Evaluation of the digital transformation from VSM to Value Stream Management 4.0

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Abstract

As recent shocks, e.g., the COVID-19 pandemic and international conflicts prove, the environment of supply chains gets more volatile and static configurations suffers from fragility. Higher variety, shorter product life cycle, increasing competition, fragility of supply chains and further issues present companies with new challenges. The application of information and communication technologies plays an important key role for companies in solving today's challenges. In this context, the combination of conventional methodologies like Lean Management (LM) and modern technologies according to Industry 4.0 is an important field of recent research. Especially, the application of Value Stream Management (VSM) in dynamic environments is widely investigated and different approaches are provided for taking information logistics into account as well as utilizing data for improving the methodology at all. Limitations of the conventional VSM are the basis for justifying the transformation to a VSM 4.0. A critical evaluation of measures for the transformation from the conventional VSM to VSM 4.0, based on a comparison of benefits and efforts for reasoning the transition from a company's perspective is missing. Aim of the paper at hand is the provision of an evaluation framework for companies, already applying the conventional VSM.

1. Introduction

Businesses face a high volatile and uncertain environment, which necessitates an adjustment and realignment of companies to the changed conditions to ensure future existence and a stable market positioning in the medium and long term. [1], [2] These changed conditions are caused by internal factors, e.g., disruptive changes in the system and process landscape and skills shortages, as well as external factors, e.g., shorter life cycles and higher product variety, and require greater flexibility under consideration of economic aspects.

Conventional business models and management approaches, such as Lean Management (LM), must be verified with regard to their topicality and validity against the background of a changing environment in general and increasing digitization and digitalization in particular. As examined in various studies, the fundamental principles of LM are still valid in the context of Industry 4.0. Rather, it is recognized, both approaches are mostly complementary and support each other. By the combined application, synergies can be created. On the one side, fundamental principles of LM, e.g., standardization and elimination of waste are the basis for a technology-based automation of processes. On the other side, the targeted application of modern information and communication technologies enables new opportunities for monitoring, analyzing and designing business processes by the utilization of important business data. The gain in additional information and transparency as well as the possibilities of data processing have a positive effect on the lean management methods. [3]–[5]

1.1. State of Research

Due to the amount of application potentials, the concept of a structured combination of well-known LM practices and modern technologies in the area of Industry 4.0 is a wide field of research. Especially, the investigation on Value Stream Management (VSM) as part of Lean Management is highly discussed in recent research. In the reviewed studies several limitations of the conventional VSM approach are pointed out, e.g. static nature, effort-intensive and time consuming procedure, inefficient in dynamic environments and similar ones. [6]–[8]. These limitations are taken as a basis for justifying a digital transformation. All considered studies in common is a missing critical evaluation of measures for the transformation from the conventional VSM to VSM 4.0, reasoning the transition from a company's perspective. The technical and related application potentials are consistently elucidated in detail, whereas the concrete benefit on the methodology on the one hand and the cost-related efforts on the other hand are not a subject of consideration.

1.2. Research Gap and Research Question

As mentioned above, a structured reasoning of the transformation from conventional VSM to VSM 4.0 is missing in regard to the reviewed studies. This is proven by a systematic literature review according to PRISMA [9], [10], which is carried out as part of a preliminary study. The scope is briefly outlined in this section. The literature is explicitly based on the scientific platforms ScienceDirect (https://www.elsevier.com), Google Scholar (https://scholar.google.com), IEEE Xplore (https://ieeexplore.ieee.org) and ResearchGate (https://www.researchgate.net). Further platforms and libraries are implicitly covered by cross references from Google Scholar. As search strings a variation of selected key words related to VSM 4.0, e.g. "dynamic value stream management", "value stream management 4.0" and "value stream mapping 4.0", combined with terms and phrases in the context of measure evaluations, e.g. "cost-benefit-analysis"/"CBA", "evaluation of digitalization measures" "and "assessment framework". In addition, the search string is extended by refining expressions as "key performance indicator" and "return on investment".

