World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:17, No:4, 2023

Modular Data and Calculation Framework for a Technology-Based Mapping of the Manufacturing Process According to the Value Stream Management Approach

Tim Wollert, Fabian Behrendt

***Abstract*—**Value Stream Management (VSM) is a widely used methodology in the context of Lean Management for improving end-to-end material and information flows from a supplier to a customer from a company's perspective. Whereas the design principles, e.g. Pull, value-adding, customer-orientation and further ones are still valid against the background of an increasing digitalized and dynamic environment, the methodology itself for mapping a value stream is characterized as time- and resource-intensive due to the high degree of manual activities. The digitalization of processes in the context of Industry 4.0 enables new opportunities to reduce these manual efforts and make the VSM approach more agile. The paper at hand aims at providing a modular data and calculation framework, utilizing the available business data, provided by information and communication technologies for automizing the value stream mapping process with focus on the manufacturing process.

***Keywords*—**Industry 4.0, lean management 4.0, value stream management 4.0, value stream mapping.

I. Introduction

THE term Value Stream Management (VSM) describes a methodology to map, analyze and improve end-to-end supply chains from a company's perspective. The value stream map is a visual model of the entire value stream and forms the core of the methodology. Based on the map of the actual value stream, an analysis is applied to identify non-value adding wastes. During the further processing, the identified wastes are eliminated according to their priority by designing an improved target value stream. Therefore, material and information flows are considered. Furthermore, not only internal conditions, but also suppliers and customers are taken into account [1, pp.701-702], [2].

The conventional procedure of this methodology is driven by a manual pen-and-paper recording, requiring several production cycles to ensure a valid data quality. During these cycles different qualitative and quantitative indicators, e. g. work-in-progress (WIP) stocks, durations, availability and uptime are measured and averaged [2, p.38]. The whole process of data gathering and data structuring is time-consuming and effort intensive. These characteristics lead to high inflexibility in dynamic environments, caused by shorter innovation cycles, decreasing lot sizes, higher variety and similar factors. For this reason, in several publications the traditional VSM is mentioned as static [3], [4].

Following the recent researches, two approaches, mentioned as dynamic VSM, smart VSM or VSM 4.0 can be distinguished [5]. The first approach proposes the enhancement of the traditional documentation by technology-orientated information, e.g. storage media and usage, but the procedure itself remains unchanged [6], [7]. The second approach foresees the utilization of data, provided by different information and communication technologies. The researches provide different ways of utilization, covering single technologies (e.g. sensors as RFID [8], [9], IoT respective IIoT [3], [10] and digital twins [11] [12]), technology systems, combining different technologies (e.g. positioning systems [13] and cyber-physical systems [14]). Furthermore, business application systems as Enterprise-Resource-Planning (ERP) [15], Manufacturing Execution System (MES) [16], Warehouse Management System (WMS) [17] and Supply Chain Management Systems (SCM) [18] are mentioned. But a concrete data model respective framework, taking the related business objects and data structures for an application study into account is missing, based on the reviewed studies.

The paper at hand provides a modular data and calculation framework for improving the conventional value stream mapping procedure by automizing respective supporting the mapping procedure with focus on the manufacturing process.

II. Applied Methodology

The applied methodology is described in the following section and visualized in Fig. 1.

The procedure is divided into five steps. At the first step the value stream map is examined and the relevant indicators for documenting and analyzing the value stream are described. The consideration is limited to the manufacturing process. In this context, both domains, logistics and operations are covered. Therefore, the information content of the value stream map is pointed out according to [19]. In a second step, each key performance indicator (KPI) is examined according to its characteristics and meaning to ensure an applicable mapping of

Tim Wollert is with the Doctoral Center for Social, Health and Economic Sciences, Magdeburg-Stendal University of Applied Sciences Osterburger Str. 25, Stendal, 39576, Germany (e-mail: tim.wollert@stud.h2.de)

Fabian Behrendt is with Magdeburg-Stendal University of Applied Sciences, Department of Economic, Osterburger Str. 25, Stendal, 39576, Germany (e-mail: fabian.behrendt@h2.de)

potential data objects, covering its original significance. The identification of potential digital data sources based on the model's requirement is done in step three. Potential sources are related to all four levels of the automation pyramid, including sensors, programmable logic controllers (PLC) as well as business application systems [20], related digital sources of information data are identified. Due to different system and process landscapes of companies the identification is generalized and different options are discussed. By combining the results of step two and three, the data structures and related KPIs are mapped in the fourth step. For all KPIs, which are not covered by a direct mapping to the raw data, calculation respective derivation rules are defined. Furthermore, different ways of mapping and data gathering as well as calculation procedures are provided to enable the modularity of this framework. In this context, static mappings and dynamic determinations of KPIs are differentiated. In the last step, the framework is verified by test data, created by processing different business scenarios. The sources of data are mainly an S/4HANA training environment (ERP) and a physical training factory Industry 4.0 model, detailly described in [21].

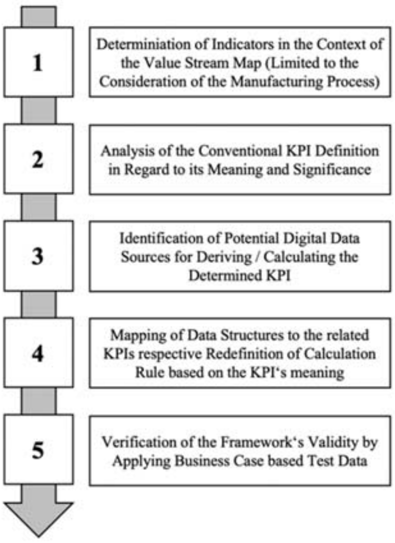

Fig. 1 Applied Methodology

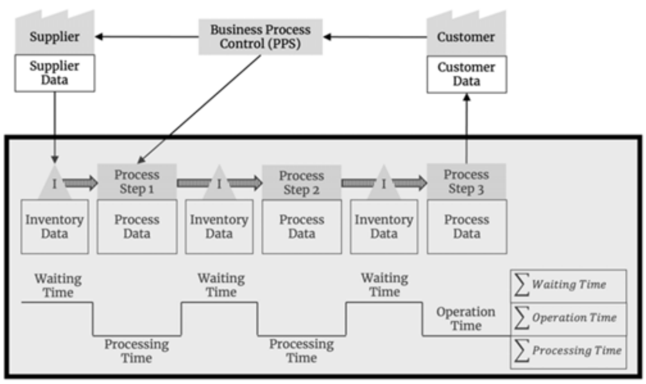

Fig. 2 Schematic Illustration of a Generalized Value Stream Map [22, p.9], [23, pp.83, 86]

