually handled.

5.0. Exploratory phase 2: Intervention of a digitalized takt-time VB with Alpha

This section starts with explaining the current state and the desired state. Then there is an elaboration of the designed solution, followed by a presentation of the evaluation of the field test.

5.1. Current state (S)

Alpha develops and manufactures wind turbines. This IBR-study unfolded within manufacturing facilities producing blades for wind turbines. The shop floor layout was an unpaced synchronous flow line (Urban and Chiang, 2016) operating with a 9 hour takt-time. Alpha had five workcells and each workcell consisted of several workstations, see Figure 3. All workcells applied identical analog takt-time VBs, and to ensure takt-time compliance, the tasks revolved around monitoring, controlling, and coping with variations in the flow of materials. Alpha conducted two types of takt-time meetings, one within each workcell and one across the workcells.

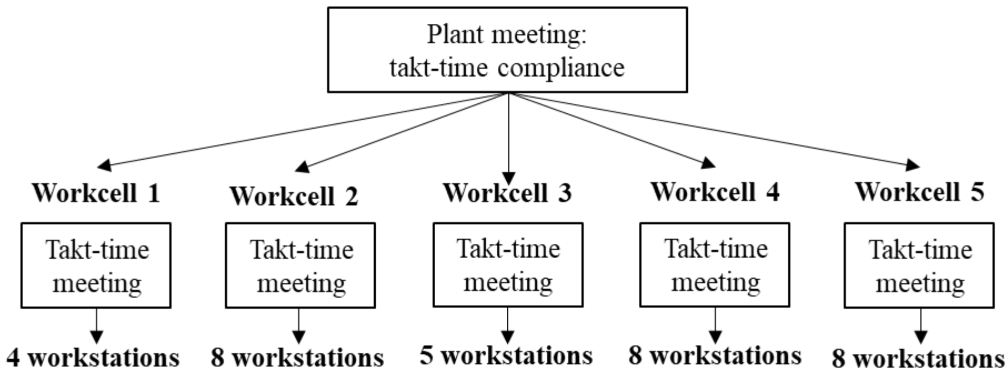

Figure 3. Takt-time meetings within workcells and across workcells.

Workcell takt-time meetings involved the workcell manager and all workstation managers. Meetings took place every third hour and lasted for around five minutes. Analog takt-time VBs monitored the progress of the manufacturing in relation to the plan, that is, whether or not the workcell was on track and thus complied with the 9 hour takt-time requirement. The content displayed on the takt-time VBs and the use of the VBs were identical in all workcells. The takt-time VBs displayed a comprehensive Gantt chart, including actual progress, planned progress, and downtime, including the reasons for deviations (the deviation code indicated why the workcell did not comply with takt-time requirement). Prior to meetings, all workstation managers updated the takt-time VB with this data.

Across workcell takt-time meetings occurred twice a day at 09.00 o'clock in shift one and at 15.30 o'clock in shift two. Normally, the participants were the plant manager, workcell managers, and specialist/managers from different departments. Because the distance between workcells one and five was around 1.5 kilometers "*We do not have the time to walk that distance between the workcells .... it is simply too time consuming"* (Workcell manager). Because of the distance and the use of analog VBs, the across workcell meetings took place without using any kind of takt-time VBs. Each workcell manager gave a brief account focusing on takt-time compliance and highlighted potential issues.

The analog takt-time VBs provided communication functionality to reveal variations between actual and planned progress, and they were useful in coping with variation by rescheduling resource allocations or implementing workarounds. However, a workstation manager highlighted "*our decisions are always based on a historical data .... we are too often doing firefighting and our focus is on reducing damage already caused."* Another workstation manager continued *"the VB only allows us to react to problems within workcells".* The consequence of accomplishing across workcell meetings without using takt-time VBs was *"…. when facing complex tasks, we really need takt-time VBs and face-to-face communication to gain a common understanding of the problem .... now we are making sketches and drawings to ensure a common understanding."* (workstation manager).

The analog VBs, combined with the use of a standardized template, allowed the workcell managers to accomplish meetings in a structured and logical way. Each workstation manager gave a brief status report on whether the workstations(s) complied with the takt-time requirement*"....we all stick to the meeting agenda, ... we are sure to address all issues within a short timeframe."* (workstation manager). However, according to the Lean manager, the practitioners are rather reactive during the takt-time meetings *"It seems that our approach to takt-time meetings results in habitual thinking .... the VB is crowded with data, but it seems they* [the participants] *do not know how to act on the data".* A workcell manager elaborated this viewpoint *".... done, the job is done! let's document it and move to the next task .... we never do follow-up, and we do not reuse the information being documented ".*

Much of the data processing occurred manually. Yet, practitioners used several IT-systems for data acquisition, storage, and visualization. Data such as master data, job-order data, released for production, and material reservations took place via SAP and by using feral systems, mainly Excel. Blue-collar workers used PRISMA[3] to clock-in and clock-out on job orders. Blue-collar workers added downtimes and causes (deviation codes) on whiteboards placed in all workstations. Prior to takt-time meetings, the workstation manager took a picture of all whiteboards and uploaded these pictures to SharePoint. Based on these pictures, a practitioner created Excel documents illustrating downtimes, including the causes, and posted these documents on takt-time VBs. The manual retrieval of data, often from various IT-systems, led a workstation manager to declare *".... the way we collect data is problematic …. in addition to being labor-intensive, the manual updates increase flaws and result in unreliable data; indeed, we distrust the data ....at our takt time meeting we have a feeling that we are left in the*

[3] PRISMA provides interoperability, for instance between PLC, SCADA, and ERP. Often companies consider PRISMA as a Manufacturing Execution System (MES).

dark". Another workstation manager called in question the use of the PRISMA application to record data *"First workers do not always clock-in and clock-out when starting their work, sometimes the workstation manager does it for all workers. Second, we often realize that the causes for downtimes posted on the takt-time VBs are too superficial to guide our actions".*

5.2. Desired state (S)*

According to Alpha's top management, the desired state would have digitalized takt-time VBs providing functionality to monitor and control the progress of manufacturing at the shop floor level. Alpha highlighted six functional requirements. Based on knowledge gained from the cross case study of Bravo and Charlie, the project team decided to add two additional functional requirements.

- Communication functionalities should allow practitioners to (i) accomplish onsite/online takt-time meetings, (ii) adapt displayed data/information to the shop floor tasks being handled, and (iii) monitor variations between planned progress and actual progress
- Structure functionalities should allow practitioners to (i) comply with standard operating procedures and (ii) accomplish systematic root-cause analyses
- Information processing functionalities should allow practitioners to (i) gain access to real-time data and reliable data, (ii) gain access to historical data, and (iii) carry out data analytics

5.3 Interventions and tests

Alpha's pursuit of takt-time VBs to fulfil the above functional requirements caused two interventions. This section elaborates the two interventions including tests and evaluations.

Intervention-1 was led by the Lean manager, and the project team consisted of Lean specialists, data specialists, workcell managers, and the authors. Six months after starting up intervention-1, the project team realized large constraints in the application architecture, which were related to the current manual data treatment and in enabling interoperability, mainly across SAP and PRISMA.

Our cross case-study illustrated that the means for eliminating architectural constraints within Bravo and Charlie were to improve interoperability among IT-systems, implement a Microsoft SQL database as an information hub, and reduce the use of feral systems. Accordingly, we (two authors) suggested taking heed of the current extent of digital encapsulation (Holmström et al., 2019) which, according to Ganev (2017), required both frontend development (what users can see) and backend development (invisible for users). We argued for automating the data treatment throughout the whole data lifecycle of shop floor data - collection, coding, storage, retrieving, manipulation, analysis, and visualization (see Dai et al., 2019) and for enhancing syntactic interoperability, semantic interoperability, and cross-domain interoperability (see Golzarpoor et al., 2018). Specifically, we considered that the means to enable intervention-1 consisted of (i) automating data collection of blue-collar workers' clock-in and clock-out on job orders and material movement downtimes, (ii) data storage and retrieval directly in SAP, (iii) implementing a web-based API to enhance interoperability, and (iv) user-friendly interfaces for capturing data and adaptable layout on the interactive screen. The project team gained common knowledge of "what users should see":

takt-time layout on the interactive screen and various sensors for data acquisition. But backend development automating all data processing and improving interoperability were purely a black box for the project team "*we are not allowed to make any changes in SAP …. and we have to apply PRISMA for entering production data*" (Project manager).

Thus, technical realities at the shop floor banged our heads against a brick wall. Strict IT-policies combined with stringent cyber security and data security (see Solms and Niekerk, 2013) undermined our proposals. Data collection of downtimes including causes and blue-collar workers' clock-in and clock-out on job orders should occur manually or via PRISMA, and SAP was a prohibited area in terms of downloading data. While these technical constraints obstructed automating data treatment such as collecting, coding, and storing data, it still seemed possible to enhance the interoperability.

