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Empowering shop floor management through a collaborative information dashboarding tool

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Abstract

Impending digitalization, driven by Industry 4.0, makes a digital transformation of the shop floor inevitable and is expected to affect LEAN practices at a shop floor management (SFM) level. The goal of this paper is to explore what digital SFM could look like in an era of digitalization through the development of an information dashboarding tool that supports the continuous improvement of processes within a manufacturing company digitally. Data visualization principles and a tangible user interface was used to create an information dashboard proposal to improve problem-solving and decision-making capabilities. Key Performance Indicators, the drivers of production, are contextualized and presented at three distinct levels (factory, department, detail) along three different timelines (has-been, as-is, could-be). The information dashboard serves as a tool for showing data but is limited by the quality of the data it presents and the culture of collaboration within the factory. The information dashboard is expected to be a useful tool for digital SFM which could be expanded if the factory digitalizes even further.

Keywords: LEAN; Industry 4.0; shop floor management; information dashboarding

1. Introduction

Over the past few decades, the manufacturing environment has become increasingly complex, leading to the rise of LEAN in the professional environment as a method to manage manufacturing at a larger scale [1]. One crucial component of LEAN manufacturing is the striving for the continuous improvement (CI) of processes within a company, also known as kaizen. To create a culture of CI, shop floor management (SFM) is often implemented as a leadership method [3]. Although an exact definition of (SFM) is not agreed upon, some commonly occurring components of SFM can be identified [2,3]. A central aspect of SFM is the fostering of problem-solving processes, in which employees are seen as, and encouraged to be, active participants [2]. Furthermore, to create transparency within and across the smaller teams in which production is organized, CI is made explicit by tracking Key Performance Indicators (KPIs), the drivers of production [2]. KPIs are unique to an organization and can, for example, include measures on safety, productivity, and quality. To operationalize CI in a company, regular meetings are held by shop floor managers in front of visual management boards containing these KPIs, located on the shop floor itself [3]. For CI to be successful, the entire manufacturing company needs to be actively involved, from upper management to individual workers on the shop floor itself [1].

As the focus on digital possibilities, driven by Industry 4.0 increase, LEAN manufacturing companies must face impending digitalization [3] that is expected to impact operations at the SFM level greatly [4]. Although many manufacturing companies are undergoing a digital transition [4], most are far from being paperless. Traditional LEAN literature even suggests the use of analog materials for information collection and problem solving to increase employee engagement [3]. Indeed, manually updated SFM boards are still a common occurrence [4] with data from the factory being updated daily to be presented in a static manner on white boards [5]. Digital boards at a SFM level are rare, and even if they are used, most seem to simply be digital copies of their analog counterparts without optimally making use of technological opportunities for enhanced information management or visualization [4]. Rather than sticking to the traditional perception of SFM boards to create digital variants, reimagining what SFM could look like with the use of information dashboarding can provide new opportunities for CI practices. An information dashboard is a set of (visual) resources that is designed to support its audience in understanding and gaining insights into the displayed data, easing knowledge discovery [6]. Such dashboards lend themselves well to customization, allowing users to configure their dashboard without any programming skills required [6].

The goal of this paper is to explore what SFM could look like in an era of digitalization through the development of an information dashboarding tool that supports more efficient, paperless LEAN meetings to promote CI. To reach this objective, relevant data, with at the heart KPIs, must be easily accessible to identify problems and solution directions in a collaborative setting, involving employees across various levels in a manufacturing company. Short background research on digitalization is completed first, before the concept proposal and its potential implementation is discussed and evaluated.

2. Literature review

As digital possibilities increase, a digital transition of the shop floor is inevitable [3]. Digitalizing has many benefits for a manufacturing company, as well as for management and employees specifically. First, automated data acquisition saves employees and managers time, as information is updated automatically. Furthermore, the merging of this acquired data becomes less complex, and more diverse opportunities become available to evaluate it [7]. When data is real-time and of high quality, early warning and prediction of issues are made possible [8]. This allows for the creation of proactive responses, rather than immediate ones. Moreover, due to digitalization, employees and managers are assisted in problem-solving and are forced to document properly [7]. This digital problem-solving and knowledge management not only makes communication cascade but also makes the communication between teams easier [7,8]. Digitalization can thus bring about many benefits and opportunities for companies. However, when data is digitalized, risks are also involved. Most of all, incorrect data can be recorded through the system, or be interpreted incorrectly; giving a wrong interpretation of the production process [7]. Furthermore, the automated acquisition and merging of data may cause employees to not identify with it anymore. This can, for instance, happen if too many KPIs are tracked. Other than losing identification, employees might be reluctant to handle the new software [7]. Digital SFM may also be seen as a management monitoring tool by employees, as it may lead to the manager spending less or too little time on the shop floor [7].