By the proposed data framework an approach is followed, A schematic illustration of a generalized value stream map is shown in Fig. 2. The area of the value stream map, marked with a greyed box shows the manufacturing process and is the object of consideration in the paper at hand. The sections supplier, business process as well as customer are not part of the research study at hand.

which takes advantage of the increasing availability of data in supply chains. On the one hand, the procedure related manual efforts can be reduced by automizing the information gathering, based on the utilization of data. On the other hand, the application of a data model opens opportunities, which impacts the strategic management of single companies and entire supply chains. In this context, process mining for monitoring and wastes analyses, simulations of value stream improvements, but also artificial intelligence driven forecasting and planning are mentioned, for instance.

The manufacturing process consists of operational and logistical model elements, mostly, but not necessarily alternately arranged. Whereas the logistical elements are focused on the total inventory in the manufacturing process (WIP-stock and storage stock), impacting the waiting times on the basis of a FIFO (first-in, first-out) order, the operational elements are related to the times, the material is processed actively (process time). The differentiation between operation and processing times refers to single material handling and batch processing.

The domains of logistics and operations are discussed in the following section.

III. Logistics in the Context of the Value Stream Map

Against the background of the conventional VSM approach, the logistical data, especially the inventory data are the baseline for calculating the overall lead time in regard to the value stream as sum of each waiting time. If the inventory indicator covers both storage stocks and WIP (work in process) stocks, the process time, consisting of operation and processing time is already considered implicitly in the waiting times and therefore not added explicitly to the sum of all waiting times when calculating the production lead time [23, pp.85-90], [24, pp. 103-109]. Not considering the WIP stocks, but only the inventory stocks, the lead time can also be calculated as sum of all inventory-based waiting times (inventory leads times) and all process times [25]. Following the modularity of the provided framework, both ways of calculation are mentioned, but the correct way is determined by the applied data and the model's definition.

The main indicators in regard to a logistical perspective on the value stream are listed in the following section and refer to one inventory element (inventory data with reference to Fig. 2).

A. Storage Capacity

The storage capacity is an indicator describing the maximum available capacity of a storage area. Having several storages, the total storage capacity is calculated by the sum of each single storage capacity.

The capacity of a storage is a static planning parameter, based on master data and covered by logistical business application systems. Examples for such systems are ERP, WMS and MES. In a company's system landscape, these business application systems are linked by interfaces and exchange master data as well as transactional data. It is pointed out that the system architecture is always individual and company-specific. This also refers to the implemented process landscape and the allocation of processes to the business applications systems. Therefore, WIP stocks can be managed by MES, but also by WMS. Furthermore, the level of detail in regard to the minimal storage element (e.g. individual storage bin vs aggregated storage area) depends on the systems functionality and its configuration.

B. Stock Quantity

The stock quantity describes the stock level in the storage. As described, there are two variants of stock - inventory stock and WIP stock. Depending on the indicator's reference, the way of calculating the total lead time differs.

The actual stock quantity is dynamically changing over time and related to transactional data. The difference of incoming and outgoing goods defines the actual stock level. Stock movements are covered by the business application systems above. In addition, sensors can be applied for automizing the stock level determination. Examples for such technologies are electronic scales, especially for bulk materials as well as camera-based systems [26]. But in general, a superior system is necessary to transform the sensor data into business data. Especially in dynamic environments, the stock level can significantly fluctuate, which leads to different waiting times based on the calculation according to the range of coverage. Therefore, averaged stock levels with reference to a specific period or target stocks can be utilized to reduce variances in the value stream map.

C. Storage Utilization Degree

The storage utilization degree is an indicator for the efficiency of utilizing the available capacity. Due to the fact that increased stocks are related to longer lead times according to the principles of lean management and cause therefore costs, storages should be avoided and, if necessary, be dimensioned as small as possible.

The determination of the storage utilization is formula-based and calculated as ratio of the actual stock quantity and the storage capacity.

D. Range of Coverage

In the context of VSM, the range of coverage is the essential indicator for calculating waiting times. Based on the FIFO-principle a component is put into stock and remains until all preceding materials on stock are consumed. Therefore, the range of coverage is calculated by the ratio of quantity on stock and the demand per period.

The range of coverage is calculated by the ratio of stock level and demand per period. Therefore, it is partially logistics-related but also depending on the sales domain, as well as the customer data in the context of the value stream map. The paper at hand is limited to the manufacturing process and therefore the indicator demand per period is seen as given and not individually considered. The actual stock quantity is already described before.

The logistical KPIs and potential digital data sources are summarized in Table I.

TABLE I
LOGISTICAL KPIS AND POTENTIAL DIGITAL DATA SOURCES

KPI	Data Source	Static/ Dynamic	Definition of data object respective calculation rule
Storage Capacity	ERP WMS MES	Static	Master data related to the data object storage (e.g. storage bin, storage location storage area). A differentiation is made between inventory stocks and WIP stocks, because the way of calculating the production lead time differs.
Stock quantity	ERP WMS MES	Static	Averaged stock level or target stock level
Stock quantity	ERP WMS MES	Dynamic	Actual stock level: transactional data related to material movements with reference to a specific storage object
Storage utilization degree	Formula and ERP/WMS/ MES	Dynamic	The storage utilization degree is calculated as ratio of the actual stock quantity and the available storage capacity

IV. OPERATIONS (PRODUCTION) IN THE CONTEXT OF THE VALUE STREAM MAP

The main indicators in regard to an operation-based perspective are listed in the following section and refer to one process element (process data with reference to Fig. 2). In general, it is pointed out, that the manufacturing process is always company specific [27]. Therefore, universal best practices are missing. Two major influencing factors, enabling the automation potential of the VSM, are on the one hand the vertical degree of manufacture including its specific characteristics and requirements, e.g. logistical handling (trade), make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO) and engineer-to-order (ETO), defining the available data sources and on the other hand the level of digitalization as well as digitalization, determining the type of available data and its quality [28], [29]. The paper at hand provides a generalized overview, taking different company's configuration into account.

