Supporting Value Stream Design Using S-BPM

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Abstract. This paper proposes that the lean production method of value stream design (VSD) can be supported by subject-oriented business process management (S-BPM). Among the potential benefits of subject-oriented VSD support are a more accurate and faster data capture and a more effective analysis and enactment of process improvements. The integration of the two approaches is possible because they are based on the same understanding of processes – as a set of asynchronous activities with decentralised control and coordination. The paper describes how some of the fundamental concepts of VSD can be mapped onto S-BPM, including commonly used parameters for analysing existing value streams and some design principles for creating future value streams.

Keywords: Lean production, value stream mapping (VSM), value stream design (VSD), S-BPM.

1 Introduction

Value stream design (VSD) is one of the most widely used methods for identifying and eliminating inefficiencies in production processes [1]. It is based on creating value stream maps for visualising sequences of production steps and a set of metrics such as inventory, transport and waiting times. The data required for populating value stream maps is captured manually, by a lean expert walking along the production line and taking notes on paper. This is a time-consuming process [2, 3] and considers only a snapshot of the process at a particular moment in time. As a result, the data may not be accurate and does not include real-time variations such as changes in customer demand and resource availability [3]. Another drawback of the paper-based VSD approach is that the enactment of process improvements is not directly supported by a process management system. Embedding VSD more systematically in the business process management (BPM) lifecycle has the potential to make lean improvements more effective and sustainable [4].

This paper argues that the overall goal of VSD and other lean production methods – to smoothen the flow of activities within a process – can be supported by the ability of S-BPM to model decentralised process control where individual activities are coordinated asynchronously. This puts S-BPM in a unique position compared to other BPM approaches such as BPMN. Those approaches are based on a view of processes as global, centralised control flows, which is inconsistent with lean thinking.

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This paper is structured as follows. Section 2 introduces the VSD method and outlines its connection to BPM. Section 3 maps key concepts of VSD, including basic structural elements, lean parameters and design principles, onto modelling constructs used in S-BPM. Section 4 concludes the paper with a discussion of potential benefits.

2 Value Stream Design

2.1 Fundamental Concepts

Identifying, analysing and improving value streams are key activities in lean production [5, 6]. They are most commonly supported through value stream design (VSD) that is a method for identifying and distinguishing value-adding and non-value adding activities [1]. Value-adding activities are commonly defined as those that the customer is willing to pay for [7]. Non-value adding activities are those that create waste and should therefore be reduced or eliminated, where waste is considered anything of the following [8]:

- Overproduction: occurs when more material, parts or products are produced than needed
- Waiting: occurs when an activity cannot proceed until another activity has completed
- Transport: occurs when there is movement of material, work in process (WIP) or finished products, which does not provide direct benefit for the customer
- Overprocessing: occurs when suboptimal machines, tools or product design lead to errors or additional work
- Unnecessary inventory: occurs when there is material, work in process (WIP) or finished products currently not in use
- Unnecessary motion: occurs when human operators, machines or equipment need to be moved unnecessarily
- Defects: can produce scrap and incur costly activities related to correcting the defects

Value stream design is generally viewed as a four-phase process: Stage 1 identifies a product family in which the individual product variants share the same or similar production steps. Stage 2 creates the current-state map, i.e. a diagram showing the as-is value stream including key parameters and lean process metrics such as overall equipment effectiveness (OEE) and total lead time. Stage 3 identifies potential for improvement and creates a future-state map that visualises a re-designed value stream. Stage 4 prepares a work plan for implementing the designed changes in the value stream. The focus of this paper is on stages 2 and 3, as they relate to the key concepts in value stream design and their mapping to S-BPM.

Value stream mapping uses iconic symbols for representing the various aspects of value streams in an easily comprehensible manner. It is usually drawn by pencil on A3 size paper [9]. An example of a (current-state) value stream map is shown in Figure 1.

