VASCO - Mastering the Shoals of Value Stream Mapping

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***Abstract*—*Value stream mapping* is a lean management method for analyzing and optimizing a series of events for production or services. Even today the first step in value stream analysis - the acquisition of the current state - is still created using pen & paper by physically visiting the production place. We capture a digital representation of how manufacturing processes look like in reality. The manufacturing processes can be represented and efficiently analyzed for future production planning by using a meta description together with a dependency graph. With our Value Stream Creator and explOrer (VASCO) we present a tool, which contributes to all parts of value stream analysis - from data acquisition, over planning, comparison with previous realities, up to simulation of future possible states.**

Keywords*–*Value stream mapping; lean management; content authoring.

I. Introduction

Value Stream Mapping (VSM) is an abstract lean manufacturing technique for optimizing the material and information flows from production up to the delivery of products to the customers. Usually, this is done by drawing current and future state maps by hand, allowing the optimization of production by identifying bottlenecks and wastes. Figure 1 shows a typical hand-drawn board template for data acquisition at the "shop-floor". The concepts of VSM are usually represented by a set of standard symbols, which got various properties attached. Typical properties, e.g., for a VSM process (which represents a production step like welding or assembly) include information about the process time, scrap rate, workers involved in the production, but can also contain data about published enhancements of traditional VSM, e.g., space useage for production and logistics, transport distance and transport time [1].

The history of designing process maps and flowcharts to represent the flows of materials and information in a factory can be traced at least back to 1915, where in a book by Charles E. Knoeppel entitled "Installing Efficiency Methods" we can find interesting graphical representations about the processes and routings in a manufacturing plant [2].

Nowadays, value stream mapping with traditional pen & paper method faces new challenges in practical utilization [3]. To prevent incorrect application, it is necessary to have company wide standards for drawing, data collection and analyzing

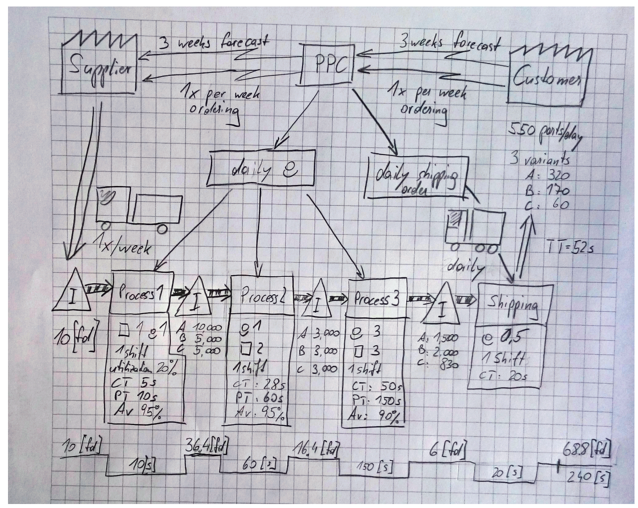


Figure 1. Typical hand-drawn VSM diagram created during a shop floor acquisition in a production facility.

current state maps. Therefore, VASCO was established to close this gap for enabling the planning of successful future state value stream maps in a digital manner.

The next section will give an overview of the related work and programs which inspired the creation of VASCO. Section 3 shows the main functionalities of VASCO, how VSM diagrams are modelled within the system and and how the automatic calculations are handled. The last section concludes our work and will give an outlook of further features.

II. Related Work

VSM was originally developed as a method within the Toyota Production System [4][5] and introduced as a distinct methodology by Rother & Shook [6]. VSM is a simple, yet very effective, method to gain a holistic overview of the conditions of the value streams within a production environment. Based on the analysis of the current state maps, flow-oriented future state maps are planned and implemented [6][7][8].

