Application potentials of a data-based Value Stream Map model in production and logistics

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Abstract

Value Stream Management in its conventional methodology underlies several disadvantages, especially in the context of effort and flexibility. The approach is characterized as time- and resource-consuming due to a mainly pen-and-paper based procedure, causing inflexibility in an increasing dynamic environment. Taking these findings into account the term static VSM in contrast to a dynamic VSM or VSM 4.0 is introduced in some studies. The fundamental principles of VSM are recognized as still valid, whereas the procedure requires improvements in regard to flexibility and accuracy to ensure a future-viability in today's environments. Recent studies show the relevance and importance of this topic and provide proposals for improving the methodology by the application of information and communication technologies. All reviewed studies have in common a selective consideration of one or more technologies for improving the methodology. Missing is a holistic analysis of the potentials of a digital value stream map, implemented as data-based model with reference to the Value Stream Management phases value stream mapping (VSM), value stream analysis (VSA), value stream design (VSD) and value stream planning (VSP). Based on a literature review for analyzing the state of research in a holistic way, the paper aims at providing a framework, consolidating all recent researches in one model.

1. Introduction

Value Stream Management in its conventional meaning foresees the pen-and-paper-based recording of process steps, work-in-process stocks and cycle times during an on-site-visit. [1]–[3] Ensuring a valid data base, several production cycles are measured and documented for calculating an average value, aiming at minimizing measurement errors and process deviations. Changes in the process require a new recording, which shows additionally the lack of flexibility and the high level of effort in an increasing dynamic environment. [4], [5] For this reason, recent studies differentiate between static VSM, describing the conventional procedure, and dynamic VSM or VSM 4.0, proposing a technology-based approach, e.g. [6], [7]
The entire Value Stream Management approach follows four steps, which are visualized in the following figure. It is pointed out, the term-related usage is not consistent, e.g. in some studies value stream mapping is abbreviated to VSM and used as term for the whole value stream management approach (according to dynamic VSM and VSM 4.0) [8]. But VSM is also defined as Value Stream Management [9], [10] and Value Stream Method [11]. Furthermore, VSM and VSA are used synonymously, describing the mapping and analysis of the current value stream, as well as the procedure at all [12]. The paper at hand refers to the phases as defined in the following figure 1.

In general, the core elements of Value Stream Management, e.g. pull, customer-orientation, demand-driven production and further ones are evaluated as still valid, but the necessity of improvement is claimed to overcome the pointed-out deficits. [13] Several research studies in recent years follow the approach to improve the conventional methodology by combining it with information and communication technologies with the aim to reduce efforts and increase flexibility. Furthermore, new possibilities are enabled by applying a data-based model. An overview of these studies including the considered technologies is given in [14].

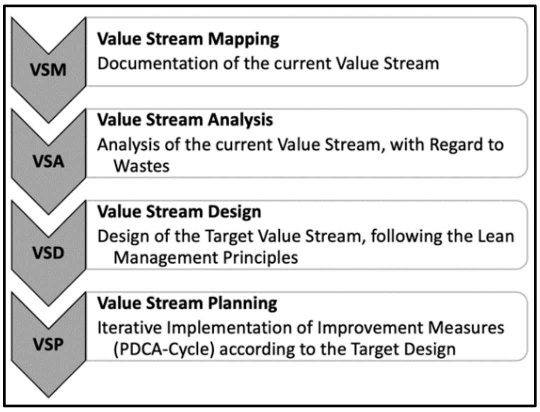

Figure 1: Phases of Value Stream Management

All reviewed studies have in common a limited view on the Lean Management approach, focusing on one or a mix of selected technologies, e.g. [15], [16] as well as on single aspects of Value Stream Management, e.g. the mapping procedure [17], [18]. Also new opportunities, e.g. a simulation-based decision-making [19], [20] , real-time monitoring and scheduling [21], [22] and the application of data-processing techniques, such as data and process mining [23], [24] are provided. But a holistic overview of all opportunities, evoking from of a digital value stream map is missing. The paper at hand aims at closing this research gap by analyzing the state of research and consolidating the findings into a framework.