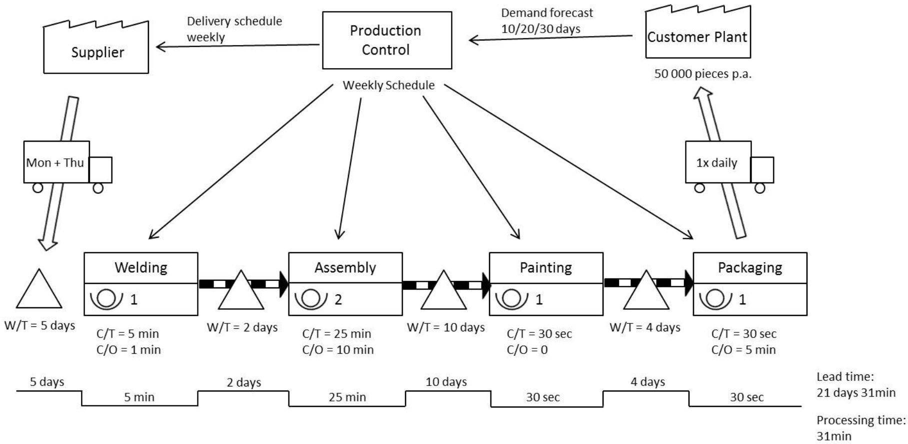

Fig. 1. Example of a value stream map

The overarching goal of value stream design – to streamline the production process – is generally described using the metaphor of "continuous flow". Similar to a smooth and steady stream of water, the continuous flow of production activities implies that within the process there are no or only minimal variations in velocity (i.e., all production steps working at the same speed, otherwise there will be either overproduction/inventory or waiting time) or direction (i.e., no unnecessary or counterproductive steps).

2.2 Decentralised Control

Traditional production lines using centralised planning and control often have difficulties to achieve continuous flow due to variations in customer demand. Decentralised approaches where control is delegated to individual production steps are better suited to react to these variations. There are various techniques such as one-piece flow and pull systems to coordinate the execution of these steps to form a continuous flow. Yet, the paradigm of decentralised control remains fundamental to the lean production philosophy. This has been seen as a major reason why lean production has been poorly supported by IT systems that tend to favour centralised control [10]. These systems are generally too inflexible to accommodate process changes and can thus become obsolete very quickly in lean production systems [3]. The same reason can be assumed for the lack of integration of value stream design and business process management (BPM) systems. There is some work on modelling value streams using BPMN [11]; however, BPMN is still based on the traditional, global control-flow paradigm and does not have well-defined execution semantics.

Support for asynchronous interaction is provided by S-BPM [12], based on the input pool concept that is not available in traditional, control-flow based approaches such as BPMN. An input pool can be viewed as a mailbox for exchanging messages with an active entity (called a "subject") in a process. When a subject is in a function state where it can receive messages (called a "receive state"), it can access its input pool and check for messages. As long as there is no message in the input pool, the subject remains in the receive state. When a message arrives, the subject removes that message from the input pool and follows the transition to the next function state as defined in its Subject Behaviour Diagram (SBD). The input pool can be structured according to behaviour options: The modeller can define how many messages of which type and/or from which sender can be deposited and what the reaction is if these restrictions are violated. The special case in which the maximum size of the input pool is set to zero corresponds to synchronous communication.

The support provided by S-BPM for asynchronous in addition to synchronous interaction has the potential to bring together two seemingly opposing concepts: VSD and BPM.

3 Mapping Value Stream Concepts onto S-BPM

Most concepts of value streams that are to be mapped onto S-BPM can be grouped in three categories: basic structural elements, parameters, and design principles.

3.1 Basic Structural Elements

Erlach [9] identifies six basic structural elements of value streams: production process, business process, material flow, information flow, customer, and supplier.

The *production process* includes all activities that transform raw materials, parts and subassemblies into a final product. In S-BPM, the most appropriate modelling construct for these activities is the subject. This is because subjects allow for the asynchronous behaviours that are the focus of analysis in value stream mapping. The overall production process can then be represented using a subject interaction diagram (SID) that connects the individual activities (i.e. the subjects) with one another via messages. As value stream maps are often concerned with coarse-grained activities [9], the more detailed behaviours of individual subjects (represented in SBDs) are typically not needed for visualising the value stream.

The *business process* includes activities dealing with order processing and production planning and control. They can be represented as subjects and their interactions, within the same SID as used for the production process.

The *material flow* represents the movement, handling and storage of raw material, work in process (WIP) and finished products along the value stream. In S-BPM, the material flow can be represented as messages with associated business objects. At first glance, this does not seem intuitive as messages are usually thought of as conveying information rather than material. However, any piece of information needs a "carrier" that may be a physical part or a container with multiple parts. As industry moves towards an internet of things where every product (or part) is tagged with bar codes or RFID tags, the view of physical objects as informational objects becomes increasingly useful and meaningful. Messages can be thought of as containers for one or more parts, each of which is modelled as a business object. The number of business objects associated with a message then corresponds to a production's batch size.

The *information flow* includes the exchange of information among individual activities of the business process and the production process. This is modelled in S-BPM using messages and business objects, analogous to the representation of material flow. To clearly distinguish messages representing information flow from messages representing material flow, in this paper we will call the former “control messages” and the latter “material messages”.

