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A VSM APPROACH TO SUPPORT DATA COLLECTION FOR A SIMULATION MODEL

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ABSTRACT

Simulation is a powerful tool to analyze and help in the decision making process of a production system. It is capable of delivering a dynamic analysis, both of the existing system and the future planned system. One major challenge with simulation projects however, is the time required at the initial stage when collecting data. For this study, Value Stream Mapping (VSM) has been selected as a complementary method for the data collection. VSM has been widely spread in industry, and it is a suitable method for identifying value streams and visualizing flows. In this study, the applicability of VSM for data collection is examined for a production system with complex and non-linear flows. The results of this study confirms that VSM can support in the data collection phase, but entails the support from subject matters.

1 INTRODUCTION

As market and customer demands change more rapidly, manufacturing companies need to able to respond to those changes quickly. One tool that has proven itself to be powerful for decision support in production development, is Discrete Event Simulation (DES) (Williams 1996). DES enables a dynamic analysis of the production system with the purpose of identifying improvements in existing production systems or to analyze the introduction of new production equipment (Skoogh and Johansson 2008). Sargent (1998) states that simulation models are being gradually applied in problem-solving and decision making.

One major challenge of the simulation project, however, is the time required in an initial stage when collecting data. Data may need to be extracted from multiple data sources and the availability of data parameters varies. Perera and Liyanage (2000) describe the inefficiency of data collection as a severe limitation of simulation projects and methods to support the data collection are needed.

Lean production originated from the Toyota Production System, has become a well-established subject within academic literature (Schmidtke et al. 2014). Value Stream Mapping (VSM) is one of its methods, which can visualize the current state of a production system and collect first-hand data from the workshop. VSM is mainly designed to manage linear flows and not valid for more complex production systems with non-linear and merging flows (Khaswala et al. 2001). There are complementary methods to VSM proposed, with tools supporting mapping of more complex production environments. Two of them are Improved VSM (IVSM) and Value Network Mapping (VNM). For this study, an approach constituted by VSM, IVSM, and VNM is presented for facilitating the data collection process for a simulation model. The approach includes a final step where data are classified based on availability. This study aims to gather data for a simulation model through this approach.

2 METHOD FOR STUDY

The sequence of actions in this study is summarized in Figure 1, where focus is to present how data have been gathered. The first step of the study was to perform a literature review to gain knowledge about data input management for simulation models, evaluate available mapping techniques and methods for classifying data. Next step was to perform interviews with key persons in the organization, where the goal was to get familiarized with the production organization prior to selecting a product for mapping. Secondary data were extracted from the Enterprise Resource Planning (ERP) system in the next step. Data were processed and analyzed to provide facts for decision-making. The analysis was complemented by focus interviews with subject matter experts to support the product selection. The selection of product was input for mapping in the subsequent step. Final steps were classifying data and conducting a detailed map, which were performed concurrently.

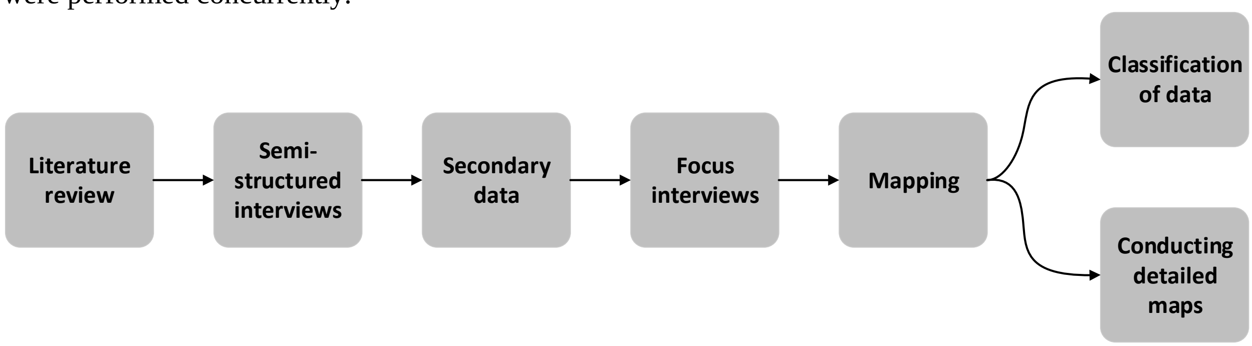

Figure 1: Sequence of actions in this study with emphasis on how data were collected

3 THEORETICAL FRAMEWORK

This section of the paper gives the outline of the theory that constitutes the approach applied for this study. Data input management is firstly discussed on a general level as well as a method for classifying data depending on availability. VSM, IVSM, and VNM are introduced and explained, and the last section presents the approach.

