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Digital Visualisation Tools to Bridge Communication Across Manufacturing – A Transdisciplinary Journey

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Abstract. The future of manufacturing is happening. Today's cyber technologies allow real-time visual control of various production processes in manufacturing through the intelligent utilisation of data. Having access to knowledge is power. Providing shop floor practitioners with the opportunity to gain and share knowledge across boundaries in manufacturing in the right way at the right time is a prerequisite to doing a proper job controlling a production line. Carrying out shop floor operations without visual control leads to actions performed in blindness based on gut-feeling decision-making and is often prone to errors. This paper investigates a practical problem of securing knowledge integration across production units on the shop floor and managerial stakeholders via a digital visualisation tool (a visualisation board (VB)). The study constitutes an instrumental case study and follows a transdisciplinary engineering process, outlining a collaborative approach with practitioners across various disciplines in a large manufacturing company in the Renewable Energy sector. The findings illustrate an unsuccessful approach to designing and deploying a digital VB. The paper's contribution is a set of lessons learned from an unsuccessful attempt that highlights the importance of socio-technical solutions to digital transformations as opposed to purely technical solutions.

Keywords. Transdisciplinary engineering, Communication across boundaries, Visualisation tools, Digital transformation, Shop floor operations.

1. Introduction

For several years, transdisciplinary research has been the focus in the context of dealing with complex and ill-defined problems in society and in engineering [1, 2]. The adoption of transdisciplinary approaches varies widely and is characterised by the environmental context of the problem [2, 3]. However, in the engineering domain, from a manufacturing perspective, Industry 4.0 (I4.0) has initiated several processes requiring transdisciplinary approaches to implement “smart solutions” on the manufacturing shop floor [2]: that is, technology implementation encompasses both technical and social disciplines [2].

Modern production systems put forward by I4.0 have increased complexity [4], resulting in complex problems of providing proper communication of information to support practitioner cognition on the shop floor when handling tasks [5]. On most occasions, shop floor tasks deal with unforeseen events that range across shop floor and departmental units in manufacturing [4], and for that reason, they cannot be easily

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predicted. In terms of the shop floor becoming a target for digitisation and digitalisation following I4.0 trends [6], both academia and industry highlight the need for better visualisation of production data in real time to guide decision-making processes for the handling of shop floor tasks [7, 8]. Following Meissner et al. [7], handling tasks relying on analogue approaches seems wasteful because too much time is spent collecting and processing data manually. I4.0 technologies have largely solved the problem of conveying information [9]; however, one of the current challenges that technology has not solved is an improvement of the ineffective transfer of information to the practitioners in close-range communication environments, such as at the team practices on the shop floor [9].

This paper investigates the problematic issue of integrating knowledge across production units and managerial stakeholders in a synchronous unpaced manufacturing setup in a large company within the Renewable Energy industry in the United Kingdom. This dictate adopting a transdisciplinary approach, as knowledge from different science fields and people from different practice communities is needed to create a solution that encompasses the stakeholders involved (see Wognum et al. [1]). Accordingly, the research constitutes a longitudinal case study that illustrates a technical solution of how to share production data from multiple data-acquisition systems through one data-stream via a digital visualisation tool to support shop floor practitioners in handling tasks in an unpaced flow-line across the manufacturing. The following research question guided the study: "*How can we ensure information delivery to the team practices on the shop floor via a digital visualisation tool for handling shop floor tasks?"*

The findings indicate that a technical solution to solve the research problem exists. However, the solution failed when tested in practice, as the research problem was not emphasised as a socio-technical system: a too high focus on the technological factors blindfolded the development when testing the solutions usage on the shop floor. This paper contributes to the theoretical discussion that technology implementations require a transdisciplinary approach encompassing technical and social disciplines. We argue that successful technology implementations require an understanding that ranges across the transdisciplinary interfaces to the problem, highlighting the need to develop both back-end and front-end capabilities in the organisation.

2. Theoretical background

Following the "smart" shop floor trends initiated by I4.0, several digital solutions to improve efficiency have been implemented on the shop floor [10, 11]. However, maintaining an uninterrupted production flow down the production line requires fast responses to deviations and access to the right knowledge of how to handle such tasks. As a shop floor is a constellation of various resources, such as manufacturing equipment, materials and the human workforce (practitioners), a heavy flow of data and information is generated. Especially on smart shop floors (with a high level of automation and computerisation), data is exchanged within the surroundings all the time [12]. Accordingly, following Jwo et al. [13], access to data is a requirement to manage manufacturing operations, as data is the focal point to handle shop floor tasks.

