Discovering information inefficiencies in manufacturing processes with modified value stream mapping

An analysis approach for facing the challenges of Industry 5.0

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ABSTRACT

Manufacturing environments that rely on empowered shopfloor workers with decentralized decision making, as proposed in the Industry 5.0 vision, call for adapted approaches to production management. Aside from personal competencies, efficient decision making in VUCA environments primarily requires high-quality, up-to-date information. Based on popular value stream mapping methods, this paper proposes an approach to systematically analyze the shopfloor decision making in terms of information efficiency. The modified value stream mapping approach (MVSM) offers support for discovering informational bottlenecks in manufacturing processes, which subsequently can be addressed with targeted optimization measures. Qualitative results from the first practical implementations indicate the capabilities, limitations and improvement potentials of the proposed approach.

CCS CONCEPTS

• **Applied computing**; • **Enterprise computing**; • **Business process management**; • **Business process modeling**;

KEYWORDS

Industry 5.0, Value Stream Mapping, Information Inefficiencies, Shopfloor Decision Making

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1 INTRODUCTION

The term Industry 4.0 (I4.0) describes the digitalization and automation of the entire production cycle, with a focus on networking and the exchange of information between humans and machines. The aim is to increase the efficiency of manufacturing processes while retaining high flexibility regardless of decreasing batch sizes [1]. The I4.0 approach seeks to reach this vision through automation with the heavy use of AI-driven technologies [2].

However, highly automated manufacturing environments tend to be too rigid when faced with unforeseen circumstances. Events like the COVID19 pandemic, climate disasters or geopolitical shifts have shown the fragility of manufacturing processes and entire supply chains in volatile environments. Learnings from these situations have led to the emergence of a new digitalization concept called Industry 5.0 (I5.0). I5.0 offers an enlarged perspective, highlighting the importance of research and innovation to support industry in its long-term service to humanity within the limits of the planet. The main change in comparison to I4.0 is the shift from a technologically-driven approach to a human-driven, sustainable and resilient approach [3].

Within this new philosophy, technology becomes a tool that should empower employees and enhance their skills to handle day-to-day challenges in VUCA environments. This also implies that standardization within the manufacturing process is only desirable up to a certain degree, since unexpected events will be handled and managed decentrally by skilled and empowered employees, without explicit instructions. This results in the need for participation and understanding of the entire value creation process [4]. Furthermore, it is essential that shopfloor workers have solid problem-solving skills, as solving individual problems cannot be automated [5].

However, the approach of deliberately not standardizing parts of the production partly conflicts with popular production management systems such as the lean philosophy, which generally regards deviations from standards as waste [6]. New approaches and models are required, which reflect this adapted philosophy and help to implement it into reality. As a first step on this journey, companies have to assess the current state of their manufacturing environment and determine how well it is suited for these challenges from a multi-perspective view, which includes technological and informational, as well as organizational and cultural aspects.

This paper specifically focuses on the informational area, which addresses the topic of decision making on the shopfloor. In environments without explicit instructions, it is essential to have access to relevant information at all times in order to be able to make effective decisions in a timely manner. The aim of the paper is to propose an approach to systematically assess the information basis on which the shopfloor decision making is built. This approach

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can be used to identify information bottlenecks and inefficiencies, which then can be addressed to start a transformation towards the I5.0 vision.

The approach is derived from the value stream mapping methodology which is presented in section two. Based on the related work the proposed approach is presented in section three. First experiences from the practical application of the approach will be discussed in section four. Conclusions and a list of references finalize the paper.

2 BACKGROUND & RELATED WORK

Typical lean approaches such as the classic value stream method aim to optimize production towards lean manufacturing. Internationally, the value stream method is successfully used with the aim of gaining a comprehensive understanding of the current manufacturing processes in the factory as well as to visualize improvement potentials transparently and holistically. The value stream method is now a standard for reducing inventories as well as lead times and improving product flow. The focus is placed on the flow of materials from the supplier to the customer and the flow of information [7, 8].

In the current era, manufacturing companies are facing increasingly volatile markets and shorter product life cycles. In order to remain competitive, they must respond flexibly and quickly to individual customer requirements, while at the same time fulfilling them efficiently. As a result, the classic value stream method has been expanded to become the value stream method 4.0 (VSM4.0). As part of this expansion, information is viewed from three new perspectives, such as waste in the handling of information, the use of information for process improvement, and the use of information to increase customer value [6, 9].

