Future Application of VSM in Digitalized Environments

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Abstract
Value stream management is one of the most applied methodologies to map, analyse and improve end-to-end supply chains from a company's perspective. By its application wastes in the logistics value streams, e. g. waiting times, negatively effecting the product's lead time are identified and eliminated in a structured way. The paper at hand deals with the topic of the future viability of the traditional value stream method, especially the value stream mapping against the background of growing system design opportunities, offered by fast technology developments in context of industry 4.0. In detail, the paper refers to the increasing digitization and digitalization of operational processes in the domains of logistics and production. Therefore, the current state of research regarding the impact of information and communication technologies (ICT) on the traditional value stream method and its potential in regard to the improvement of complex supply chains is investigated. For this purpose, a literature review according to PRISMA [1, pp. 1–4], [2, pp. 1–9] is followed with the aim to determine the research status quo, from which a research gap is derived.

1. Introduction
In a globalised world, manufacturing companies are in competition with their entire supply chains. Volatile markets necessitate increasing flexibility to ensure a company's competitiveness by the ability of agility. Key prerequisite is a deep market knowledge, fostered by transparency along all stages of the supply chain. In this context digital technologies have an important role, enabling the recording and provisioning of real-time data as well as the automated recognition of pattern in big data pools, supporting decision-making activities. [3]
Value stream management is related to the principles, methodologies and tools of lean management and represents a holistic framework for structured decision making in context of supply chains. [4, pp. 622, 623] Additional to the company's internal logistics processes also external material and information flows from suppliers and to customers are considered. The method can be divided into four phases, which are named value stream mapping (VSM), value stream analysis (VSA) and value stream design (VSD) and value stream planning (VSP). [5, pp. 249, 250], [6] The present paper is limited to the first phase VSM.
The value stream method is a well-known and field-tested approach, applied by companies to improve logistics related processes, also taking production-related activities into account. In detail, the method supports the structured reduction of the overall lead time by eliminating wastes, e. g. stocks, which negatively affects the material flow. Therefore, a quantitative comparison of value-adding durations and non-value-adding durations is performed to calculate the effective lead time as sum of both types of duration and a key performance indicator for measuring the process efficiency as ratio of both values. [7, pp. 2–6]
The procedure of the traditional value stream mapping is characterized by a time consuming and effort intensive procedure, caused by manual-driven recording of process steps, WIP stocks and cycle times during an on-site-visit. Several production cycles are measured, documented and consolidated to an average to ensure a valid data base, cleansed from potential measurement errors. [7, pp. 1, 6–12], [8, p. 3066] Changes in the value stream necessitate a new end-to-end recording, what indicates the rigidity in connection with dynamic surroundings, requiring more flexible

structures. [9, pp. 1, 2] This issue is considered in some publications which differentiate the traditional value stream method as static VSM due to its rigid data base and the flexible, optimized VSM as dynamic one. [10], [11]
These circumstances lead to the central question, if the value stream method in its traditional setup is still a reasonable tool for optimizing value streams from the perspective of a company, strived to reduce wastes in a more and more digitized and digitalized environment. Furthermore, the question is, if synergies by integrating ICT can be achieved and how.
Prior studies refer to these scientific issues from various perspectives and on different levels of detail. The references are named and analysed in the following sections. Aim of the paper at hand is the determination of the current state of research to designate in a second step the concrete research gap. To achieve this, a systematic literature review on appropriate topic-related literature is carried out.

2. Applied Methodology

By a combined search for key words regarding the value stream method and key words regarding industry 4.0 an extensive selection of studies and literature can be found, making the alignment of the traditional value stream method and technologies in context of industry 4.0 a subject of discussion. Following the paper's is aim, mentioned in the previous section, a systematic literature review is carried out according to the PRISMA approach, which is briefly described below.