To execute a digital transition, manufacturing companies need to classify themselves in one of four maturity stages [9]: (1) passive (reactive) management and control in which data is collected mostly via analog means; (2) real-time management and control in which smart sensors make real-time data available; (3) predictive management and control in which larger amounts of data is used to make predictions on e.g. disturbances; and (4) proactive management and control in which the system can autonomously make decisions based on prediction results. Currently, SFM often takes place in the first stage: passive management and control. Thus, the aim of digitalization in many cases is to move SFM towards the next stage: real-time management and control. According to Clausen [10], a habitual managerial mindset can inhibit such a digital transition. Moreover, even if manufacturing companies are already gathering data digitally, visualization and analysis of this data is often still lacking [10].

2.1. Designing for digitalization

To visualize data gathered from the manufacturing environment, the visual management principles of Bateman [11] can be applied. These principles refer specifically to the visualization of data in management dashboards, a type of information dashboard. An dashboard should reflect the flow and structure of the subject [12,13], i.e., the shop floor, and thus calls for logical data contextualization. Moreover, it is key to choose the right graphical tool for the visualization and contextualization of data. Few [14] emphasizes that the focus of an information dashboard should be on functionality and usability. To increase the usability of an information dashboard, tangible user interfaces (TUI) could be applied. This means that instead of the usual interaction with a digital world through a touch screen or keyboard and mouse, physical representations of a digital object are used as an input to manipulate the digital output [15]. The use of such physical objects could play a key role in contextualization and problem solving [16]. Interaction with objects plays a significant role in our ability to define relations and aid in the cognitive processes by contextualizing information in such a way, using those objects, that our mind is doing less of the "thinking". Not only interaction of an individual with a TUI could provide a lowered threshold for cognitive processes, but there is also strong evidence that interaction between multiple people (using TUIs) contributes to improving problem-solving [16,17].

In conclusion, digitalization on the shop floor has many benefits but also poses some risks, such as employee reluctance to use the new technology. As employee participation in problem-solving is crucial in SFM, the to-be-designed information dashboard tool should mitigate this risk. Furthermore, companies need to be aware of which maturity stage they are in to be able to move to the next stage (i.e., real-time management and control). When designing for digitalization, several visual management principles need to be considered with of especial importance the need for picking the right tool and structure (i.e., contextualization) to display the data. TUIs provide an interesting starting point in creating an information dashboarding tool for SFM to support CI, as they can play a key role in contextualization and problem solving, helping users in connecting the available data to the reality of the shop floor.

3. Concept proposal

To empower SFM in LEAN manufacturing companies that are moving towards (or are currently) in real-time management and control, an information dashboarding tool is proposed. The aim of this tool is to aid management in finding problems and solution directions for CI collaboratively with all types of employees, within and outside the management department. Gathered data is visualized and analyzed in a digital environment and format rather than the commonly used analog format.

3.1. The information dashboard

The proposed information dashboard provides intuitive access to factory data through a table which combines touch screen possibilities and a tangible user interface to facilitate the exploration of different KPIs with multiple users at the same time (Figure 1). The dashboard acts as a window to the databases of the company and contextualizes this data within the floor plan of the factory, where users can zoom in and out between factory, department, and detail level information. Contextualizing this data is important to show the flow and structure of the information, as required by the aforementioned visual management principles. Moreover, it prevents a loss of identification with the data and thus increases the chance of correct interpretations. Aside from providing information at three distinct levels, the information can be viewed across three different timelines as well: has-been, as-is and could-be. This allows users to analyze data to discover problems and potential solution directions based on the past, current and potential future states of the factory.

