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X-Solver: Virtualization of Value Stream Management (VSM) to optimize complex value networks

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Abstract

Companies from different sectors are facing several challenges, e.g. the shortening of product life cycle, the individualization of products. This increases the complexity of supply chain networks and requires well-established and common communication rules to ensure a lean manufacturing. One of the lean methods that is widely spread and accepted in practice is the Value Stream Management (VSM). Although VSM aims to optimize the value-adding process, it is still operated with pen and paper. In the context of Industry 4.0, a virtualized VSM is more needed than ever. Also, the lack of standardization of VSM constitutes another drawback in complex supply chain networks. Networks that were not considered by current VSM-methods. This paper presents the concept of a model used to virtualize the VSM. It will help the companies optimize complex value networks and facilitate the collaboration procedures creating thus a reliable information management tool.

Key words: *Value Stream, Lean Manufacturing, Process Modelling, Supply Chain Networks*

1. INTRODUCTION

To stay the course, companies have to deal with many difficulties that compel them to deliver products or services with a high quality and reduced costs within a very short time. This makes it more and more problematic for the enterprises to get a successful positioning towards three interdepending factors: quality, time and money [18]. Thus, most companies have recourse to lean tools to tackle the undergone obstacles. One method that is widely spread in the industry [1, 4] and has been proven useful [3, 15] is the Value Stream Management (VSM). The VSM consists of the mapping, design and planning of the value stream. This helps managers and engineers to identify waste in the value stream, understand the root cause of that waste and reduce the non-value added activities. Thereby the production flow as well as the information flow are depicted. [15, 8, 2, 6, 11, 10]

In today's context, which is prompted by the Industry 4.0, the need of virtualized approaches and methods to configure a digital shadow is more crucial than ever. This digital shadow allows the processing of real activities (e.g. manufacturing), products and services using reality-like settings without reality-related investments (e.g. testing prototype). Furthermore, it enables the simulation of future unpredictable scenarios (e.g. the behavior of a system in disturbance). As regards the Value Stream Management, it is still operated with pen and paper. Hence, it should be uplifted to a digital level in order to maximize the benefit of the method and its usefulness in practice. Although several VSM-tools have been developed in the past decades, they do not offer the possibility to link many value stream maps. This neglected aspect is necessary to apply the VSM in complex supply chain networks, i.e. networks involving a large number of suppliers [14].

To virtualize the VSM-method, a model is developed and constitutes the focus of this paper, which is structured as follows: At first, relevant existing modelling languages are introduced. In the third section, the objective and the research methodology are explained. Section 4 presents the developed model for the virtualization of the VSM-method and its advantages. Cross-enterprise supply chain networks are outlined in section 5. In Addition, the relevance of the here proposed model for these networks is explained. Section 6 explains the validation of the new model. The last chapter contains the conclusion.

2. RELATED PROCESS MODELLING LANGUAGES

Many authors dedicated works to process modelling, either to outline some modelling languages, to develop them or to compare them to each other. Söderström et al. [17] argue that four elements (Time point, activity, state and event) are reflected by much of the process modelling languages. In this context, the time point is the smallest measuring unit that describes the time. The activity represents the action that could change the state. Events link the above mentioned elements and are noticed by the user. Söderström et al. [17] present three languages that are representative of the main types: activity-oriented, state-oriented and communication-oriented.

2.1 Event-driven Process Chain (EPC)

Activity-oriented process modelling languages mainly incorporate a chain of activities within a process and the dependencies between each other [17], e.g. which activity starts before the other or whether two activities are parallel. Representative of this type is the Event-driven Process Chain (EPC). The EPC was originally developed by the Institute for Business Informatics (IWi) from the University of Saarland [7]. The concept consists of functions represented by soft rectangles and events illustrated by hexagons. These two elements are interconnected by means of arrows. The interdependencies are given by logical operators (AND, OR, XOR). The activities can be executed only if the required event(s) are validated. For example, the activity “Welding process” can be performed only if the event “Welder ready” AND the event “Parts available” are validated as TRUE (Figure 1).

Wolff [20] points out that the EPC is a good model to apply on the VSM since it is possible to represent the material and information flows. However, the method does not support process-related and flow-related data, e.g. process time.

Moreover, the EPC is based on the element event, which could generate a huge amount of unnecessary information to the value stream maps, especially for complex ones. In a value stream map, such information are given by symbols or parameters.