3.1 Data Input Management

Data collection is one of the first steps of a simulation project and involves a number of activities to receive the right data parameters; identify the data parameters of interest, collect all information necessary to make them suitable as simulation input, convert raw data to data that are quality assured and document all steps of this process (Skoogh and Johansson 2008). These activities may sound forthright but building a simulation model of a system for the first time implies to identify the characteristics and operations of the system first. Perera and Liyanage (2000) suggest that interviewing stakeholders of the project, a walk-through of the system of interest, and using operator instructions are information sources that can support this. The main objective is to become familiar with operating rules of the system and it is stressed by Law (2007) that no single person or document is sufficient in this process.

An obstacle when building a simulation model of a new system may be the degree of data documented and available. Data of the system can be well documented in computer-based systems, easy to access and to extract data from. On the end of the scale, data may be printed down only in a manual system. Perera and Liyanage (2000) state that the data collection process may require data collection from several data sources in a company, which requires extensive time. In proportion to the total time required for a simulation project, the data input management corresponds to a substantial part of it (Skoogh and Johansson 2008). This amplifies the importance of performing this step in a structural manner. What has been recognized from interviews with simulation practitioners, is that data collection often is done ad hoc (Perera and Liyanage 2000). Especially when the system becomes more complex.

3.2 Classification of Data

During the process of collecting data, a problem that can be encountered is the absences of available data for the data elements selected to represent the system. To address this problem, Robinson and Bhatia (1995) have suggested a way of classifying data based on the availability. They suggest three categories presented in Table 1 and each category is further explained in the respective subheading.

Table 1: Classification of data based on availability (Robinson and Bhatia 1995)

Category	Description
A	Available
B	Not available but collectable
C	Not available and not collectable

3.2.1 Category A

For many systems, data have already been collected for other purposes and it is, therefore, important to take advantage of the prior efforts. It is, however, important to verify the source of already collected data, so it is extractable and valid for the case examined (Skoogh and Johansson 2007). It is not uncommon to find documented data in different sources; collection system, automated or manual, that are used for the purpose of assessing the system, Enterprise Resource Planning (ERP), Material Planning Systems (MPS) and Manufacturing Execution Systems (MES). Other sources may be from previously performed studies, e.g. Lean efforts (Skoogh and Johansson 2008).

3.2.2 Category B

Data for Category B are not available in any system or from previously performed studies but data can be collected. A common method for collecting data is simply by using a stopwatch and follow the product flow, measuring the parameters selected for the study. Other applicable methods for collecting data are frequency studies and video analysis. Since this process of collecting data most probably involve manual work to a large extent, it is a time-consuming process (Skoogh and Johansson 2008).

3.2.3 Category C

To manage the last of the three categories implies to estimate the data. It can be a less time-consuming process compared to Category B when the assumptions are based on process experts. Robinson (2004) has introduced three options that can support the work of estimating data; discuss with the subject matters of the parameter e.g. machine vendor or production engineers, review data from a comparable system in the same or another organization, and lastly there are standardized data available for some process that have been measured and stored.

3.3 Mapping Methods

VSM is mainly suitable for production systems with linear flows and does not address the challenge with complex product structure and intertwined routings (Thomassen et al. 2015). The real setting of many companies is of "high variety – low volume" type implying hundreds of industrial parts and products for a value stream (Braglia et al. 2006). Khaswala et al. (2001) emphasize that mapping multiple products that do not have the same material flows are something VSM fails to manage. IVSM and VNM are two methods that aim at facilitating mapping for more dynamic manufacturing systems with non-linear flows. These were selected to examine how they can support the mapping of complex production systems. The following sections present VSM, IVSM, and VNM to provide the basis for the approach of this study.