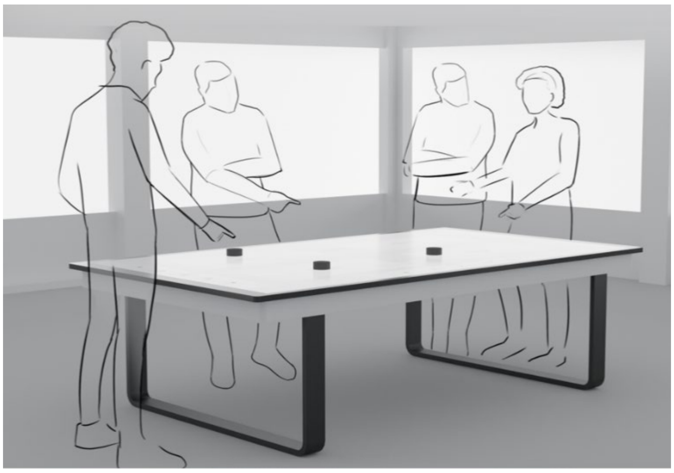

Fig. 1. An optimization meeting around the information dashboard.

The information dashboard itself has 5 basic functions:

- Compare KPIs between different sections of the production line
- Access data of a specific section within the production line (for example a machine, workstation, or department)
- Reconfigure data of a section and save the configurations
- See the effects of configurations on the KPIs of the whole production line
- Compare configurations in different scenarios

As mentioned previously, the interface of the information dashboard shows the factory floor plan through three different information levels. At the factory level, users can access and compare data between different departments within the factory. At the department level, users can access and compare data between different machines within the factory. When viewing either the factory or department level, a physical puck can be placed on a department or machine to access detailed information, like a list of safety incidents or statistics of the productivity of the machine (Figure 2). The puck functions as both a physical representation of the current source of information that is selected, as well as a tool for navigation through KPI relevant data which is related to the selected object. Subsequently, from the information shown, different scenarios can be created by altering department/machine KPI performance or quantities. These created scenarios can then be saved and used for comparison with the current situation, giving insight into potential solution directions for CI. By using multiple pucks, multiple departments/machine windows can be opened at the same time and be viewed separately or be used to compare different departments/machines, enabling collaboration between the involved parties.

Fig. 2. Additional information accessed by use of the puck.

To navigate between levels and to manage the shown information, the dashboard contains four different toolbars: (1) the level toolbar, to switch between the factory and the department level; (2) the KPI toolbar, to select the to be shown KPIs; (3) the period toolbar, to select the period from which the data is shown; and (4) the scenario toolbar, to switch between created scenarios and be able to compare them.

3.2. Required hardware

Touch gestures or pucks can be used to control the dashboard interface. Two technologies are applicable to capture such inputs: Protective Capacitive (PCAP) touchscreen and infrared (IR) frame and overlay [18].

PCAP screens use a conductive layer underneath protective glass to accurately identify the touch location [19], whereas IR touchscreens project an IR light grid on top of a display, and touch is captured as distortions in the grid [18]. PCAP screens are durable, which is ideal for an industrial environment, whereas the IR LEDs are sensitive to dust, which could be a dealbreaker in an industrial environment. PCAP touchscreens have a relatively high purchase cost, potentially a barrier for the implementation of new technologies, whereas an IR frame comes at a considerably lower price range.

Industrial suitability is determined to outweigh the costs, as reliability of the system is crucial. Therefore, a PCAP screen is recommended to be the most appropriate choice for the factory setting in which the information dashboard will be located.

As a PCAP screen is recommended, the puck design requires three capacitive touch points that conduct electronic signals similarly to human fingers. The three touchpoints allow for stable and comfortable rotation, increasing the usability of the product, and let the touchscreen detect a triangular input to trigger a navigation menu to display KPI relevant data.

3.3. Connection to the IT landscape

To display KPI relevant data, the information dashboard will need to be connected to a manufacturing company's available Business Management Software (BMS) that stores this data. In addition to BMS, some companies might make use of a Digital System Reference (DSR). A DSR is the collection of the actual real-time state of the production facility, as well as a digital representation of the intended- and potential state to act as a source for organization and management of shop floor data [20]. As a DSR can provide real-time data through e.g., smart sensors, it can result in more accurate data portrayal on the information dashboard.