2.2 UML State Diagram (UML SD)

State-oriented languages model states in the sequence of their occurrence including the required conditions [17]. The UML State Diagram is a representative model for the state-oriented languages. The State Diagram belongs to many other diagrams introduced within the UML [16]. The UML SD illustrates the states (of a process for example) in form of soft rectangles. These rectangles contain entry activities that are executed while entering the state in opposition to exit activities that are completed while exiting the state. Between these two types of activities, there is a third one: the ongoing activity that is taking place during the state. Internal transitions are also a part of the state symbol. These are “useful for modeling interrupt situations that do not change the state” [16]. The states are interconnected with arrows that model the change of states (external transition). The arrows could be associated with trigger events that might provoke an action before the state or be followed by a guard condition (Boolean expression) that has to be fulfilled before the state.

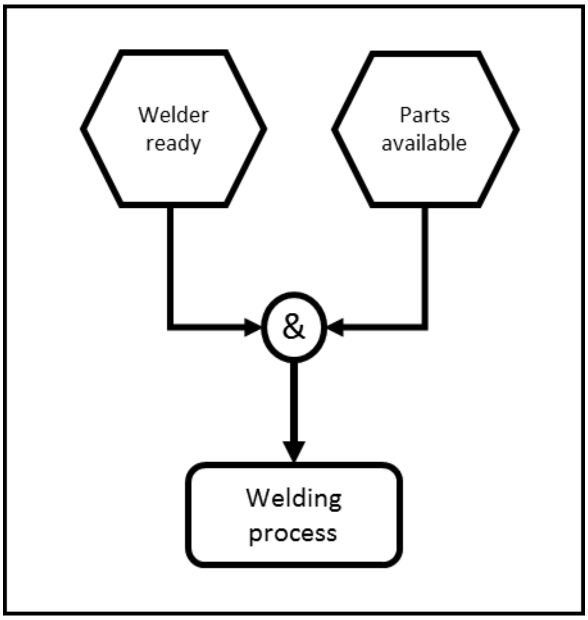

Figure 1. Example of EPC process modelling

The UML State Diagram gives the opportunity to model the different components of the VSM. However, the level of details is over-engineered when it comes to the VSM. Thus, some details could be replaced with VSM-symbols. Also, the UML SD focuses on the element state. This is not suitable for VSM since it only captures one state i.e. the actual value stream state.

Figure 2 shows an example of the UML SD. Here, the ongoing activity is the welding process. The events “Welder ready” AND “Parts available” have to be fulfilled in order to execute the ongoing activity. The “Workpiece clamping” is an entry activity while the “Workpiece unclamping” is an exit activity.

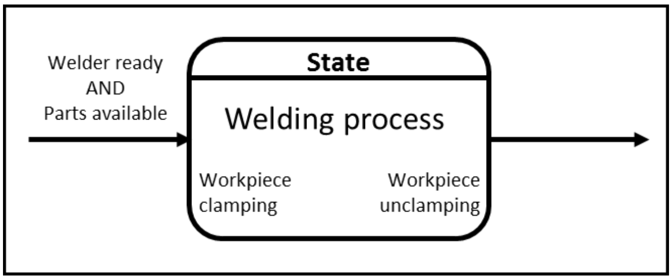

Figure 2. Example of UML SD process modelling

2.3 Business Modelling Language (BML)

As far as the communication-oriented process modelling languages are concerned, the communication processes between users and systems are highlighted [17]. Here is the Business Modelling Language (BML) seen as a representative modelling language. It gives the opportunity to track the sending and receiving of the messages between systems and users according to certain rules and priorities. Thus, the sending is represented by a convex box, whereas the receiving is given by a concave box. The element state is depicted by a circle. An hourglass symbol represents the timer (start and expire timer). A rectangle symbolizes an automated business activity. The choice of which communication streams to follow is done in compliance with business rules. In the BML, this automated decision is indicated by a rhombus [5].

Since value steams are not only information flows, it is not recommended to use the BML in the field of VSM. Similar to the EPC, the user cannot attach process-related data to the BML model.

In the Figure 3 the Welder should wait until he receives the welding instructions. After a delay, the system notifies that the parts are available. Once the welding is completed, the welder sends a confirmation.