The enhancing interoperability proposal dealt with designing and implementing an SQL database. The SQL database acted as an information hub to access and store data from various IT systems. We developed (i) an SQL database that enhanced accessibility and storage of data from SAP, PRISMA, and applied sub-systems, (ii) software code for a web-based API to inquire and retrieve data from the SQL database, and (iii) a web-based solution including software code for visualizing data on the interactive screen. The purpose of developing the two web applications was to provide opportunities to tailor data inquiry, retrieval, and visualization on the digital takt-time VB for the task being handled. The solutions functioned within a test environment, but the project manager turned it down "*your API solution seems to be a good idea and it might be the only way for us to go, but it does not comply with our IT policies and information security …. Sorry to say this, but your solution borders on being too naïve….*". Actually, the proposals did not facilitate a breakthrough. It seemed that our technical talk was lost on the project team, and at last the project manager put the intervention on hold.

However, the Covid-19 pandemic restarted the intervention as Alpha's top management ordered nearly all white-collar workers to work from home. This forced the project team to develop a solution allowing online access to takt-time VBs in a rush. Top management accepted that the intervention did not fulfill all eight functional requirements. The designed application architecture appears in Figure 4. A Microsoft SQL database functioned as an information hub to access and store data from SAP, PRISMA, and different subsystems. Microsoft's Power Apps was instrumental in designing the interactive takt-time VB screen layout, used to retrieve data from the SQL database, and to visualize data on the VB. The layout of the interactive screen looked broadly like the analog takt-time VB.

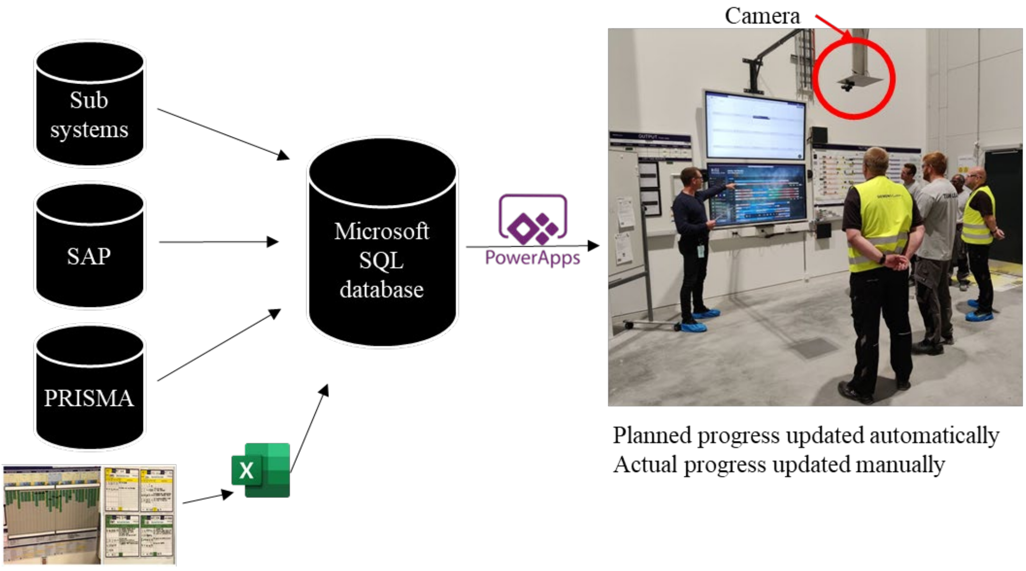

Figure 4. The application architecture of intervention-1.

Testing and evaluating intervention-1 started during the Covid-19 lockdown. By now, Alpha had used the digitized takt-time VBs for nearly two years, i.e., both during and after the pandemic. The test took place within the manufacturing environment and demonstrated that intervention-1 offered online access to the takt-time VB. In addition, an embedded camera (in the middle of the red circle in Figure 4) afforded online access to shop floor meetings. The Microsoft SQL database retrieved master data, job-order data, and material reservations directly from SAP and from a manually updated Excel spreadsheet. Yet, the main part of data collection still occurred manually. Blue-collar workers would manually register clock-in and clock-out on job orders via PRISMA and the registrations of downtimes, including causes, did not change. The managers still registered downtimes and causes on whiteboards and took a picture of the whiteboard. Afterwards, the data was downloaded to the SQL database. Finally, the digitized takt-time VB updated the planned progress automatically, but actual progress would be manually updated by workstation managers.

An evaluation based on the TTF framework proved enhanced communication functionalities, mainly due to the combined online access to both the takt-time VBs and to the shop floor meeting (via the camera) *"....online access was paramount for us during the lockdown* [Covid-19 lockdown] *and now we have realized that it reduces wasted time during the meetings.... plant takt-time meetings are more effective now as we have access to all takt-time VBs across our workcells."* (Workcell Manager). Likewise, practitioners adapted the displayed information to the tasks being handled to gain a common understanding of problematic situations. A workcell manager declared "*ad-hoc involvement of a specialist is much easier now .... all workers are more open-minded*". However, we observed a TTF misfit in relation to monitoring variation between planned and actual progress; planned progress was updated automatically, but actual progress was still updated manually.

The structural functionalities allowed practitioners to accomplish both brief shop floor meetings and systematic root-cause analyses. We noticed several fit situations both within workcell takt-time meetings and plant meetings. For instance, at the outset of shop floor meetings, the display on the VB was tailored to comply with the standard operating procedures, but later on, if facing a problematic situation, the practitioners strove to only display necessary information to gain common knowledge of the problem, which led to "…. *the workers are more proactive during the meetings*" (Lean manager).

The information processing functionalities were only partly improved. Practitioners could access historical data if that data were retrievable from the Microsoft SQL database, i.e., data already downloaded to the SQL database. Having access to historical data allowed practitioners to "*recall how we previously handled malfunctions".* (Workstation manager). Likewise, the Lean manager declared *"…. having direct access to historical data makes it possible to analyze trends such as the number of malfunctions in workstations"*. However, the evaluation revealed some misfits. The takt-time VB did not allow practitioners to use machine learning algorithms to carry out data analytic. Instead, they used Excel to perform simple data analytics. The manual registrations of downtimes, including causes, and the manual clock-in and clock-out on job orders via PRISMA entailed displaying data that was not real-time, and the reliability of data was often an issue during the meetings.

Intervention-1 did not arrive at the desired state. Given that top management was keen on having a digital takt-time VB fulfilling all eight functional requirements, a new project team was formed. A data scientist acted as the project manager, and the team consisted of data scientists, hardware specialists, software specialists, and the authors. Lean specialists were partly involved in intervention-2.

Intervention-2 - The practical knowledge gained during intervention-1 indicated that crucial means to reach the desired state were (i) automating data collection of blue-collar workers' clock-in and clock-out on job orders and of the material movement downtime via sensors and cameras, (ii) automating data storage and retrieval directly into either SAP or into an SQL database via an Industrial-PC (IPC), (iii) enabling interoperability by implementing a web-based API, including developing software code, and (iv) adopting the layout of the interactive screen designed in intervention-1.

While issues related to cyber security and data security were indisputable, the project manager challenged Alpha's IT-policies. In particular, the demand of applying PRISMA for data collection was challenged. At the end, the project manager bended the IT-policies, and top management accepted designing an application for data collection and storage without interfacing the PRISMA application. However, PRISMA could not be replaced before the digital takt-time VB was field tested and fully implemented, requiring shop floor practitioners to register data twice. The project team did not consider this as an issue. Despite this, we highlighted that both Bravo and Charlie had experienced reluctance among blue-collar workers to register data twice.

The application architecture of intervention-2 appears in Figure 5. Compared with intervention-1, the real technical breakthrough implemented in intervention-2 revolved around automating data collection and enhancing interoperability.

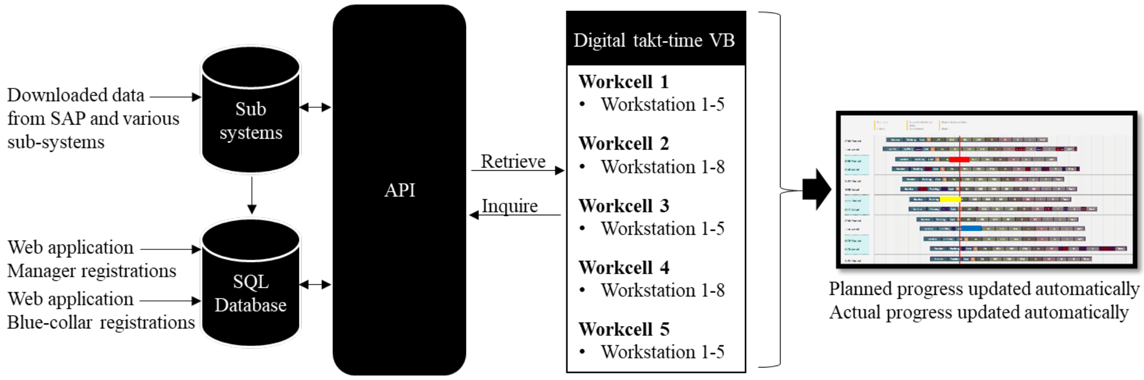

Figure 5. The application architecture of intervention-2.