Central element of the value stream map is the structure of the value stream, including all value stream activities. All KPIs are mapped to the related activities. Furthermore, each activity impacts the overall process time and is analyzed in subsequent phases in the context of the VSM approach according to wastes (value stream map, value stream analysis, value stream design and value stream plan) [7], [30]. The main indicators in regard to a manufacturing perspective on the value stream are listed in the following section and refer to one process element (process data with reference to Fig. 2).

A. Activities and Sequences

An activity is defined as process step in the value stream, required for transforming factors into a product. The activity is determined in regard to the input, e.g. raw material and output, e.g. machined component as well as the duration time. Both, value-adding and non-value-adding times are included. Furthermore, different activity types, e.g. setup, machining, assembly, cleaning and similar ones can be differentiated. Each one with its own duration time. Activities can be linked in different sequences. Besides a sequential sequence, parallel sequences and alternatives sequences exist (see Fig. 3). Also overlapping of activities or other dependencies like minimum respective maximum waiting times, e.g. due to heat treatment occur in practice. The structure of these different variation is documented in the value stream map and forms the central framework.

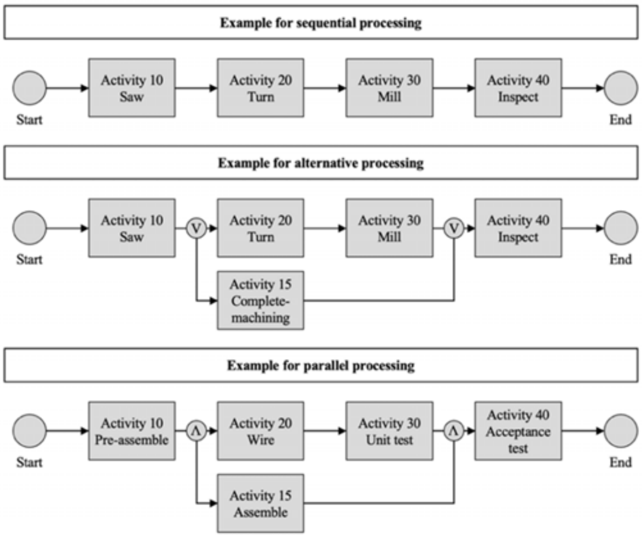

Fig. 3 Sequence of activities

The manufacturing process in the shopfloor is mainly controlled on the basis of a list of activities, among other mandatory information. Against the background of the level of consideration different data objects can be utilized for mapping the activity framework, differing on the degree of determination. The object routing represents an essential master data object, which simplified describes the process steps (operation respective activities) and its sequence (including, overlaps and process-related waiting times, the utilized resource, also called work center, the required time and type of activity (see Fig. 4). Furthermore, one routing can be assigned to different materials, processed in the same way, but requiring separate material numbers for identification and differentiation. Whereas the routing can also include alternative sequencies and pool resources (cluster of similar work centers), detailly planned and scheduled production orders are assigned to specific resources at a specific time. Therefore, the list of activities in regard to the production order is more concrete and determined, compared to the list of activities in regard to the production order.

With regard to the S/4HANA training environment, the routing and the bill of material (BOM) form the production version, which is essential for the material requirement planning (MRP I) as well as the manufacturing resource planning (MRP II), one of the key elements of ERP systems. Based on demands and requirement dates (customer-depended or customer-independent), the required quantities and start dates (mostly based on backwards scheduling) are determined. In the context of self-made materials, planned orders as transactional data objects are created during the MRP run. In the next step, these planned orders are conversed into concrete production orders. All objects – routings, planned orders, production orders - contain information regarding the activities and represent potential data sources. It is pointed out that the information derived from these objects are planning parameters. Due to the fact that deviations and disturbances can occur in the area of manufacturing, also the planning of production orders can differ from the actual production process. Therefore, it is possible top combine production orders as framework and confirmed operations as actual activities. The data object confirmation is explicitly reviewed in one of the following subsections in the context of process times.

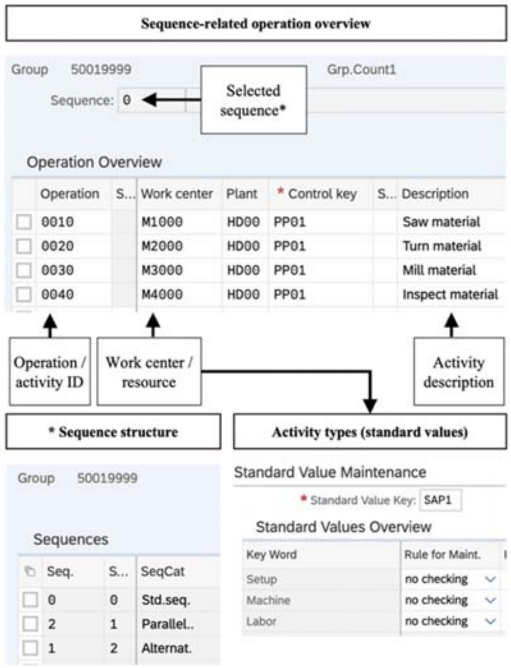

Fig. 4 Data-based activity framework

Routings as well as production orders can be managed in ERP systems, but also MES. Furthermore, the activities and sequence of activities can be recorded by online tracking and tracing of individual materials. By this approach, it is necessary to assign a unique number respective identifier to each material. This identifier is recorded before and after processing. Technologies in this context are RFID [8], [31], barcode and similar ones, enabling a digital twin of the material [11], [32].

As mentioned above, for each activity specific KPIs are documented, which are mandatory for the identification of wastes. Based on the activity framework, the essential KPIs are considered in the following section according to [23, pp.46-66].

B. Uptime/Utilization

In the context of the paper at hand, both terms – uptime and utilization – are synonymously used. The uptime respective utilization is an indicator for the effectively available capacity, used for planning issues. 100% uptime means, the full capacity is available. But in practice, downtimes due to service, maintenance, repair and other measures lower the available capacity.

