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Automation of the Manufacturing Process Mapping in the Context of VSM by Utilization of ERP Data

Tim Wollert[1,*] and Fabian Behrendt[2]

[1]Doctoral Center for Social, Health and Economic Sciences, Magdeburg-Stendal University of Applied Sciences Osterburger Str. 25, Stendal, 39576, Germany

[2]Department of Economic, Magdeburg-Stendal University of Applied Sciences, Osterburger Str. 25, Stendal, 39576, Germany

[*]Corresponding author. Email address: wollerttim@gmail.com

Abstract

Value stream management (VSM) as part of lean management is a holistic approach for mapping, analyzing and designing end-to-end supply chains from suppliers to customers from a company's perspective. The method aims at the systematical identification and elimination of wastes to reduce lead time and by this the overall costs. In its conventional methodology, VSM, especially the mapping of the as-is value stream, is time consuming and resource intensive due to a mainly manual procedure, which necessitate multiple recording cycles to ensure a reliable data quality. Due to changing conditions in the fields of applications, e. g. intensifying competition and higher varieties of products, companies are forced to become more flexible to secure and strengthen future market positions. Against this background the inflexible characteristic of the conventional VSM is a major disadvantage, threatening its future viability. The targeted combination of the existing field-tested framework and the application potentials of modern information and communication technologies (ICT) plays an important role in eliminating the mentioned disadvantage of VSM. The present paper deals with the topic of automizing the manufacturing process mapping by utilizing data provided by enterprise resource planning (ERP) systems. For this purpose, the elementary indicators of VSM with focus on the manufacturing process, recorded during an on-site visit, are reviewed. Based on this review, related business and data objects of common ERP are identified and mapped to the specific indicators. Furthermore, calculation rules for indicators, not covered by ERP-systems, are proposed. Finally, a data framework as modular enhancement of the conventional VSM methodology is provided, which supports the automation of the mapping process and by this reduces manual efforts.

Keywords: Lean Management 4.0; Value Stream Management (VSM), Value Stream Mapping 4.0; Enterprise Resource Planning (ERP)

1. Introduction

Lean management in its entirety consists of tools, methods and principles, aiming at the increase of efficiency by decreasing wastes. The origin of the holistic management approach is the Toyota Production System (TPS), derived from best practices in the automotive industry and steadily improved. (Kwiatkowski et al., 2016, pp. 31, 32) One of the core elements of lean management is the consideration of processes as value streams, differentiating value-adding and non-value-adding activities. In that regard the VSM is a widely used methodology to map, analyze and improve end-to-end supply chains, taking internal as well as external resources (supplier and customer) into account. (Oberhausen & Plapper, 2015, p. 144)

As mentioned in the abstract, the conventional respective traditional VSM is characterized as time consuming, resource intensive, static and inflexible due to a mainly manual procedure, requiring repetitive measurements to ensure a valid data base for analysis. This property is an essential disadvantage, especially in regard to changes in the process, which mostly necessitate a fully new recording of the entire end-to-end value stream. The environment's conditions from a company's perspective are changing. Globalization increases the market pressure and companies are in competition with their whole supply chain network. Higher dynamics and volatility in market environments require greater flexibility. Shorter innovation cycles, decreased lot sizes, wider variety, more frequent technology changes are only a few of the effects, to be considered in the value stream design. For this reason, the future viability of VSM in its traditional way is questionable. (Lugert & Winkler, 2019, pp. 1, 2) Related to this question, an increasing number of publications is available, making the VSM and its future viability against the background of rising digitization of processes, enabled by the steadily increasing performance of digital ICT a subject of discussion. In general, most of the publications focus on the utilization of sensor data and similar industry 4.0 technologies, e. g. digital twins or cyber-physical systems. More specific details regarding approaches to improve the traditional VSM are provided in the section

State of Research.

The present paper aims at the provision of a conceptual data framework, mapping the manufacturing process related VSM indicators to ERP business and data objects. This data framework is an improving enhancement of the existing field-tested VSM methodology, utilizing available business data to reduce the time and resource efforts for gathering information and mapping the as-is value stream as well as to get more flexible towards changes in the value stream.

Therefore, the specific key performance indicators (KPI) of the conventional VSM as well as the procedure itself are reviewed. Furthermore, the corresponding ERP business and data objects are derived. The mapping includes both, master data and transactional data. For VSM indicators, not directly covered by the ERP data base, a calculation model is proposed.