To illustrate the communication between the proposed information dashboard, available BMS and potential DSR, an information flow diagram is created (Figure 3). Starting at the left side of the diagram, the shop floor interfaces make required data from the BMS available to workers on the shop floor (such as a list of tasks, or questions for quality control), and gathers relevant data from these worker (such as completed tasks, answers to questions about quality control) to feed back to the BMS. Moreover, the DSR can automatically collect relevant real-time data such as machine error codes. The information dashboard, once placed into the manufacturing environment, then needs to interact with the BMS and potential DSR to access the right data. As each type of BMS has a different data communication method when it comes to sharing information, a translation step needs to be made. Middleware is introduced, to act as an interpreter between the operating system of the information dashboard, and each different type of available BMS (and possible DSR). The BMS (and/or DSR) will send relevant information to the middleware when requested by a user on the information dashboard. Data created by users on the information dashboard, such as scenarios, are stored separately in the table's cloud storage.

3.4. Implementation advice

Implementing the information dashboard requires an approach where both the client - a manufacturing company- and the information dashboard provider are actively involved. The first step to implement the proposed information dashboard is to tailor the solution to the client through the selection of relevant KPIs. The way in which KPI relevant data is displayed could be subject to tailoring as well. With the rise of Industry 4.0 most aspects of factories are being digitized [21], and as a result, this data is often already captured and stored in BMS.

The value of the proposed solution depends entirely on the amount and accuracy of the data that can be accessed and contextualized. However, the extent of digitalization will differ for each client. As a result, the missing capturing and or digital systems will need to be set up, next to a solid Internet connection, if not yet available, to facilitate the different data flows. Moreover, the middleware facilitating the connection between the information dashboard and BMS/DSR needs to be established. Once the correct data can be gathered, stored, and accessed, this data still needs to be mapped on a floor plan of the factory in question, providing the necessary contextualization. The duration of the implementation process highly depends on the extent of the client's digitalization. In the ideal case, all the data is already being collected and this data only needs to be accessed and contextualized.

After setting up the system, the information dashboard should be placed in a central space within the factory, preferably on the shop floor itself. Here, the information dashboard functions as a location to gather around for meetings but also as a place for employees and managers to retrieve information at any time. The setting of the optimization meetings becomes a literal "gathering around the table" in comparison to the traditional presentation with an audience. This allows for a certain level of interaction with each other as stakeholders and lessened hierarchy in perspectives on analyses.

As the information dashboard is proposed to be placed on the shop floor, a certain robustness is required. The proposed PCAP screen used is a proven and reliable technology, which is not sensitive to dust or other particles which may be present in a factory environment [19]. Other than that, there is no need for dynamic or electronic parts to use the puck on a PCAP screen.

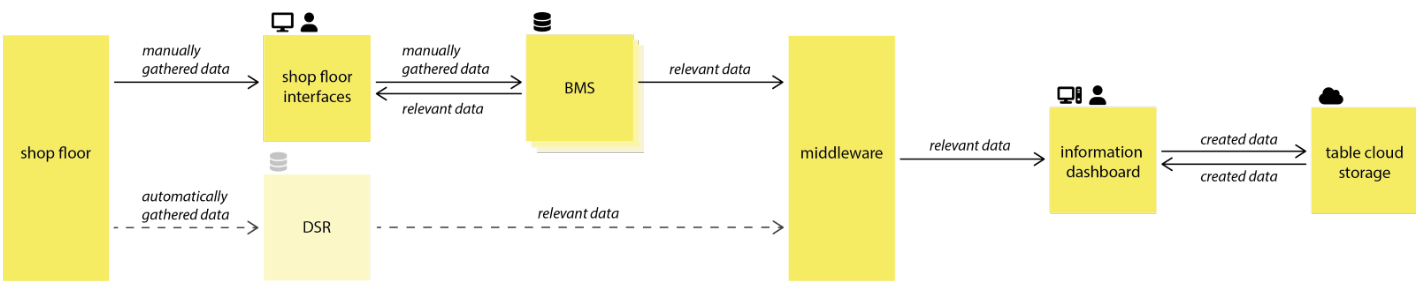

Fig. 3. Information flow diagram.