Business application systems for production planning and control cover the management of resources (personal resources, e.g. operators as well as physical resources, e.g. machines and production lines) as master data objects. Examples for such systems are especially MES and ERP systems. Furthermore, logistical work centers must be mentioned, which are used for logistical activities, e.g. packaging. These work centers can be included in MES or ERP, but also WMS. The uptime is a work center specific parameter. In most cases, the parameter is manually maintained and in this case static (see Fig. 5). But it is also possible to calculate the uptime dynamically as ratio of confirmed hours on the work center per period and the available capacity in this period.

C. Number of Operators/Resources

The number of operators respective resources is defined as the quantity of resources, which provides the same processing characteristics (e.g. skills of operators and technologies of resources) and therefore are interchangeable. Depending on the business process, an increased number (more than one) enables the reduction of lead time due to the parallelization of activities. Production lots of greater than one can be processed parallel by different resources and several operators can work on one material (e.g. assemble). In the context of value stream mapping, personnel resources and physical resources are differentiated.

As the number of operators and resources impacts directly on the work center's available capacity the same business applications systems as for the indicator uptime can be utilized as potential data sources. The indicator is an essential master data parameter, which is in general static (see Fig. 5).

D. Capacity

In the conventional value stream map the number of operators and resources per process step and per shift are documented. Personnel resources, e.g. mechanical engineers, electricians or similar operators are identified by #Op, whereas technical resources are identified by #Res. Under the assumption, both operators and resources, involved in processing one production step, are exclusively assigned to one activity (process step) and all activities in the value stream follow the same shift schedule, this information is sufficient. Mostly this characteristic is given in the context of a levelled series production. But in complex and dynamic production systems different areas of a production can have different shift schedules, especially in connection with time-consuming operations, which make a synchronization of process steps difficult, e.g. heat treatment. Therefore, it is not possible to calculate the value streams output only based on the number of operators and resources. The effective capacity is a more precise KPI in that regard. This consideration gets more complex in business scenarios, one work center is utilized by different value streams. The total capacity must be proportionally assigned to the related value stream based on the capacity demands. The ratio can be both fixed, e.g. one third to two third, or dynamic with reference to the production scheduling. The requirement is mainly influenced by the configuration of production, e.g. series production versus workshop production.

As the previous KPIs, the capacity is assigned to the work center. Therefore, the capacity can be derived from the same data sources. Fig. 5 shows the management of capacities related to a specific work center (M1000) in the S/4HANA training environment. Furthermore, it is possible to maintain different types of capacity per work center, e.g. to enable a separation of technical and a personnel capacity planning by different formulas. The total available standard capacity per day is calculated as product of <daily operating time>, <uptime>, and <number of resources> and referenced to the plant calendar. In addition, individual shifts can be maintained with a period of validity.

In the following section the different types of production related times, differentiated in connection with the VSM approach, are reviewed in detail.

E. Changeover Time/Operation Time/Processing Time

The KPI changeover time is the time required for setting up a machine, e.g. exchanging tools, materials, fixtures and similar production factors. During this time, the machine is not available for value-adding processing. Mostly a changeover is necessary, when the lot of one product is finished and the production of a lot of a different product or variant of the previously produced product begins. In regard to the conventional VSM approach, this KPI is defined as the time between finishing the last good piece of material and starting the first good piece of material. Especially, in regard to manufacturing processes like injection molding, the machine requires a discharge of the residual material and a startup for the succeeding material. Also, this scrap is included in the changeover time.

The operation time and processing time refer to the duration in which a part is in process and includes times for human labor, e.g. assembling as well as machine processing, e.g. machining. Furthermore, value-adding activities and non-value-adding activities, e.g. auxiliary activities like clamping a material in a fixture, are taken into account. Waiting times due to disturbances are not covered in this context, but considered by the KPI uptime. Both types of time are differentiated by the characteristic of the manufacturing process. The operation time is used in those cases, where a single material is processed at one time and all materials of one lot are sequentially processed. In contrast, the processing time is used in that cases, where more than one material is processed in one process. In this regard two further cases are distinguished:

1. The flow is continuous and materials enter successively a chained production process. The production process consists of several processing steps. One example for such a manufacturing process is a conveyor belt, connecting several work stations.
2. The flow is discontinuous and several materials are

simultaneously processed in one processing step as a batch. One example is the process of heat treatment at which various materials are merged into one batch and processed together at the same time.

The type of time is relevant for calculating the cycle time, which is considered at a later point in the paper at hand.