2. State of Research

Several studies are published discussing the improvement potentials of VSM by applying ICT. In essence, the traditional VSM is mostly mentioned as static due to its inflexibility. In addition, the limitations are pointed out, for which adaptions are required to ensure its future viability in dynamic environments. To differentiate the new approaches against the conventional one terms like dynamic and smart VSM as well as VSM 4.0 are proposed. (Lugert & Winkler, 2019; Balaji et al., 2020; Tamás, 2016) The following overview is based on a selection of publications.

In general, two fundamental approaches to enhance the scope of VSM can be distinguished. On the one side, the framework is enriched by the documentation of applied ICT along the value stream, taking the information flows, the information direction (into or out of the process steps) and the corresponding activity into account. The conventional methodology of an on-site visit remains. By the structured visualization, technological wastes, e. g. media disruptions and analog information media like paper are identified as well as eliminated in a structured way. (Meudt, 2016; Haschemi & Roessler, 2017; Meudt, 2020) On the other side, the VSM methodology is improved by the utilization of data, gathered from industry 4.0 technologies. Most of the reviewed technology-orientated publications propose the application of ID-technologies, especially radio-frequency identification (RFID) to enable a real-time tracking of materials (Ahmed et al., 2014; Ramadan et al., 2016; Gladysz & Buczacki, 2018). In addition, the utilization of sensors (be Isa et al., 2019), indoor positioning systems (Tran et al., 2021), cyber-physical systems (CPS) (Arey et al., 2021), internet of things (IoT) (Zarrar et al., 2021), digital twins (Mayr et al., 2018) and industry 4.0 technologies in general (Tripathi et al., 2021) are discussed. It is suggested to automize the mapping procedure of VSM by applying algorithm such as Big Data (Shahin et al., 2020) and process mining (Zanon et al., 2021) to the gathered data. Based on a given data model, simulations support the decision making in regard to design questions (Szentesi et al., 2016).

According to the classification of the automation pyramid, illustrated in Figure 1, all mentioned technologies are related to the levels 0 to 2, whereas the technologies, assigned to level 3 und 4 are less discussed.

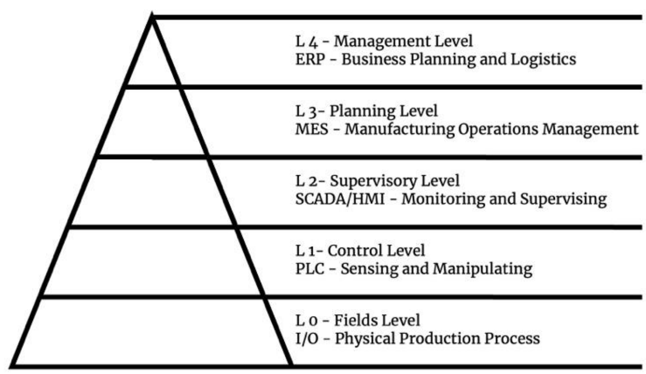

Figure 1: Automation Pyramid for Classification of Information Technologies in Industries (Martinez et al., 2021, p. 3)

In the reviewed publications business application systems in general and Manufacturing Execution System (MES), Enterprise Resource Planning (ERP), Warehouse Management Systems (WMS) and similar systems in particular are briefly outlined as potential data sources, but a detailed concept, describing the way of data utilization is missing. (Wagner et al., 2018; Ramadan et al., 2020; Ramadan & Salah, 2019)

The present paper deals with the investigation of the pointed-out research gap by analyzing the information demand of the traditional VSM and providing a mapping framework, limited to ERP business and data objects.

3. Applied Methodology

The conventional VSM is a primarily manual pen-and-paper process and the recording of the entire value stream including all parameters and process KPIs requires an on-site visit. Durations are measured by stopwatch and averaged with relation to the corresponding process activities. To ensure a valid data quality and avoid measurement errors, the value stream is recorded multiple times and validated. The overall methodology follows an iterative process. Changes in technologies, products or similar impact the value stream configuration and thereby value stream KPIs. To ensure a valid state of the map, the entire process is reviewed and updated. Due to these circumstances the approach is described as very time-consuming, resource-intensive and static. Against the background of increasing dynamics in supply chains these properties are a major disadvantage of the traditional VSM methodology. (Lugert & Winkler, 2017) The framework, described in the following aims at the reduction of this disadvantage.