As for data collection, the project team developed two web applications depicted at the lower left corner of Figure 5. The two web applications enabled real-time data collection via interactive screens and stored data directly in the SQL database via IPC, that is, data collection and storage without interfacing with PRISMA. One web application forced blue-collar workers to clock-in when starting each production task and clock-out when finishing the task, which increased the number of registrations. The second web-application required managers to instantly register any delay in the flow of materials (deviations and causes). To improve interoperability, the project team (i) developed an SQL database functioning as an information hub to store data directly from the two abovementioned web applications and to access necessary takt-time data from SAP and various subsystems, mainly SharePoint and Excel files, (ii) developed a web-based API including software codes to inquiry data and retrieve data from the SQL database, and (iii) developed a web-based solution including software code for visualizing data on the interactive screen (digital takt-time VB in Figure 5).

The test and evaluation of intervention-2 demonstrated completely different results. Within a testing environment, the data scientists proved that the user-interface on the interactive screen, including the two web applications, afforded blue-collar workers to clock-in and clock-out, and workstation managers to register delays (downtime and causes). Data were coded and stored correctly in the SQL database, and data could easily be retrieved. The retrieved data could be displayed on the interactive takt-time VB screen, and the displayed data was adaptable. The data scientists did successfully update both planned progress and actual progress on the takt-time VB automatically. A red vertical line illustrated planned progress, and three color signs indicated different reasons for a delay: red symbolized actual delay within a workcell, blue indicated an expected delay, and yellow signified that a workcell had finished all production tasks but downstream issues made it impossible to move the product. Lastly, the test of the data analytics functionality proved that data could be exported from the SQL database to Power BI to accomplish data analytics. Intervention-2 provided all eight functionalities within a testing environment.

The TTF evaluation of intervention-2 drew on a 24-hour test at the manufacturing shop floor over two shifts. Technology-wise the takt-time VBs functioned as expected, but at the time the technical solution was put into practice, the practical realities at the shop floor obviously showed that the project team lacked sufficient OM knowledge in terms of controlling unpaced synchronous flow lines. One of the two workstation managers appointed to supervise the test stated *"we did not have any guidelines for supervising the test .... we only got a brief introduction to the test and he* [the project manager] *did not inform us how to evaluate the test"*. The other workstation manager claimed that "*the workers did not really understand how to register data .... and they could not understand why to do the registration twice*". The challenges with the data registrations could be the workers' reluctance to carry out superfluous tasks, but more likely an inappropriate design of user interfaces for data registration caused the misfit situation within four of the five workcells. The five workcells had different requirements for data registration and instead of developing customizable user interfaces, a one-size-fits-all user interface had been developed.

The test resulted in some data storage in the SQL database, but the data foundation was insufficient to carry out a valid TTF evaluation of the extent to which the digitalized VB afforded communication, structural, and information processing functionalities. Frankly, practical realities on the shop floor resulted in an unsuccessful field test.

6.0. Explanatory phase – Prerequisites for achieving VB-shop floor task fit

This section commences with verifying our working hypothesis, answering the research question, and finally, we present the implications of the study, limitations, and future research.

6.1. Clarification of working hypothesis and prerequisites for achieving TTF

The *best explanation* (Niiniluoto, 1999) of the working hypothesis "*the current functionality of VBs is inadequate to handle shop floor tasks*" draws on the cross-case study of Bravo and Charlie. Current VBs displaying analog representations (i) provide the ability to communicate within the shop floor, but a fundamental requirement for providing that functionality is physical proximity, (ii) inhibit across shop floor communication and, to some extent, inhibit communication within the shop floor if the VB is crowed with information, (iii) inhibit proactiveness because the structure functionalities result in habitual thinking, and (iv) lack information processing functionalities because of one-way updates, that is, representations such as graphs, bar charts, and notes are manually posted on VBs.

Current VBs displaying digital representations (i) provide online involvement in meetings and in handling tasks, (ii) provide structure functionality that allows practitioners to tailor the digitally displayed representations to the task being handled, which has a positive influence on motivation and proactiveness, (iii) provide information processing functionalities that allows practitioners to accomplish two-way updates of a large part of manufacturing data, uploading data to VBs and downloading data to IT systems, and (iv) provide retrieval and analyses of historical data. The study reveals three TTF misfits: (i) the current VBs inhibit the use of real-time data, (ii) data reliability is an issue, and (iii) advanced analytics is still impossible. As one of the interviewed managers declared, "*the management of shop floor is not carried out effectively if we cannot see actual performance .... Gemba walk will be much more effective if we have a kind of online visual control on the fly*".

The second exploratory phase gradually revealed "*what are the prerequisites for achieving fit between VBs and contemporary shop floor tasks?*" Intervention-1 exposed serious constraints in Alpha's application architecture, which revolved around manual data treatment and lack of interoperability. The appointed project manager (Lean manager) was very well versed in OM topics, but technical topics related to backend development to automate data treatment and enable interoperability were a black box. In an attempt to open the technological black box, we favored TM knowledge at the expense of OM knowledge, which paved the way for suggesting three groups of technical prerequisites.

Technically, information and data should flow like water in a tube from one system to another without delay or sorting. Just like Bravo and Charlie, Alpha has implemented several versions of SAP which, in combination with the use of a few feral IT systems, results in information islands. Hence, a technical prerequisite is to eliminate information islands by enhancing interoperability (Golzarpoor et al., 2018). The proposal is to design and implement an information hub, an SQL database, to access and store data from various IT systems. For data inquiry and retrieving data from the SQL database, we suggest writing software code for a web-based API.

A second prerequisite revolves around automating the data life cycle (Dai et al., 2019; Jwo et al., 2021) with regards to blue-collar workers' clock-in and clock-out on job orders and registration of downtimes in material movement via sensors and cameras. Data storage and retrieval should take place in either an SQL database via an IPC or directly into SAP; the latter seems unlikely as Alpha considers SAP as a prohibited area.

A third prerequisite is adaptable user interfaces. Because appropriate user interfaces are paramount for social interaction, knowledge sharing, and handling tasks (Blumer, 1969; Paiva et al., 2008), we suggest developing a web-based solution for capturing data and for visualizing data on the interactive screen, both having adaptable interfaces. Table 3 summarizes the desired state (S*) in the left column, the actual state ($S'^{\text{Int-1}}$) of intervention-1 in the mid column, and the actual state of ($S'^{\text{Int-2}}$) of intervention-2 in the right column.

(S*) Communication functionalities allow practitioners to	($S'^{\text{Int-1}}$) Intervention-1 Test & evaluation	($S'^{\text{Int-2}}$) Intervention-2	
		Test	Evaluation
• Accomplish onsite/online takt-time meetings	Fit	Fit	Misfit
• Adapt displayed data/information to shop floor tasks being handled	Fit	Fit	Misfit
• Monitor variations between planned progress and actual progress	Misfit	Fit	Misfit
(S*) Structure functionalities allow practitioners to			
• Comply with standard operating procedures	Fit	Fit	Misfit
• Accomplish systematic root-cause analyses	Fit	Fit	Misfit
(S*) Information processing functionalities allow practitioners to			
• Gain access to real-time data and reliable data	Misfit	Fit	Misfit
• Gain access to historical data	Fit	Fit	Misfit
• Carry out data analytics	Misfit	Fit	Misfit

Table 3. Task-Technology Fit in intervention-1 and intervention-2.

As it appears in Table 3, intervention-1 did not arrive at the desired state because of inadequate backend development. Intervention-1 provided valuable VB functionalities, but it inhibited practitioners to monitor variations between planned and actual progress continually, to access real-time and reliable data, and to carry out data analytics. Intervention-2 resulted in a digitalized VB providing all eight functionalities within a testing environment. The project team possessed comprehensive TM knowledge entailing technical solutions that were railroaded through. Indeed, OM topics were black boxes during intervention-2, for instance, the one-size-fits-all user interface for data registration. Accordingly, as illustrated in Table 3, the test of intervention-2 revealed a technically workable solution, but within the OM context, the evaluation proved to be an unworkable solution.