2. Applied Methodology

The applied methodology is shown in the figure below and described in the following section.

2.1. Phase 1 – Literature Review

In the first phase a structured literature review according to PRISMA [25] is applied. The literature review is a preliminary study and forms the basis of the paper at hand. Therefore, the procedure is not detailly described at this point, but the main conditions are pointed out.
In a first step potential sources are identified. Therefore, the key words for search and the data basis are defined. The search result consists of sources, which are screened in the second phase. In the context of this study the key listed words were considered:

Phase 1 – Literature Review according to PRISMA
1.1 Identification of Sources 1.2 Screening of Sources 1.3 Analysis of Sources
Phase 2 – Consolidation of the Findings into one Value Stream Map Framework
2.1 Determination of Domains and specific Indicators 2.2 Identification of potential digital Data Sources 2.3 Mapping of the Data Structures to the Indicators 2.4 Consolidation of the content-based Findings into one Value Stream Map Framework
Phase 3 – Consolidation of the Findings into one Value Stream Management Framework
3.1 Description of Data Processing Techniques 3.2 Assignment of Techniques to the Value Stream Management Phases

Figure 2: Applied methodology

- “VSM 4.0” / “DVSM”
- “Value Stream Management 4.0” / “Dynamic Value Stream Management”
- “Value Stream Method 4.0” / “Dynamic Value Stream Method”
- “Value Stream Mapping 4.0” / “Dynamic Value Stream Mapping”
- “VSA 4.0” / “Dynamic VSA”
- “Value Stream Analysis 4.0” / Dynamic Value Stream Analysis”
- “VSP 4.0” / “Dynamic VSP 4.0”
- “Value Stream Planning 4.0” / “Dynamic Value Stream Planning 4.0”
- “Wertstrom 4.0” / “Dynamischer Wertstrom”
- “Wertstrommanagement 4.0” / “Dynamische Wertstrommanagement”
- “Wertstrommethode 4.0” / “Dynamische Wertstrommethode”
- “Wertstromanalyse 4.0” / “Dynamische Wertstromanalyse”
- “Wertstromdesign 4.0” / “Dynamisches Wertstromdesign”
- “Wertstromplanung 4.0” / “Dynamische Wertstromplanung”

Based on the available quantity of sources and the types of publications in regard to the search terms, three scientific knowledge libraries were identified as suitable source bases (accessed in February 2023):

- ResearchGate (https://www.researchgate.net)
- GoogleScholar (https://scholar.google.com)
- IEEEXplore (https://ieeexplore.ieee.org/)

In total, 2.551 potential sources are screened by the application of inclusion and exclusion criteria in a second step.

- The source is a scientific study, published as conference paper.
- The source is available as full-text.
- The language of the source is English or German.
- The source is relevant to the topic of a digital value stream map.
- Redundancies are eliminated.

53 papers, published during 2012 and 2023, are considered for further analysis. The key results of the analysis are summed up in the following tables. Due to the fact, one paper can refer to different topics, it is noted, the sum of all categories does not reflect the total number of papers.
The main focus of the reviewed paper is on the application of a digital value stream map for automizing the mapping of the value stream and the technologically supported analysis of wastes, referring to the first two phases value stream mapping (N=50) and value stream analysis (N=41). The third phase value stream design is considered in 27 papers, whereas the fourth phase value stream planning is considered in several studies, but not a subject of research in regard to Value Stream Management against the background of a procedure's digitalization and digitization, e.g. [26]. In contrast, the application of a digital value stream map for improving the operations is mentioned in 11 papers.

Table 1: Quantitative distribution of papers, referring to the phases of Value Stream Management

Category	Papers
Value Stream Mapping	46
Value Stream Analysis	37
Value Stream Design	26
Value Stream Planning	0
Operations	10

Two approaches can be distinguished on a higher level of consideration. On the one hand, a content-related extension of the conventional value stream map is proposed. The types of extension differ and relate to different domains in process management. On the other hand, potentials for the application of data-driven techniques on a digital value stream map model are investigated. Both research directions are also mentioned in [27] with focus on the mapping procedure. The proposed approaches are linked to the phases VSM, VSA and VSD as well as the utilization against the background of operations in production and logistics.