Several best practices and uses cases in regard to the traditional VSM are accessible. Based on a selection of studies, the VSM approach is described in a first step to outline the major features of the methodology. As described in section 1, the core aspects of VSM remain, but the data frame, proposed in the paper at hand, enhances to methodology to reduce manual efforts and get more flexible. Due to the paper's limitation to the manufacturing process mapping, the focus of the summary is on the recording of the production process and especially on the production related KPIs. In the second step ERP business and data objects related to the recorded information are determined. The definition is generalized to create a universal mapping framework, applicable to common ERP systems, but the framework is validated by a business scenario, mainly created in an SAP S/4HANA training environment, provided by Magdeburg-Stendal University of Applied Sciences.

3.1. Procedure of Conventional VSM

At the beginning of VSM a product family is identified, for which the value stream is mapped. This product family defines the scope. The first phase of VSM refers to the documentation of the status quo (value stream mapping), which is then analyzed (value stream analysis) according to wastes. The findings form the baseline for designing a target process (value stream design). Therefore, six elements are considered during the mapping process, as mentioned following: the manufacturing process (1), taking internal and external activities into account, the business processes (2) in general and the production planning and control process in particular (often supported by a production planning and scheduling (PPS) system), material flows including WIP-stocks and Kanban cycles (3) as well as information flows (4), and both, customer (5) as demand and supplier (6) as supply of the value stream. (Molenda et al., 2019, pp. 5, 6). The paper at hand is limited to the first element and concentrates on the manufacturing process.

The mapping process is structured by four steps. Based on the previously listed elements, the documentation starts with the framework, outlining the customer in the right upper corner in the map, the activities of the production process as activity boxes in the correct order in the lower section and the supplier in the left upper corner of the map. In the second step, material and information flows are visualized by directional arrows, connecting the objects in the map in a logical manner. In the third step, the documented elements are enriched by assigning the recorded process data respective KPIs, e. g. demand quantity, delivery cycles, processing time, operator quantity and so on. The following section spends a detailed consideration on the KPIs and the meaning for VSM. In the last step, the map is finalized by adding timelines and calculations to determine lead time, value-added times and the process efficiency. (Langstrand, 2016, pp. 8–15) A simplified schematic sketch of a value stream map is shown in Figure 2. For more detailed information regarding the model notation a reference is made to relevant literature.

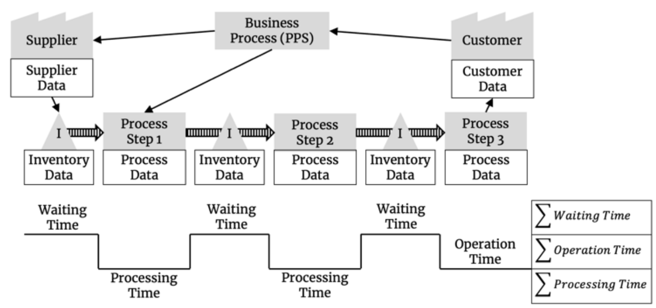

Figure 2: Schematic Sketch of a Value Stream Map (Erlach, 2013, pp. 83, 86; Molenda et al., 2019, p. 6; Oberhausen & Plapper, 2015, p. 147)

In regard to the indicator's naming, the publications distinguish from each other, but the content-related meaning is similar. Also, the scope of to be recorded process data is differently defined. In general, it is said, the required scope is determined by the purpose and the more indicators are documented, the better the value stream can be analyzed in its entirety to design an improved target process. (Langstrand, 2016, p. 11) The following defined indictors are a selection of the essential KPIs, forming the minimal basis for describing the manufacturing process' activities and calculating the overall value-added process time, production lead time and process efficiency. (Erlach, 2013, pp. 48–58, 308–311, 2020, pp. 59–71, 118–122; Langstrand, 2016, pp. 11–15; Plapper & Andre, 2011, pp. 8–12)

Uptime

The indicator uptime is a measure for the possible utilization degree of resources. Maintenance, repair and other comparable activities (not setup) lead to downtimes and thereby lower the maximum available utilization time. The maximum uptime is 100%.

No. of operators/ resources [Op/Res]

The indicator number of operators/ resources is the quantity of interchangeable resources, providing the same processing characteristics, skills or technologies. By increasing the number of resources, the lead time can be reduced due to parallelization of activities. In this context personnel resources [Op] and physical resources [Res] are distinguished.

Capacity Availability

The indicator capacity availability defines the daily time availability of the work center. The total day capacity is calculated by the shift duration and number of shifts per day or the daily work time multiplicated with the number of resources. Furthermore, the capacity availability is reduced by breaks.

Change over time [CO]

The indicator change over time is defined as setup time for exchanging tools, fixtures and other equipment, when changing the product. In this time the resource is not available for processing. Lean tools as SMED (single minute exchange of die) aim at the reduction of this time, because it is not value-adding.