3.3.1 VSM

VSM is a paper and pencil method that enables to map all actions required to bring a product from start to finish, both the value-adding and nonvalue-adding activities seen from the customer's perspective. It has been explained by Rother and Shook (2009) and it implies to walk along the value stream, drawing the processing steps and collect data. It is important to view the flow from the perspective of the customer and therefore start the mapping from the end of the flow right before shipping of the product. VSM is performed for one product family at a time, so an initial step is to identify the product family. A product family is characterized by a group of products that proceed through similar processing steps and over shared equipment. Focus is to include both material and information flow that impact the value stream of the product when mapping (Liker and Meier 2004).

VSM presents the current status and first-hand data are collected. Data that are not available, can be measured by using a stopwatch while mapping. Besides providing the current state, VSM aids to identify the nonvalue-adding activities, known as wastes. The seven wastes are overproduction, waiting, transporting, processing, inventory, motion and defects. When the current state and sources of waste are identified, the next step is to map the future state with no sources of waste. To facilitate the realization of the future state an implementation should be formulated that will guide improvement efforts. A yearly value stream plan that includes a plan of step-by-step activities, measurable goals and clear deadlines should be established (Rother and Shook 2009).

3.3.2 IVSM

IVSM is based on an iterative procedure and combines a classical VSM with tools derived from the manufacturing engineering area (Braglia et al. 2006). It is successful in handling complex Bill of Material (BOM) and merging flows, as well as multiple products with non-identical routings. IVSM comprehends sevens steps, that are performed in an iterative process until the desired lead time is reached and no more improvements can be identified. The structure of IVSM is visualized in Figure 2.

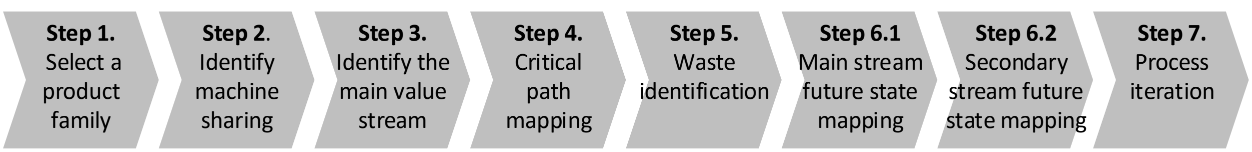

Figure 2: Procedure of IVSM including seven iterative process steps (Braglia et al. 2006)

The focus is on the first steps of IVSM and the identification of waste and mapping of the future state are excluded. The explanation is therefore narrowed down to explain step 1-4 with available tools that are found applicable for this study in Table 2.

Table 2: Description of step 1-4 of IVSM and applicable tools (Braglia et al. 2006)

Description of step 1-4	**Tools**
Analysis of volume or revenue for each product family.	Pareto-diagram, Machine-Part Matrix (MPM), Multi-Product Process Chart (MPPC)
Identify shared equipment by several product families that are probably constraints of the flow.	Analyzing routing Rearranged MPM
A critical value stream should be identified for a system with multiple flows merging.	BOM Total Lead Time
Mapping of the critical path highlighting shared resources and percentage of respective product.	VSM procedure and standard icons

3.3.3 VNM

VNM was designed to manage the situation of multiple flows in a value stream that merge (Khaswala et al. 2001). VNM has the capability of identifying identical or similar flows in a value stream that can be merged, as well as considering all in-house and outsourced parts that constitute the BOM. The steps of VNM are presented in Figure 3.