By juxtaposing the findings of intervention-1 and intervention-2, we suggest a fourth prerequisite which revolves around the engineering-OM transfer (Van Aken et al., 2016). Via their professional knowledge and social interaction, practitioners involved in the digital transformation of the shop floor VBs must be able to transcend the boundaries between OM knowledge and TM knowledge; the engineering-OM transfer requires the ability to translate knowledge and transform knowledge.

6.3 Implications of the study

Practical implications of this empirically driven study indicate that current VBs displaying analog representations are still valuable but induce information islands and necessitate physical proximity. VBs displaying digital representations provide practitioners the opportunity to transcend boundaries, both intra- and inter-organizationally, and to recall and rely on past solutions through their functioning as a memory system. However, managers should pay heed to the fact that "*what you see is not necessarily what you get*". This IBR study witnessed user-friendly and adaptable VBs, but the digital representations were mainly the result of purely frontend development via Microsoft Power BI, PowerApps, and Excel software solutions. Such VBs do not provide practitioners with all of the functionalities needed in a smart manufacturing context.

Smart manufacturing companies are (still) struggling with serious constraints in their application architecture. Current application architecture constrains the free flow of data and information. Unhindered access to data is a pivotal requirement for tailoring a shop floor VB in the context of smart manufacturing, which requires both frontend and backend development. This study suggests that managers handle all three "technical" prerequisites, that is, frontend development of user-friendly interfaces to capture data and to ensure an adaptable layout on interactive VB screens and backend development to eliminate information islands by enhancing interoperability and ensuring automation of the whole data life cycle. This paper advises managers to ensure that frontend development and backend development go hand in hand.

Practitioners face huge difficulties in coping with the current digital transformation of manufacturing shop floor. For instance, during intervention-1, the project team was reluctant to dig deep into TM knowledge, and the project team accomplishing intervention-2 considered OM knowledge less important. Despite it only had a minor effect that we brought TM knowledge to the fore in intervention-1 and OM knowledge in intervention-2, our findings illustrate that the digital transformation of shop floor VBs will end up on a dead-end road if TM knowledge and OM knowledge are kept apart. Managers should pay attention to how practitioners include both OM knowledge and TM knowledge and understand that the achievement of common knowledge is a process of social interactions in which practitioners' reflective conversations involve both OM and TM issues.

The theoretical implications emerge by appreciating the gap between the actual states (S^{Int-1} and S^{Int-2}) and desired state (S*) to reopen the *means-end relationship* (Dewey 1933; Simon, 1988). If juxtaposing the gap with the *means* (M) that address the project teams' interpretation of the desired state and the reciprocity between contextual knowledge gained during the IBR and the scientific knowledge teams, then some interesting findings emerge.

Researchers such as Hultin and Mähring (2014), Torres et al. (2019), and Østerlie and Monteiro (2020) examined the usability of "digit(i/ali)zed" VBs without opening up the black box of technology. These studies contributed valuable information, but it is impossible to clarify whether the studied VBs were digit**i**zed or digit**ali**zed. Being actively involved in Alpha's IBR, we realize the consequences of this confusion of concepts in relation to gaining common knowledge. Thus, to avoid conceptual ambiguities, this paper suggests using the notions of digitized VB and digitalized VBs to clarify differences in the provided functionalities and the extent of digital encapsulation. In contrast to a digitized VB, a digitalized VB requires a completely digital encapsulation.

This IBR proves that the use of means to achieve the desired state depends on what practitioners have in mind. In Intervention 1, a lean mindset was instrumental in the arrival at actual state, while a data science mindset was at the forefront during Intervention 2. We, the authors, were aware of the fact that the practitioners' mindset would influence their actions (Paiva et al., 2008), their reflective conversations (Schön, 1983), and their social interactions (Blumer, 1969). Accordingly, to transcend the boundaries between OM knowledge and TM knowledge, we pushed the knowledge pendulum towards the TM means to challenge the "lean mindset" and later on towards the OM means to take on the "data science mindset". However, the effect was minor, and we ascertained that it is a rather challenging task to accomplish the digital transition of manufacturing shop floors, which contrasts with the mainstream of TM research (Tao et al., 2018). This study suggests that both practitioners and academia should develop the abilities to combine OM knowledge and TM knowledge, which extends Holm's (2018) findings demonstrating that the digital transition of the manufacturing shop floor requires blue-collar workers to gain new knowledge.

This paper asserts that the prevalent research on smart manufacturing shop floors does not reflect realities on manufacturing shop floors and suggests reconciling theory and practice. Apparently, Lewin's (1945) wise words "*there is nothing as practical as a good theory*," have rough times in the current digital turn of a manufacturing shop floor. For example, the desired state of Alpha's IBR echoes the purpose of Zhang et al.'s (2017) conceptual paper - providing practitioners with real-time data to manage an unpaced assembly line, but this is the only similarity. Likewise, TM researchers (cf. Dai et al, 2019) prescribe a smooth digital transition of manufacturing shop floors and explore useful knowledge to clarify the desired state. Also, OM researchers (cf. Torres et al., 2019) consider technology as a black box and explore useful knowledge to create applicable VBs. It seems prevalent theories are useful to clarify the desired state, but the *means* to achieve the desired state are either decoupled from reality or unintelligible when it comes to guiding interventions of digitalized VBs.

When comparing the gap between the actual state and the desired state with the literature that addresses the impact that digital transformation of manufacturing has on the usability of VBs at a theoretical level, another group of interesting findings appears. A stream of TM researchers (Zhang et al., 2017; Kusiak, 2018; Tao et al., 2018; Dai et al., 2019) contributed valuable and detailed information about the advantages of visualizing real-time data and using machine learning and artificial intelligence to accomplish data-driven analytics. By contrast, a group of valuable OM researchers (Parry and Turner, 2006; Fullerton et al., 2014; Beynon-

Davis and Lederman, 2017; Torres et al., 2019) considers technology as a black box and pays heed to the usability of VBs to communicate, coordinate, prioritize daily tasks, and monitor and report performance.

To shed light on a contributory cause to the above gap, this paper suggests that the *means* and *ends* are poles apart. TM researchers put a laser light focus on the *end* (desired state) – visualizing real-time data, data-driven decisions, and predictive analyses - but refrain from clarifying the OM *means* to achieve the *end* (cf. Dai et al., 2019). For OM researchers, the *end* is the usability of VBs to ensure effective execution of manufacturing, shop floor management, and the like, but the *means* to achieve the *end* does not open up the black box of enabling technologies (cf. Torres et al., 2019). In this IBR study, we have clarified the importance of combing OM knowledge and TM knowledge with practical knowledge as *means* to achieve the *end*. For example, the *means* to gain a detailed understanding of current VB-shop floor tasks fit/misfit draws on both OM research and TM research. The *end*, our desired state, is to align VB functionalities with smart manufacturing shop floor tasks and the *means* to achieve the *end* requires the ability to combine OM knowledge and TM knowledge.

Combining OM knowledge and TM knowledge triggers reflections upon Van Aken et al.'s (2016) engineering-OM transfer. To "*transfer*" indicates that OM knowledge and TM knowledge are transferable. Information is transferable but because of knowledge is personalized information and related to actions (Paiva et al., 2008), OM knowledge and TM knowledge might acquire meaning when researcher and/or practitioners are using that as *means* to achieve the *end* (Dewey, 1933). This study proved that TM knowledge was untransferable in intervention-1, and OM knowledge was untransferable in intervention-2. In intervention-1, the project team was incapable of translating our TM proposals into workable *means,* and the project team in intervention-2 neglected to transform the technical solution to fit in with the OM realities on the shop floor. We assert that the digital turn of manufacturing necessitates transcending the OM knowledge and TM knowledge dualism. To transcend boundaries between OM knowledge and TM knowledge, this study suggests that the engineering-OM transfer requires the ability to translate knowledge and transform knowledge.

6.3. Limitations and future research

Although this study puts forward prerequisites for digitalizing VBs adapted to smart manufacturing shop floors and contributes to theoretical and practical understandings, the method employed has limitations. First, interviews and observations were accomplished in Bravo and Charlie, and the IBR unfolded in Alpha. The criterion for selecting these three companies from among the 16 companies being followed prior to the study in this paper was the use of both analog VBs and digitized VBs; the remaining 13 companies only apply analog VBs. This might bias our findings and thereby favor the use of and advantages of VBs displaying digital representations. Second, the extent of the data collection for the exploratory cross-case study and the exploratory IBR is extremely diverse. The cross-case study draws on three observations of shop floor meetings and three semi-structured interviews in both companies. Our involvement with Alpha was a longitudinal and much more thorough study. Because the exploration of Alpha has contributed to the authors' empirical understanding, the omission of observations and interviews from Alpha might negatively influence the trustworthiness of our best explanation of our working hypothesis. Third, because the study involves only three companies, the generalizability can be questioned. Due to the latter limitation, a proposal for future work is to empirically study to what extent the identified four prerequisites can enable the development of digitalized VBs in various industries and manufacturing setups. Such research could also involve feasibility studies concerning the nexus between the three technical prerequisites and the prerequisite revolving around the engineering-OM transfer.