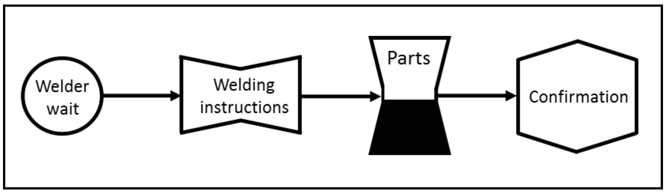

Figure 3. Example of BML process modelling

2.4 Further process modelling languages

The Business Process Modelling Notation (BPMN) was developed by White in [19]. The four pillars of this language are flow objects, connecting objects, swimlanes and artifacts. Among flow objects are events, which are represented by circles. These events are caused by triggers and have an impact on the process flow. Based on the time of impact three types of events are identified: start, intermediate and end events. The activities (soft rectangles) are flow objects that reflect a performance delivered by the business. Another type of flow objects are gateways represented by a rhombus. They describe the behavior upon decisions. All these types of flow objects are interconnected by means of the connecting objects. The sequence flow (solid line, solid arrowhead) models the activities' order. Exchanged information between process participants are shown by the message flow (dashed line, open arrowhead). Associations of artifacts (dotted line, line arrowhead) illustrate inputs and outputs of activities. The third constituent of the BPMN are the swimlanes, which consist of two elements: pools and lanes. The former refer to process participants and delimit the number of activities owned by one participant in case of several participants. The latter are subdivisions of pools where the activities are arranged in categories. The above explained associations allow to add artifacts to the description of the process. These are data objects (document symbol with name), group or grouping (soft rectangles with dashed lines) and annotations to add information (represented by a dotted line, a bracket and the information in text).

As far as the BPMN is concerned, Wolff [20] sees that it is difficult to identify the potentials within the value streams due to missing process-related data. A drawback for using the BPMN to model value streams is that message flows go not beyond pools and sequence flows do not cross limits of lanes. This is not suitable for the application of a multi-level value stream map.

The Process-Oriented Analysis (POA) [12] describes processes by means of flows and states by means of conditions. The former represent a static description of a system that shows activities, which have to be performed (soft rectangles). Such activities are linked with inputs and outputs. The latter represent a dynamic description, which is used to depict the behavior of a system, i.e. the condition of state changes and their occurrence sequence. Here again rectangles with connecting arrows and text information are used.

To summarize, most of the process modelling languages allow the representation of material and information flows when applied to the VSM. Such languages also give the possibility to arrange the different constituents in the right sequence of occurrence and to model the required interdependencies. However, the superfluousness of details threatens the clarity targeted by the VSM. Some details could be replaced by VSM-symbols (e.g. FIFO-flow symbol), others are generally not needed in value streams, like events. Important information, such as process-related data, are not supported by much of the modelling languages. Partitioning issues are another worth mentioning aspect, especially when working with many value streams or multi-level value streams.

3. OBJECTIVE AND RESEARCH METHOD

3.1 Objective

This work intends to create a simple but reliable model that can be used to represent the value stream method in an abstract way. This model should be understandable by VSM experts, managers as well as by engineers in the context of virtualizing the VSM-method, i.e. developing an appropriate IT-solution. The proposed model should cover all the aspects of Value Stream Management and offer possibilities to optimize the value streams, and so assisting the user during the design phase. Furthermore, it is expected to integrate complex supply chains networks into this IT-solution. Hence, the model should also consider these networks.

3.2 Research hypotheses

From the motivation (cf. section 1) and the above stated objective (cf. section 3.1) the following research hypotheses arise out:

1- VSM can be modelled and analyzed using a meta-modelling language.

2- The developed meta-model to describe the VSM-method can integrate cross-enterprise supply chain networks.

3.3 Research questions

Derived from the research hypotheses (cf. section 3.2) the research questions are:

1- Is it possible to abstract the VSM on a meta-level so that a model can be created to describe and analyze the VSM?

2- Could the developed model also describe cross-enterprise supply chain networks?

3.4 Research methodology

To answer the first research question (cf. section 3.3) a literature review of relevant process modelling languages was conducted. The suitability of the reviewed languages was checked by focusing on the advantages and drawbacks of applying these models to the VSM (cf. section 2). The gained insights were used to create modelling elements that are appropriate to the current work (cf. section 4). These elements were applied in a real case to develop an IT-solution for VSM (cf. section 6). The second research question (cf. section 3.3) was treated according to an already designed model for cross-enterprise supply chain networks (cf. section 5).