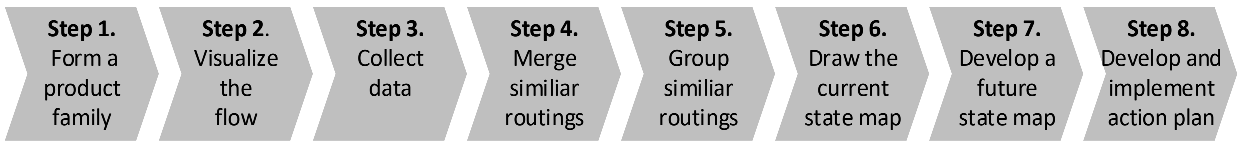

Figure 3: Procedure of VNM including eight steps (Khaswala et al. 2001)

This study focuses on the five first steps of the method that supports the identification of the product family for mapping and Table 3 explains these steps further. Description and tools applicable for each step are summarized.

Table 3: Description of step 1-5 of VNM and applicable tools (Khaswala et al. 2001)

Description of step 1-5	**Tools**
The relationship between product and process need to be analyzed for BOM structures.	Product-Process Matrix (P-P Matrix) Product-Component Matrix (P-C Matrix)
Routing of the component in the same product family is mapped and visualized in the physical factory layout.	BOM, Operations Process Chart, Multi-Product Process Chart (MPPC), Flow Diagram
Information about the operation, storage, transport, delay and inspection steps are recorded.	Enhanced Flow Process Chart (FPC)
Similar flows are merged to limit the no. of flows.	Modified Multi-Product Process Chart (MMPCC)
Components with the same routing are grouped.	Machine-Part Matrix (M-P Matrix)

3.4 Approach for Data Collection

Figure 4 visualizes the suggested approach to collect data for this study. It is a combination of VSM, IVSM and VNM and tools have been chosen to support the selection of product for mapping.

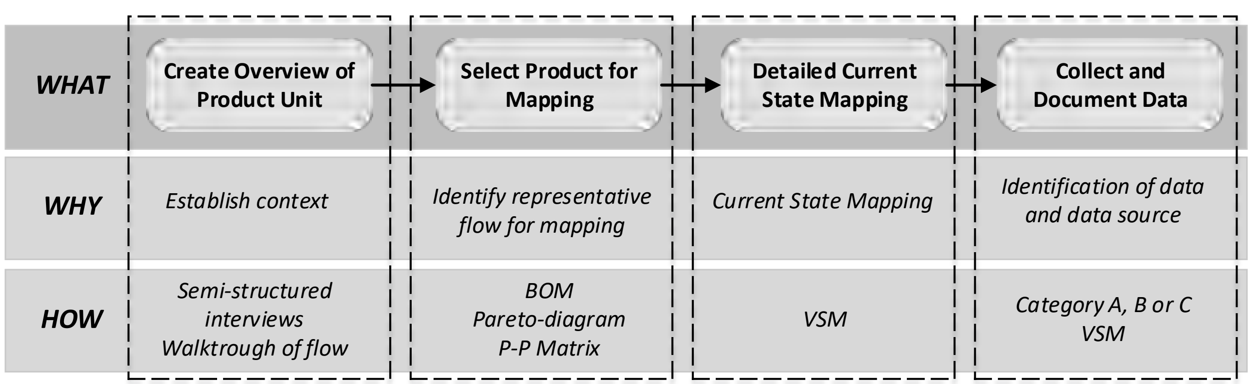

Figure 4: Approach combining VSM, IVSM, and VNM with a final step where classifying data

Emphasize is on the selection of product family since it is a crucial step when managing complex production environment. The BOM, used in both VNM and IVSM, will provide information to determine the product hierarchy and interdependencies of production steps. Pareto-diagram, from IVSM, visualizes a high-volume analysis for respectively product. The P-P matrix, product-process relationship from VNM, will reveal the flow of the product and enable to compare process steps for similar products. Results from this step present data and analysis that support the selection of a representative product to map in the next stage.

Classifying data is an important step of this approach since it identifies data that are available and data that require more activities. When collecting, questions should be asked, whether the data parameter of interest is already available, collectable or can be estimated. This should facilitate a plan of how to address data that are not available.

4 CASE COMPANY

RUAG Space Group, Sweden, is a contender on the communication satellites market which is experiencing market changes. The production facility located in Gothenburg is a specialized manufacturer of components for communication satellites which are characterized by high quality, customization and low volumes. Existing production involves a high degree of manual work and extensive tests are performed to verify products to specific customer requirements. The future market will require development towards an industrialized production in terms of vastly increased volumes with reduced lead times at reduced cost levels.