Operation Time [OT]

The operation time includes primary processing times respective main times, e. g. when a component is processed, and secondary processing times respective ancillary process times, e. g. a component change. Setup times respective change over times are excluded.

Processing Time [PT]

If the order quantity is one, the processing time is equal to the operation time. If the order quantity is greater than one, two cases are distinguished:

1. The materials enter successively a chained production process, which consists of several processing steps. The flow is continuous.
2. A couple of materials is grouped to a batch, which is simultaneously processed in one processing step, e. g. heat treatment. The flow is discontinuous.

Cycle Time [CT]

The indicator cycle time is defined as the required time, to complete one operation cycle, taking the number of resources, available for processing the operation, into account. The cycle time must be less than the customer takt time to fulfill the demand. Otherwise, additional resources are necessary. In case of only one resource is available, the cycle time is identical to the operation time. In case of i parallel utilized resources, the cycle time is the operation time, divided by i. The relation between operation time, process time and cycle time is described by the following formula with [P] for number of identical parts in the final product and [PQ] for process quantity (quantity of parts, processed in one process). The formula is related to operation n.

$$CT_n = \frac{OT_n \times P}{Res_n} = \frac{PT_n \times P}{PQ \times Res_n} \tag{1}$$

Waiting Time/ Range of Coverage [RC]

According to the principles of lean management, stocks in production are waste and cause longer lead times. This principle is based on FIFO (first in, first out). FIFO means, the material, laying on stock the longest time, is consumed first. Following FIFO, the waiting times regarding one operation, also called inventory lead time or range of coverage [RC] is defined as sum of queued buffer stocks, called WIP (work in process) and stock quantity [SQ], divided by the daily demand of the final product [DD], multiplicated with the number of identical parts in the final product [P]. After this period, the stock is turned over one time and the processing of the tracked material continues. Under the assumption of 100% yield the range of coverage in days is defined by following formula.

$$RC_n = RC_{Stock_n} + RC_{WIP_n} = \frac{WIP_n + SQ_n}{DD \times P} \tag{2}$$

Production Lead Time [PLT]

The indicator production lead time is the overall duration from start of production, when the material enters the production process until the end of production, when the material is finalized and put on stock or delivered to customer. Based on the definition of RC, the lead time is defined as sum of all RC_n. The operation respective processing time is taken indirectly into account by considering the WIP_n, but not including the direct processing and operation times. The calculation is described by the following formula.

$$PLT = \sum_n RC_n \tag{3}$$

Due to the fact, in practice the sum of all value-adding times is much less than the range of coverage, the formula for the production lead time is simplified the sum of all the waiting times, not considering the process time at all.

The production lead time in the meaning of conventional VSM is visualized in Figure 3.

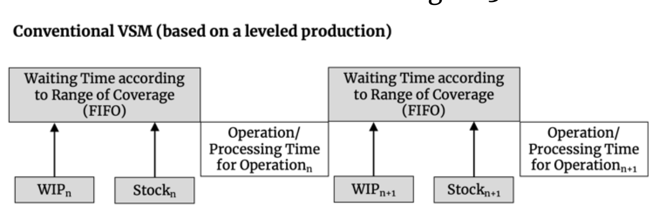

Figure 3: Production Lead Time according to the conventional VSM

Process Efficiency [PE]/ Degree of Flow [DF]

The process efficiency [PE] is the primary indicator of VSM, describing the degree of value-adding in the manufacturing process and showing the time-related improvement potentials. PE is defined as the ratio of operational times (sum of process times and operation times) to the lead time. The degree of flow is the process efficiency, standardized to the working time [WT] per day.

$$PE = \frac{\sum_n (OT_n + PT_n)}{PLT} \quad (4)$$

$$DF = \frac{\sum_n (OT_n + PT_n)}{PLT \times WT} \quad (5)$$

Levelling the production is one of the major targets of lean management to avoid peaks in the capacity utilization. Against this background the lean method every-part-every-interval (EPEI) aims at the demand-driven calculation of optimal lot sizes to minimize the production lead time. Beside the period-related demand the mentioned indicators are mandatory inputs for these calculations. The mapping framework for deriving the VSM indicators from ERP data is described in the following section.