Compared to its predecessors, the VSM4.0 has been extended so that it can be used to collect and visualize informational inefficiencies but also digital improvement opportunities. The characteristic horizontal process boxes are combined with a vertical list of storage media which are used to transfer information within the manufacturing process. The matrix which emerges by combining the horizontal with the vertical axis enables the documentation and analysis of the data flow as well as the data usage [6, 10]. Schneider furthermore extends the VSM4.0 with the digitalization potentials and whether this process information can contribute to stabilization by showing the node filled or not filled. In the last step, potentials and fields of action are assessed and a concept for action is derived [6, 11].

As part of an empirical study (of various industrial sectors, mainly globally operating large corporations but also SMEs), in which the requirements for the extended value stream method were analyzed, 86 % of the experts see the decision-making authority with the human being despite all the technological possibilities. The system should therefore merely offer suggestions for value stream optimization, but not act autonomously [9].

This aspect will be addressed in this paper and the VSM4.0 was modified to focus more on human decision making. Since the flexibility of human decision making cannot be replaced by standardization and automation in VUCA environments, it is important to optimize information retrieval for efficient decision making. For this purpose, a modified value stream mapping method was developed, which will be discussed in the following section.

3 PROPOSED APPROACH

The lean philosophy strives to maximize standardization to minimize waste within processes, but as outlined in the previous sections, this way of thinking reaches its limits when applied to an environment in which uncertainty and flexibility are the main characteristics. Instead of trying to force standardization under these circumstances, it is more purposeful to empower shopfloor employees to be able to handle non-standardizable situations by themselves. This not only requires skilled personnel, but also a high-quality and up-to-date information basis for optimal decision making. In order for this vision to be realistically implementable a coordinated framework of cultural, organizational and technological aspects is required. The proposed approach seeks to provide partial support in analyzing the initial situation on the shopfloor in terms of information transfer and information usage in order to establish a starting point for the transformation towards I5.0. Since it can be classified as a variant of the value stream mapping method the proposed approach will henceforth be referenced as modified value stream mapping (MVSM).

The initial step of the MVSM consists of a holistic process mapping that not only captures the flow of the material similar to the value stream method, but also the information on which shopfloor workers base their decisions during the working process. It is essential to do this by observing the real work process and not to rely on existing process documentation, which may be outdated or incorrect, thus creating a distorted picture of reality.

Figure 1 visualizes the core components of the MVSM. Workplaces with corresponding work actions are positioned from left to right and represent the flow of the product as it progresses through the production line. The transition from one workplace to another occurs whenever the product is buffered, and the material flow is therefore temporarily stopped (as indicated by the triangle symbols).

The available information basis is visualized from top to bottom and clustered into multiple categories, which can be individually created as needed. Every piece of information as well as every action is assigned to a horizontal and vertical line, respectively. Each intersection between the lines represents a possible information/action pair. These pairs show actions within the manufacturing process where workers had to perform decisions and the corresponding piece of information represents the basis of the decisions. If the pair actually exists in the observed process it is marked with a predefined symbol. The type of symbol encodes the type of medium which was used to transfer the information. In the MVSM three different types of medium are distinguished: Analog, digital (time-delayed) and digital (real-time). Analog information like printed documents, oral correspondence between workers, etc. has the lowest level of digitization. Time-delayed digital refers to information that is stored in digital form, but is not automatically kept up to date (e.g. locally saved documents, etc.). Real-time digital information refers to information that is stored in digital form and furthermore linked to a central system, that always provides the latest information (e.g. ERP systems, systematic knowledge management, etc.).