Systematic literature review according to PRISMA
Initially published in 2009, PRISMA, an acronym for "Preferred Reporting Items for Systematic reviews and Meta-Analyses ", describes a guidance for systematic literature review, providing a checklist for a completeness check concerning the reporting of systematic reviews or meta-analyses as well as a flow chart, dividing the whole review process into specific phases. Each phase consists of steps, referred to the checklist, which aim at the structured concentrating of the data source to excluded not relevant sources. [1, pp. 2, 5, 6, 8]
The PRISMA 2020 statement is an update of the described approach. Therefore, the checklist and the flow chart were reworked to take findings gained from systematic reviews during the last decade into account. Thereby, some items are dropped, new items are added and some items were described more detailed. However, the core process remains on a gross level, even if the phases are more specific and not named anymore as in the former publication from 2009. [2, pp. 1, 2, 5–8]
In essence, the underlying methodology follows the PRISMA scheme, visualized in the figure below.
The three phases are detailly described in the following sections.

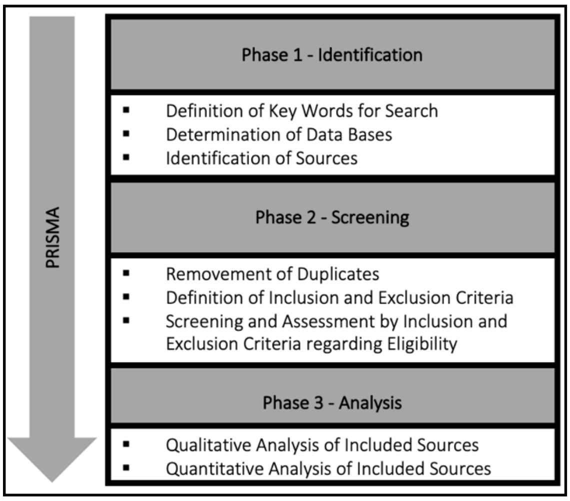

Figure 1: PRISMA Scheme [1, p. 8], [2, p. 8], [12, p. 5]

Phase 1 – Identification
In the framework of the PRISMA approach the key words for search were taken into account:

- „Wertstrom 4.0"/ "Wertstrom 4.0"
- „Wertstromanalyse 4.0"/ "Wertstromanalyse 4.0"
- „VSM 4.0"/ "VSM 4.0"
- „Value Stream Mapping 4.0"/ "Value Stream Mapping 4.0"
- „Dynamische Wertstromanalyse"/ "Dynamische Wertstromanalyse"
- „Dynamic VSM"/ "Dynamic VSM"
- „Dynamic value stream mapping"/ Dynamic value stream mapping"

As data bases the scientific knowledge libraries were used (date of access: 02/07/22):

- ResearchGate (https://www.researchgate.net)
- Google Scholar (https://scholar.google.com)
- IEEE Xplore (https://ieeexplore.ieee.org/)

The raw search results are documented in an Excel-based table to apply filter operations and meta-analyses. The results of each analysis are described in the following section of the paper at hand.
In phase 1 N = 1258 records were identified. It is pointed out, the search result at Research Gate is limited to an output of N = 100 records for every search operation, tried out during the systematic literature review. Regarding the used key words, every search cycle resulted in N = 100 records. For this reason, the completeness of these search cycles cannot be ensured. The table below gives an overview of the search results related to data base and key word for search. To ease the readability,

the applied interpunction for searching is not considered in the table.

Table 1: PRISMA Identification Result – Phase 1

Search Key Word	Data Base	Records
Wertstrom 4.0	ResearchGate	100
	IEEE	0
	Google Scholar	5
Wertstromanalyse	ResearchGate	100
	IEEE	0
	Google Scholar	43
VSM 4.0	ResearchGate	100
	IEEE	0
	Google Scholar	48
Value Stream Mapping 4.0	ResearchGate	100
	IEEE	3
	Google Scholar	146
Dynamische Wertstromanalyse	ResearchGate	100
	IEEE	0
	Google Scholar	4
Dynamic VSM	ResearchGate	100
	IEEE	0
	Google Scholar	64
Dynamic value stream mapping	ResearchGate	100
	IEEE	1
	Google Scholar	244

In sum, the overall search result contains N = 1258 records (ResearchGate N = 700, IEEE N = 4 and Google Scholar N = 554).