The *customer* and the *supplier* represent the destination of finished products and the source of raw materials, respectively. They may be organisations that encapsulate their own processes and value streams, and are treated as black boxes. This corresponds to the notion of external subjects in S-BPM.

A SID visualising most of these basic structural elements is shown in Figure 2. It is based on the value stream example presented in Figure 1, and can be seen as a subject-oriented representation of it. In this Figure the grouping of the business process and the information flow on the one hand, and of the production process and the material flow on the other hand, has been done for presentational reasons only. In reality, the two types of processes and the two types of flows are hardly possible to separate from one another, especially for future-state value streams where information flows and production flows are tightly interleaved (as will be shown later in this paper).

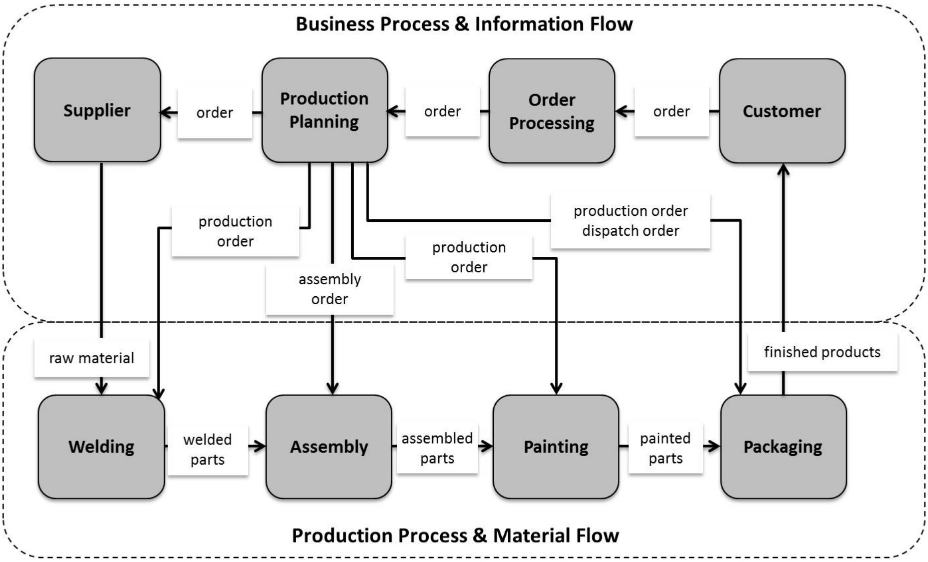

Fig. 2. Subject Interaction Diagram showing the basic structural elements of a value stream

3.2 Parameters

Value streams can be assessed with respect to a number of lean metrics that can be derived from individual parameters. Most approaches to VSD propose the following key parameters: cycle time, changeover time, waiting time, transport time, inventory, rework rate, scrap rate, and number of operators. Most of them can be related to characteristics of individual subject behaviours, as illustrated in Figure 3 for the assembly subject.