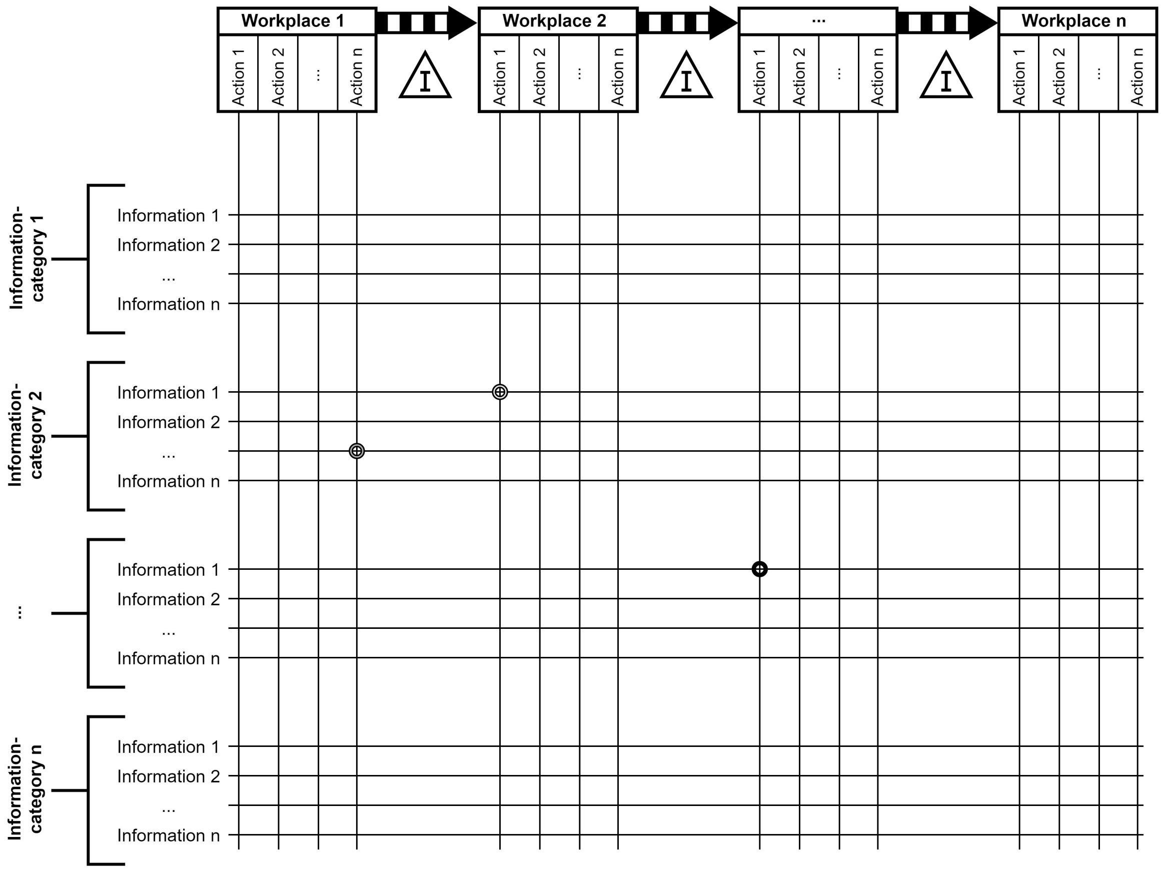

Figure 1: The combination of the actions per workplace with the required information forms the basis of the MVSM. The symbols at the line intersections (information/action pair) encode that certain information was needed to make a decision within a certain action. The shade of the symbol encodes the type of medium that was used to transfer the information.

When performed for the whole manufacturing process this two-dimensional grid visualizes the interplay between the physical product and the information that is needed to finish the product. The simple model, shown in figure 1, already provides a first level of analysis of the observed manufacturing process but is not yet sufficient to provide meaningful insights for optimization since it lacks quantitative measures. Therefore, two additional measures have to be added for each information/action pair – the lead time (LT) for the action and the information retrieval time (IRT). The LT describes the time span between the beginning and the end of the action and also includes the time to retrieve information that was needed to carry out the action. The IRT is a subset of the LT and is measured as the period of time from when the need for information arises to when the information is obtained.

By dividing the LT by the IRT a third measure can be derived – the information retrieval time ratio (IRT ratio) which ranges between 0 and 1 and indicates how large the share of the IRT is compared to the LT of the action. High values generally indicate inefficient information transfer and therefore a hindrance to the ability of workers to make efficient decisions. By identifying activities with a high IRT ratio, decision making bottlenecks in production can be revealed. In order to better visualize this perspective, the tabular form shown in figure 1 needs to be transformed into a diagram that focuses on the IRT ratio.

$$IRT\ ratio = \frac{IRT}{LT}$$

Figure 2 shows a possible variant of such a visualization. Each circle in the diagram shows an information/action pair (with corresponding workplace/action as caption) which is located in the diagram according to the IAT ratio and the medium through which the information was transferred. Aside from the IAT ratio, which is a relative measure, the radius of the circle further shows the absolute information retrieval time.

This condensed view represents an easy to interpret, yet insightful approach for uncovering potential information inefficiencies within the manufacturing process, which prevent workers from utilizing their full capabilities. Workplaces with high IRT ratios and high absolute IRT are major production bottlenecks in the context of VUCA environments. Addressing these workplaces with targeted innovations can improve both performance metrics and increase the robustness of the manufacturing process as a whole.