Table 2: Quantitative distribution of papers, referring to the underlying concept

Category	Papers
Extension of the conventional Value Stream Map (contend-based)	28
Application of data-driven techniques (function-based)	36

The consolidation of the findings in detail is described in the following two sections.

2.2. Consolidation of the Findings into one Value Stream Map Framework

The conventional value stream map consists of six elements according to [28, pp. 25–30], [29, pp. 31–38] and form the value stream. These elements are

- Customer
- Production process
- Supplier
- Business process
- Material flow
- Information flow

The content-based extensions, proposed in the reviewed studies, are related to the production process and can be assigned to three different domains, visualized in the following figure.

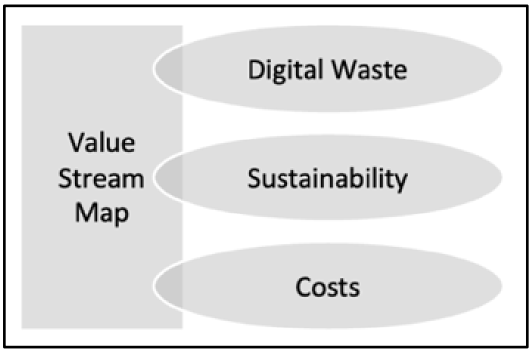

Figure 3: Modular extension of the conventional Value Stream Map

The quantitative distribution of papers is shown in the table below.

Table 3: Quantitative distribution of papers, referring to the domains of Value Stream Map extension

Category	Papers
Digital Waste	15
Sustainability	8
Costs	7

2.2.1. Digital Waste

Wastes in the context of Lean Management are mainly contributed to material handling. But due to the growing digitization and digitalization in the fields of production and logistics, the logistics of information gets increasingly important. Considering this fact, the term information logistical waste is introduced to take the logistics of information into account. Two examples for digital waste are media interruptions and data redundancies, requiring manual synchronizations. As indicators storage media, flow direction and usage are applied. [30], [31] Furthermore, digital KPIs, describing, inter alia, the horizontal and vertical integration, are defined for evaluating the maturity of digitalization and analyzing improvement potentials. [18], [32]

The domain of digital waste requires a cross-system view on the information logistics to create a holistic overview of the related information flows, the origins of the data and its usage. In this context, event-driven process and data-mining supports the automated mapping and analyzing. Prerequisite is a framework, as it is proposed at the end of this section.

2.2.2. Sustainability

Recent developments towards higher awareness for ecology are considered by the domain Sustainability. To identify the activities with the highest ecological improvement potential, the consumption of water, gas and electricity as well as the CO_2 (carbon dioxide) and NOx (nitrogen oxide) emission is documented with assignment to the related activity. Value Stream Management approaches with focus on sustainability are also mentioned under the terms of sustainable VSM (SVSM) and energy VSM (EVSM). [12], [33], [34]

In regard to the consumption of resources and emissions, sensor / process data are potential data sources. Modern machines with a PLC (programmable logic controller) control provide the export of consumption-related information, which can be analyzed with refence to specific machine operations. Furthermore, retrofits of sensors and consumption meters for machines without a PLC control are offered by several suppliers. The data gathering based on such a measurement also supports the integration of manual workplaces, e.g. for assembly. The logical interpretation of the raw data requires calculation rules. [35, pp. 152–153]