3.2. Mapping of ERP objects to VSM elements

After defining the manufacturing process related VSM indicators in detail, business and data objects are introduced for mapping the VSM indicators to ERP data as basis for a mapping framework proposal. In general, business application systems as ERP or MES consists of different data types, representing different system layers. SAP for example is based on organizational data, e. g. company code, master data, e. g. routings and transactional data, e. g. orders. There is a hierarchical dependency between the objects. Production orders are based on routings and bill of materials, which are referenced to a plant. (Drumm et al., 2019, pp. 62–83) The following proposed framework is mainly focused to the utilization of master and transactional data.

ERP systems are complex business application systems and open numerous options fur individualization to match the customer's demand.

Work center information

Work centers are ERP business objects, defined as master data and representing resources, able to process operation related activities in production, quality, maintenance and other environments. A work center can be a personal individual or group of individuals as well as a machine, assembly place, production line or a pool of technical resources. Work centers are used in routings as planned resources and in production orders for capacity planning, scheduling, costing and further applications.

The activities, a work center can process, are defined as standard values, controlled by the standard value key, assigned to the work center. By this, setup times and value-adding process times, can be distinguished as shown in Figure 4.

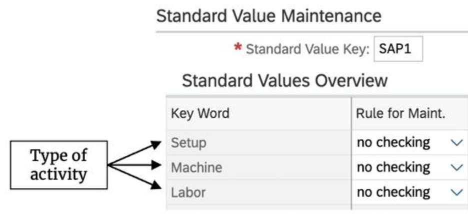

Figure 4: Activity Types of Work Center

For finite production planning and scheduling, the available capacity is maintained with regard to the work center, as shown in **Figure 5**. The total capacity is defined by start and end time, breaks, number of resources and the capacity utilization.

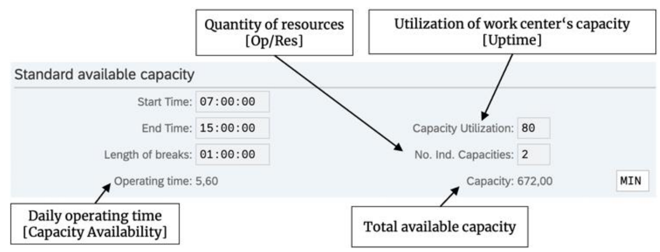

Figure 5: Work Center's Capacity

The mapping of the ERP data objects to VSM indicators is illustrated by the indictor's naming in the square brackets.

Routing information (standard value)

As work centers, routings are ERP business objects and belong to master data. Routings are based on work centers and describe a sequence of activities, to be carried out to produce a material. Beside a sequential flow (main sequence), parallel and alternative sequences can be defined. Each operation in the routing requires a work center. Based on the standard value key assigned to a work center, operation related standard values can be maintained for each activity type. The capacity demand with regard to setup, processing, tear down and others is calculated by formulas, defined in the work center configuration (master data maintenance). The routing maintenance is shown in Figure 6. The business scenario consists of the activities sawing (1), machining (2) and mounting (3)

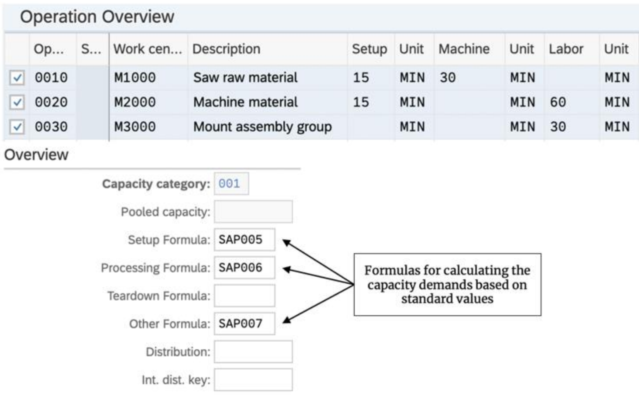

Figure 6: Routing Maintenance and Calculation of Capacity Demand

Based on the routing information a first draft of the activity map can be derived. It is pointed out that the routing is a master data object and not fully determined. In general, work centers in routings can be pool work centers (group of similar work centers) and the determination of a concrete work center is done during the detailed planning and scheduling of a production order. Furthermore, production quantities are missing and thus the resulting capacity demand cannot be calculated.

Production order information

The ERP business object production order is related to transactional data and created manually or as conversion of a planned order, created during the MRP (material requirements planning) run to cover a planned or customer requirement. Planned orders contain information regarding the to be produced material and its quantity, the components based on BOM-explosion (bill of material) as well as the start and delivery date. During the production order creation, the routing is selected. By the capacity and scheduling formulas the production order is scheduled and planned against finite capacities. Furthermore, an availability check for components can be applied. The result is an (partially) determined production order to be released for production.