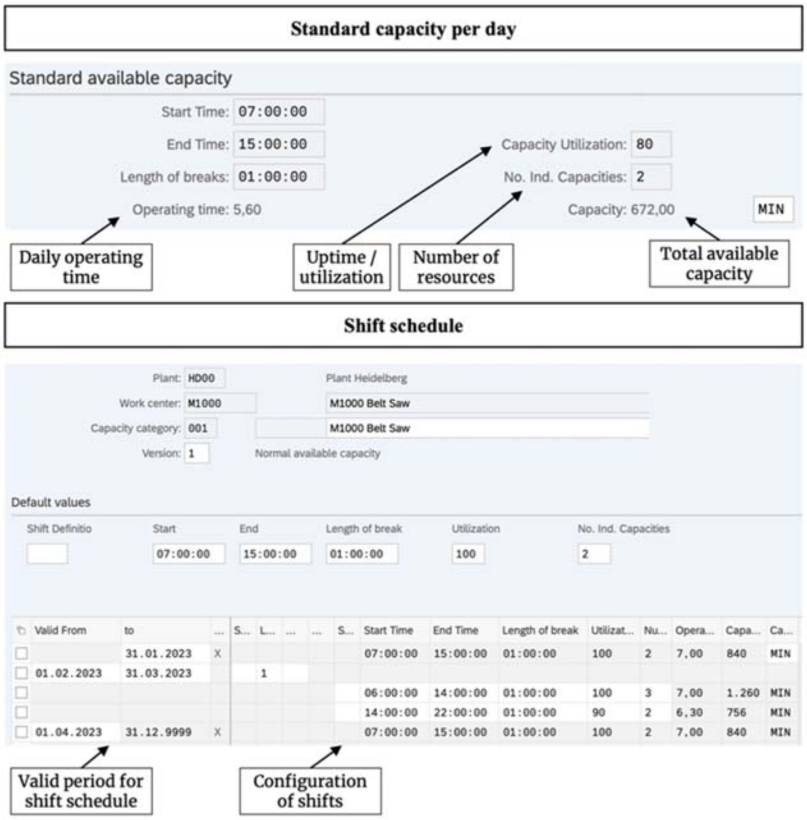

Fig. 5 Capacity of work centers

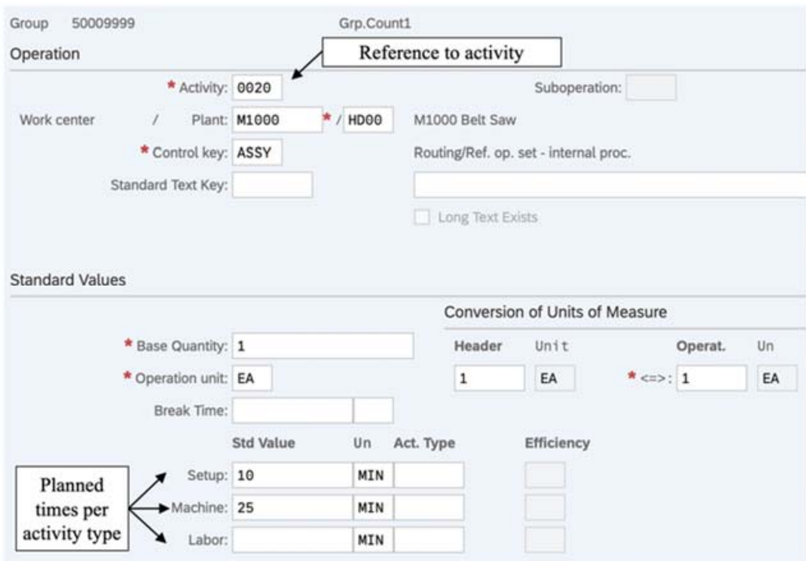

Fig. 6 Planned times per activity/operation

As described in the previous section, production-related business application systems, e.g. ERP and MES enable the differentiation of activities types, e.g. setup, labor, machining, assemble, maintain, repair and more. The configuration is company-specific. In connection to the S/4HANA ERP training environment, these types of activity are defined by the standard value key (see Fig. 4). By the management of routings, the times for these different types of activities are maintained for each

World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:17, No:4, 2023

activity (see Fig. 6). Due to the connection between routings, planned orders and production orders described above all data objects are equally utilizable.

The resultant capacity demand as well as production lead time in connection to the scheduling process are determined by individual formulas assigned to the specific capacity category. By this, the impact of multiple resources, different base quantities, lot size, operation splits and further effects are taken into account (see Fig. 7).

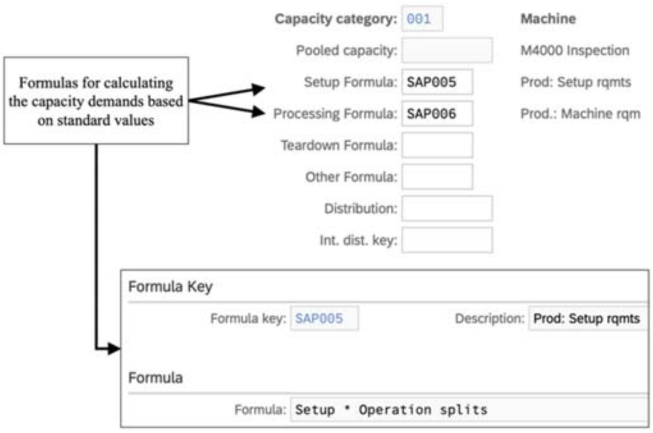

Fig. 7 Calculation of capacity demands

It is pointed out that the mentioned data sources are master data and empirical values used for planning. For this reason, the data are characterized as static and may be error-prone. A higher accuracy of the KPIs can be achieved by the utilization of actual data, based on operation-related confirmations. In addition, the enlargement of the data pool by historical data allows the calculation of mean values as well as the structured identification of deviations. In the following section two ways of deriving the operation respective process time from confirmations are shown based on the type of confirmation. In general, event-based confirmations, e.g. start and end event and time-based confirmations, e.g. 60 min of setup, can be distinguished. Depending on the operation progress partial and final confirmations exists. In general, a confirmation contains several information like the related order and operation, the time stamp of record, the activity type, the confirmed quantities, which are differentiated into scrap, yield and rework, the reason for deviations and more. Confirmations can be directly recorded by ERP systems or indirectly by MES, which routes the confirmation information into the ERP by interfaces. Furthermore, the recording can be done manually by user and a graphical user interface (GUI) or automized by utilizing machine data, gathered from the PLC respective sensors. Data acquisition terminals in the area of production enables the decentral recording of confirmations by operators. The utilization of confirmation data is visualized in Figs. 8-10 and detailly described in the following section.

The first outlined scenario is visualized in Fig. 8. The event <start of processing> in regard to operation 0010 can be raised for instance by identifying a material at a specific work station before processing. The identification can be done by reading and writing NFC-units (near field communication) e.g. RFID tags, barcode, optical sensors (camera) or similar technologies, which are partially implemented in a laboratory scale for the training factory Industry 4.0 model and approved by different business scenarios (for further details, see [21]. After processing, the event <end of processing> is recorded. The duration between these both events is the process time. Depending on the confirmed quantity, the calculated process time is the operation time (quantity of one) or processing time (quantity of more than one). This scenario is based on the assumption, the event-based confirmation is final and no further confirmations on that operation are expected. After finishing operation 0010, the material follows the residual production process. As well as for operation 0010, operation 0020 is started and finished by two separate events. The described way of consideration enables the determination of the actual waiting time between two process steps respective operations, which is not covered by the conventional VSM approach (waiting times are defined as range of coverage, following the FIFO principle). After finishing operation 0010, the further processing continues at work center M2000 according to operation 0020. Therefore, M2000 is the deferring resource, not considering logistical activities in the meantime, e.g. the transport from one work center to the next one. The actual waiting time can be derived from the planned availability of the related work centers, the confirmation about the finalization of one operation and the start of the following operation. It is defined as the temporal intersection of the duration between end of a preceding operation and its succeeding operation and the availability of the work center for processing the succeeding operation. Considering logistical activities, the waiting time can be enhanced by the duration between finalizing one operation and the material's pick up respective its arrival at one work center and the start of processing.