2.2.3. Costs

The third domain refers to costs and aims at the identification of cost drivers in the areas of production and logistics. In this context, the arising expenses for rates, e.g. labor, machining and transportation, consumed and scrapped materials, energy (in relation to sustainability) and similar ones are tracked. Furthermore, opportunity costs, e.g. for the non-utilization of capacities are defined. [36]–[38] In cases, a value stream is not deterministic, but different variants of the value stream exist, e.g. due to alternative technologies or multiple production lines for one product, the application of event-based process-mining enables the monitoring of variant-specific costs as well as the determination of the cost-optimal variant. [19] Costs for material consumption can be calculated by the material and quantity, withdrawn on the production order and the material price. Work center related costs can be derived from the actual confirmed activities on one operation. Based on the confirmed time exposure on an activity, e.g. setup, machine or labor, the activity type, formula and cost center specific rates, the actual costs are calculated. The derivation of both cost factors is visualized in figure 4.

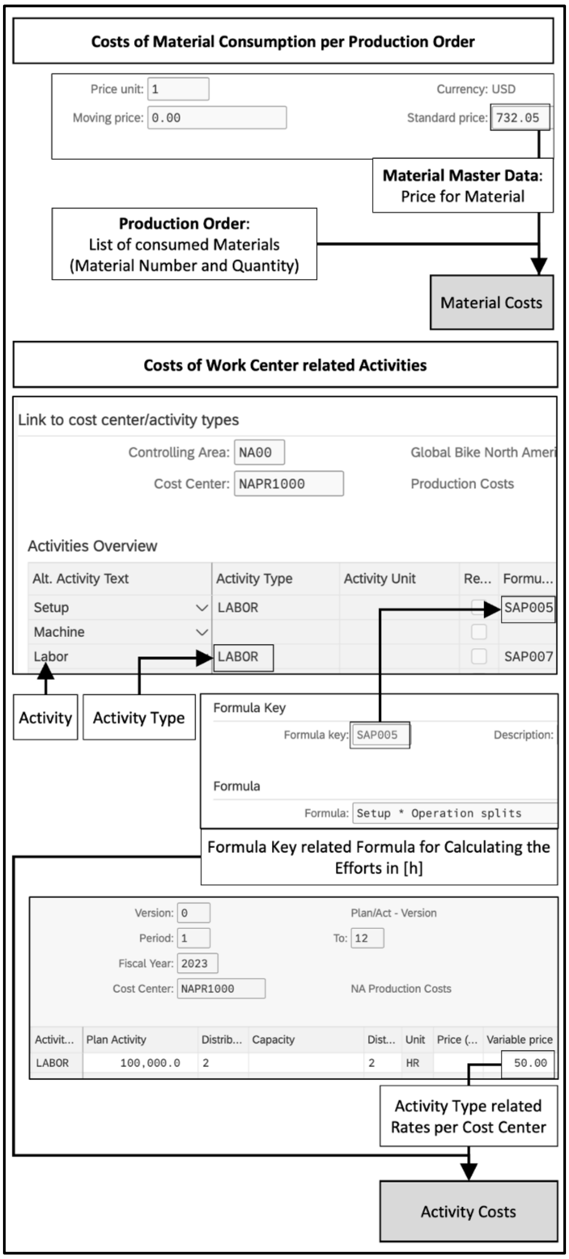

Figure 4: ERP-based cost mapping for activities and material consumption

Potential data sources are cost-tracking business applications systems, e.g. enterprise resource planning (ERP) and manufacturing execution system (MES).

Value Stream Map Framework

As pointed out at the beginning of this section, the content-based extension of the value stream map by the three domains is limited to the production process. For this reason, residual elements remain and are explicitly not considered. To merge the three domains into one framework, the framework, described in [39] is adapted (see figure 5). Companies that apply Lean Management in general and Value Stream Management in particular differ from each other in regard to products, business model, system and process landscape. Therefore, companies follow different strategies and aims. The corresponding requirements for the use of a tool or management approach like Value Stream Management are also various. Following the Lean Management philosophy, the gathered information should match the required data base and not exceed the necessity in terms of waste. For this reason, the proposed value stream map framework is designed in a modular way. According to the company's environment only the data are gathered, which are necessary for improving the value stream. To the same extent it is possible to adjust the proposed framework according to the company's need.