In comparison to the ERP business object routing, the production order is more determined on a planning level, considering production quantities and the resulting planned capacity demands, calculated by the work center related formulas. Production orders are a valid source for automizing the activity mapping in regard to the manufacturing process in the context of VSM.

Confirmations on production orders

Confirmations are created on operations and document the actual progress of a production order. Partial and final confirmations belong to transactional data and enable the recording of activity-related times, work centers, time stamps and further information on production orders respective single operations. In modern industries, data acquisition tools are applied to support decentralized recording of operational data in real-time. Two kinds of confirmations can be distinguished – on the one hand event confirmations, e. g. start of processing and on the other hand time confirmations, e. g. 2 hours of labor time. Based on the type of confirmation and the related activity type the VSM indicators operation time [OT] respective processing time [PT] can be determined. A clear assignment of the confirmation time to one of the two indicators can be made according to the confirmed quantity. As mentioned in the previous section, a quantity of one is related to the operation time, whereas a quantity greater than one is related to the processing time. Focusing on production data, a calculation of waiting time [WT], equivalent to the range of coverage [RC], defined as time difference between the end of the last confirmation on an operation and the start of the succeeding operation is proposed. At this, the work center's availability, maintained in the master data, is taken into account.

For event-based confirmations the time start and stop time stamps are available, as visualized in **Figure 7**. The calculation of the effective waiting time is the idle time, reduced by the time of the work center's unavailability.

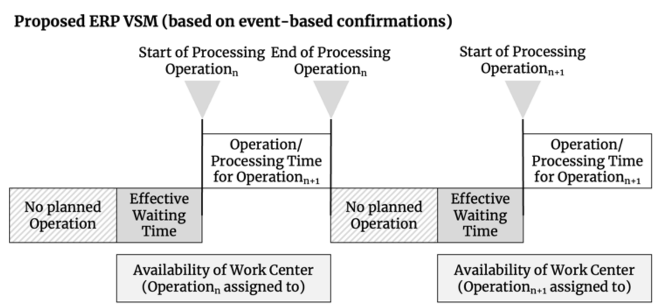

Figure 7: Calculation of operation, processing and waiting times based on event-based confirmations

For time-based confirmations the time stamps are not directly available, but can be derived from the existing information. The creation date and creation time correspond to the stop time stamp. By subtracting the confirmed duration, the start time stamp can be calculated, as visualized in Figure 8.

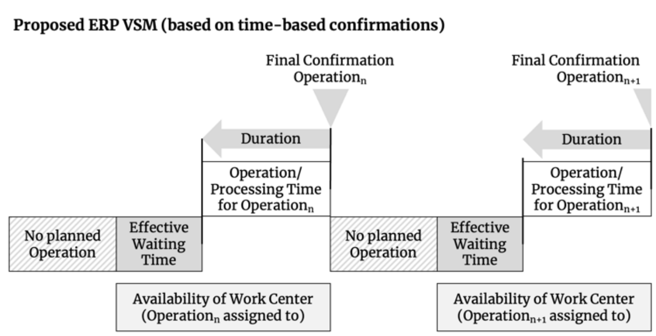

Figure 8: Calculation of operation, processing and waiting times based on time-based confirmations

The further calculation for waiting times is equal to the described one related to event-based confirmation.

Based on the VSM indicators, derived directly and indirectly from the ERP business application system as described in the proposed framework the residual indicators, listed in section 3.1 can be calculated.

4. Results and Discussion

Aim of the paper at hand is the proposal of a data framework as enhancement of the traditional VSM to improve the application of VSM in dynamic environments by utilizing ERP-related business data. To achieve this objective, the VSM procedure and relevant indicators with focus on the manufacturing process are reviewed to determine the essential information baseline. In a further step, concrete ERP business and data objects, which cover directly or indirectly the required information baseline of VSM are determined. Both areas are joined by designing a concrete mapping framework. The present paper provides a validated mapping framework, which allows the derivation and calculation of manufacturing process related VSM indicators from a selection of relevant ERP data. The data basis consists of master data as well as transactional data, created during a business scenario. The framework's validation on operational data proves the fundamental feasibility, but it is pointed out, the business case underlies several restrictions, which are mentioned in the following listing.

- The framework follows the assumption of a sequential processing. Overlapping is not considered.
- The availability of the work center is based on start and end time of one shift. Multiple shifts per day are not considered.
- The utilization of the work center is based on maintained master data. A validated calculation based on planned times and confirmed times offers improvement potentials.
- The framework is limited to production related data. Logistics-related data, e. g. WIPs and stocks, are not considered.
- Interdependencies between different production lines, utilizing same resources (bottle necks) are not considered.