With I4.0 to the fore on the shop floor, an increase of the diversity of data and information is expected [14], along with an increasing number of complex tasks. Without proper access to data and information on the shop floor when handling tasks, manufacturing does not stand a chance of remaining competitive and viable [7, 8, 15].

Generally, in the context of a smart manufacturing (automated and computerised), the handling of shop floor tasks involves a team of practitioners having different disciplinary affiliations and knowledge, as different competencies and knowledge background is required to handle some tasks [16]; for instance, blue-collar workers, technicians, engineers, data specialist, team- departmental-, and plant manager(s). The handling of tasks constitutes a social practice of having frequent shop floor meetings [17].

At shop floor meetings (which take place in the production space [18]), the team of practitioners are gathered to receive a context-specific information update and handle associated tasks [19]: the task handled are often unforeseen derived from variations within the production plan. Shop floor meetings are highly standardised with a short duration time, some companies conduct these meetings every day (some, several times per day), while others hold weekly meetings, all depending on the production setup [20]. Visualisation tools such as visualisation boards (VB), this being a dashboard with various printouts attached, play a central role in the shop floor meeting practice [21].

For many years VBs have been considered of high material value in handling shop floor tasks, serving as a communication tool bridging communication across units in the manufacturing [22, 23]. Given the fact that the practitioners at the shop floor meetings have different backgrounds and different understandings, which might lead to different interpretations of the information visualised on the VB, the functionality of VBs is to transmit cues triggering a common understanding affording social interaction to guide the practitioners' handling of shop floor tasks [20, 24].

However, in the light of implementing digital solutions on the shop floor to increase performance, both academia and manufacturing now propose having a digital transformation of the VBs [7, 25, 26]. Given the new technological opportunities for connectivity of systems, analytics, and visualisation, VBs are considered a potential target for a digital transformation. Moreover, a digital transformation of VBs paves the way for increased utilisation of production data [14, 15, 27], which might benefit practitioners when handling shop floor tasks. Following the technology management literature, a digital transformation on the shop floor seems to constitute a straightforward way forward [14, 15, 27]; however, this does not seem to be the case regarding VBs. A study performed by Clausen et al. [26] reveals that the current widespread use of analogue VBs is prone to both social and technical hindrances and is regarded as a problem of a transdisciplinary character.

2.1. Towards digital VBs – a problem across transdisciplinary boundaries

Following Buer et al. [8], the digital transformation in manufacturing shows a slow-paced progress as many companies are still operating and exploring digital solutions at a more fundamental level than I4.0. However, even though digital technologies are taking hold in today's manufacturing environment, it seems that the understanding of a digital transformation as a sociotechnical system is immature [28], and that companies lack an understanding and practical experience of handling a situation that needs to encompass both technological and social factors [7]. Currently, it appears that the conventional belief suggesting that a higher level of digital initiatives requires less human interaction is misdirecting practitioners on the shop floor, as it currently seems to be the case that the technological factors are playing the central role [29]. However, although the technological factors are receiving great attention, practitioners are experiencing several technical hindrances when it comes to a digital transformation of the shop floor VBs.

According to Clausen et al. [26], manufacturing is trapped by the difficulty of overcoming the technical system requirements. It seems that poor conditions for automated data acquisition, access to valid data, inconsistent IT systems and immature IT architectures are hindering the integration of information and knowledge across manufacturing and thereby the digital transformation of VBs. Without well-functioning manufacturing information systems such as manufacturing execution systems (MES) transferring real-time production data across the manufacturing [30, 31], companies depend on solving tasks using production data collected by manual means. This leaves practitioners with limited transparency of operations and impacts the handling of tasks, as relying on production data determined by worker discretion is often prone to errors [32].

Furthermore, Meissner et al. [24] and Clausen et al. [26] address some of the social aspects to consider in having a digital transformation of VBs. They portray the cultural challenges of managing the transition processes of technical and organisational issues, as the transition processes call for changing the habitual way of working. Due to the companies ' current technical and managerial competence levels, the transition process is expected to become resource-demanding in time and training. In addition, Meissner et al. [24] add that there might be a risk that the practitioners on the shop floor will show resistant behaviour if they are not satisfied with the digital solution. Hence, the practitioners must be involved in the solution design to achieve their acceptance.