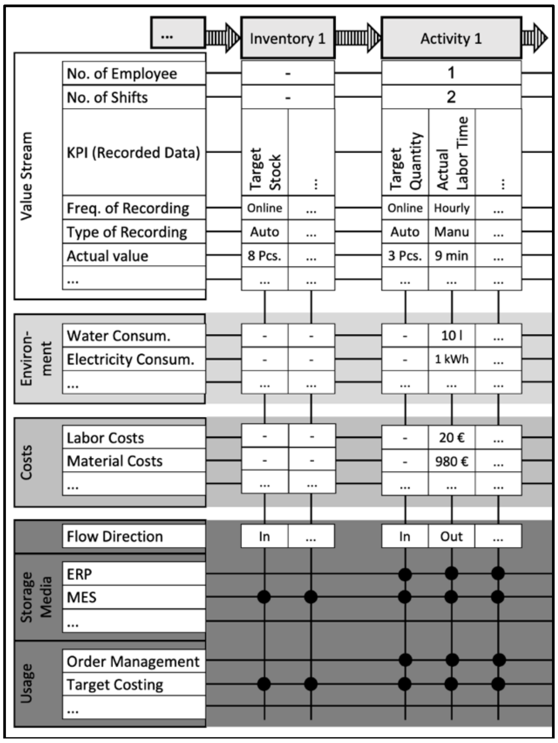

Figure 5: Modular Value Stream Map framework

Consolidation of the Findings into one Value Stream Management Framework

The implementation of a digital value stream map is not limited to the value stream mapping, but also opens opportunities in regard to the residual phases of Value Stream Management as well as the operations of logistics and production. In this context, data-driven techniques enable the automation or at least the part automation of information processing. Figure 6 visualizes the four areas of application potentials, which are detailly elucidated in the following section.

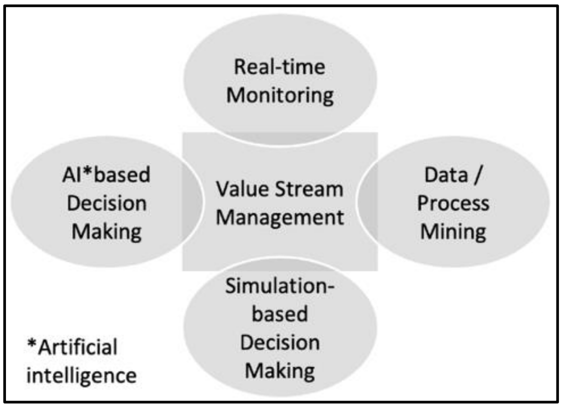

Figure 6: Data-processing techniques in the context of Value Stream Management 4.0

The quantitative distribution of papers is shown in the table 4.

Table 4: Quantitative distribution of papers, referring to the categories of data-processing techniques

Category	Papers
Real-Time Monitoring	8
Data / Process Mining	17
Simulation-based Decision Making	27
AI-based Decision Making	3

2.2.4. Real-Time Monitoring

To avoid high costs for rework and disposal, deviations, e.g., quality issues must be identified as early as possible. A continuous tracking and tracing of material along the entire value stream including specific process data in real-time supports a deviation management based on a steady comparison of planned and actual parameters. [40, pp. 116–124] In this context, the digital value stream map model is the to be observed framework. The implementation of technologies like digital twins, internet of things (IoT), RFID (radio frequency identification) and similar ones for identifying material according to the lot size one concept, is proposed to enable the real-time monitoring. The gathered data are referenced to the unique material and used for deriving the trace. Furthermore, the availability of current data opens opportunities towards dashboarding functionalities. For this reason, the application of real-time monitoring is appropriate to the operations of production and logistics as well as VSP, especially the documentation of impacts on the value stream, emerging from applied improvement measures. [22], [41]–[43]

2.2.5. Data / Process Mining

During the production process different types of data are gathered. The available raw data must be structured, assigned and interpreted for usage. This is done by the application of data and process mining techniques. For this reason, the technique is suitable for the initial, but also continuous VSM as well as VSP. [17], [23], [41], [44]