5. Conclusion and Outlook

VSM is still a valid approach for designing end-to-end supply chains, but requires some improvements to ensure future viability. The major disadvantage is its inflexibility and static characteristics, reinforced by increasing dynamics and volatility in market environments. The consideration of changes and the related update of the value stream map is time consuming and resource intensive. In this context the automation of the manufacturing process mapping as part of VSM by utilization of ERP data is investigated.

The provided framework improves the traditional methodology of VSM by reducing manual efforts and increasing flexibility. But as pointed out in the previous section, there are some limitations and constraints in applying the framework. Against this background, the proposed framework is limited to the mapping of the manufacturing process. Furthermore, several assumptions according to the configuration of the manufacturing process, e. g. no overlapping respective parallelization of activities are made. For a holistic mapping framework, covering the entire VSM approach in a universal way, further explorations are necessary. In detail, these explorations refer to the utilization of especially logistic-related data, but also procurement-related data (supplier, material, lead time) as well as sales-related data (customer, demand, ordering cycle).

References

Ahmed, A., Hasnan, K., Aisham, B., & Bakhsh, Q. (2014). Integration of Value Stream Mapping with RFID, WSN and ZigBee Network. *Applied Mechanics and Materials*, *465–466*, 769–773. https://doi.org/10.4028/www.scientific.net/AMM.465-466.769

Arey, D., Le, C. H., & Gao, J. (2021). Lean industry 4.0: A digital value stream approach to process improvement. *Procedia Manufacturing*, *54*, 19–24. https://doi.org/10.1016/j.promfg.2021.07.004

Balaji, V., Venkumar, P., Sabitha, M. S., & Amuthaguka, D. (2020). DVSMS: Dynamic value stream mapping solution by applying IIoT. *Sādhanā*, *45*(1), 38. https://doi.org/10.1007/s12046-019-1251-5

be Isa, J., Segerer, B., Miller, A., Kaffenberger, C., Dräger, T., Korn, C., Franz, M., Boppert, J., & Latzel, S. (2019). Automatisierte Wertstromanalyse auf Basis mobiler Sensornetzwerke. *Zeitschrift Für Wirtschaftlichen Fabrikbetrieb*, *114*(11), 711–714.

Drumm, C., Knigge, M., Scheuermann, B., & Weidner, S. (2019). *Einstieg in SAP ERP: Geschäftsprozesse, Komponenten, Zusammenhänge: erklärt am Beispielunternehmen Global Bike* (1. Auflage). Rheinwerk.

Erlach, K. (2013). *Value stream design: The way towards a lean factory*. Springer.

Erlach, K. (2020). *Wertstromdesign: Der Weg zur schlanken Fabrik* (3. Auflage). Springer Vieweg.

Gladysz, B., & Buczacki, A. (2018). Wireless technologies for lean manufacturing – a literature review. *Management and Production Engineering Review*. https://doi.org/10.24425/119543

Haschemi, M., & Roessler, M. P. (2017). Smart value stream mapping: An integral approach towards a smart factory. *3rd International Congress on Technology-Engineering & Science*, 273–279.

Kwiatkowski, M., Lorenc, K., Nowicka, D., Prosół, H., Sikora, M., & Pham, L. (2016). Lean Management as an instrument of sustainable development of enerprises. *Management Systems in Production Engineering*, *nr 1 (21)*. https://doi.org/10.12914/MSPE-05-01-2016

Langstrand, J. (2016). *An introduction to value stream mapping and analysis*. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A945581&dswid=-432

Lugert, A., & Winkler, H. (2017). Von der Wertstromanalyse zum Wertstrommanagement: Wie die statische Lean-Methode mit Industrie-4.0-Lösungen zu einem dynamischen Managementansatz weiterentwickelt werden kann. *Zeitschrift für wirtschaftlichen Fabrikbetrieb*, *112*(4), 261–265. https://doi.org/10.3139/104.111703

Lugert, A., & Winkler, H. (2019). Zukunftsfähigkeit der Wertstrommethode im Kontext von Industrie 4.0. *Logistics Journal Nicht-Referierte Veröffentlichungen*, *2019*. https://doi.org/10.2195/lj_NotRev_lugert_de_201901_01

Martinez, E., Ponce, P., Macias, I., & Molina, A. (2021). Automation Pyramid as Constructor for a Complete Digital Twin, Case Study: A Didactic Manufacturing System. *Sensors*, *21*, 4656. https://doi.org/10.3390/s21144656