In summary, the reviewed studies can be divided into three categories regarding the impact of digitalization in the context of VSM 4.0 from a company's perspective.

The studies of the first category refer to the application potentials of VSM 4.0, focused on the utilization of technologies. A quantitative evaluation of the proposed digitalization measures is not taken into account, e.g. [11]–[13]. For an overview of technologies, see [14]. The second category refers to studies, which provide indicators for evaluating the information logistic, considering e.g., the digitization rate, data availability and data usage. The data are used for evaluating digital waste in the value stream (VS) with focus on production and logistics, e.g. [15]–[18]. The third category contains studies, providing a maturity model for assessing the digital mature in the process based on, inter alia, vertical and horizontal integration, automation rate and digitization rate. [19]–[21] In addition, the correlation of LM tools in general and Industry 4.0 technologies [22] as well as the correlation between production targets (costs, quality, time and flexibility) and technologies [23] are investigated, but without relation to VSM 4.0. In summary, the identified evaluation frameworks are merely related to the VS, but not to the methodology itself. According to the first category, the proposed technologies are missing a quantitative reasoning or impact evaluation. This leads to the central research question of how the impact of a transformation from the analog methodology VSM to the digital one VSM 4.0 can be evaluated, especially against the background of maximizing the benefits of digitalization measures.

1.3. Aim of the Paper at Hand

Aim of the paper at hand is the provision of an implementation framework for assessing the impact of transformation measures in comparison to the conventional VSM methodology. Therefore, a key performance indicator (KPI) system is provided, consisting of a selection of possible indicators, grouped by various perspectives of consideration. Due to different business models, products, strategies and operational targets it is necessary to design a universal master model. The choice of applicable KPIs, matching the company's strategy is company-specific.

2. Applied Methodology

The applied methodology is divided into two phases, which are visualized in the figure below.

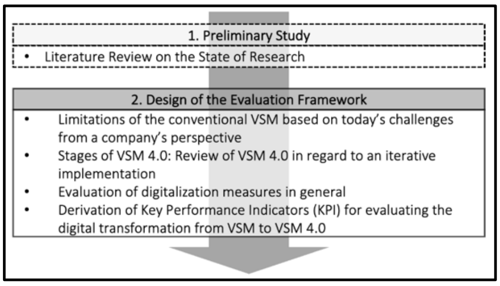

Figure 1: Applied Methodology

2.1 Phase 1 – Preliminary Study

The first phase of the applied methodology is the conduction of a preliminary study to identify the recent state of research related to the paper's topic. As pointed out in the previous section, the VSM 4.0 related studies, identified in the literature review are not directly suitable for achieving the paper's aim. For this reason, the design of the evaluation framework follows a deductive approach, reviewing the evaluation of digitalization measures in general and deriving a framework for VSM 4.0 in particular.

2.2 Phase 2 – Design of the Evaluation Framework

In the following sections the activities, mentioned in accordance to phase 2, are elucidated.

2.2.1 Limitations of the conventional VSM

The environment of supply chains is in change and therefore, companies must meet arising requirements to ensure the company's existence in the future. Table 1 shows a selection of challenges, companies face in their today's business.

Table 1: Selection of Business Challenges

Challenge	References
Increased Product Variety	[7], [24], [25]
Decreased Lot Sizes	[6], [7], [26]
Shorter Product Life Cycle	[17], [25], [26]
Increased Volatility	[17], [21], [27]
Higher Complexity	[21], [24], [25]
Digital Transformation	[3], [17], [28]

Based on the business challenges, the characteristics of the conventional VSM is investigated. The major limitations, requiring a redesign with focus on digitalization, are listed in Table 2.
In summary, the methodology of the conventional VSM is characterized as inflexible, inefficient and too simplified. Furthermore, the considered information in the Value Stream Map is incomplete in the context of information logistics and the application of information and communication technologies.