4. NEA-MODEL TO DESCRIBE THE VSM

In the context of the X-Solver project [I], a model has been developed to describe the Value Stream Management method. It aims at creating an innovative IT-solution that takes into consideration complex value stream networks. NEA-model would assist the user with the mapping of the current state of value streams, the identification of potentials as well as the design phase. It should also help the value stream manager to implement the planned measures.

One of the strengths of value stream mapping is the overview of the whole value stream that is achieved during the first phase of VSM [15]. Hence, VSM allows the visualization of the following elements:

- processes
- interconnecting flows
- relevant data of each process and each flow

For that reason, the clarity about the considered system brought by the VSM is a strong benefit of such method. This clarity enables the detection of value-added and non value-added activities [15]. The VSM does not only highlight the issues within the system, but also supports the solving of these problems as well as the implementation of the solution. Many features of the VSM take their origin from the lean principles making it a comprehensive method. VSM-theory is reflected by the VSM-elements described above. Thus, the elements of the suggested model have to support all VSM-elements. The logic behind the modelling elements should be easy to understand, since the model is intended to be used by both managers and engineers (in this case software engineers) who are relying on the model to generate a virtualized solution of VSM.

Therefore, the needed model for X-Solver has to fulfill the following requirements:

1- Clarity; the modelling elements have to represent contents as much as needed and as few as possible. It is hereby ensured that not so many unnecessary information in the final map appear which can confuse the user of VSM. Accordingly, wastes in the value stream would not be properly recognized. Thus, the practicability of VSM would not be exploited.

2- Ease of understanding; the model is primary needed to virtualize the VSM. Software engineers, as first stakeholders, are to be considered as they are not familiarized with the VSM-method, its syntax and its logic. Hence, the model should communicate with the different stakeholders by means of an abstract understandable modelling language.

3- Coverage of all VSM-elements; although a model is seen as an abstraction of a more detailed approach, the developed modelling elements must reflect all elements of VSM in order to offer a complete and extensive transfer of the VSM-theory to the virtualized level.

For the model development, common elements of the VSM are considered. These are aggregated in three categories that constitute the three building blocks of the NEA-model (Nodes-Edges-Attributes model):

- **Nodes:** represent production processes, business processes, customers, suppliers and processes with shared resources.
- **Edges:** illustrate PUSH material flows, FIFO material flows, PULL material flows (consisting of supermarkets and withdrawal), external material flows, Just-in-Sequence deliveries, milk-run deliveries, express deliveries, manual information flows, electronic information flows
- **Attributes:** regroup operators, resources, data boxes, (indication of) repetitive processes, (indication of) bottlenecks, stocks, warehouses, truck transports, other means of transport (ship, plane, train), internal transport means, distribution center, external logistics, information (could be a data set, a document or a list), (indication of) synchronization of two value streams, production

Kanban-cards, withdrawal Kanban-cards, Kanban-cards in batch size, (indication of) Load Leveling, (indication of) Go-See Scheduling, order backlogs and Kaizen flashes.

The edges interconnect nodes, thus creating the sequence of occurrence of nodes in the value stream. Attributes consist in characteristics that specify the nodes or the edges. This means that nodes and edges can be completed by attributes to have more details. This kind of details is directly related to the recorded state, the type or the form of nodes and edges. Figure 4 illustrates an example of how elements of VSM are represented by the NEA-model.

In Figure 4, two process symbols are interconnected with a PUSH material flow. In case of a manufacturing set-up, this means that the manufactured parts go from process 1 to process 2 according to a PUSH principle. The material flow is associated with an extra information, i.e. the warehouse where the manufactured parts in process 1 are stored before they are moved to process 2. The NEA-model simplifies the above described stream and transforms it in two nodes (node 1 and node 2) interconnected with an edge 1 that is linked to an attribute 1. In this manner, the above introduced requirements are respected. The NEA-model does not add unnecessary information that will possibly overload the mapping of the value stream. Furthermore, it encompasses all VSM-elements in form of three objects. This categorization of VSM-elements is indeed useful for software engineers since it facilitates the understanding of VSM on one side, and the transferring of the VSM-theory into a virtualized tool on the other side.