3. Methodological considerations

The paper draws on Stake's [33] instrumental case study of one of the production facilities in a large international manufacturing. The production facility is located in the United Kingdom and provides insight into the complex issue of integrating knowledge across a plant to handle shop floor tasks. The research question is investigated by following the development of a digital shop floor visualisation tool being a takt-time VB. The authors have been involved in developing digital VBs in the company since 2020. By participating in developing a digital VB to handle shop floor tasks, we aim to develop an empirical understanding that contributes to the ongoing discussion of the importance of transdisciplinary approaches when developing smart solutions on the manufacturing shop floor.

The data collection illustrates the need for a transdisciplinary approach. The analysis is based on Dubois and Gadde's [34] systematic combining approach of being iterative in going- back and forth between empirical data and theory. Adopting this approach seemed beneficial in bridging the empirical materials and expanding our understanding of the subject when investigating the research question. The abductive logic guided the data collection through the authors' gradually expanding understanding of the empirical- and theoretical material. The empirical material is comprehensive due to a two-year-long collaboration. Table 1 provides an overview of a top-layer perspective of the primary data sources and primary people involved in the study of investigating the research question. As an additional note to table 1, it is shown that the production workers are entirely disregarded by only being represented by their team lead or production unit managers. The production workers are not included in the study because they are not included in the shop floor meetings as the team leaders represent their voice. Although the production workers deliver the data input to the designed solution, the case company did not include them before testing it on the shop floor.

Table 1. Data collection overview

Data source	Shop floor level	Management level
Observations	Shop floor meetings involving: team leaders and production unit managers	Daily management Gemba meetings involving: production unit managers, manufacturing specialists, data collectors, lean department, quality department, operational excellence department, digitalisation department, finance department, supply chain department, the plant manager
Unstructured- and semi-structured interviews	Team leaders and production unit managers	Manufacturing specialists, data collectors, lean department, digitalisation department, specialists, operational excellence department, plant manager
Workshops	KAIZEN workshop –VB design: team leaders and production unit managers, lean department (facilitator)	Design workshops: lean specialists, production unit managers, digitalisation department and operational excellence manager
Company documents	Production planning documents, Production data reports (deviation reports, performance reports etc.), lean project reports and similar	Project documents, management reports, VB design documents and similar

4. Case description

The case company develops and manufactures wind turbines, and the production facility which constitutes the research case produces blades. The manufacturing setup is a synchronous unpaced flow-line, defined as a takt-time production by the company. The production line constitutes five production units with varying cycle times. Currently, analogue visualisation tools (takt-time VBs) are applied to monitor and control the progress of the workstations in the production units by conducting shop floor meetings every two or three hours. Shop floor meetings are highly standardised and is completed within two-five minutes; the meetings are not held across production units.

4.1. The current state – applying analogue takt-time VBs

The analogue takt-time VBs display a comprehensive Gantt chart showing planned and actual progress of accomplishing activities in each workstation. The takt-time VB is updated manually at the shop floor meetings; updating the takt-time VB frequently is crucial for handling tasks, as the update identifies whether the workstations are on or behind the plan. Unplanned deviations happen every day and result in more tasks to solve. If tasks are not solved right away in one of the production units it might cause a production stop, which influences the whole flow line across the plant. However, it is often the case that deviations are identified too late, as the necessary information do not reach the team practices at the workstations in time. It is only team leaders and production unit managers that attend the shop floor meetings. For that reason, it comes down to the individual team leader how well the information is shared with the team practices (the production workers) at the workstations.

Production data are collected through different means. Some data is written down on paper, others directly on the takt-time VBs, or through manual bookings in a MES system.

Unit lead time, process cycle time, downtime, deviations, and overtime constitute the collected production data. The MES system is limited to capture all types of production data. In order to document the production data written on paper/VBs, team leaders are taking pictures of the writings and uploading them on a SharePoint site, from where a data collector team will type the production data into excel sheets. Much time is spent on data cleansing as the collection methods are prone to errors (e.g., illegible writings or wrong bookings in the MES). The production data is shared in multiple SharePoint folders. The data collector team together with the lean department analyse the production data. Performance reports are distributed in the plant every Monday. The report is briefly presented at a Gemba management meeting; the information does not reach the shop floor's team practices sufficiently.