7.0. Conclusion

The verification of the working hypothesis "*the current functionality of VBs is inadequate to handle shop floor tasks*" reveals that VBs displaying analog representations are not yet outdated. These VBs are still usable for guiding practitioners' social interaction and knowledge sharing, but their usability requires physical proximity. VBs displaying digital representations provide additional VB functionalities such as interactive upload and download of data, simple Excel analyses, adaptability of displayed representations, and elimination of the physical proximity requirement. However, current VBs lack functionalities to visualize real-time and reliable data and to carry out advanced analytics.

By answering the research question, "*what are the prerequisites for achieving fit between VBs and contemporary shop floor tasks*" the study suggests four prerequisites: first, automation of the data life cycle - data collection, data coding, data transmission, data cleansing, data integration, data compression, data storage, data analytics, and data visualization; second, standardized IT interfaces to enable syntactic, semantic, and across boundary interoperability; third, user-friendly interfaces to capture data and to ensure an adaptable layout on the interactive VB screen; and fourth, transcending boundaries between OM knowledge and TM knowledge.

Key implications are as follows: (*i*) current VBs displaying analog representation are not outdated but have restricted functionalities, (*ii*) current VBs displaying digital representations afford additional functionalities but are still lacking functionalities, (*iii*) the digital transformation of shop floor VBs ceases because TM knowledge and OM knowledge are poles apart, and (*iv*) four prerequisites for developing shop floor digitalized VBs were identified.

References

Barratt, M., Choi, T. Y., & Li, M. (2011). Qualitative case studies in operations management: Trends, research outcomes, and future research implications. *Journal of Operations Management*, 29(4), 329-342. https://doi.org/10.1016/j.jom.2010.06.002

Bateman, N., Philip, L., & Warrander, H. (2016). Visual management and shop floor teams – development, implementation and use. *International Journal of Production Research*, 54(24), 7345-7358. https://doi.org/10.1080/00207543.2016.1184349

Bendoly, E., & Cotteleer, M. J. (2008). Understanding behavioral sources of process variation following enterprise system deployment. *Journal of Operations Management*, 26(1), 23-44. https://doi.org/10.1016/j.jom.2007.03.002

Beynon-Davies, P., & Lederman, R. (2017). Making sense of visual management through affordance theory. *Production Planning & Control*, 2, 142–157. https://doi.org/10.1080/09537287.2016.1243267

Blumer, H. (1969). *Symbolic interactionism: Perspective and method*, University of California Press.

Brown, J.S., & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning and innovation. *Organization Science*, 2(1), 40–57. https://doi.org/10.1287/orsc.2.1.40

Browning, T. R. (2010). On the alignment of the purposes and views of process models in project management. *Journal of Operations Management*, 28(4), 316-332. https://doi.org/10.1016/j.jom.2009.11.007

Bryman, A., & Bell, E. (2007). *Business Research Methods*, Oxford University Press.

Cagliano, R., Canterino, F., Longoni, A., & Bartezzaghi, E. (2019). The interplay between smart manufacturing technologies and work organization. *International Journal of Operations & Production Management*, 39(6-8), 913-934. https://doi.org/10.1108/IJOPM-01-2019-00933.

Caniato, F., Doran, D., Sousa, R., & Boer, H. (2018). Designing and developing OM research – from concept to publication, *International Journal of Operations & Production Management*, 38(9), 1836-1856. http://doi.org/10.1108/IJOPM-01-2017-0038

Chandrasekaran, A., de Treville, S., & Browning, T. (2020). Intervention-based research (IBR)—What, where, and how to use it in operations management. *Journal of Operations Management*, *66*(4), 370-378. https://doi.org/10.1002/joom.1093

Cimini, C., Pirola, F., Pinto, R., & Cavalieri, S. (2020). A human-in-the-loop manufacturing control architecture for the next generation of production systems. *Journal of manufacturing systems*, (54), 258-271. https://doi.org/10.1016/j.jmsy.2020.01.002

Clausen, P., Mathiasen, J.B., & Nielsen, J.S. (2020). Smart Manufacturing through Digital Shop Floor Management Boards. *Wireless Personal Communications*, (115), 3261-3274. https://doi.org/10.1007/s11277-020-07379-y

Dai, H.N., Wang, H., Guangquan, X., Wan, J., & Imran, M. (2019). Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies. *Enterprise Information Systems*, 1–25. https://doi.org/10.1080/17517575.2019.1633689

Dewey, J. (1933). *Essays and How We Think*, Carbondale, Southern Illinois University Press.

Dewey, J. (1938). *Logic: The Theory of Inquiry*, (12), Carbondale, Southern Illinois University Press.

Fichman, R. G., & Kemerer, C. F. (1993). Adoption of software engineering process innovations: The case of object orientation. *Sloan management review*, 34(2), 7-22.

Fullerton, R. R., Kennedy, F. A., & Widener, S. K. (2014). Lean manufacturing and firm performance: The incremental contribution of Lean management accounting practices. *Journal of Operations Management*, 32(7-8), 414-428. https://doi.org/10.1016/j.jom.2014.09.002

Golzarpoor, B., Haas, C. T., Rayside, D., Kang, S., & Weston, M. (2018). Improving construction industry process interoperability with Industry Foundation Processes (IFP). *Advanced Engineering Informatics*, *38*, 555-568. https://doi.org/10.1016/j.aei.2018.09.001

Ganev, D. (2017). *Build applications with Meteor: full stack development*, Birmingham, Packt Publishing.

Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS Quarterly*, 19(2), 213-236. https://doi.org/10.2307/249689

Graves, S. C. (1981). A review of production scheduling. *Operations research*, 29(4), 646-675. https://doi.org/10.1287/opre.29.4.646

Hernes, T., & Schultz, M. (2020). Translating the distant into the present: How actors address distant past and future events through situated activity. *Organization Theory*, *1*(1), 1-20. https://doi.org/10.1177%2F2631787719900999

Holm, M. (2018). The future shop-floor operators, demands, requirements and interpretations. *Journal of Manufacturing Systems*, (47), 35–42. https://doi.org/10.1016/j.jmsy.2018.03.004

Holmström, J., Ketokivi. M., & Hameri. A.P. (2009). Bridging practice and theory: A design science approach. *Decision sciences*, 40(1), 65-87. https://doi.org/10.1111/j.1540-5915.2008.00221.x

Holmström, J., Holweg, M., Lawson, B., Pil, F. K., & Wagner, S. M. (2019). The digitalization of operations and supply chain management: Theoretical and methodological implications. *Journal of Operations Management*, 65(8), 728-734. https://doi.org/10.1002/joom.1073

Hultin, L., & Mähring, M. (2014). Visualizing institutional logics in sociomaterial practices. *Information and Organization*, 24(3), 129-155. https://doi.org/10.1016/j.infoandorg.2014.05.002

Ji, W., & Wang, L. (2017). Big data analytics-based fault prediction for shop floor scheduling. *Journal of Manufacturing Systems*, (43), 187-194. https://doi.org/10.1016/j.jmsy.2017.03.008

Jwo, J. S., Lin, C. S., & Lee, C. H. (2021). Smart technology–driven aspects for human-in-the-loop smart manufacturing. *The International Journal of Advanced Manufacturing Technology*, 114(5), 1741-1752. https://doi.org/10.1007/s00170-021-06977-9

Kaipia, R., Holmström, J., Småros, J., & Rajala, R. (2017). Information sharing for sales and operations planning: Contextualized solutions and mechanisms. *Journal of Operations Management*, *52*, 15-29.

Ketokivi, M., & Choi, T. (2014). Renaissance of case research as a scientific method. *Journal of Operations Management*, 32(5), 232-240. https://doi.org/10.1016/j.jom.2014.03.004

Kusiak, A. (2018). Smart manufacturing. *International Journal of Production Research*, 56(1-2), 508-517. https://doi.org/10.1080/00207543.2017.1351644

Lewin, K. (1945). The research centre for group dynamics at Massachusetts Institute of Technology. *Sociometrics*, 8, 128-135. https://doi.org/10.2307/2785233

Liker, J.K., & Meier, D. (2006). *The Toyota Way Fieldbook*. New York, McGraw-Hill.