Table 2: Limitations of the conventional VSM

Limitation	References
Effort-Intensive	[29]–[31]
Time-Consuming	[6], [29], [31]
Manual (Pen & Paper)	[7], [30], [32]
Static (unable to capture dynamics)	[7], [33], [34]
Past Snapshot (no Real-Time)	[6], [21], [35]
Reduced Accuracy due to averaged Values	[29], [35], [36]
No Capturing of Product and Process Variants	[6], [29], [35]
Lack of digital Data Processing due to analog Data	[12], [30], [37]

2.2.2 Stages of VSM 4.0

The present paper aims at the provision of an implementation framework for assessing the impact of transformation measures in comparison to the conventional VSM methodology. In this context, it is necessary to examine the VSM 4.0 concept with regard to a phased implementation.

Based on the reviewed literature, two stages of VSM 4.0 can be differentiated, whereas the conventional VSM forms the core, as visualized in Figure 2.

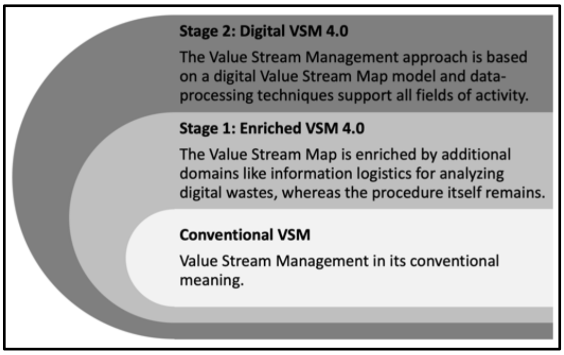

Figure 2: Stages of VSM 4.0

Stage 1 - Enriched VSM 4.0: The Value Stream Map is enriched by additional information, especially concerning information logistics, as described by [38]–[40]. Target is the visualization of digital waste by assessing the storage media for information, its usage and similar information. In this context, 8 types of information logistic waste are distinguished. The methodology itself remains unchanged compared to conventional VSM. [18]
Stage 2 – Digital VSM 4.0: The application of stage 2 is a disruptive transformation of the procedure in comparison to the conventional due to the transition from an analog paper-based model to a digital data model of the Value Stream Map, but it also offers new opportunities, e.g. the simulation of improvements, continuous data gathering and monitoring, as well as the utilization of data processing techniques like data and process mining. [41]–[43]

It is pointed out, that stage 1 and stage 2 are independent from each other. For example, the conventional Value Stream Map can be transformed to a digital model without data enrichment. The corresponding selection of additional information must be tailored to the needs of the company.

2.2.3 Evaluation of Digitalization Measures in General

In regard to its impact, digitalization measures can be evaluated value-based in three different ways, all based on a comparison of an initial state and the improved state (predicted or measured). The measurement of KPIs is suitable for both, processes as well as methodologies. [44]–[46], [47, pp. 43–46, 63]

Direct comparison of indicators, e.g., cycle time, resource utilization, output. An overall evaluation is made more difficult by the different units, e.g., seconds, percentage and pieces. By this approach a holistic assessment is difficult due to different units. Therefore, a further option is the application of utility values, which have a value in a defined range, e.g., 1 to 10. By the application of weighted utility values an overall evaluation under consideration of priorities on specific dimensions is supported.

Ratio of two indicators for determining the proportionate change, e.g., effectivity increase, also classified as index indicator.

Cost-orientated comparison, for which all changes are brought to a cost level, e.g., the time saving multiplicated with a rate per period is equal to the cost savings. By this approach an overall evaluation is possible due to a standardized reference value.

For a holistic evaluation it is necessary to compare the benefits of digitalization measures on the one side with its costs on the other sides. Measures with low costs / high benefits are preferable to measures with high costs / low benefits. The related KPI is mentioned as costs-benefits analysis (CBA), defined as difference between costs and benefit. On this occasion, one-time costs, e.g., the implementation costs for a software and ongoing costs, e.g., license costs are distinguished and have an impact on the amortization period. In addition, in the area of accounting the calculation of the indicator return on investment (ROI), defined as ratio of benefits and costs, is used. [48], [49, pp. 20–28]

2.2.4 Derivation of KPIs for Evaluating the Transformation to VSM 4.0

In regard to the previous section, the KPIs for evaluating the impact of digitalization measures against the background of a transformation from conventional VSM to VSM 4.0 are distinguished into four main dimensions, shown in figure 3.