Phase 2 – Screening

After consolidating all records from the different data bases, all duplicates are removed. Further on, the inclusion and exclusion criteria are defined. All records are excluded, which do not fulfil the inclusion criteria, mentioned in the listing below.

- The record is in German or English language.
- The record belongs to the document type article, thesis, conference paper or chapter.
- The record is directly or indirectly related to the search topic and its relevance is proven.
- The record is available as full-text. If not, but the abstract suggests a significant insight into the record's content, the record is included with restrictions.

Applying the availability check, two categories are differentiated according to the last criteria. The result is shown in the following table.

Table 2: PRISMA Screening Result – Phase 2

Category	Characteristic	Records
Cat. 1	Full-text available	28
Cat. 2	Full-text not available, but adequate abstract	13

Even if the content of a record is summarized in the record's abstract and key words are highlighted, the integrative consideration of these records happens on a gross level and deeper analyses on the content in detail are constrained. However, the abstract provides a thematical tendency and must be included for an entire view. Therefore, in the following tables the quantities of full-texts and abstracts are pointed out separately, keeping this limitation of review in mind.

3. Results and Discussion

Based on the procedure, elucidated and reasoned in the former section, the baseline for the analyses is N = 41 records.

Phase 3 – Analysis

In general, the record's context can be differentiated into two thematical streams. For three-fourth of the reviewed records (N = 30) the methodology of VSM in context of digitalization according to the principles of industry 4.0 is the major topic (e. g. [13]–[15]) whereas for one-fourth of the records (N = 11) the horizon of consideration is widened to a holistic review of lean management as a whole (e. g. [12], [16], [17]). Due to the widened view of the second stream the level of detail regarding the analysis of VSM is lesser. In total, all records have in common, ICT are an important factor, impacting the future application of VSM. By the utilization of ICT in an increasingly digitized environment the volume of available data grows. For this reason, on the one hand the control of information flow gets more important. On the other hand, ICT foster transparency by providing real-time data of processes, which ease the tracking and tracing of value streams in the domains of production and logistics. The consideration of ICT in relation to the traditional VSM follows two approaches, as pointed out in [18]. Both approaches aim at the extension of the traditional framework, but in different ways.

For the first approach the standard procedure remains. During on-site visits the documentation of VSM-related KPI is enriched in regard to the digital information flow. In detail, the records refer to the documentation of the information storage media and its usage, visualized by visualized by swim lanes below the traditional value stream map as well as its flow direction from the activity's perspective (into or out of), illustrated by directed arrows. The approach's central target is the identification of media breaks and technical instabilities, which cause wastes in the handling of information. The knowledge regarding weaknesses in the information flow allows the structured improvement and harmonization of the process and system landscape from a technology perspective. [5], [13, pp. 93–102], [15], [19]–[21] Additional one record suggest the enhancement of the traditional VSM by technology-driven KPI, to be recorded for each activity in the value stream. In detail, the three KPI vertical and horizontal integration rate, material and information automation rate and digitization rate are stated. [22], [23]. A utilization of digital data for improving the methodology itself is not considered. As described in the former sections, the traditional VSM is primary a pen-and-paper process and, therefore, time- and effort-intensive. Already mentioned disadvantages of the traditional procedure, reinforced by dynamic environments, decreasing lot sizes, shorter innovation and product cycles as well as wider variety can be eliminated by significantly reducing the recording efforts. The second approach aims at the utilization of real-time and historical data gathered from the production and logistics processes by ICT to automate the mapping of value streams (process documentation). Moreover, the integrative orchestration and exploitation of real time data increases transparencies and accuracy in the value stream map. Beside the automated documentation in context of mapping the value stream the approach enables taking countermeasures in short time in case of deviations in the planned processes based on experiences gained from former production cycles (process monitoring). By the operational application of technologies materials can be identified and tracked, sensed and positioned as well as located. The following tables gives an overview of the distribution of the framework type, mentioned in the reviewed records.