Maccarthy, B. L., Fernandes, F. C. (2000). A multi-dimensional classification of production systems for the design and selection of production planning and control systems. *Production Planning & Control*, 11(5), 481-496. https://doi.org/10.1080/09537280050051988

Mathiasen, J.B. (2017). Doing product development activities: The role of experience and ends-in-view. *International Journal of Innovation and Learning*, 22(4), 524-543. https://doi.org/10.1504/IJIL.2017.087494

Meissner, A., Grunert, F., & Metternich, J. (2020). Digital shop floor management: A target state. *Procedia CIRP*, 93, 11-315. https://doi.org/10.1016/j.procir.2020.04.083

Niiniluoto, I. (1993). The aim and structure of applied research. *Erkenntnis*, 38(1), 1-21. https://doi.org/10.1007/BF01129020

Oliva, R. (2019). Intervention as a research strategy. *Journal of Operations Management*, *65*(7), 710-724. https://doi.org/10.1002/joom.1065

Paiva, E. L., Roth, A. V., & Fensterseifer, J. E. (2008). Organizational knowledge and the manufacturing strategy process: a resource-based view analysis. *Journal of Operations Management*, 26(1), 115-132. https://doi.org/10.1016/j.jom.2007.05.003

Parry, G.C., & Turner, C.E. (2006). Application of lean visual process management tools. *Production Planning & Control*, 17(1), 77–86. https://doi.org/10.1080/09537280500414991

Peirce, C. S. (1878). *Photometric research*, W. Engelmann.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., ... & Nee, A. Y. C. (2021). Enabling technologies and tools for digital twin. *Journal of Manufacturing Systems*, *58*, 3-21

Rajan, K., & Safiotti, A. (2017). Towards a science of integrated AI and Robotics. *Artificial Intelligence*, 247, 1–9. https://doi.org/10.1016/j.artint.2017.03.003

Schmenner, R. W., & Swink, M. L. (1998). On theory in operations management. *Journal of Operations Management*, 17(1), 97-113. https://doi.org/10.1016/S0272-6963(98)00028-X

Schön, D.A. (1983). The Reflective Practitioner, New York, Basic Books, Inc., Publishers.

Simon, A.H. (1988). The science of design: Creating the artificial. *Design Issues*, 4(1-2), 67–82.

Slack, N., & Brandon-Jones, A. (2019). Operations Management, 9th edition, Pearson.

Sousa, R., & Voss, C. A. (2002). Quality management re-visited: a reflective review and agenda for future research. *Journal of Operations Management*, 20(1), 91-109. https://doi.org/10.1016/S0272-6963(01)00088-2

Stake, R.E. (2000). *The case study method in social inquiry*, in R. Gomm, M. Hammersley, P. Foster (Eds.), Case Study Method: Key Issues, Key Texts, London, SAGE Publications.

Stoop, P. P., & Wiers, V. C. (1996). The complexity of scheduling in practice. *International Journal of Operations & Production Management*, 16(10), 37-53. https://doi.org/10.1108/01443579610130682

Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of Manufacturing Systems*, 48, 157–169. https://doi.org/10.1016/j.jmsy.2018.01.006

Torres, D., Pimentel, C., & Duarte, S. (2019). Shop floor management system in the context of smart manufacturing: a case study. *International Journal of Lean Six Sigma*, 11(5), 837-862. http://dx.doi.org/10.1108/IJLSS-12-2017-0151

Urban, T. L., & Chiang, W. C. (2016). Designing energy-efficient serial production lines: The unpaced synchronous line-balancing problem. *European Journal of Operational Research*, 248(3), 789-801. https://doi.org/10.1016/j.ejor.2015.07.015

Van Aken, J., Chandrasekaran A., & Halman, J. (2016). Conducting and publishing design science research. *Journal of Operations Management*, 47, 1-8. https://doi.org/10.1016/j.jom.2016.06.004

Wang, X., Yew, A. W. W., Ong, S. K., & Nee, A. Y. C. (2020). Enhancing smart shop floor management with ubiquitous augmented reality. *International Journal of Production Research*, 58(8), 2352-2367. https://doi.org/10.1080/00207543.2019.1629667

Weick, K. E. (2002). Puzzles in organizational learning: An exercise in disciplined imagination. *British journal of management*, 13(2), 7-15. https://doi.org/10.1111/1467-8551.13.s2.2

Zhang, Y., Wang, J., Liu, S., & Qian, C. (2017). Game theory based on real-time shop floor scheduling strategy and method for cloud manufacturing. *International Journal of Intelligent Systems*, 32(4), 437-463. https://doi.org/10.1002/int.21868

Zigurs, I., &Buckland, B. K. (1998). A theory of task/technology fit and group support systems effectiveness. *MIS Quarterly*, 22 (3), 313-334. https://www.jstor.org/stable/249668

Østerlie, T., & Monteiro, E. (2020). Digital sand: The becoming of digital representations. *Information and Organization*, 30(1), 100275. https://doi.org/10.1016/j.infoandorg.2019.100275

Co-author statement – PAPER III

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
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Declaration of co-authorship*

Full name of the PhD student: Pernille Clausen

This declaration concerns the following article/manuscript:

Title:	Chasing digitalized visualization boards: Achieving fit between visualization boards and shop floor tasks
Authors:	John Bang Mathiasen and Pernille Clausen

The article/manuscript is: Published ☐ Accepted ☐ Submitted ☒ In preparation ☐

If published, state full reference:

If accepted or submitted, state journal: Journal of Operations Management, in third review

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	C
2. Planning of the experiments/methodology design and development	B/C
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	C
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

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In case of further co-authors please attach appendix

Date: 16.08.22

Signature of the PhD student Pernille Clausen

*As per policy the co-author statement will be published with the dissertation.

PAPER IV

Teaching Old Dogs New Tricks-Towards a Digital Transformation Strategy at the Shop Floor Management Level: A Case Study from the Renewable Energy Industry

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Teaching Old Dogs New Tricks - Towards a digital transformation strategy at the Shop Floor Management level: A case study from the Renewable Energy Industry

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Abstract. To stay competitive in a "winner takes it all" market, adopting digital technologies on the shop floor level in manufacturing seems inevitable. However, accomplishing a digital transformation does not seem to be an easy task to overcome. Without the right approach and mindset, practitioners will not be able to succeed. The conventional belief suggesting that a higher level of automation and digitalization result in less human interaction is misdirecting practitioners in having an increased focus on the technical factors, leaving the social factors out. In light of this situation, this paper tends to study the preconditions for implementing a digital transformation strategy considering both the social and technical factors at the shop floor management level.

Keywords: Smart Manufacturing, Digital Transformation Strategy, Digital Maturity, Shop Floor Management, Socio-Technical systems.

Introduction

At present, the term "Smart Manufacturing" defines the future paradigm of the manufacturing industry, also known as Industry 4.0 [1, 2, 3]. A smart manufacturing shop floor is characterized by automated and computerized production equipment with a continuous stream of a high volume of data [3]. The shop floor management (SFM) level has experienced dramatic changes in data-storage and data-processing technologies [4], which has led to new opportunities in collecting and analyzing data, making shop floor managers change how decisions are made [1]. However, making these changes happen does not seem to be an easy task for manufacturers to overcome [5].

"Digital transformation strategy" is one of the most current topics for the manufacturing industry; however, the transformation process is a complex issue, and the realization of such strategies face many difficulties [6, 7, 8, 9]. To accomplish a transformation process, it is crucial to understand the organizational adoption process, including the technological- and social factors. Following Schumacher et al. [7], manufacturing companies lack a clear understanding of the digital transformation concepts to identify the capabilities needed to capitalize on them. Significantly, the conventional belief suggesting that a higher level of automation and digitalization result in less human interaction is misdirecting the perception of having a digital transformation. Having a one-sided perspective, focusing on the technological factors, misses a focal point [10]: "… when it comes to digital transformation, *digital* is not the answer. *Transformation* is" ([11] p. 2.). Hence, a digital transformation does not involve investigating technologies to solve specific problems; it entails an adaptation of a socio-technical system [10].

Given this, this paper aims to understand how digital transformation strategies interplay with manufacturing at the SFM level. The following research question guide the study: *What are the preconditions when considering a digital transformation at the SFM level?* The paper present a single-case study of a large international company within the Renewable Energy Industry. The research combines a mixed method including semi-structured interviews and a survey.

Theory

Theoretical Background

SFM describes the continuous workflow of identifying deviations through various performance measures and initiate decision-making processes to solve SFM tasks [12]. Flows of data, information, and resources such as manufacturing equipment, materials, and human resources (practitioners) influence SFM. For that reason, the applicability of data and information is paramount for decision-making processes [5].