2.2.6. Simulation-based Decision Making

The implementation of a digital value stream map opens opportunities in regard to simulative techniques. The quantitative simulation supports the creation of different solution scenarios and the reasoned selection of the optimal one. The term simulation describes in this context the conscious adjustment of model parameters, e.g., the increase of capacities. For this reason, the fields of application refer to the phases VSD and VSP in particular. In contrast to physical mock-ups (PMU), which are often used in the context of value stream planning, following the iterative improvement according to the Deming-circle, the design parameters of digital mock-ups (DMU) can be adjusted and validated with less efforts, whereas PMUs require a physical adaption and can be damaged or destroyed during a validation process. Due to this characteristic of DMUs the simulation based decision-making saves time as well as costs. But also in regard to operations, the simulation of alternative value streams can be applied against the background of disruption management, e.g. the failure of a machine in a production line and the transfer of a production process to an adjacent resource. [20], [45]–[47]

2.2.7. AI-based Decision Making

Like the simulation-based decision making, the AI-based one supports the decision-making process by the utilization of the available data. But in contrast to simulations, which require a simulation model with entities and defined relations, the AI-orientated approach aims at the application of data analytics for the identification of correlations in the data pool. Therefore, it is appropriate for VSA, VSD and VSP as well as for operations, especially in the context of gaining a deeper system understanding and making predictions. [43], [48], [49]

3. Results and Discussion

Aim of the paper at hand is the determination of recent developments in the fields of research in regard to Value Stream Management 4.0 and its consolidation into one framework. By the structured literature review two major approaches are identified – one aiming at the content-based extension of the value stream map and the other one proposing data processing techniques on a digital value stream map model for improving the methodology at all. Both approaches are subdivided into different categories, representing the thematic focus of the considered studies. The resulting categories are summarized in the following listings.

Extension of the Value Stream Map

- Digital Waste
- Sustainability
- Costs

For each domain potential data sources and mappings are derived. Furthermore, a modular framework, consolidating the findings, is provided.

Data-processing Techniques in the Context of Value Stream Management 4.0

- Real-time Monitoring
- Data / Process Mining
- Simulation-based Decision Making
- AI-based Decision Making

All techniques are elucidated and according to its application potential assigned to the different phases of Value Stream Management 4.0 as well as to the operations of logistics and production.
As pointed out in the abstract and introduction, in regard to the reviewed studies a holistic overview of all opportunities, evoking from of a digital value stream map is missing, because of the limiting focus on one topic. By the paper at hand this research gap is closed and the recent research is brought together in one study. There are limitations, which must be mentioned at this point. The paper at hand is limited to the consideration of recent research fields. As pointed out, the provided frameworks are modular and its application requires an adjustment according to its purpose. Missing is an evaluation of the digitalization measures in comparison to the conventional Value Stream Management. Therefore, a deeper analysis of the resulting or expected benefits is missing. Furthermore, a technical concept for integrating the different data sources into one data pool as data basis for the data processing techniques, mentioned in this paper, is required.

4. Conclusion and Outlook

Different fields of research in the context of Value Stream Management 4.0 exists, making various perspectives on the topic a subject of discussion. The number of relevant publications proves the topic's relevance. Missing is an entire overview for all research streams. By the paper at hand this identified research gap is closed, as reasoned in the former section, but there are still issues, which require further research. The reviewed papers are focused on the provision of individual solutions, addressing a sub-area of Value Stream Management 4.0. The application is reasoned by limitations of the conventional ones and arising opportunities by modern technologies, but a proposal of indicators for an overall evaluation of the benefit from a company's perspective is missing, reasoning the transformation from the conventional procedure to the digitalized one. Furthermore, a technical solution for merging the recent researches into one framework is missing. Currently, different technologies are considered independently from each other, but a successful implementation requires a holistic solution, taking all types of technologies into account. Dealing with the above-mentioned issues is topic of future studies.

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