Two daily Gemba meetings are held online via Microsoft Teams at 9.00 AM and 3.30 PM. The meetings are held online to accommodate a high number of participants across the plant. The Gemba meetings are the only planned events that serve to align operations across the production units on the shop floor. Information regarding monitoring and controlling the production line is primarily shared between production managers and the lean department from the five production units. If tasks are handled at the meeting, it is done retrospectively as events only are reacted upon after they occur; the information becomes first visible through experiencing a deviation as not having access to production data in real-time limits transparency of operations.

4.2. Towards the desired state – the development of digital takt-time VBs

In 2020 the plant initiated a project of having a digital transformation of the analogue takt-time VBs; the VB should release new functionalities to ensure that the team practices on the shop floor is sufficiently supported when handling tasks by:

- Visualise production data in real-time
- Make production data easily accessible and available for all
- Provide transparency of ongoing operations across the production
- Bridge communication between management and shop floor
- Eliminate the time spent on administrative tasks (e.g., updating the VBs manually) to allocate more time on other tasks
- Improve conditions for monitoring and controlling the production through advanced analytics (be proactive towards the handling of tasks)

The project was paused after launching a prototype test in December 2020, as the test results were not considered successful. Although the preliminary planning of the project had been approved ahead of the project execution by top management, the complexity of ensuring a digital takt-time VB that fulfilled the above functionalities was something the project team were unable to deliver. The project team experienced a need for full collaboration across the whole plant; something they not calculated for.

The authors of this paper followed the project from its beginning in 2020 until it was paused in January 2021. As the project is of high importance within the company, the plant wanted to take up the project again in 2022. To avoid making the same mistakes, the plant requested a comprehensive pre-planning before writing a new project application. One of the authors was invited to visit the plant for five weeks in November and December 2021 to support getting the project up and running again. During these five weeks, the author worked full-time to develop a "status quo" report of the previous work done to document the learnings from the failures.

4.3. Knowledge integration via digital takt-time VBs – the learnings from failure

The investigation carried out by the author led to a clear understanding of the reasons for the project's failure in 2020; the project team focused solely on the technical aspects of the project (the back-end development for a digital takt-time VB) without receiving buy-in from the stakeholders on the shop floor (production workers, team leaders and production unit managers). The project team believed they had a profound understanding of the solution requirements, but later, it was revealed that they were unaware that the five production units needed different features on the digital takt-time VB. They assumed as since the same type of production data was collected in all five units, the solution interface and features should be identical for all units. Although the units rely on the same type of production data, they apply it differently when solving tasks as they run into different types of deviations. As the need for extensive customisation for the digital takt-time VBs was identified too late in the software development process, the team could not deliver a satisfactory solution to the shop floor.

Moreover, the practical issue of collecting production data in real-time was a complex task to overcome for the project team. The project team was limited in rethinking the current data collection approach of going from manual to automated collected data, as top management evaluated this being too comprehensively. The project team then strived to develop a solution that aimed to eliminate the multiple systems in which production data was stored and difficult to access. The vision was to develop a new data flow system that allowed access to production data via one SQL database. Figure 1 provides an overview of the top-layer design solution integrating knowledge to the team practices via a digital takt-time VB.

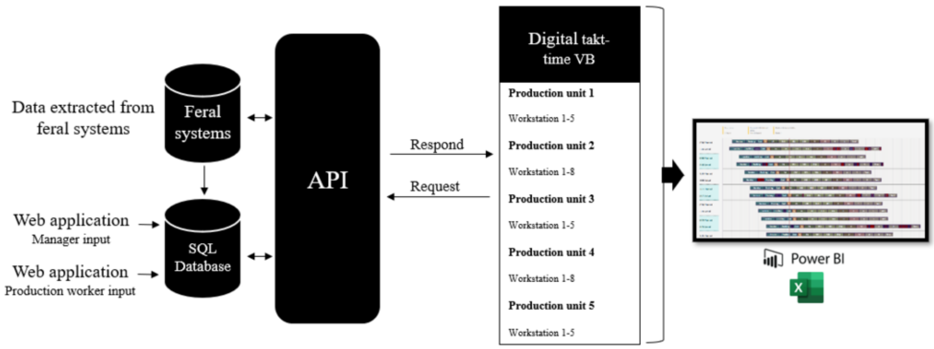

Figure 1. Overview of the design solution for the digital takt-time VB

From the proposed design solution visualised in Figure 1, a web-based application to collect production data was developed to ensure production data input from the production workers and managers. To ease the data access, the web application is connected to a SQL database which is further connected to a web-based Application Programming Interface (API) to improve interoperability among IT systems by standardising interfaces. The solution proposes a new data collection system that does not have limitations in registering relevant production data. However, the data must still be registered manually; for that reason, using the web application demands more control of making valid bookings in the system to avoid retrospect invalid bookings. However, top management has decided that the web application must not substitute the bookings currently made in the MES system (a global company requirement). Hence, the new solution results in more time spent on collecting data for the production workers.