A value stream includes all activities, i.e. value adding, non-value adding and supporting activities that are necessary

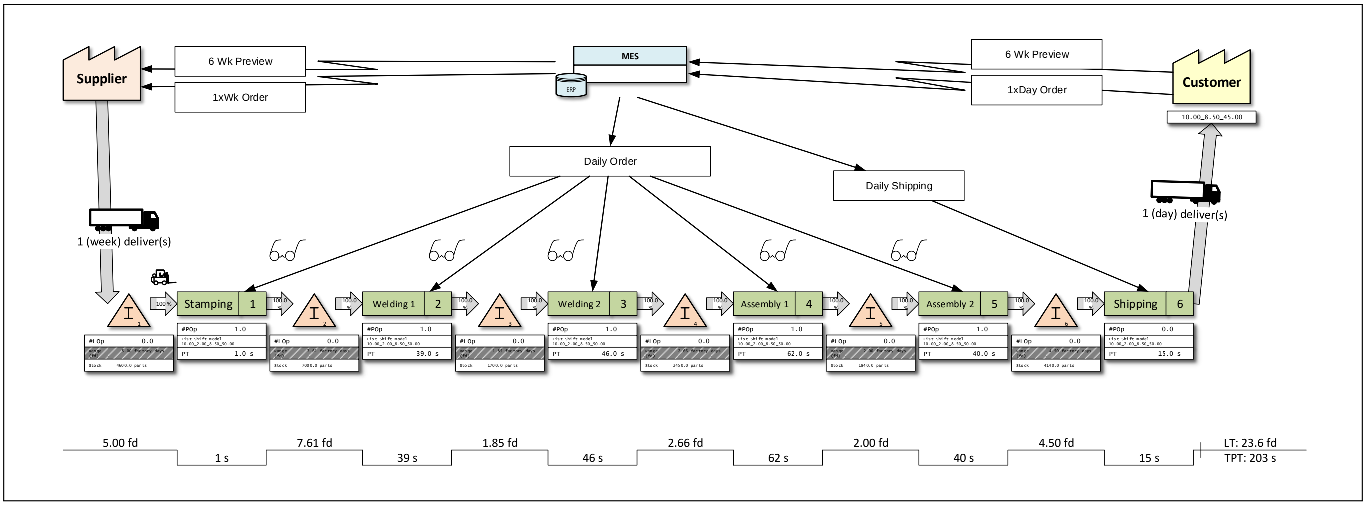


Figure 2. A typical VSM diagram, describing the value chain in production from the supplier to the customer.

to create a product (or to render a service) and to make it available to the customer. This includes the operational processes, the flow of material between the processes, all control and steering activities and also the flow of information [3]. In order to assess possible improvement potential, VSM considers, in particular, the entire process time (sum of time of all production steps) compared with the overall lead time (time from the customer ordering to the moment of delivery). The greater the distinction between operating time and lead time the higher the improvement potential [7].

Value stream simulation can be used in lean manufacturing to support the optimization of production. It allows an early stage insight into productivity, effectiveness and service level without the need of creating very detailed and time consuming simulation models. This means that a simulation in lean management workshops can now be done by lean experts instead of relying in simulation experts. Traditionally VSM is a pen & paper tool that captures the state of the system at the state it was drawn. Component based modeling divides the simulation into a set of simulation blocks [9]. These blocks can be used to create value stream maps that are generic and reusable. In our application VASCO, we also support several reusable blocks that allow the user to easily create value stream diagrams that are reusable in a standardized way. By utilizing standard simulation building blocks one can easily know the state of the system under different circumstances allowing for better decision making. Another important aspect of using value stream maps and specially in a digital form, is that the production and delivery processes are optimized from the customers' point of view [6].

VSM is also seen as a tool to show the outcomes in a shorter period of time at minimal costs. The lean consultants can now represent and capture the current state of the process at a certain state and time and start projecting the future proposed state of the value stream. Based on lean concepts the two states can be simulated and key measurements are assessed. These simulation results can easily demonstrate the improvements [10]. In manufacturing, there are three types of operations that are undertaken to represent a type of waste that might occur: non-value adding, necessary but non-value adding and value-adding operations [11]. The first type is pure waste with unnecessary actions that should be completely eliminated. The second type involves actions that are necessary but might be wasteful. The third type are value-adding operations representing processes that convert raw materials into finished products.