Table 3: Type of VSM Framework Extension

Framework Extension Type	Full-Text	Abstract	Records
Documentation	7	1	8
Technology Utilization	21	12	33

Regarding the scope of technologies, utilized for automate mapping in context of VSM, the reviewed records can be distinguished according to the application of one single technology or a combination of several ones to one holistic solution, called system. In general, the following single technologies and technological systems are mentioned in the reviewed records:

- ID-technologies (e. g. RFID, barcode)
- Wireless technologies (e. g. wireless sensor network, Zigbee, Cloud computing)
- Big Data
- Machine learning
- Process mining
- Simulation
- Industry 4.0 ICT (in general)
- Positioning systems
- Cyber-physical systems (CPS)
- Digital twin/ digital shadow
- IoT and IIoT
- Application systems (e. g. ERP, MES and WMS)

Technological systems are based on the targeted combination of elementary technologies (CPS are amongst others based on wireless sensors, actuators and IoT). For this reason, a clear distinction and classification of the named technologies and systems is not possible. Indeed, the mentioned technologies are characterized by intersections.
The following referencing of technologies does not comprise completely all records, which relate to the named ICT and are therefore counted in table 4, but is a selection of exemplary records, which primary focus on its utilization.

Table 4: Potential Technologies for VSM 4.0

Technology	Full-Text	Abstract	Records
RFID/Auto-ID	10	4	14
Wireless Technologies	4	2	5
Big Data	6	0	6
Machine Learning	6	1	7
Process Mining	1	3	4
Simulation	7	0	7
Industry 4.0 ICT	10	2	12
Positioning System	1	0	1
Cyber-Physical System (CPS)	5	0	5
Digital Twin	2	1	3
IoT/IIoT	7	1	8
Application System	4	1	5

Mainly the deployment of RFID – or similar technologies to support the identification and tracking of material movements is proposed. [14], [24]–[26] As enhancement of RFID the application of a holistic indoor positioning system (cameras, optical sensors and more) is suggested to benefit from real-time positional data. The data analysis allows the evaluation of non-value-adding activities, also called wastes, especially regarding waiting times, stocks and transports, which cannot be directly derived from RFID data. [27] In the same context the usage of wireless network in general [28] and wireless sensors or Zigbee [29], [30] in particular are mentioned to gather more process-orientated data, which can be analyzed by procedures of big data analytics and can support machine learning and decision making algorithm. [4], [31], [32] Following the tendency of wireless technologies, Internet of Things (IoT) and Industrial Internet of Things (IIoT) [11], [33] for the communication between objects by network to establish a digital twin [4], respective a digital shadow [34] to link the physical and digital worlds are introduced. Furthermore, the implementation of cloud computing to merge the collected data from different technologies at one place is described [35]. To put the named features into a nutshell, the term of cyber-physical system, abbreviated CPS, is mentioned to take the bilateral interaction between both worlds into account. [36]–[38] In addition, in some records industry 4.0 technologies without any reference to a concrete technology are pointed out as potential for improvement of the traditional lean managements methods in general and VSM in particular. [39]–[41]

Regarding the recording, preparation and provision of operational data the utilization of process mining operations is recommended to automate the mapping process. [42]–[44] The creation of a data model forms the base of extensive operations, e. g. the simulation of business scenarios based on changing parameters. Even if simulations do not support primarily the automation of the mapping procedure of VSM, because the existence of a simulation model is prerequisite for the execution of simulations, the drawn scenarios underline the potential of a data-driven models in the design of value streams. [14], [45], [46]

To sum it up, regarding the second approach a mix of concrete technologies and technological systems is mentioned for automate the mapping methodology of value streams in dynamic environments and gathering findings out of the available data pools. All records refer to generalized frameworks, outlining technologies, but mainly missing a specific implementation scheme, in general and a concrete reference model for deriving VSM elements und KPI from the accessible data, in particular.