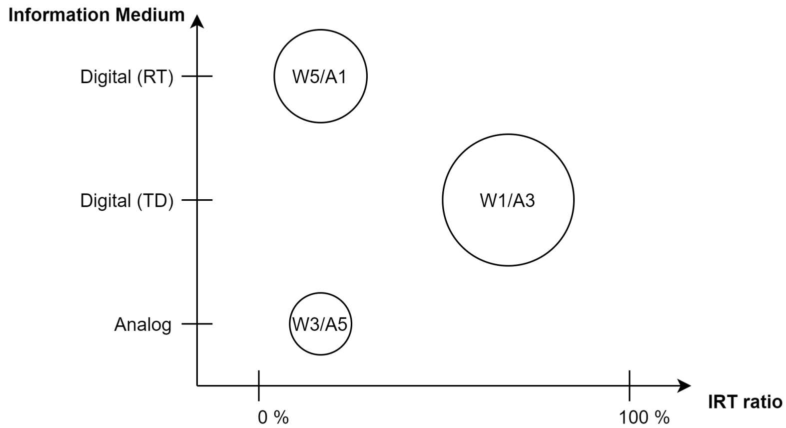

Figure 2: The IRT bubble chart shows a condensed view of the information efficiency for the whole manufacturing process. The size of the bubbles encodes the absolute information retrieval time (W = Workplace, A = Action, RT = Real-Time, TD = Time-Delayed).

4 PRACTICAL TEST FINDINGS

To evaluate the practical implementability of the approach and gather qualitative feedback, a testing phase was conducted in a laboratory environment and in a manufacturing facility of an industrial partner company. Participants were asked to observe a manufacturing process of their choice and document their findings according to the proposed methodology. Afterwards the participants were interviewed and asked to provide feedback on the helpfulness and usability of the MVSM as an approach for finding optimization potentials in manufacturing processes. Due to the grid-like structure, the MVSM lends itself to being implemented in a spreadsheet software for a first prototype. Such a tool was created as part of the testing phase to increase the accessibility for practitioners. Following feedback was aggregated from participants who tested the tool:

- Comprehensive training is required for persons to be able to use the MSVM in an effective way. Since certain conditions, which may be important for the considered process, cannot be captured by observation alone, systematic questioning of workers can also be required during the data collection, which has to be trained beforehand.
- A minimum of two persons is recommended to perform the data collection on-site, in order to better distribute the workload. It is advisable to divide the tasks in such a way that one person mainly observes and asks supplementary questions to the workers, while one person documents the findings according to the presented approach.
- The usability of the MVSM tool and corresponding hardware is a critical success factor. Handling a laptop to document the findings can be problematic in manufacturing facilities. Optimally the MVSM should be implemented on a robust, handheld device for better usability.
- Prior to the data collection, it should be agreed upon how granular individual actions should be recorded in order to avoid confusion on-site. The appropriate granularity has to be individually defined depending on the process under consideration.
- Similar to other value stream mapping approaches, the MVSM also relies on piece-goods-processes as its foundation. Therefore, the presented approach is not well suited in scenarios with continuous manufacturing processes as it contradicts the concept of discontinuous material flow.

This qualitative feedback provides indication for improvement potentials and limitations of the proposed approach. Further investigations have to be carried out with larger participant groups and more industrial companies to fully validate the MVSM and ensure its applicability in real industrial situations.

5 CONCLUSION

The MVSM presents a modification of popular value stream mapping methods with a focus on discovering inefficient information retrieval as part of a manufacturing process. It provides support for discovering where worker decisions take place, which pieces of information are used to make the decisions and how efficient the information retrieval is. The MVSM is designed for analyzing and documenting the current manufacturing process state but does not provide recommendations for further optimization of the detected information inefficiencies. Models for systematic information efficiency optimization are subject to further research. First practical tests have shown that the usefulness of the approach is not only dependent on the methodology itself, but also on how it is implemented as a practical tool. Further investigations have to be carried out, to increase usability and therefore facilitate practical applicability.

As stated in the previous sections, the analysis of information flow is only one of many important aspects for transforming manufacturing processes according to the I5.0 vision. Other established approaches and methods in production management must also be challenged and, if necessary, evolved in order to be effective within the context of VUCA environments.

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