The capture of information to a digital form is often not sufficient. From the point of view of using a digital tool to capture the state of a process, there are several applications that can be used and are available. However, in their paper, Shararah et al. [9] introduce the Value Stream Map Simulator using ExtendSim (VSMSx) as a powerful tool designed to facilitate the implementation of lean manufacturing by simulating the value stream map through standardized simulation building blocks. The company Siemens created as part of their Product Lifecycle Management - PLM product line, an optional extension library called Plant Simulation Value Stream Mapping Library [12]. The company immediately reported productivity increases by as much as 20 percent and improvements of 60 percent related with the reduction of inventories and cycle time. Other benefits such as investment risk reduction (through early feasibility analysis capabilities), better line planning and allocation and significant increases in the resource utilization were also highlighted. The capability of being able to define what-if scenarios without disturbing existing production systems during the planning process is pointed as one of the most important features of any VSM planning tool. Plant simulation is also referred as an important feature of such systems, because it facilitates the comprehension of complex production systems and processes. Resource utilization, material flows and supply chains maybe therefore optimized. The question of "Why perform value stream mapping in Plant Simulation?" is also debated in this technical report. Factors such as the reduction of cost for data collection by reducing the number of objects describing the processes (by utilizing pre-defined logic blocks) or the reduction in analysis effort through automated analysis modules have an important role in deciding to use VSM. In order highlight the dynamic effects (which remain hidden in the static paper based mapping of the value chain), a digital representation (through computer simulation) of the value stream is required.

According to Nash & Poling [13], the value stream mapping has some disadvantages associated with it. It points to the fact that originally, VSM did not include any significant monetary measure for value. It is the stakeholders responsibility to determine determine which activity can be marked as value as well as which activity can be marked as waste. The task of decision-finding may take a lot of valuable time.

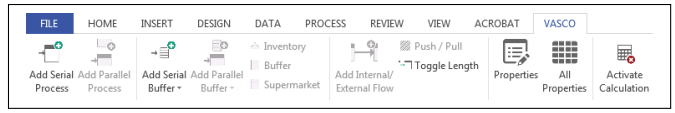
Another important challenge arises from the fact that there is the need to not only capture data and information about the processes and the information flows involved, but also it is beneficial to have a digital representation of how these processes look like in reality [14], in fact ultimately we would like to achieve what is sometimes called ”The Digital Twin Concept Model” [15]. Similarly, in our approach we are taking the steps necessary to provide this type of vision. When we analyze the current arrangement of an assembly line and we capture this information on a VSM diagram (current state). At a later stage we do not want to come back to the production area to visual re-check the arrangement of machines, workers, to discover how are the parts actually delivered and stored or to know what are the space constrains to be able to describe and demonstrate how the actual work of the existent implemented processes is being performed. To have a better view of what should be improved when preparing the future state VSM, it is desirable that the new digital tool for the creation of VSMs can allow the users to capture and then to find annotations in the form of pictures, videos or 3D representations of the past, current and future reality of the production sites. Therefore, every time a user is handling a VSM diagram, he will be able at any step of the process to access these digital catalog of the different processes, that are now linked to the VSM digital representation.

A field research on available standard software tools showed a lack in possibility of detailed analysis. While some tools just provide basic drawing aids for creating value stream maps (e.g. Microsoft Visio [16]), other tools like iGrafx [17], Plant Simulation [18] or SmartDraw [19] also support lead time calculations and basic simulation. None of them considers the availability of data in production lines, which is a big deal nowadays in order to cope with all the complexity and achieve transparency. Nevertheless, detailed analysis and transparency of value streams are needed to reveal improvement potentials.