Beside the technology-focused approaches, operational respective business application systems are pointed out as potential data sources, bringing the sensor data into a reference framework (e. g. optical sensors signal for counting production quantities). As examples for application systems the categories ERP, MES, WMS and SCM are pointed out, but as for the technology-focused approach without outlining any concrete design details for such a data framework. [47]–[49]

The quantities of records, mentioning each type of technology, are shown in the following table. The consideration is limited to the view on records related to the technology framework. Due to the fact, some of the records refers to more than one technology, the sum of all quantities is greater than the total of N = 33 records.

As part of the meta-analysis the historical development of the number of publications, referring to the paper's topic, is analyzed to evaluate the relevance of this topic. A structured overview is provided by the following table.

Table 5: Historical Distribution of Publications

Year of Publication	Full-Text	Abstract	Records
2012	0	1	1
2013	0	0	0
2014	0	1	1
2015	0	0	0
2016	4	1	5
2017	2	1	3
2018	6	1	7
2019	4	3	7
2020	6	1	7
2021	6	2	8
(2022)	(0)	(2)	(2)

The first record was already published in 2012, but the topic did not seem to have the scientific relevance as it has today. Only from 2016 on, the number of publications was greater than one and remains constantly between 7 and 8 in the years 2018 to 2021. The historical development shows the increased relevance during the last years. In 2011 the term industry 4.0 was introduced the first time as a holistic technology concept, but its realization depends on the development of performant technologies at low prices, which ensure an economical use. As described in the former sections the digitalization of VSM is mainly pushed by reasons of (economic) efficiency. Technologies own an enabler role regarding this issue. Costs decrease, while performance and availability increase. This trend fosters the relevance of combining digital technologies and lean management in general and VSM in particular.

4. Conclusion

In conclusion, the core of the value stream method is also in connection to an increasingly digitized

and digitalized environment an appropriate tool for enterprises to map, analyse and improve supply chains, especially regarding logistical material handling and information flows. But for its future application extensions and adaptions with regard to the application of ICT are required to ensure the economic efficiency as reasoned in the former sections. Its scientific relevance is underlined by the historical development of publication counts during the recent years. Different approaches are followed to increase the transparency in value streams and take advantage of the increasing technology utilization in supply chains, e. g. RFID, (I)IoT, cloud computing, (GPS-controlled) positioning systems and so on. In general, the targeted application of ICT in supply chains offers high efficiency potentials and enables VSM to become future-proof. In this context two approaches are distinguished – a documentation and a technology-orientated one. With regard to the second approach and applying the automation pyramid for the classification of technologies, visualized in the figure below, it is constituted, the reviewed records in the paper at hand are mainly focused on ICT, assigned to the categories L 0 – fields level, L 1 – control level and L 2 – supervisory level. The utilization of technologies of L 3 – planning level and L 4 – management level, especially business application systems is less covered, but more pointing out potentials for future developments of VSM.
These issues lead to three central questions, constituting the research gap.

- How can the data of L 3 and L 4 technologies in combination with data, processed by L 0, L 1 and L 2 technologies be utilized, to improve/ automate the value stream mapping in complex supply chains?
- What kind of data is required and which type of business application system is a suitable data source for the automation of the value stream mapping?
- How can the data be extracted, transformed and transferred into a concrete data model, forming a universal reference model for different use cases?

Dealing with the above-mentioned research questions is topic of following studies.

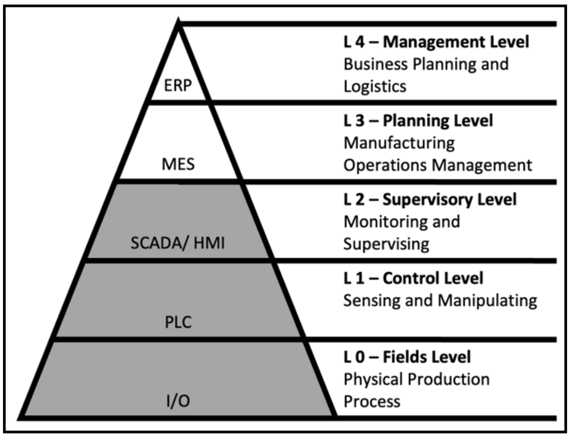

Figure 2: Automation Pyramid for Classification of Technologies [50, p. 3]

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