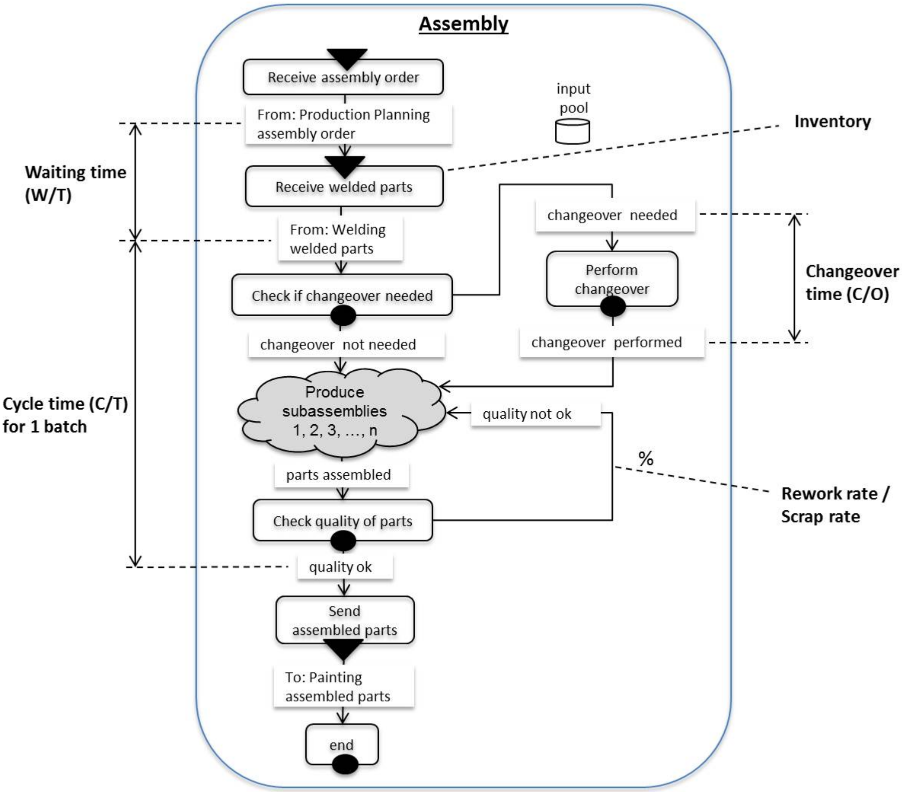

Fig. 3. Value stream parameters derivable from subject behaviour

Cycle time (C/T) is the time it takes to complete a production activity for one unit of the product. Using the SBD, this can be derived from the point in time that a subject has accepted a material message from an upstream subject and the point in time that this subject is ready to send a material message to a downstream subject.

Changeover time (C/O) is the time it takes to perform any necessary preparation (e.g., cleaning and setting up a machine) for switching from producing one product to producing another. This time can be measured from the moment a subject identifies a need for changeover to the moment the changeover is performed.

Waiting time (W/T) is the time that an activity needs to wait for the results of an upstream activity. This time can be measured from the moment a subject commits to executing an activity (by accepting an initial control message such as a production order) to the moment the subject receives the required material message.

Transport time is the time it takes to move raw material, WIP or finished products between two activities in the value stream. Transport can be modelled as a subject that acts as an intermediary between two other subjects in the value stream. The time this subject takes after receiving a material message from the upstream subject until sending it to the downstream subject then corresponds to the transport time.

Inventory represents the number of units of raw material, WIP or finished products stored between activities in the value stream. In S-BPM, this corresponds to the number of business objects associated with material messages in the input pool of a subject.

Rework rate is the relative number (or probability) of defects causing rework. Rework can be represented in a SBD as a loop or exception handling behaviour [12]. Rework rate is then the relative number of business objects for which the loop or exception handling behaviour needs to be executed.

Scrap rate is the percentage of failed WIP or defects that cannot be eliminated through rework. In S-BPM, scrap can be modelled as including those business objects that have been deleted (or, alternatively, marked as “scrap” in a specified field, and sent to a “recycling” subject). Scrap rate can then be calculated as the relative number of deleted business objects with respect to the total number of business objects.

Number of operators represents how many human operators are involved in a production activity. In S-BPM, this corresponds to the number of human agents that have been assigned to a specific subject.

3.3 Design Principles

A number of conceptual design principles have been developed as potential solutions for lean value stream designs [4]. This Section discusses only those principles that have an effect on the process aspects of the value stream and on the way they are represented in S-BPM.

One-piece flow is the closest one can get to realising continuous production flow [9]. This approach aims to reduce batch sizes to just one (work-) piece, each of which is produced in the takt time determined by customer demand. Transport times are reduced to almost zero through a compact and often U-shaped physical layout of workstations. The synchronisation of activities and thus the elimination of waiting times within these production cells are usually achieved by using the same human operator to perform all production activities on the same workpiece. S-BPM can address one-piece flow in two ways: One way is based on the same mappings between value streams and S-BPM as presented earlier, in particular with each activity or workstation corresponding to a different subject. In one-piece flow the same human operator is assigned to all of these subjects. Sending and receiving material messages between these subjects still represents the transport of workpieces from one workstation to another, but without waiting times as the maximum size of all input pools is set to zero (since it is the same operator embodying the sending subject and the receiving subject so there is a “natural” synchronisation). Another way of modelling one-piece flow in S-BPM is based on taking the notion of a production cell as the “integration of formerly separated production processes” [9] literally, by modelling the production cell as one subject. The activities performed at every workstation are then modelled as function states in the subject behaviour diagram of the “production cell” subject.

Supermarkets are buffers that store small quantities of material between production activities. They often have a number of “shelves” for different product variants. The supermarket approach is a pull system that can be used when one-piece flow is not feasible or economic. Supermarkets can be represented as intermediary subjects that receive material from upstream subjects and can distribute this material on request to downstream subjects. Figure 4 shows the example of a supermarket subject that interacts with the assembly subject and the painting subject. Shelves can be interpreted as sets of material messages in an input pool that are grouped together according to their message labels indicating different product variants (P1, P2 and P3 in Figure 4). *Kanbans* are part of the supermarket system and represent requests from downstream activities for the production of material by upstream activities. They are modelled as (control) messages in S-BPM. *Withdrawal kanbans* are messages from downstream subjects to a supermarket subject, requesting a specific type of material to be made available from one of the supermarket's shelves. As shown in Figure 5, the supermarket subject responds by taking the requested material message from its input pool and sending it to the downstream subject. If this results in reducing the current number of material items on the respective shelf below a pre-defined minimum, the supermarket subject additionally sends a control message to an upstream subject. This control message represents a *production kanban* that is a request for new material to be produced and sent to the supermarket to replenish the concerned shelf.