Smart manufacturing combines advanced manufacturing capabilities and digital technologies in today's production environment [13]. Some of the opportunities within this merger provide data-driven decision-making support for shop floor managers through improved data processing and data analytics that generates better intelligence about the situation at the shop floor [1]. "Digital Transformation" can be defined as using digital technologies (information technologies) to disrupt the business model [8, 10]. However, what we frequently label as "digital technologies," are not that new anymore, as they have been around the last few decades [14].

The digital transformation seizes today's modern world, but understanding the socio-technical system that correspond with the users of the situation is immature [8]. To date, the gains of accessing the digital world are continuously increasing. It appears to be clear; technology has significantly impacted several manufacturing contexts by increasing efficiency in several parameters. However, technology does not play the centric role. In the end, it all comes down to people and values [15]. Following Schwab [15], the future should be shaped by putting the social factors first (people) and empowering them. This demands a socio-technical evolution of the human role in manufacturing systems enabled by emerging digital technologies [10, 16]. Although shop floor managers show increased interest to invest in a digital transformation, they lack knowledge regarding their current digital maturity status [7], which leave them with impossible conditions to formulate an operational digital transformation strategy.

Formulating a digital transformation strategy

"Digital transformation starts when you create a transformative vision of how your firm will be different in the digital world, and then engage your employees to make the vision a reality" ([17], p. 95). Hence, mapping the right path for the digital transformation is crucial, if not, the steering will take you in a wrong direction. Following Westerman [11], technology in itself, do not provide any value to a business, and it never has. For instance, analytics at the SFM level is not about databases and machine learning algorithms; they support understanding the production performance for optimization purposes. Meaning, technology should be understood as a tool applied by people (tool users): When significant opportunities in applying digital technologies on the shop floor are detected, we must bear in mind that the actual tool users need to be convinced [17].

A digital transformation is a change process, and it interferes with the habitual ways of doing things. Some practitioners might not feel motivated to understand the change processes within a digital transformation due to several reasons (e.g., some feel that they are paid to do a job and not change the job, and some are afraid that technology is replacing their job positions). Following Westerman et al. [17], the digital transformation starts at the top of the company, as it requires positions with significant influence to develop the strategy and communicate it throughout the organization. The people on the middle and lower levels are in charge of operationalizing the strategy; meanwhile the shop floor practitioners can start identifying new ways to accommodate it. Although a digital transformation strategy is designed to target an individual level within the company, the strategy still needs to be company-wide as the transformation will affect the whole business [18]. However, for sure, a digital transformation does not happen overnight and must be led and guided carefully.

The term "strategy" refers to a detailed plan for achieving success [19]: Digital transformation strategy is the key building block to manage the increasing complexity within today's smart manufacturing context [20]. For that reason, it is fundamental to align its endogenous factors (the company's business strategy and its IT infrastructure and IT application systems) [18]. Developing a digital transformation strategy is individual and needs to reflect the company guidelines and accommodate the whole organization.

Several research institutions, consultancy firms, and manufacturing companies have taken advantage of “digital maturity” concept to address the advanced issue of formulating and implementing a company-wide digital transformation strategy [18]. For that reason, several digital maturity models are available to identify initiatives that are consistently aligned with the company's capabilities to populate a digital transformation strategy [21]. For instance, Schumacher et al. [7] present an Industry 4.0 digital maturity model that includes 62 maturity items grouped into nine company dimensions: Strategy, Leadership, Products, Customers, Operations, Culture, People, Governance, and Technology. Conducting the maturity assessment, applying maturity models like Schumacher et al. [7] generally structures the collection of company data using a standardized quantified questionnaire composed of close-ended questions answered by company representatives that have a clear and basic understanding of the digital transformation concepts (e.g., Smart manufacturing, digitalization, data-driven decision-making and other belonging terms).

Methodology

This study aims to understand how digital transformation strategies interplay with manufacturing at the SFM level. To do so, we aim to investigate the preconditions when considering a digital transformation on the shop floor in a large manufacturing company within the Renewable Energy Industry. The empirical study is based on a single-case study combining semi-structured interviews with a survey [22]. The empirical material makes up 17 semi-structured interviews with managers related to digital transformation projects at the SFM level (all managers are considered representatives of the digital transformation strategy within the company) and a survey.

The company carefully selected the respondents to participate in the interviews. The average employment seniority of the respondents is eight and a half years. Due to the global Covid-19 situation, it was not allowed for the authors to physically conduct the interviews. For that reason, all interviews were conducted remotely through the digital communication platform Microsoft Teams. Each interview lasts an average of 45 minutes; the interviews were recorded, and the recordings were applied to draw up minutes from each meeting. The survey was constructed via an online platform and distributed to the interviewed managers to verify and derive a clear and generalized overview of the interview data and enhance the study's credibility. 10 of the 17 interviewed managers answered the survey (the answers were anonymized). Both the semi-structured interviews and the survey questions were designed to answer the same questions to derive an answer to the overall research question investigated in this study. The questions asked within the interview and in the survey were constructed based on the preconditions set up by Schumacher et al. [7] when evaluating a company's digital maturity level.

Case study

The case company has invested a considerable amount of resources in operationalizing the overall company digital transformation strategy. However, being a large international corporation with more than 25 000 employees worldwide, the company has met several challenges in successfully making the strategy operational, especially at the SFM level. The objective is to implement more digital solutions to establish a decision-making practice that is data-driven that strives to become analytical when solving tasks within SFM teams.

When new digital initiatives are considered on the SFM level, the attention is on the technological factors and how to make the technology operational. Currently the social factors, the shop floor practitioners, that in the end must complete the implementation and interact with the new conditions are not a primary focus. The digital transformation strategy is currently communicated from a company-wide level, meaning that its interpretation fluctuates in every plant, and no local guidelines are available. Table 1. presents the findings from the interviews clarifying why the managers do not consider the company's current digital transformation strategy operational on the SFM level.

Table 1. Why the digital transformation strategy is not operational (interview data).

The interpretations of the current digital transformation strategy
- It lacks clear organizational guidelines (e.g., what to do, how to do it, whom to involve)
- It is not clear and confuses all (no common understanding can be achieved)
- It does not accommodate the different leadership approaches
- The strategy does not accommodate our current digital maturity state (we do not know whether we are ready ➔ most digital oriented projects are run in the dark)
- It does not accommodate the different working cultures across the plants
- Conflicting performance indicators between internal departments and organizations
- Different interpretations of understanding the digital transformation strategy

- Managers and practitioners on the shop floor lack understanding of the content within the digital transformation strategy and do not know why it is relevant (they have not been involved enough)
- Different prioritization levels (the strategy is not aligned across units, departments, and plants)

When asking the managers about their current understanding level of the digital transformation strategy, the results reveal fluctuating answers. Table 2. summarizes how the answers are divided based on the survey data.

Table 2. The current understanding level of the digital transformation strategy (survey data).

The current understanding level of the digital transformation strategy	Yes	No
Does the digital transformation strategy appear clear?	10 %	90 %
Are you aware of the digital maturity level on the SFM level?	20 %	80 %
Are you feeling equipped to take part in digital transformation initiatives?	50 %	50 %

When asking the managers what they considered as the preconditions to make a digital transformation strategy operational at the SFM level, their answers were quite alike without large deviations. The answers are presented in Table 3.

Table 3. The preconditions for an operational digital transformation strategy (interview data).

The preconditions for an operational digital transformation strategy at the SFM level
- Understand the need for the digital transformation strategy and clarify its content (what, why and where is it necessary?) - Digital maturity evaluation (technology- and human wise) - Develop understandable operational targets that provides a positive business model - Identify the current standpoint digital maturity wise (to identify the realistic achievements?) - The strategy should be divided and localized (it is impossible for the whole organization to accommodate and follow a general "superficial" strategy) - Rethink the communication model (all should possess the same understanding and meet the digital transformation initiatives with same prerequisites) - Consider the digital transformation as a change process (it requires full organizational commitment and it takes time to overcome old habitual mindsets and procedures) - Develop standardized procedures and tools to guide the digital transformation

Results

Based on the empirical findings, the preconditions for developing an operational digital transformation strategy on the SFM level have been conceptualized into a three-stage journey model, see Fig. 1.