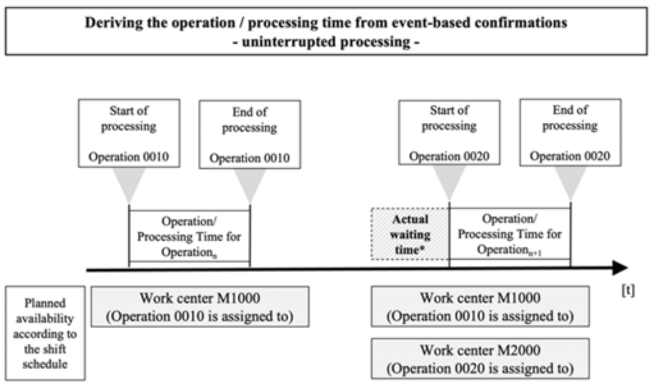

Fig. 8 Event-based confirmations (1)

As visualized in Fig. 8, the scenario shows an uninterrupted processing of operation 0010, but also during the processing of a batch or one material, waiting times can occur. This scenario is shown in Fig. 9.

The waiting time during one process step, e.g. operation 0010 is defined as the time a material is waiting at a work center for its processing and the work center's availability.

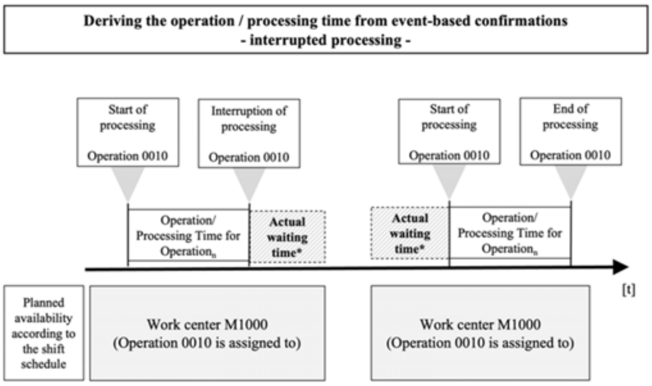

Fig. 9 Event-based confirmations (2)

The second type of confirmations is time-based. Whereas for event-based confirmations, the operation respective processing time is calculated as the temporal difference between two specific events, the process time is directly given by time-based confirmations. For determining the actual waiting time, the start date and time must be calculated. Having the start time, the procedure for calculating the waiting time remains as already described in the context of event-based confirmations. Also, the consideration of logistical activities and interruptions of process steps is supported. The business scenario is visualized in Fig. 10.

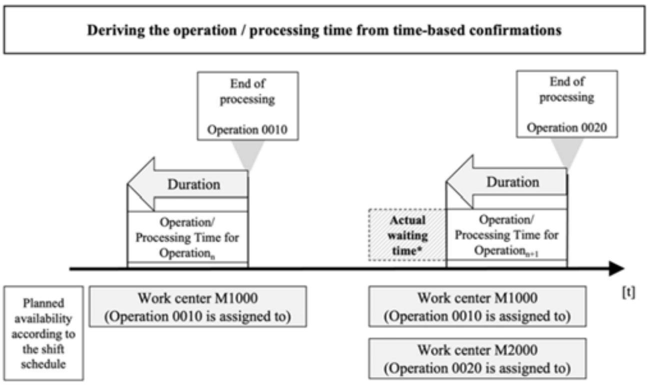

Fig. 10 Time-based confirmations

F. Cycle Time

The cycle time is an important indicator for analyzing the levelling of the manufacturing process by comparison of all cycle times. The production line is synchronized or in flow, if the cycle times of all activities are similar. Under these circumstances, there are no process-related waiting times. Furthermore, the cycle time of each operation must be less than the customer takt time. The takt time is a KPI, which is defined as the time required for matching the customer demand based on the resource's availability per period and the demanded quantity in the specific period. If the customer takt time is higher than a cycle time, the demand cannot be fulfilled by the available resource capacity. Therefore, bottle neck resources and potential risks in the manufacturing process can be identified. This gathered information is an essential input for the subsequent phases of the VSM approach, especially the value stream design, which follows the target to eliminate wastes and risk.

The cycle time is defined as the time for completing a cycle of production of one final product with regard to a specific operation respective activity. Based on the type of process time (operation time or processing time), the formula for calculating the operation-related cycle time differs [23, pp.50-53], [24, pp. 62-65].#

$$< cycle\ time > = \frac{<operation\ time> \times <no.of\ identical\ parts\ per\ product>}{<no.of\ equal\ resources>} \quad (1)$$

$$< cycle\ time > = \frac{<processing\ time> \times <no.of\ identical\ parts\ per\ product>}{<no.of\ equal\ resources> \times <process\ quantity>} \quad (2)$$

If the number of identical parts per product is one and the number of available resources, interchangeable due to a similar technology, is also one, the cycle time is equal to the operation time.

The KPI cycle time is calculated by formulas (1) or (2). In this context, the formula takes the KPIs, mentioned in the previous section, into account. Therefore, the KPI is not derived from any data source, but determined by formula based on the available information.

The automatized determination of the activity-orientated framework as well as the production related KPIs and its potential data sources, elucidated in the previous sections, are summed up in Table II.

V. Results and Discussion

The paper at hand aims at the provision of a modular data and calculation framework for automizing the mapping of the manufacturing process against the background of the VSM approach by utilizing the available business data. The investigated data are provided by different information and communication technologies, related to all levels of the automation pyramid. The modularity of the framework takes different production configurations, process and system landscapes into account and therefore, enables a universal application due to an adaptability according to company-specific conditions.