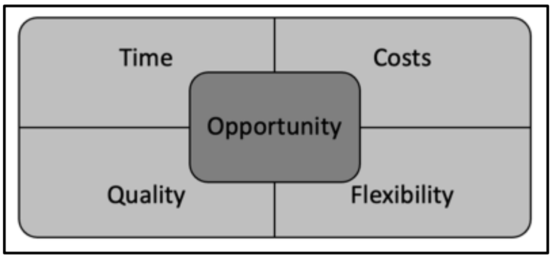

Figure 3: Dimensions of an VSM 4.0 Evaluation Framework

It is about the dimensions of time, costs, quality and flexibility, whereby a dependency between the dimensions can be determined. For example, a reduction of cycle times leads to a cost reduction. Furthermore, there is a fifth dimension, impacting all four dimensions. This is opportunity, which only arises from the operational application of technologies according to stage 2 of VSM.

The following listing shows a selection of suitable KPIs for evaluating digitalization measures in the context of the transformation from conventional VSM to VSM 4.0.

2.2.5 Selection of KPIs regarding the dimension time

Value Stream (VS) Mapping time: Absolute indicator, defined as time, required for mapping an entire VS. Used for comparing the time for manual recording and mapping by person and the time for automized recording by data / process mining based on events.

VS Analysis time: Absolute indicator, defined as time, required for analyzing an entire VS in regard to wastes. Used for comparing the time for manual analyzing by person and the time for automized analyzing based on machine learning (ML) / artificial intelligence (AI)

VS Design time: Absolute indicator, defined as time, required for designing a target VS in regard to wastes. Used for comparing the time for manual designing by person and the time for automized designing based on simulations as well as machine learning (ML) / artificial intelligence (AI)

VS Planning time: Absolute indicator, defined as time, required for planning and applying improvement measures for achieving the target VS. Used for comparing the time for the conventional PDCA-cycle (Plan-Do-Check-Act) based on a physical mock-up (PMU) and the time a

system-supported PDCA-cycle, simulating measures at a digital mock-up (DMU) for validating its impact before its implementation.
Time Effectivity: Ratio of the time for the improved state and the initial state for evaluating the effectivity of the measure on the dimension time.

2.2.6 Selection of KPIs regarding the dimension costs

Costs: The generalized indicator costs refers to all cost factors, e.g., the labor costs for lean manager as well as the costs for the operation of data platforms as storage area for process data, gathered according to the digital VSM 4.0 approach. In this context, partial and total costs can be considered.
Savings: In contrast to costs, saving refer to the elimination of costs, e.g., due to time savings in the processing.
Cost Effectivity: Ratio of the costs for the improved state and the initial state for evaluating the effectivity of the measure on the dimension costs.
Costs-Benefits: According to CBA the difference of benefit and costs is calculated. A value greater than zero (benefit is greater than the costs) is advantageous, whereas a value less than zero is disadvantageous. A value of zero shows, that benefits and costs are equal.
Return on investment: The ROI is defined as ratio of benefits and costs and is a measurement for the return in dependencies from the capital investment.

2.2.7 Selection of KPIs regarding the dimension quality

Accuracy / Data Quality (in general): The conventional VSM is based on a pen-and-paper procedure. To avoid measurement errors, a few production cycles are recorded and the values averaged. However, each recording is a snapshot of the production. By a continuous data gathering according to the digital VSM 4.0 approach, an entire overview including a data history is captured. Statistical methods can be applied to evaluate the data quality, e.g., mean and variance.
Sample Size: Number of gathered values, recorded for an indicator, e.g., process time.
Currency: Time after the last VS validation / last mapping.
Process coverage: Ratio of recorded VS and production cycles in a specific period.

2.2.8 Selection of KPIs regarding the dimension flexibility

Variance: Ratio of number of production cycles, following the standard VS (or alternatives VS) and total number of production cycles.
Variety: Number of variances of the production cycle.
Responsiveness: Time between a change in the VS and its capturing in the Value Stream Map.