5 RESULTS

The results section follows the sequence presented in Figure 4 and the sub-headings specify tools that have been applied from VSM, IVSM, and VNM. Figures presented serve to illustrate examples of results obtained in order to explain the applicability of the approach. The result section refers to product A which is one of three products that RUAG manufactures.

5.1 Create Overview of Product Unit

Key persons with either management responsibility or supporting function were interviewed with the aim to build a basic understanding of the production organization for product A. Figure 5 illustrates the product hierarchy for product A divided on three levels. Operations at level 3 give an RF Assembly and LO Assembly respectively, that will be assembled together with an RF Cover, level 2, to establish a product A, level 1. Manufacturing for product A involves mainly assembly of sub-parts to a final product, referred to as Top Assembly in Figure 5.

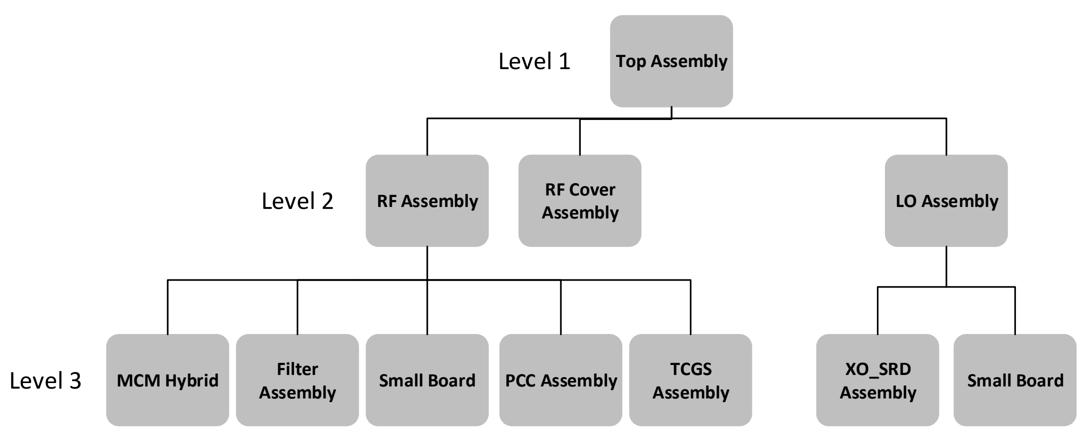

Figure 5: Product hierarchy Product A

The production organization for product A involves five sub-functions; assembly, environmental testing, inspection, product quality assurance and test. Manufacturing of product A is labor intensive inferring a low level of automation. The flexibility of personnel is of high priority, but it is still hampered by the amount of training that is required to perform operations. The product mix for product A are four main versions, but since all products are designated by a specific customer there are almost no identical customer projects. This implies that there are even more variants generated as a result of customization and product A is engineered-to-order in most cases.

5.2 BOM Structure

The BOM structure for product A was studied to understand the product hierarchy and the overall flow, see Figure 6. It contains information about the part no. and description of part, information about part type and parent part no., as well as classification. Part type is divided into manufactured, purchased and purchased (raw). Only manufactured parts are of interest for this study, since it is the group including value adding activities.

Description of part provides detailed information about the type of part for a specific customer project. When analyzing the flow, it is of interest to identify what sub-assembly a part belongs to. Classification provides this information, assigning e.g. LOKRX1 ASSY to LO Unit. Parent part no. tells where the part is located in the product hierarchy. For instance, LOKRX1 ASSY belonging to class LO Unit has the parent part no. 1000062627 that corresponds to TOP ASSY. The product hierarchy presented in Figure 5 and sub-flows that should be mapped were identified based on the BOM.