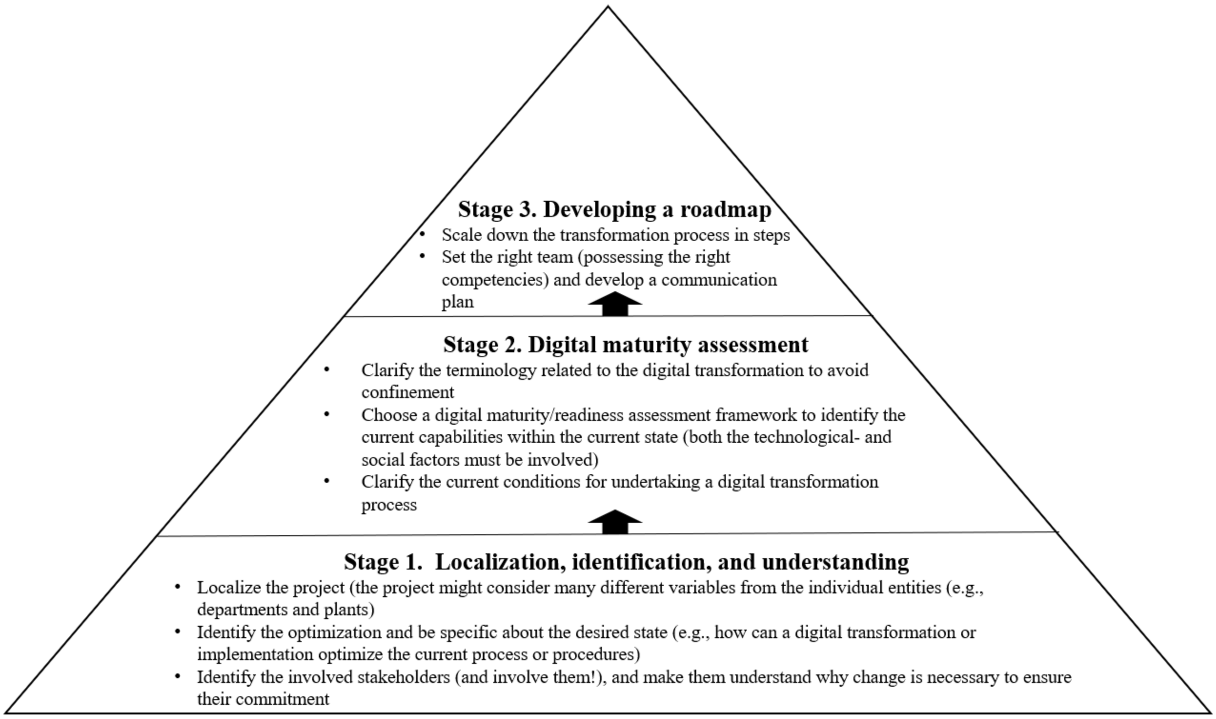

Fig. 1 The preconditions for a developing an operational digitalization strategy at the SFM level (interview and survey data).

Following the empirical material, the first precondition when developing a digital transformation strategy on the SFM level consider localizing the exact area for improvement from where the specific optimization needs must be identified to provide argumentation and develop an understanding of why a digital transformation should happen, see stage 1, Fig. 1. Hence, the digital transformation strategy should target local transformation initiatives on a plant- or department level rather than the whole organization.

Conducting a digital maturity assessment seems inevitable. The managers declare that an operational strategy must reflect the conditions present in the environment. These findings echo the results presented by Westerman et al. [17] and Schumacher et al. [7], among others. In this second stage, see Fig 1., the assessment parameters should be carefully selected and encounter both the technological- and social aspects. The managers demonstrate an increased need to carefully consider the social factors, as they make up the conditions for a successful implementation of the technology. These findings fit the phrase presented by Westerman et al. [17], referring to technology as a tool, and how the tool is applied by the tool users are the focal point within a digital transformation.

It seems essential that the digital transformation strategy is perceived as a change management process [11, 17]. The managers declare that the working environment is heavily influenced by different cultures and leadership approaches, meaning that the current working procedures applied must be considered when introducing new approaches. Furthermore, the practitioners need to be well equipped (possess the right mindset, tools, and support) to step out of their old procedures to welcome new initiatives. Hence, formulating a digital transformation strategy constitutes a learning journey roadmap that must be executed through well-defined standardized procedures and communicated in a way that accommodates the primary stakeholders, see stage 3, Fig. 1.

Conclusion

At the outset, this paper investigated the preconditions for developing a digital transformation strategy at the SFM level. Literature and empirical findings point out that the focal precondition is to emphasize the social factors when formulating a digital transformation strategy to develop commitment from the primary stakeholders when implementing digital initiatives. Based on the empirical findings, the preconditions to develop a digital transformation strategy at the SFM level have been conceptualized in a three-stage journey model: *Stage 1. Localization, identification, and understanding*, *Stage 2. Digital maturity assessment*, and *Stage 3.* The model suggests that the company should localize the transformation strategy to a plant- or department-level as the implementation must accommodate the environmental requirements in the different working environments.

References

1. Tao, F., Qi, Q., Liu, A., & Kusiak, A. Data-driven smart manufacturing. Journal of Manufacturing Systems, 48, 157-169 (2018).
2. Kusiak, A. Smart manufacturing. International Journal of Production Research, 56(1-2), 508-517 (2018).
3. Cagliano, R., Canterino, F., Longoni, A., & Bartezzaghi, E. The interplay between smart manufacturing technologies and work organization. International Journal of Operations & Production Management, 39(6-7-8), 913-934 (2019).
4. Dai, H. N., Wang, H., Xu, G., Wan, J., & Imran, M. Big data analytics for manufacturing internet of things: opportunities, challenges and enabling technologies. Enterprise Information Systems, 14(9-10), 1279-1303 (2019).
5. Meißner, A., Grunert, F., Metternich, J. Digital shop floor management: A target state. Procedia CIRP, 93, 311-315 (2020).
6. Hess, T., Matt, C., Benlian, A., & Wiesböck, F. Options for formulating a digital transformation strategy. MIS Quarterly Executive, 15(2), 123-139 (2016).
7. Schumacher, A., Erol, S., & Sihn, W A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises. Procedia Cirp, 52, 161-166 (2016).
8. Liere-Netheler, K., Vogelsang, K., & Packmohr, S. Drivers of digital transformation in manufacturing. In 51st Hawaii International Conference on System Sciences (HICSS), Waikoloa, Hawaii, pp. 3926-3935. Shidler College of Business (2018).
9. Lichtenthaler, U. Building blocks of successful digital transformation: Complementing technology and market issues. International Journal of Innovation and Technology Management, 17(01), 2050004 (2020).
10. Schmid, A. M. Beyond resistance: Toward a multilevel perspective on socio-technical inertia in digital transformation. Twenty-Seventh European Conference on Information Systems (ECIS2019), Stockholm-Uppsala, Sweden, pp. 1-19 (2019).
11. Westerman, G. Your company doesn't need a digital strategy. MIT Sloan Management Review, 59(3), 1-5 (2018).
12. Müller, M., Alexandi, E., & Metternich, J. Digital shop floor management enhanced by natural language processing. Procedia CIRP, 96, 21-26 (2021).
13. Helu, M., Libes, D., Lubell, J., Lyons, K., & Morris, K. C. Enabling smart manufacturing technologies for decision-making support. In ASME 2016 international design engineering technical conferences and computers and information in engineering conference. American Society of Mechanical Engineers Digital Collection (2016).

14. Hirsch-Kreinsen, H. Digitization of industrial work: development paths and prospects. Journal for Labour Market Research, 49(1), 1-14 (2016).
15. Schwab, K. The fourth industrial revolution. Currency (2017).
16. Frank, A. G., Dalenogare, L. S., & Ayala, N. F. Industry 4.0 technologies: Implementation patterns in manufacturing companies. International Journal of Production Economics, 210, 15-26 (2019).
17. Westerman, G., Bonnet, D., & McAfee, A. Leading digital: Turning technology into business transformation. Harvard Business Press (2014).
18. Colli, M. Designing the transformation towards a digital supply chain: How to match the Industry 4.0 agenda to contextual needs and translate it into value (2020).
19. Cambridge Dictionary. (2020). Strategy. Retrieved May 11, 2021, from https://dictionary.cambridge.org/dictionary/english/strategy
20. Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., & Ivanova, M. A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0. International Journal of Production Research, 54(2), 386-402 (2016).
21. Mittal, S., Khan, M. A., Romero, D., & Wuest, T. A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). Journal of manufacturing systems, 49, 194-214 (2018).
22. Yin, R. K. Case study research and applications: Design and methods. Sage publications (2017).

Co-author statement – PAPER IV

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Declaration of co-authorship*

Full name of the PhD student: Pernille Clausen

This declaration concerns the following article/manuscript:

Title:	Teaching Old Dogs New Tricks - Towards a digital transformation strategy at the Shop Floor Management level: A case study from the Renewable Energy Industry
Authors:	Pernille Clausen and Benjamin Henriksen

The article/manuscript is: Published ☒ Accepted ☐ Submitted ☐ In preparation ☐

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If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No ☒ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	A
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	B
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	A

Signatures of the co-authors

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In case of further co-authors please attach appendix

Date: 16.08.22

*As per policy the co-author statement will be published with the dissertation.