Feral systems that might provide relevant data to support handling tasks being gathered outside the production (e.g., warehouse information and employee training log) are connected to the web application via the API. This makes it possible to access and to stream data to the digital takt-time VB in a one-data stream point from the SQL. Data will be easily accessible by being converted to excel files, which makes it possible to conduct PowerBI analytics at the digital VB.

On paper, the proposed design solution meets most of the listed functionalities for increased knowledge integration listed in section 4.2 to support the handling of shop floor tasks. However, when the test was performed, it was revealed that the solution was not feasible, as the production workers would not spend more time making bookings. The production workers were first introduced to the project and the solution when they were requested to participate in the test. Only a few people on the shop floor were aware of the ongoing digital transformation of the analogue takt-time VB. If the project team had spent more time on the shop floor, they would have detected that getting the production workers to make data bookings in the MES is something they are not good at, as they have no understanding of why to do it; no one has emphasised its importance. The production unit managers are responsible for the bookings, but due to a heavy workload, it is easy to neglect this area. Furthermore, the production workers are measured heavily on performing their tasks on time, so spending time on bookings is considered a waste of time. They generally have low trust in the system, as they experience system failure several times per week.

5. Discussion and concluding remarks

Following Wognum et al. [1, 2], the implementation of “smart solutions” (like a digital takt-time VB) must be handled through a transdisciplinary approach as it deals with both technical and social disciplines. The case presented in this paper illustrates a complex manufacturing implementation like Wognum et al. [2]; however, the handling hereof was not based on a transdisciplinary approach that emphasised both the social and technical factors of the solution. For that reason, the case makes up an excellent example of why such implementations require adopting an approach that range across disciplines. The case learnings emphasise the need for full identification of the environmental setting in which a solution must be implemented to accommodate all contexts of the problem to ensure a successful implementation, as suggested by Mitchell et al. [3].

This paper aimed to investigate how to ensure information delivery to shop floor team practices through a digital visualisation tool supporting the handling of shop floor tasks, a subject being heavily discussed in recent years [10, 11, 14]. Being one of many in the Technology Management literature, Jwo et al. [13] argue that access to data is the focal point for handling shop floor tasks in manufacturing. Following the enormous emphasis on the technical aspects of the implementation of smart solutions in the literature, it seems to be the case that companies are stuck with this conventional belief. The case findings echo this approach. Although access to data is key for every digitalisation project, the transformation aspect does not exist without considering the social aspects, as in this case, people are the users of the outcome from the digital transformation; the solution should be guided by their demands.

The case data witness that ensuring information delivery to the team practices on the shop floor via a digital visualisation tool does not only consider technical aspects, although it seems like it when you read the research question aloud. Even though the company succeeded in developing a technical solution that ensures information delivery to the team practices, the solution was useless. It was not built on the conditions to match the social factors that constitute the operational environment for the solution. The tool was unable to fulfil its purpose in two areas; first, it was unsuccessful in getting data into the system, and second, it was not designed with the right features to support the production units to handle their tasks due. Both failures were prone to a development process not ranging across disciplines; a solution developed to the shop floor did not include the shop floor. Hence, the company lacked experience in implementing a smart solution through a transdisciplinary approach; in general, a problematic issue in manufacturing [7, 28].

The focal point of this research was to investigate how to ensure information delivery to the team practices on the shop floor via digital takt-time VBs to handle shop floor tasks; it seems the answer to this question relies on **how to approach** this transdisciplinary problem. Rather than describing **how to attempt** a successful digital transformation of digital VBs, the results obtained an answer on **how not to attempt it.** The case illustrated that a technical solution exists; however, the solution did not prove successful when implemented. The lessons learned from the unsuccessful attempt indicate that a digital VBs not can be implemented without understanding the use contexts and conditions on the shop floor; when these are known, the prerequisite to guide the development of a solution can be outlined.

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