3.5. Workflow integration

Several scenarios are discussed to explore in what ways the proposed information dashboard can be integrated in the workflow of LEAN manufacturing companies to support CI practices. Although the information dashboard is not able to solve problems itself, a solid basis for discovering problems and solution directions is provided by the contextualization of relevant data in the factory environment.

Shop floor manager meeting: Productivity improvements
All shop floor managers within the factory have come together to discuss the production flow between their departments. By activating the production flow KPI in the factory overview over the past six months, the assembly department is identified as a major bottleneck. Zooming in shows that one of the assembly steps is a lot slower than the others. The shop floor managers tweak the productivity of this step and find that its output needs to be increased by 31% to solve the bottleneck. At the next daily shift meeting, the shop floor manager mentions the problem and it becomes clear that finding the right parts for assembly is a tedious process that could be improved. He/She notes the solution direction down and schedules a group-oriented kaizen to brainstorm concrete ways to solve the bottleneck.

Employee team meeting: Safety improvements
Several employees of a department have been brought together with their shop floor manager for group-oriented kaizen and gather around the information dashboard. One employee raises concern about safety within the department – just last week, he tripped and fell, spraining his wrist. Whilst in the factory view, he activates the safety KPI that shows their department has a high incident rate. One employee places a puck on the department to discover what kinds of accidents are most common. The displayed statistics show that most accidents constitute slips and falls that take place early in the morning. The shop floor manager orders an inspection of the shop floor which shows visibility in certain parts of the department is poor. After better lighting is installed to prevent future accidents, the information dashboard indeed shows a lowering of the incidence rate.

Gathering quick insights: Machine standstill
A machine has come to a standstill due to a blockage. When the shop floor manager arrives at the site, the employee operating the machine has resolved the blockage already. Still, the shop floor manager is curious to see how frequently such a problem occurs and, after discussing the issue with the employee, consults the information dashboard to gather more insights. He starts by comparing the downtime of the blocked machine with that of a similar one in the factory by placing a puck on each. The machine in question seems to be blocked a lot more frequently than the other machine. However, when changing the timeline to view the data of last month, the machines have more similar downtime statuses. The shop floor manager decides to order a thorough inspection of the entire machine to see what the cause could be, rather than simply having the employees continue to fix the blockages.

4. Evaluation

To evaluate whether the proposed solution holds any merit, a working prototype was built to evaluate the solution with different stakeholders. This prototype consists of two separate components: one focused on interactions on the department/factory level (built with Adobe XD) and one focused on the interactions on a detail level (built with Unity). A 55” 4K screen, with an IR touch overlay and frame, was used to display and interact with the information dashboard and a 3D printed puck served as a prototype for the tangible interface.

The prototype was used to hold a user test with four participants. These participants are familiar with the location used for the prototype and either have a management function or work directly on the shop floor, hereby fitting the envisioned target group of the product. The participants were given different contextualized tasks, centralized around navigating through different information levels and usage of the puck to obtain in-depth information on department or machine level. While executing these tasks, the participants were asked to elaborate on their actions by explaining their decisions aloud. These comments were noted down alongside observations that were made by the research team, to draw a conclusion on the comprehensibility of the prototype.

The test results revealed that the information dashboard is intuitive, but only after getting to know its abilities and limits. The participants suggested an initial training for toolbar navigation and puck usage would solve this issue. The latter was confirmed to be a useful addition as it served as “an additional hand to hold on to a topic or information.” Moreover, rather than using the information dashboard, some shop floor employees were inclined to answer a question based on their prior knowledge. This shows the engagement of the employees with the material and indicates that the information dashboard can support discussion points by backing up such speculations by using data. Potential value was seen in our idea to personalize the information dashboard by tailoring the choices of KPIs to the needs of each individual company. One participant even suggested to replace the KPIs with the provision of instructions, material use and energy consumption to make the information dashboard fit a university workshop. Lastly, the participants concluded that the information dashboard is a promising means to facilitate discussions in a manufacturing company, so long as said company is open for non-hierarchical collaboration. If the hierarchical organization in a company has strict separation between shop floor employees and management, it might be that the information dashboard cannot reach its full potential due to the exclusion of shop floor employee knowledge.