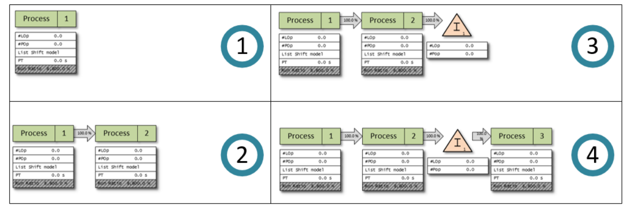
To address the challenges in mastering the increasing complexity in the VSM data models, we are developing a highly customizable tool for authoring and managing value streams. The next section gives an insight on the key features of VASCO.

III. VASCO MAIN FUNCTIONALITES

VASCO is implemented as a Microsoft Visio Plugin. This allows to reuse the drawing and connecting shapes functionality already provided by Visio. A VASCO value stream diagram can be combined with other shapes and features included by Visio or other 3rd-party AddIns. One important aspect in the design of the VASCO focuses on the user experience. Figure 3(a) shows the ribbon toolbar for VASCO. All available control elements are optimized for the fast creation of VSM diagrams, especially adding and positioning process or buffer symbol. Typical repeating tasks are automated like the adding of serial process/buffer symbols, where VASCO already connects the



(a) The Vasco ribbon which offers a support for fast generation of VSM diagrams.



(b) Drawing a simple VSM.

Figure 3. With minimum user interaction the drawing process in Figure 3(b) can be achieved with our Vasco toolbar shown in Figure 3(a)

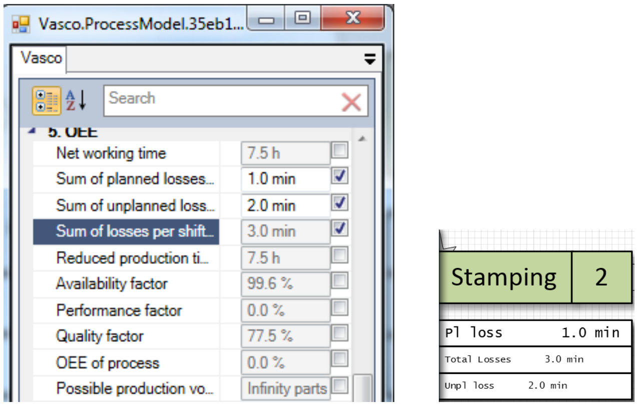
two symbols using an internal flow connector. The inserted process/buffer stays selected, so that the user can immediately use the commands ”Add serial process”/”Add serial buffer” multiple times. Figure 3(b) shows how to create a VSM diagram. From (1) to (4) using only mouse clicks - or if you are on a touch device, then only 4 touch events are needed, which is much faster then a hand-made drawing. Therefore, the usual manual steps of transforming the hand-made drawings into digital documents is now completely obsolete when using VASCO.

A. *Definition of VASCO symbols*

As seen in figure 2 a value stream consists of a variety of standardized shapes and information. VASCO adds properties and the calculation logic to the VSM shapes to the main VSM symbols:

Figure 4. The standard VSM symbols (from left to right): Supplier, Customer, Process, Buffer, External flow, Internal flow.

- The **supplier** is the manufacturer which ships the goods into the factory.
- The **customer** is a company, merchant or another entity who orders goods and requires them to be shipped regularly. The customer determines the demand and the resulting takt time, which is a key value driving almost all calculations within a value stream.
- The **process** is a step, which adds value to goods by altering or modifying it.
- The **buffer** is an intermediate step where the factory goods are stored. This storage might be an input for the next process, a general depot for delivering goods to the customer or from the supplier.
- The **external flow** connects a supplier or a customer with a buffer or a process.
- The **internal flow** connects buffers and processes with each other. The main difference between an external



(a) The complete property model of the stamping process.