Part No	Description	Qty per	Part Type	Parent Part No	Classification
1000062627	KRX1 TOP ASSY		Manufactured	*	TOP ASSY
1000060243	RF COVER ASSY REC (D GASK PROF)	1	Manufactured	1000062627	Board & Filter
1000062632	RFKRX1 ASSY	1	Manufactured	1000062627	RF Unit
1000062637	LOKRX1 ASSY	1	Manufactured	1000062627	LO Unit
1000027247	RFIF HYBRID ASSY (14/12) Ceramic, 1	1	Manufactured	1000062632	MCM
1000033518	IFOP HYBRID ASSY (12 GHZ) CERAMIC,	1	Manufactured	1000062632	MCM
1000060382	LNA HYBRID ASSY (14 GHZ) Kovar, 3 t	1	Manufactured	1000062632	MCM
1000062935	PCCP100AIR PW ASSY	1	Manufactured	1000062632	Board & Filter

Figure 6: BOM structure for Product A

5.3 Select Product for Mapping

For the selection of product that will be mapped, manufacturing orders for product A were needed for the analysis. Manufacturing orders from the time span of 2013-2017 were extracted from the ERP system and imported into an Excel-sheet, where every row is representing one manufacturing order. The Excel-sheet, Figure 7, contains information about order no., project name and id, part description, product unit, and classification.

Order No	Project Name	Project ID	Part Description	Product Unit	Classification	Part No
42158	Project 1	P1	IFOP HYBRID GROUP C TEST	A	MCM	1000047117
43238	Project 2	P2	CC TOP ASSY FM	A	TOP ASSY	1000066613
43239	Project 2	P2	CC TOP ASSY FM	A	TOP ASSY	1000066613
43240	Project 2	P2	CC TOP ASSY FM	A	TOP ASSY	1000066613
43113	Project 3	P3	IP LO FILTER 3.55 ASSY FM	A	B&F	1000046772
42902	Project 3	P3	IP LO FILTER 1.6 ASSY FM	A	B&F	1000046792

Figure 7: Excel sheet with manufacturing orders for Product A extracted from ERP system

Part description, part no. and classification is the same information as from the BOM. Product unit tells if it is product A, B or C, in this example, only product A is presented. Project name and project id tell what customer the part belongs to; in this example the information is removed since it is not crucial information for the selection. From data extracted from the ERP system, a big data set aided the analysis of which part type of product A that has the biggest volume share in terms of units.

5.3.1 High-Volume Analysis

Every part type in the Excel-sheet belongs to a class, e.g. CC TOP ASSY FM belongs to TOP ASSY, and it was of interest to study the volume distribution of the part types for each class. A Pareto-diagram was therefore established for each class in order to do a high-volume analysis for respectively class, and the result for class TOP ASSY is presented in Figure 8.

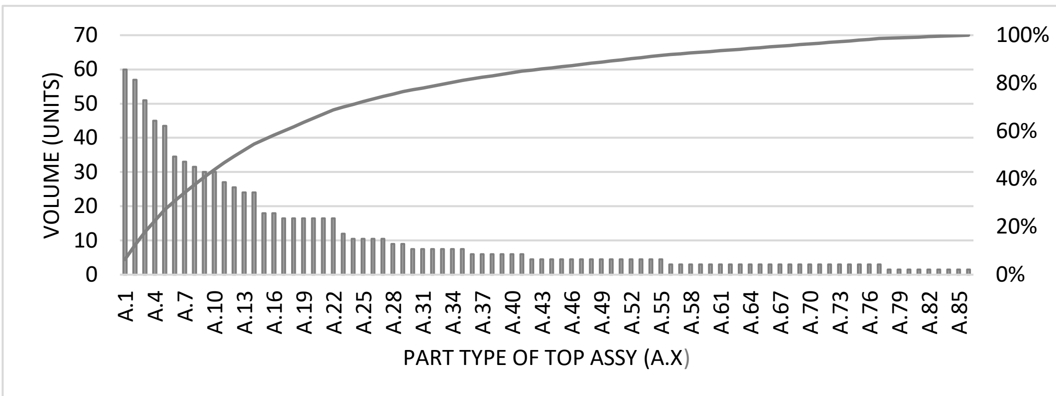

Figure 8: Pareto-diagram TOP ASSY Product A

Each bar in Figure 8 represents the total units for the respectively part type of TOP ASSY for the last four years. Part type A.1 corresponds to a total volume of 60 units for instance. The line illustrates the volume share for all part types and for product A.1 the volume share is 6 %. The line and the trend of the bars indicate that there are a few part types that correspond to a large proportion of the total volume. For the P-P Matrix, the eight variants with the biggest share of the total volume were selected from the Pareto-diagram.