A five-step procedure, detailly described in the previous section, is followed to reach the aim. Based on the essential KPIs and principles of VSM in regard to the mapping of the manufacturing process, the framework is designed and verified in several iterations, in which different business scenarios are applied and evaluated. Beside a sequential processing, alternative and parallel sequences are considered. The implementation of a unique identifier enables the tracking and tracing of single pieces in a batch production. By the provided concept, gathered data and KPIs are directly assigned to the related operation. By this operation-based consideration, effects as temporal overlaps of two successive operations (especially occurring in continuous flow productions), as well as orders with a flexible processing order of operations, (e.g. processing of operation 0040 before operation 0020) do not negatively impact the information in the value stream map at all.

TABLE II
OPERATION KPIS AND POTENTIAL DIGITAL DATA SOURCES

KPI	Data Source	Static/ Dynamic	Definition of data object respective calculation rule
Activity framework	ERP MES	Static	Master data: operation/activity- related number, sequence and work center in the routing Transactional data: operation/activity-related number, sequence and work center in the planned order respective production order with reference to a specific material
Activity framework	ERP MES	Dynamic	Online tracking and tracing of a specific material by the use of a unique identifier and the utilization of actual data records, e.g. confirmations
Uptime/ utilization	ERP MES	Static	Information, assigned to the master data object work center
Uptime/ utilization	Formula and ERP/ MES	Dynamic	Formula: Dynamic calculation of KPI as ratio of confirmed hours on the work center per period and the available capacity in this period
Number of operators/ resources	ERP MES	Static	Information, assigned to the master data object work center
Capacity	ERP MES	Static	Information, assigned to the master data object work center
Changeover/ operation/ processing time	ERP MES	Static	Master data: operation/activity- related data in the routing referring to the activity type setup. Transactional data: planned order and production order with reference to a specific material, based on a routing information Furthermore, a changeover matrix, relevant for detailed scheduling and planning of productions contains the changeover time in regard to a preceding and succeeding material. The planned duration for the changeover is dynamically determined based on the sequence of production
Changeover/ operation/ processing time	ERP MES Machine/sensor data	Dynamic	Dynamical determination of the changeover/ operation and processing time, based operation/ activity-related confirmations with reference to a production order. In addition to the manual recording of confirmations, e.g. by an production data acquisition terminal, the confirmation can be recorded by the formula-based evaluation of machine and sensor data.

The verification is mainly based on a S/4HANA training environment (ERP) and a physical training factory Industry 4.0 model. For this reason, both business application systems as well as shopfloor-orientated sensor and machine data are included in the consideration. Furthermore, the framework covers static and dynamic ways of determining the related KPIs. Especially, the dynamic determination enables a higher accuracy compared the utilization of static master data, which underlies a potential risk of deviation from actual data, and the manual recording of KPIs according to the conventional VSM methodology.

The application of different business scenarios proves the applicability of the framework. Furthermore, the efforts for re-recording respective updating the value stream could be significantly decreased, once the mapping according the framework configuration is initially set up (e.g. selecting the correct data sources and mapping the data objects as well as formulas to the business objects, e.g. work centers). In addition, a dynamic design of the value stream map as data model opens up new options, e.g. the simulation of parameter changes and its specific impact on the value stream.

As pointed out at the beginning, the consideration is limited to the manufacturing process, which is detailly examined. With reference to Fig. 2, the essential domains of supplier (supply respective input of the manufacturing process) and customer (demand respective output of the manufacturing process), which directly affect the manufacturing process, are currently not taken into account in the provided framework.

VI. CONCLUSION AND OUTLOOK

The number of publications, referring to the VSM approach and its future viability in dynamic and digitalized environments, proves the scientific relevance of this field of research. Summarized, all reviewed publications point out the general validity of the fundament principles of VSM, but also recommend an enhancement respective optimization of the methodology – on the one hand proposing an enrichment of the model's information, considering the perspective of digital media and on the other hand taking advantage of the available data, enabled by the increasing digitalization in the domain of business processes. The latter with the aim to automize, at least support the information gathering and mapping. A detailed analysis of the current state of research can be seen in [33].

Aim of the paper at hand is the provision of a concrete modular data and calculation framework for automizing the value stream mapping procedure by utilizing the available business data. The investigation is limited to consideration of the manufacturing process. As stated in the previous section, the aim is reached and different data sources and ways of deriving and determining the related KPIs are pointed out. But there are some aspects, which require further research. Especially the integration of supplier and customer information into the discussed framework due to its significance to the manufacturing process (demand and supply) is a mandatory issue to design a holistic VSM framework. Furthermore, the potentials, enabled by a digital model of the value stream map must be investigated in the next step.

REFERENCES

[1] A. Lugert, K. Völker, and H. Winkler, "Dynamization of Value Stream Management by technical and managerial approach," presented at the Procedia CIRP, Jun. 2018, vol. 72. doi: 10.1016/j.procir.2018.03.284.

[2] J. Mangers, M. Minoufekr, P. Plapper, and C. Oberhausen, "Verbesserung unternehmensübergreifender Prozessabläufe," Jun. 2020.

[3] V. Balaji, P. Venkumar, M. S. Sabitha, and D. Amuthaguka, "DVSMS: dynamic value stream mapping solution by applying IIoT," *Sādhanā*, vol. 45, no. 1, p. 38, Feb. 2020, doi: 10.1007/s12046-019-1251-5.

[4] A. Lugert, A. Batz, and H. Winkler, "Empirical assessment of the future adequacy of value stream mapping in manufacturing industries," *J. Manuf. Technol. Manag.*, vol. 29, no. 5, pp. 886–906, Jan. 2018, doi: 10.1108/JMTM-11-2017-0236.