2.2.9 Opportunities

The enrichment of the Value Stream Map according to stage 1 does not require a digital data model as described for stage 2. Therefore, the opportunities of enriching the Value Stream Map by indicators for analyzing information logistical wastes are not considered at this point due to the focus on evaluating digitalization measures.
Automizing the Mapping Procedure: A digital Value Stream Map model enables the automation of the mapping procedure and vice versa. In this context technologies such as IoT [50], [51], digital twin[11], [52], business application systems [53], [54] and cyber-physical systems (CPS) [55], [56] are mentioned in recent research.
Real-Time Monitoring: Enabled by the automized mapping procedure, process data are gathered in real-time. This enables a real-time monitoring by a continuous comparison of the target VS and the actual one. [56], [57]
Data and Process Mining: Based on the gathered data, the Value Stream Map is created by techniques of data and process mining. Furthermore, variants of the VSM can be visualized. [32], [41]
Simulation: Based on the digital Value Stream Map simulations can be applied for a virtual evaluation of digitalization measures before testing in practice. This opportunity saves time and efforts as proved in the context of digital engineering.[12], [30], [37]
Big Data / AI / ML: Big Data, AI and ML can support or automate the activities in the areas of Value Stream Analysis and Value Stream Design by the identification and evaluation of correlations. [26], [51]

3. Results and Discussion

The paper at hand aims at the provision of a framework, supporting a critical evaluation of measures for the transformation from the conventional VSM to VSM 4.0, which is based on a comparison of benefits and efforts for reasoning the transition from a company’s perspective. The target group for such a framework are companies, which already apply the conventional VSM approach.

As a systematic literature review against the background of a preliminary study proved, a proposal for such a framework is missing in the recent research. By the paper at hand this identified research gap is closed. Different KPIs, related to the dimensions time, costs, quality and flexibility are provided. Furthermore, opportunities arising from the transition to a digital Value Stream Map are pointed out, which are not covered by applying the conventional methodology.

By the paper at hand, a two-stage implementation plan for the transformation from VSM to VSM 4.0 is provided. Whereas the first stage is restricted to the consideration of information logistical data in the Value Stream Map without improvement of the methodology itself, but at least taking the digital landscape of companies into account, the second stage takes advantage of all potentials of a fully-digitalized methodology.

At this point, two limitations of the consideration are pointed out.
The evaluation framework is derived from approaches for evaluating digitization measures in general. A higher reference to VSM 4.0 requires an aligning of the KPIs with the pursued goals and challenges of companies, which already apply conventional VSM and undergo a digital transformation.
Recent studies are focused on proposing application potentials, considering different technologies and approaches. Missing is a universal proposal for merging the heterogenous data for further data-processing operations, which is mandatory for estimating efforts related to the VSM 4.0 transition, especially in regard to a BCA and ROI consideration.

4. Conclusion and Outlook

Value Stream Management is a well-known methodology for improving end-to-end supply chains. But the environment of companies is in change, which leads to arising new challenges. Against this background, the conventional VSM suffers several limitations, which are overcome by the proposed application of modern information and communication technologies according to VSM 4.0, as detailly discussed in various studies.

Due to the diversity of companies in regard to strategy, business model and products as well as the internal configuration, especially process and system landscape, companies differ in terms of their competencies, strengths, weakness and needs. For this reason, the decision for a digital transformation from the conventional VSM to VSM 4.0 requires a critical evaluation. As proved by a systematic literature review, such an evaluation framework is missing in recent studies. By the paper at a universal evaluation framework is introduced, covering the dimensions time, costs, quality and flexibility. Furthermore, opportunities in regard to VSM 4.0 are listed.

As pointed out in the previous section, there are some limitations, which lead to further research questions:
What is the concrete demand and the expected benefit for a transition from conventional VSM to VSM 4.0 from a company's perspective? What goal is being pursued?
How can a technical concept for the realization of VSM 4.0 be designed, providing a solution for merging all data from heterogenous data sources, like sensors and business application systems for further data-processing operations?

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