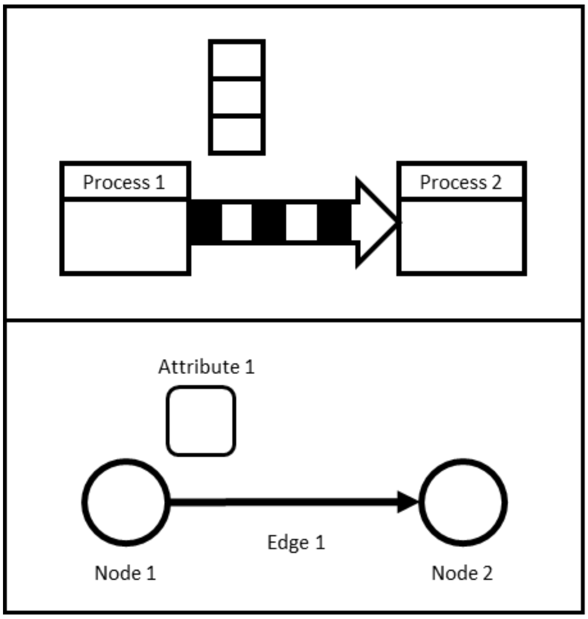

Figure 4. Representation of VSM-elements with the NEA-model: VSM-elements (top), NEA-model (down)

5. COMPLEX SUPPLY CHAIN NETWORKS

Supply Chain Networks (SCN) are defined by the Council of Supply Chain Management Professionals (CSCMP) as “a network of interconnected elements of manufacturing plants, distribution centers, points-of-sale, as well as raw materials, relationships among product families, and other factors” [13]. Lin & Shaw [9] see SCN as autonomous or semi-autonomous business entities interconnected in two direction (from supplier to customer and vice versa). These entities collaborate with each other to produce goods or services.

Since Supply Chain Networks involve more than one supplier, they exceed the borders of simple supply chains (composed of one supplier, one production plant and one customer) leading thus to several enterprise profiles, i.e. value stream structures, manufacturing systems, management systems, etc. In most of the cases, these profiles possess a huge amount of differences, especially when it comes to communication. It is very difficult for participants of one SCN to align their value streams with each other. The lack of standardization in terms of symbols intensifies the complexity of SCN.

Oberhausen and Plapper [14] propose a multilevel approach to analyze the collaboration between participants of a supply chain network. This approach provides a framework to optimize the information flow in the whole network. It defines four levels of application of the VSM-method, each of them with a corresponding level of details. The macro level is the supply chain network as a whole. A partition of the macro level that includes transport routes is called meso level. If only one production plant (with its customers and suppliers) is considered, the level is described as micro. The smallest level of the approach is the nano level, which is for single processes. Each of the levels can be seen as a value stream map.

Due to the complexity of supply chain networks, a model that abstracts relevant elements of these networks and aggregates them to an alphabet is suitable. When applying the above explained multilevel VSM-approach with the NEA-model, it is possible to facilitate, even more, the collaboration between participants of one SCN. On one hand, it could serve as a meta-language for the participants to communicate in a standardized way and exchange important information avoiding confidentiality issues. On the other hand, software engineers could more easily develop an IT-solution for Supply Chain Networks, since the NEA-model is a meta-language that condenses the VSM-knowledge into an intelligible syntax.

6. VALIDATION

The NEA-model is currently being applied in a real software development case with an industrial partner, the “Deutsche MTM-Gesellschaft Industrie- und Wirtschaftsberatung mbH Softwarehaus”.

Since the NEA-model based IT-solution is not yet commercialized and due to confidentiality agreements, the first results delivered by the use of the NEA-model are here omitted.

7. CONCLUSION

The discussed process modelling languages are not suitable to describe the Value Stream Management method. Either they provide more describing objects than needed or they lack the modelling of some important VSM properties. The NEA-model resolves these shortcomings by means of a meta-language that preserves the clarity of the map and ensures a sound transfer of the VSM-theory to a virtualized VSM-solution. Moreover, the proposed modelling elements and the correspondent logic should be understandable by different stakeholders. With gained insights from the multilevel VSM-approach and the NEA-model, it is possible to optimize the collaboration within complex cross-enterprise Supply Chain Networks.

8. ACKNOWLEDGMENTS

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