5. Discussion

5.1. Limitations of the concept proposal

The goal of this paper is to explore how digital SFM could use information dashboarding to facilitate efficient, paperless LEAN meetings to promote CI. The proposed concept is an information dashboard which allows users to explore KPIs of their working environment to foster identification of problems and potential solution directions.

Four limitations were identified which might limit this design from fulfilling its purpose. First, the effectiveness of the dashboard is dependent on the culture of the manufacturing company. It is essential that the manufacturing company allows for non-hierarchical discussions, such as collaboration between shop floor workers, SFM, and upper management. As the tool is designed for companies who wish to improve their CI meetings, manufacturing companies with a traditional organizational structure will not benefit from the full potential of the tool. Second, the middleware should be fitting to a variety of business management software. Each type of software used by potential clients will have different APIs and interfaces. We suggest that future research focuses on how to select which BMS to develop the middleware for, as it is not viable to develop middleware which can connect to all types of BMS from the first version. Fitting to the previous limitation, the third limitation of the concept proposal is the tailoring required to implement the dashboard at a client. Each client will have their own specific selection of KPIs, as well as their own specific IT infrastructure. For a client to implement the dashboard on their shop floor, meetings and programming work are required to ensure that the company gets access to the KPIs they wish to see. Finally, the effectiveness of the solution depends on the data accuracy that is available within the IT environment of the company. Incorrect data can lead to incorrect conclusions.

5.2. Short-term opportunities

To further develop the information dashboard, it is essential that user interface/user experience research is conducted to optimize the usability of the dashboard. Aside from optimizing the information dashboard itself, we foresee the possibility to create an ecosystem of products around the information dashboard to increase the value of the proposed concept. These additions are regarded as short-term improvements, since it is expected that these suggestions could be added to the dashboard with relative ease, once a functional dashboard is in use by clients. The first proposed addition is the use of mobile extensions. Offering a mobile extension of the dashboard, in the form of an application on a tablet or smartphone, could further empower shop floor managers by enabling them to view machine data and digitally leave notes at machines whilst on the shop floor. Next to that, a company might want to display up-to-date and concise KPI information in a variety of locations on the shop floor. Presentation screens could be placed throughout the manufacturing facility to make information gathered or created in the dashboard even more accessible.

5.3. Long-term opportunities

Currently, the tool is designed to be used for real-time management and control, the second stage of maturity of digitalization as described by Zhuang [9]. If companies grow in maturity and strive to shift to predictive- and eventually proactive management and control, the concept proposal could be further expanded to capitalize on this transition.

As manufacturing companies mature in their usage of IT to facilitate decision-making, and collected data becomes more relevant and accurate, the concept, which is placed as a junction between the BMS and DSR could be used to create simulations to facilitate predictive management. In other words, as companies mature in their approach to data collection and processing, the concept could grow in maturity as well.

Another long-term opportunity is to further expand the proposed ecosystem of devices which can aid in contextualizing data on the shop floor. Augmented reality (AR) has proven itself as a useful tool to aid in visualizing data and problem-solving [22] and can be used to further enhance mobile extensions by overlaying and contextualizing data on the shop floor. We suggest future studies to consider how AR (but also other immersive data visualization technologies, such as VR or MR) can be applied effectively on SFM level with the proposed information dashboard as a central information hub.

6. Conclusion

Digitalization in the manufacturing environment knows its benefits and risks. It was found that awareness of the maturity stage of a manufacturing company allows for a digital transition towards the next stage, realizing the benefits while possibly also preventing risks. We proposed an information dashboard that companies currently in, or moving towards, a real-time management and control stage can implement. The dashboard contextualizes information within the floor plan of the factory, and users can zoom in and out between various levels of detail in different timelines. User tests of a functioning prototype show that it is possible to support professionals with problem-solving on the shop floor.

The concept is dependent on a match with management style of the manufacturing company, the quality of the middleware which connects the dashboard to a company's BMS and DSR, the extent to which KPIs can be tailored to the company's wishes, and accuracy of data available. Therefore, more research is required into the feasibility of developing a generalized dashboard that is sufficiently tailored to the wishes of a manufacturing company.

By implementing an effective dashboard which reaches its main goal of making contextualized data available in a collaborative setting to foster CI practices in SFM, we can prevent LEAN manufacturing companies from becoming data-rich, but insight-poor in an era of digitalization.

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