(b) Selected attributes of the property model displayed below the process symbol. 5(a).

Figure 5. The properties of the stamping process and how the process is displayed on the VASCO sheet.

and an internal flow is that a internal flow might connect a process with multiple buffers or processes. This means that the internal flow is augmented with a property called material spreading which defines how many percent of material spreads from one process or buffer to their successors.

A valid *value stream graph* consists of one supplier at the start, one or more customers at the end, one or multiple processes, and zero or multiple buffers. Each of the processes and buffers are connected with internal flows and two external flows connecting the supplier and customer with the network.

B. Intelligent Symbols

One of the significant features of VASCO is that all symbols defined in Section III-A, are fully customizable by a configuration file. This configuration file defines which properties are added to the symbol. These properties can be classified into two major categories: manual input values or calculated values. The manual values are entered by the user, whereas the calculated values depend on a formula consisting of manually entered or other calculated values. The formula definition is also part of the configuration file and can be modified even at run-time.

For example, let's have a process which drills a hole into a plate. This process has two manual input values. The value adding time which is the time period when the drill actually drills the hole and the setup time. The setup time is the time period needed for positioning the drill and the time the assembly line needs to bring the plate into position. With these two values in the process it is possible to add a third value, the process time which automatically calculates the sum of the setup time and the value adding time. This automatic calculated value can be displayed on a databox in the process shape (see Figure 5). If a value of these properties changes, all dependent values are updated immediately (see Figure 5(a)).

One special case of calculated values is when the values not only depend on the local process, like in the example above, but also in other places from other symbols, like the following processes. These special calculations are called graph calculations. The graph calculations are also defined in the configuration file, but require a complete value stream graph in order to perform their calculations. For this, VASCO has two different modes. The first mode, is the design mode. In this mode, the user can add processes, buffers and connect them with each other. The calculations which are only local are calculated in this mode. The second mode is the calculation mode, where all graph calculations calculate their value. In this mode it is not possible to add, remove or connect symbols with each other.

To get a better picture about the calculation mode consider a customer who requires 100 items. We have 3 processes which are connected in series. Each process has a scrap rate of 10%. Now each of the processes has to accommodate the scrap rate of the following processes and produce more goods. That in the end the customer gets his 100 items. Therefore, in our example the first process requires 139 items. This example can become arbitrarily complex with parallel processes and the material spreading in internal flows. In the calculation mode all values are live updated and displayed. So if the customer requests that the factory delivers more items, it is then immediately visible how many more raw material the first process requires. This is also the reason why it is not allowed to edit the path, remove or add further processes during the calculation mode, as all values would be invalid with a unfinished value stream graph.

When a user adds a new intelligent symbol to a diagram, e.g., a buffer, this symbol becomes now automatically the current selected symbol. This allows the automation of the possible next choices for symbols that can be added to the diagram (connected to the current symbol). In this way, when the user looks to the application main toolbar, only symbols that are possible to be connected to the previous symbol, are available for a next drop in the diagram. When the user intent is to connect two symbols, e.g., the user wants to connect a buffer with a process, the user pre-selects these two symbols. After this step, the application automatically highlights the possible connections that can be added between the selected symbols. The users reported that these methods significantly improve the productivity and the usability of our application interface. These and other improvements will be the target of future studies, where we will access the overall usability of the tool and compare it with other existent VSM applications.

C. Key Performance Indicators and Data Lines

As referred in the related work section, an important aspect in the analysis of VSM diagrams is the extraction and automatic calculation of *Key Performance Indicators* (KPI).

Key performance indicators can be calculated local, e.g., for a single process (e.g. OEE rate) or buffer (e.g. local lead time) but also for the whole graph /value stream (e.g. total lead time). These values are calculated automatically and are visualized in several data lines below the drawn value stream. As an example for the several supported data lines in VASCO, the time line consisting of total process time and lead time is shown in Figure 2.