5.3.2 P-P Matrix

The P-P Matrix for TOP ASSY is presented in Figure 9 with processes in the top row and part type (product) in the first column. Processes were first mapped at the operation level but were later abstracted to work center level because a better overview was desired. Work center corresponds to a physical location where all operations are performed before the product is transported to next process, and it was therefore considered as a suitable detailed level when analyzing the product-process relationship. As can be seen in Figure 9 there are almost no identical flows and the complexity of the process flow is high. For TOP ASSY, the same work center is recurring several times while manufacturing. One reason is that inspection will be performed after every operation step to verify the quality.

Process / Product	Object Manager	Kitting	Manual Assy Electr.	Mech. Measurement	Top Assy Inspection	Top Assy Test Eng.	Top Assy Acc. Test	Top Assy Test Eng.	Top Assy Acc. Test	Manual Assy Electr.	Top Assy Inspection	Top Assy QC	Manual Assy Electr.	Top Assy Acc. Test	Manual Assy Electr.	Top Assy Acc. Test	Manual Assy Electr.	Top Assy Inespection	Top Assy Acc. Test	Mech. Measurement	Top Assy Inpsection	Manual Assy Electr.	Top Assy QC	Object Manager	Manual Assy Electr.	Top Assy Inpsection	Manual Assy Electr.	Top Assy Inpsection	Top Assy QC	Object Manager
Product A.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X			X	X	X	X
Product A.2	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X			X
Product A.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X			X	X	X	X
Product A.4	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X		X	X	X	X	X	X			X	X	X	X
Product A.5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X			X
Product A.6	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X			X
Product A.7	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X			X
Product A.8	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X			X

Figure 9: P-P Matrix for TOP ASSY

5.3.3 Focus Interviews

With the information about volume share within each class and the product-process relationship, it was still not apparent which product that should be selected. To a large extent did the component on a lower hierarchy level with the biggest volume share belong to the parent on a higher hierarchy level with the biggest volume share as well. It was not always true however, complicating the selection of product family that would be representative. The P-P Matrix in the previous section indicates that there are almost no identical flows and handling procedures for the different part type, which implies that similar flows could not be grouped to simplify the mapping. The decision was done together with the same group of personnel involved in the initial interview part. Based on Pareto-diagram and P-P Matrix, the group should select either of two options:

1. Individually select the most representative, highest volume, part within each sub-assembly.
2. Select the most representative, highest volume, at the top level of the product structure as the parent unit and part at lower hierarchy level comes as a result of that decision.

The group recommended option number 2 and since product A.1 correspond to the highest volume according to figure 8, this was chosen as product for mapping.

5.4 Current State Mapping

Routing for product A.1 was extracted before initiating the mapping. This was done with the aim to have a solid understanding of the process flow when the mapping and the routing were on an operation level. Mapping was performed together with the personnel at workshop floor level, with one person representing each sub-function; assembly, environmental testing, inspection, product quality assurance and test. An example of one of the sub-flows is presented in figure 10. Each box represents an operation and the triangles represent storage in-between. There is an information arrow in the beginning of the flow, indicating a start of a manufacturing order. Information about an order and how the operations should be performed can be found in the ERP system.

Questions were also asked about data parameters that should be documented as a procedure of VSM and that will become data input for the simulation model. Data parameters of interest and identified from VSM were process time, cycle time, change over time, batch size, no. of operators, dedicated or shared resource, scrap rate, WIP, and transportation distances.