Fig. 4. Kanban-based pull system as interactions involving a supermarket as an intermediary subject

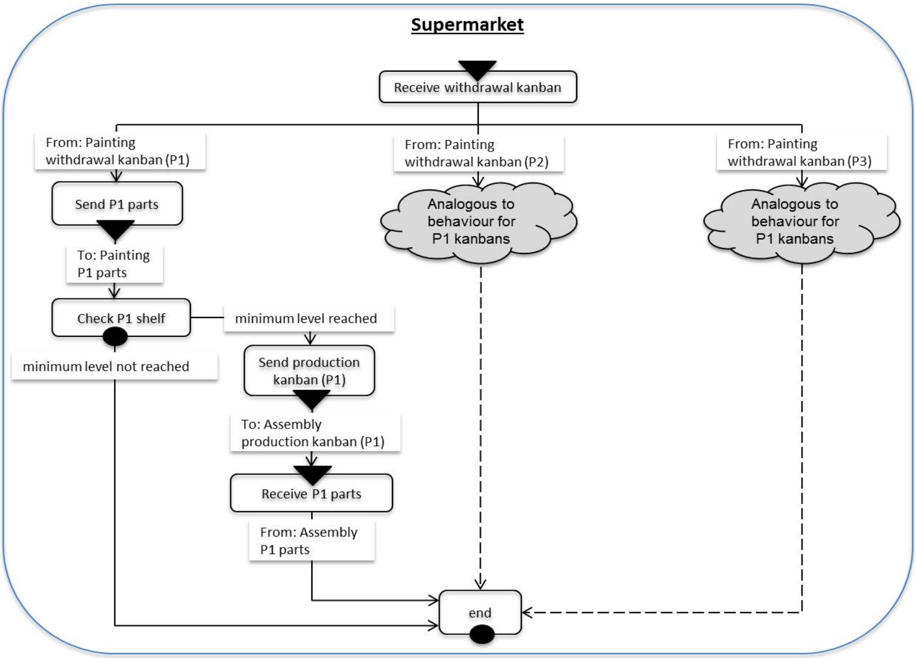

Fig. 5. Subject behaviour of the supermarket

FIFO lanes are small inventories with first-in-first-out (FIFO) processing and a pre-defined maximum of material items to be stored. They can be modelled as input pools in which material messages are time-stamped on entry and then prioritised accordingly. The maximum size of the input pools is specified. When the current number of messages in a pool reaches this specified maximum, any new messages are refused. The sending subject then remains in its sending state until the receiving subject has processed some of the items in the FIFO lane and the new message can be accepted into the input pool.

4 Conclusion

The mapping between VSD and S-BPM brings together two seemingly opposing fields. One is the field of lean production that aims to locally coordinate individual activities to achieve a continuous flow. The other field is BPM that has traditionally focussed on a top-down control of activities. S-BPM, with its view of processes as (potentially asynchronous) interactions between autonomous subjects, opens up the possibility to bridge the two fields and provide benefits to each of them.

Lean production can benefit from subject-oriented process management in two broad areas: capturing as-is processes (or current-state maps) and enacting to-be processes (or future-state maps). As-is processes can be accurately described and analysed when they are executed by a subject-oriented process management system. It reduces the need to rely on manually captured data that can only provide snapshots of a process. Using suitable KPI management systems, value streams can be monitored and analysed for longer timeframes to include the consideration of variations in the data. The design of to-be processes can be supported by subject-oriented simulation, by testing different design alternatives and different production scenarios (e.g. variations in customer demand, product variety, and resource availability). The S-BPM methodology also supports "dry runs" of improved processes prior to their implementation on the shopfloor. These validation runs may also increase workers' acceptance of process changes and enhance their understanding of lean concepts in general. Finally, the formal underpinnings of S-BPM allow directly enacting process model changes using existing IT standards across the ISA-95 automation pyramid [13].

The benefits of applying lean thinking in business processes have long been recognised; yet, to date this integration has been achieved only on a methodological level [4] due to the conflicting paradigms of lean thinking and traditional BPM approaches. The mappings developed in this paper between VSD and S-BPM can provide the basis for developing computational support for the analysis and design of lean business processes.

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