When discussing with the main key holders (manufacturing and production consultants or VSM and processes simulation owners) involved in the event of capturing processes and information flows (as well as many other related information

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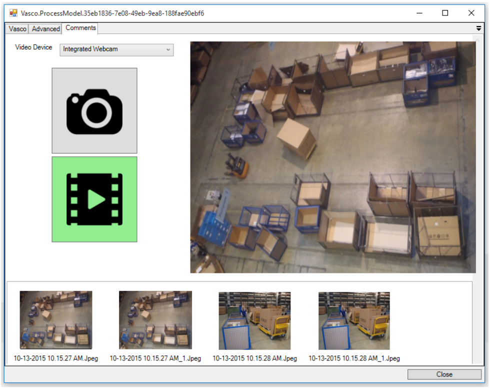

Figure 6. The Comments plugin allows to annotate VSM symbol with photos and videos taken from the camera of a tablet.

VASCO KPIs

Flow rate / Flussrate	1.39	[%]
Lead time / Durchlaufzeit	36.51	[fd]
Processtime / Prozesszeit	3.38	[min]
Total number of employees / Anzahl Mitarbeiter ges.	6	[#/day]
Production / Produktion	5	[#/day]
Logistics / Logistik	1	[#/day]
Employee productivity / Mitarbeiterproduktivität	75	[parts/pers.]

Figure 7. The Key Performance Indicator giving an overview of the operating numbers in the factory.

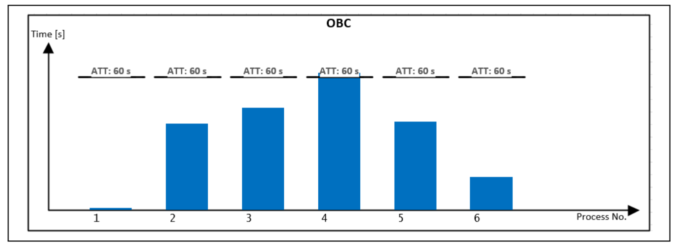

Figure 8. OBC showing the process time in relation to the takt time.

captured now in a digital form), one of the most desired features is the capability of calculating improved business metrics. These metrics allow the evaluation of factors that are critical to the success of an organization. In our tool, we calculate and present metrics that are related with human resources, costs, performance and workload balancing management. These are essential to the reduction of costs and to the improvement of performance of processes and persons.

We present results to the users in a concise way through resume maps in each step of the calculations procedures. This is a realistic and simple way to digitally represent the past, current and future reality inside all manufacturing sites.

D. Extensibility

One key-feature of VASCO is extensibility. While self being an Microsoft Visio addin, it can be customized by plugins itself. The basic version of VASCO is already shipped with three plugins, extending the basic functionality of the tool:

- **Comment-Plugin** VASCO was designed to make the acquisition and calculation of a new value stream easier and to replace the pen & paper acquisition. With the pen & paper method it is always possible to add different comments to the different symbols. In order to give the VASCO user a similar feature during the acquisition a comment plugin was created. This comment plugin enhances every symbols on a VASCO page with a comment tab (see Figure 6). When we observed during the data acquisition process that users sometimes only copied key figures from a machine into this comment tab, we further enhanced the comment-plugin with a snapshot ability. With this snapshot ability the user doesn't need to copy the values himself. The user only has to take a snapshot with the tablet. It is also possible to record a video with the comment plugin. This can be done to record different views of the machine or to record the voice of the person who does the acquisition so that there is not even the need to write textual facts in the comments box.
- **KPI-Plugin** The KPI-Plugin adds an additional visual features (see Figure 7) to the Visio page. This shape displays the key performance indicators of the factory in a clear fashion. Once a VASCO graph is complete and VASCO itself is in calculation mode, the values are calculated and automatically updated when a value in the graph changes.
- **OBC-Plugin** The operator balance chart (OBC) visualizes the total amount of work of each process compared to the takt time. An OBC supports the critical task of redistributing work elements among operators. This is essential for minimizing the number of operators needed by making the amount of work for each operator very nearly equal to, but slightly less than, takt time [20]. Figure 8 shows the OBC chart of the given example.