Mayr, A., Weigelt, M., Kühl, A., Grimm, S., Erll, A., Potzel, M., & Franke, J. (2018). Lean 4.0—A conceptual conjunction of lean management and Industry 4.0. *Procedia CIRP*, 72, 622–628. https://doi.org/10.1016/j.procir.2018.03.292

Meudt, T. (2016). Value stream mapping 4.0: Holistic examination of value stream and information logistics in production [Wertstromanalyse 4.0: Ganzheitliche Betrachtung von Wertstrom und Informationslogistik in der Produktion]. *ZWF Zeitschrift Fuer Wirtschaftlichen Fabrikbetr*, *111*(6), 319–323.

Meudt, T. (2020). *Wertstromanalyse 4.0*.

Molenda, P., Jugenheimer, A., Haefner, C., Oechsle, O., & Karat, R. (2019). Methodology for the visualization, analysis and assessment of information processes in manufacturing companies. *Procedia CIRP*, *84*, 5–10. https://doi.org/10.1016/j.procir.2019.04.291

Oberhausen, C., & Plapper, P. (2015). Value Stream Management in the "Lean Manufacturing Laboratory." *Procedia CIRP*, *32*, 144–149. https://doi.org/10.1016/j.procir.2015.02.087

Plapper, P., & Andre, C. (2011). Wertstrommethode – Value Stream Mapping. *Qualitätsmanagement in Dienstleistungsunternehmen*, *Köln: TÜV Media*, 1–27.

Ramadan, M., Alnahhal, M., & Noche, B. (2016). RFID-Enabled Real-Time Dynamic Operations and Material Flow Control in Lean Manufacturing. In H. Kotzab, J. Pannek, & K.-D. Thoben (Eds.), *Dynamics in Logistics*. Springer International Publishing. https://doi.org/10.1007/978-3-319-23512-7_27

Ramadan, M., & Salah, B. (2019). Smart Lean Manufacturing in the Context of Industry 4.0: A Case Study. *International Journal of Industrial and Manufacturing Engineering*, *13*(3), 174–181.

Ramadan, M., Salah, B., Othman, M., & Ayubali, A. A. (2020). Industry 4.0-Based Real-Time Scheduling and Dispatching in Lean Manufacturing Systems. *Sustainability*, *12*(6), 2272. https://doi.org/10.3390/su12062272

Shahin, M., Chen, F. F., Bouzary, H., & Krishnaiyer, K. (2020). Integration of Lean practices and Industry 4.0 technologies: Smart manufacturing for next-generation enterprises. *The International Journal of Advanced Manufacturing Technology*, *107*(5), 2927–2936. https://doi.org/10.1007/s00170-020-05124-0

Szentesi, S., Tamás, P., & Illés, B. (2016). *Improvement possibilities for the method of value stream mapping*.

Tamás, P. (2016). Application of Value Stream Mapping at Flexible Manufacturing Systems. *Key Engineering Materials*, *686*, 168–173. https://doi.org/10.4028/www.scientific.net/KEM.686.168

Tran, T.-A., Ruppert, T., & Abonyi, J. (2021). Indoor Positioning Systems Can Revolutionise Digital Lean. *Applied Sciences*, *11*(11), 5291. https://doi.org/10.3390/app11115291

Tripathi, V., Chattopadhyaya, S., Bhadauria, A., Sharma, S., Li, C., Pimenov, D. Y., Giasin, K., Singh, S., & Gautam, G. D. (2021). An Agile System to Enhance Productivity through a Modified Value Stream Mapping Approach in Industry 4.0: A Novel Approach. *Sustainability*, *13*(21), 11997. https://doi.org/10.3390/su132111997

Wagner, T., Herrmann, C., & Thiede, S. (2018). Identifying target oriented Industrie 4.0 potentials in lean automotive electronics value streams. *Procedia CIRP*, 72, 1003–1008.

Zanon, G., Santos, L., Santos, E., Szejka, A., & Pinheiro de Lima, E. (2021). *Process Mining and Value Stream Mapping: An Incremental Approach*. https://doi.org/10.1007/978-3-030-76310-7_14

Zarrar, A., Rasool, M. H., Raza, S. M. M., & Rasheed, A. (2021). IoT-Enabled Lean Manufacturing: Use of IoT as a Support Tool for Lean Manufacturing. *2021 International Conference on Artificial Intelligence of Things (ICAIoT)*, 15–20. https://doi.org/10.1109/ICAIoT53762.2021.00010