[5] K. Erlach, M. Böhm, S. Gessert, S. Hartleif, T. Teriete, and R. Ungern-Sternberg, "Die zwei Wege der Wertstrommethode zur Digitalisierung: Datenwertstrom und WertstromDigital als Stoßrichtungen der Forschung für die digitalisierte Produktion," *Z. Für Wirtsch. Fabr.*, vol. 116, no. 12, pp. 940–944, Dec. 2021, doi: 10.1515/zwf-2021-0216.
[6] T. Meudt, "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 Z. Fuer Wirtsch. Fabr.*, vol. 111, no. 6, pp. 319–323, 2016.
[7] L. Hartmann, T. Meudt, S. Seifermann, and J. Metternich, "Value stream method 4.0: holistic method to analyse and design value streams in the digital age," *Procedia CIRP*, vol. 78, pp. 249–254, Jan. 2018, doi: 10.1016/j.procir.2018.08.309.
[8] M. Ramadan, Z. Wang, and B. Noche, "RFID- Enabled dynamic Value Stream Mapping," presented at the Proceedings of 2012 IEEE International Conference on Service Operations and Logistics, and Informatics, SOLI 2012, Jul. 2012, pp. 117–122. doi: 10.1109/SOLI.2012.6273515.
[9] B. Gladysz and A. Buczacki, "Wireless technologies for lean manufacturing – a literature review," *Manag. Prod. Eng. Rev.*, 2018, doi: 10.24425/119543.
[10] P. Tamás, "Process improvement trends for manufacturing systems in industry 4.0," *Acad. J. Manuf. Eng.*, vol. 14, p. 7, Dec. 2016.
[11] N. Frick and J. Metternich, "The Digital Value Stream Twin," *Systems*, vol. 10, p. 102, Jul. 2022, doi: 10.3390/systems10040102.
[12] P. Zuhr, *An approach for target-oriented process analysis for the implementation of Digital Process Optimization Twins in the field of intralogistics*. 2021, p. 191. doi: 10.46354/i3m.2021.emss.025.
[13] T.-A. Tran, T. Ruppert, and J. Abonyi, "Indoor Positioning Systems Can Revolutionise Digital Lean," *Appl. Sci.*, vol. 11, no. 11, Art. no. 11, Jan. 2021, doi: 10.3390/app11115291.
[14] D. Arey, C. H. Le, and J. Gao, "Lean industry 4.0: a digital value stream approach to process improvement," *Procedia Manuf.*, vol. 54, pp. 19–24, 2021, doi: 10.1016/j.promfg.2021.07.004.
[15] H. Ljunglöf and D. Skogh, "Value Stream Mapping with Microsoft Dynamics AX," Feb. 2022.
[16] T. Wagner, C. Herrmann, and S. Thiede, "Identifying target oriented Industrie 4.0 potentials in lean automotive electronics value streams," *Procedia CIRP*, vol. 72, pp. 1003–1008, 2018.
[17] M. Ramadan and B. Salah, "Smart Lean Manufacturing in the Context of Industry 4.0: A Case Study," *Int. J. Ind. Manuf. Eng.*, vol. 13, no. 3, pp. 174–181, Feb. 2019.
[18] M. Ramadan, B. Salah, M. Othman, and A. A. Ayubali, "Industry 4.0-Based Real-Time Scheduling and Dispatching in Lean Manufacturing Systems," *Sustainability*, vol. 12, no. 6, Art. no. 6, Jan. 2020, doi: 10.3390/su12062272.
[19] T. Wollert and F. Behrendt, *Automation of the Manufacturing Process Mapping in the Context of VSM by Utilization of ERP Data*. 2022. doi: 10.46354/i3m.2022.mas.001.
[20] E. Martinez, P. Ponce, I. Macias, and A. Molina, "Automation Pyramid as Constructor for a Complete Digital Twin, Case Study: A Didactic Manufacturing System," *Sensors*, vol. 21, p. 4656, Jul. 2021, doi: 10.3390/s21144656.
[21] F. Behrendt, O. Lehner, A. Rettmann, N. Schmidtke, and T. Wollert, *Process analysis of a teaching and learning factory environment to demonstrate Industry 4.0 solutions by using the Smart Logistics Zone approach*. 2022, p. 10. doi: 10.1109/GOL53975.2022.9820054.
[22] P. Plapper and C. Andre, "Wertstrommethode – Value Stream Mapping," *Qual. Dienstleistungsunternehmen*, vol. Köln: TÜV Media, pp. 1–27, Jan. 2011.
[23] K. Erlach, *Value stream design: the way towards a lean factory*. Heidelberg; New York: Springer, 2013.
[24] K. Erlach, *Wertstromdesign: der Weg zur schlanken Fabrik*, 3. Auflage. Berlin (Heidelberg): Springer Vieweg, 2020.
[25] J. Langstrand, "An introduction to value stream mapping and analysis," 2016, (Online). Available: https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A945581&dswid=-432
[26] K. Umamaheswari, M. Susneha, and B. S. Kala, "IoT based Smart Cold Storage System for Efficient Stock Management," in *2020 International Conference on Communication and Signal Processing (ICCSP)*, Jul. 2020, pp. 0051–0055. doi: 10.1109/ICCSP48568.2020.9182426.
[27] W. Nan, Q. He, Z. Zhang, T. Peng, and R. Tang, "Framework of automated value stream mapping for lean production under the Industry 4.0 paradigm," *J. Zhejiang Univ. Sci. A*, vol. 22, pp. 382–395, May 2021, doi: 10.1631/jzus.A2000480.
[28] J. Gosling and M. M. Naim, "Engineer-to-order supply chain management: A literature review and research agenda," *Int. J. Prod. Econ.*, vol. 122, no. 2, pp. 741–754, Dec. 2009, doi: 10.1016/j.ijpe.2009.07.002.
[29] Z. Atan, T. Ahmadi, C. Stegehuis, T. de Kok, and I. Adan, "Assemble-to-order systems: A review," *Eur. J. Oper. Res.*, vol. 261, no. 3, pp. 866–879, Sep. 2017, doi: 10.1016/j.ejor.2017.02.029.
[30] V. Manupati, M. Mobin, L. Varela, and C. Gangal, "Application of value stream mapping for cycle time reduction in production of link and roller assembly," *Int. J. Serv. Oper. Manag.*, vol. 33, Mar. 2018, doi: 10.1504/IJSOM.2019.10022078.
[31] N. A. Phuong and T. Guidat, "Sustainable value stream mapping and technologies of Industry 4.0 in manufacturing process reconfiguration: A case study in an apparel company," in *2018 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*, Jul. 2018, pp. 85–90. doi: 10.1109/SOLI.2018.8476750.
[32] T. Tran, T. Ruppert, G. Eigner, and J. Abonyi, "Real-time locating system and digital twin in Lean 4.0," May 2021, pp. 000369–000374. doi: 10.1109/SACI51354.2021.9465544.
[33] T. Wollert and F. Behrendt, *Future Application of VSM in Digitalized Environments*. 2022. doi: 10.25673/85958.