E. Data Model and Calculations

This section describes the data model used in VASCO, and discusses some implementation aspects of the evaluation.

1) Graph Structure: Naturally, the elements of a value stream map can be represented using a graph structure. A graph $G = (N, E)$ consists of a set of nodes N together with a binary relation E on the set. Each concept of a VSM (e.g. a process or a flow) is represented by a node $n \in N$ in the graph, connections between VSM concepts are represented by a directed edge $e \in E$ between the corresponding nodes.

Each node, or concept, contains a set of named properties. These properties can either be set to a constant value, or can be calculated from other properties.

2) Evaluation of Calculated Values: Our key observation was that the dependencies of calculated values need to be represented in the data model of the system for an efficient evaluation. Therefore, VASCO contains a second graph structure that represents the dependencies of calculated values. This allows an efficient re-evaluation if the user changes a property value, as only dependent values will be recalculated.

A calculated value may depend on values from other nodes in the graph, in this case the concrete dependency

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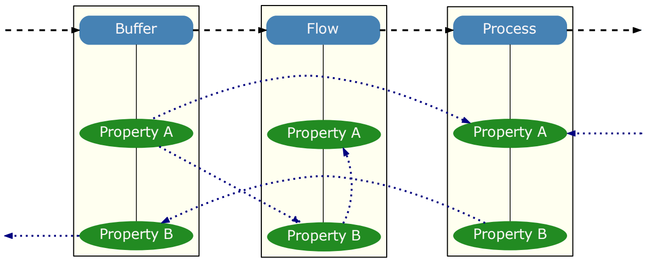

Figure 9. The data model of VASCO captures the structure of the VSM graph.

graph depends of the VSM neighborhood of the concept node containing the calculated value, therefore changes in the VSM graph structure also entail changes in the dependency graph.

An example of this graph structure can be seen in Figure 9. In this example the connection between Buffer, Flow and Process are shown with black dashed lines. Furthermore, the dependencies of calculated Properties are represented by a second graph (blue dotted lines), e.g. property A of Buffer depends on property B of Flow and property A of Process. VASCO contains a meta-representation of VSM objects and the dependencies of their calculated properties such that the dependency graph will be automatically created from the VSM graph.

IV. Future Work & Conclusion

With VASCO it is possible to use only one tool throughout the complete work-flow of value stream analysis. It dramatically simplifies the data acquisition at the shop-floor and offers a large tool set for analyzing and improving the production/logistic value chain.

Also the extraction of production metrics can be done at any stage of the work-flow creation, allowing the users to immediately have calculations feedback about the impact of their changes when designing future state maps. Lastly, by using our tool the users can capture information along the entire value stream analysis process, starting with visits to the production sites, where the users can capture images and videos of the working processes as side annotations, up to the creation of a new diagram based on previous processes workflow states with comparisons between multiple state realities of the existent manufacturing processes, where the users can still access all the annotated information about old and current manufacturing processes.

Future work will concentrate on combining and integrating VASCO with other professional simulation tools. This allows to simulate various combinations and new arrangements for the future state of the VSM. Another important aspect is the integration of sustainability criteria within a VSM, that will significantly help manage and reduce the amount of waste, resulting from the manufacturing processes. This will also provide new metrics and KPI's that help to capture each company production reality in a digital way.

User experience is always a primal focus in all industrial applications. We are planning experiments where the users will perform fundamental tasks with our tool. With the help of an eye tracker equipment, we will record data about the way users perform their tasks and about their individual preferences.

It is our intention to assess how our tool is used in reality by the final users and to study its usability. We expect to be able to use this data to improve the overall experience of the users and as a way to boost the productivity of the users when working with our tool.

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