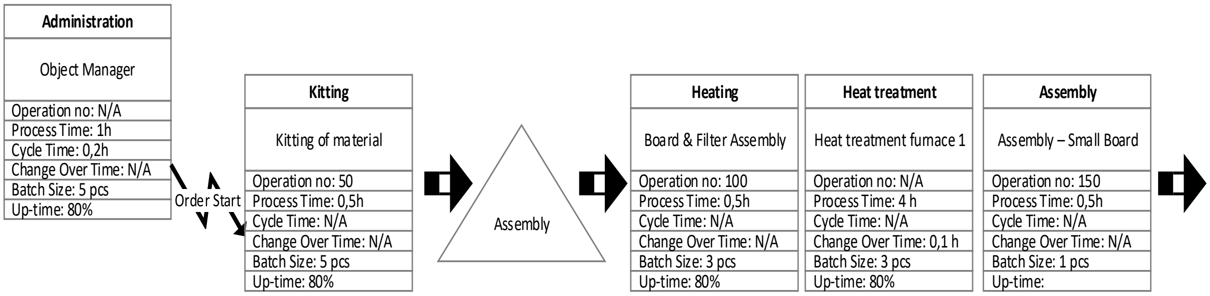

Figure 10: Example of current state map with data parameters for a sub-flow

5.5 Classification of Data

From mapping activities, available data were collected and documented in the data boxes as Figure 10 exemplifies. The final step was to classify the data parameters from Figure 10, according to the availability and the result is presented in Table 4. As can be seen in Table 4 there are data to all three categories. Category A data can be obtained directly from the data boxes for each process. Category B and C will, on the other hand, require more work implying measuring and estimating.

Table 4: Classified data in category A, B, or C and source for data

Data parameter	**A**	**B**	**C**	**Data source**
Process time (P/T)	X			ERP-system
Cycle time (C/T)	X			ERP-system; process time/batch size
Change over time		X		Measure with stopwatch or estimate
Batch size	X			ERP-system/Manufacturing order
No. of operators	X			Data from manager for the production segment
Scrap rate			X	Non-conformance report (NCR)
WIP			X	Manually count WIP in the value stream
Transport distance		X		Measure in either 2D-drawing or physically in the workshop

6 DISCUSSION

The intention of the study was to evaluate how VSM can support the data collection for a simulation model of a production system. It was believed that VSM with its benefits of visualizing value streams and collecting data directly from the workshop floor, would facilitate the data collection. VSM was supplemented with IVSM and VNM, to support data collection for a production system with non-linear and complex flows. To evaluate the availability of data in the production system, a final step was to classify the data into categories A, B or C depending on availability.

The case company has a complex production setup, with high variance and an engineer-to-order environment. Manufacturing of product A mainly implies manual and labor intensive work, with long cycle times. Previous knowledge about the production setup and data availability was limited, and therefore a suitable case for assessing the approach.

From the results, it becomes apparent that the selection of product family for mapping is not a straightforward procedure. Applying tools from IVSM and VNM could support this step, e.g. with the analysis of Pareto-diagram and P-P Matrix to statistically detect and motivate products which would be selected for further analysis. It was also seen from the result that this information was not enough for making a decision about product for mapping. Focus interviews with personnel from the organization had to support this step. This emphasizes the complexity of the organization and that analysis of data is not enough in this case for the selection.

The ability to visualize the flow before even start building the simulation model will provide valuable information for the model builder. It captures the sequence of processes in a straight line visualizing recurring operations in the same physical work center. The last step when categorizing the data provides important information about which data that already are available and which are not. With the understanding of the situation a strategy for complementing data can be planned.

7 CONCLUSIONS AND FUTURE WORK

VSM in combination with IVSM and VNM can support the initial data collection, and IVSM and VNM provide especially beneficial tools for the selection of product family. They derive data and facts about the current state that can facilitate selection of the most representative product for mapping. However, it was seen in this case that the tools analyzing secondary data were not enough. They had to be complemented with the knowledge of the organization. One suitable modification of the approach based on the result would be to include the focus interview as part of the approach. Classification of data as a last step, helps to identify data available and a strategy for the data that need to be either collected or estimated.

VSM is beneficial when in quest of a picture of the current situation, but it serves not the objective of providing dynamic data which is required for a DES. To convert static data to dynamic data has not been included in this study but will be the next step when building the simulation model. This will be a future work that is needed to complement this structured approach for collecting data for a simulation model.

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