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Combining factory simulation with value stream mapping: a critical discussion

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Abstract

Value Stream Mapping (VSM) is employed for the analysis of manufacturing processes. The VSM analysis leads to improve the process through the reduction of non-value added steps. The optimization is often verified by computer simulation (CS) before actual implementation in the factory. The two approaches imply a different underlying conceptual model of production: a deterministic flow of material against a stochastic queuing network. The authors discuss the critical issues, but show, with the help of an automotive case study, that they could produce positive outcomes if the goals are carefully chosen and if some rules of use are respected.

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Keywords: Value stream mapping; Discrete events simulation; Just in time

1. Introduction

Value Stream Mapping (VSM) is widely established in industry (Rother and Shook, 2003; Womack and Jones, 2002; Stadnicka and Antosz, 2013), particularly in the mass production sectors, like the automotive industry (Belokar at al., 2012; Palak and Sheth, 2014).

There are occurrences of the method in manufacturing processes (Rahani and al-Ashraf, 2012; Jeyaray et al., 2013; Grewal 2008; Singh and Sharma, 2009), in business processes (Teichgräber and de Bucourt, 2012) and in administrative ones (Joseph and Ronald, 2012).

The method helps to improve manufacturing processes (Gunaki and Teli, 2015), assembly processes (Kadam et al., 2012; Álvarez aet al., 2009), processes concerning product development (McManus and Millard, 2002; Hugh et al., 2002) etc.

Analyzing a value stream map it is possible to discover problems whose solutions can let the company achieve better results. Even if the solutions for the problems, which were discovered in Value Stream Analysis (VSA) is apparent, there is still the necessity to verify it against the actual production in the factory. It is a risky and expensive task that could be shortened by having recourse to computer simulation (CS). CS saves time and gives the possibility of having a deeper insight on the process performances. Examples of simulations implementation together with value stream analysis we can find in literature (Abdulmalek and Rajgopalb, 2007; Chukukere et al., 2014). However, the preparation of a model of a manufacturing system (MS), which will be analyzed in CS is also time consuming. That is why some authors question when we really need to simulate and if it is necessary.

An overlooked question is if the input data and the results of VSM and CS could be the same. In the following it is shown why the answer to the question is no and what should be done to make comparable both the inputs and the outputs.

The paper presents a case study in which a production flow of vulcanized sleeves is analyzed with the use of VSA and existing problems are identified. The improved MS was modelled by CS and the proposed modifications to the process are validated to make a deeper insight in the process on the base of results obtained from the simulations.

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Nomenclature

M_{CD}	monthly client demand [pcs/month]
T_W	working time a day [s/day]
T_B	break time [s/day]
IQ	inventory quantity [pcs]
D_{CD}	daily client demand [pcs/day]
R_{ON}	required number of operators

2. Building the VSM

VSM starts from mapping of the present state of MS, then improvements are proposed in order to eliminate non-value added activities and the results are presented in the future state map (FS). To develop the current state map it is necessary to gather information concerning client orders, shipment frequency and quantity, processes involved in products manufacturing, processes' cycle times (CTs), changeover times (COs), number of operators, materials deliveries' frequency and quantity, inventories' quantity and places, working time, problems existing in MS. Table 1 presents and discuss the necessary data to build VSM.

Table 1. Definition of the variables necessary to build the VSM model (par=parameter, in=input, out=output).

Variable	Unit	Type	Definition
Sequence of processes		par	material flow, can be in parallel or in series.
Size of batch	[pcs]	In	Number of pieces which go through a process together
Operators per process		In	Number of operators performing each process
Average Cycle Time (CT) for each process	[s]	In	Time elapsed for one product from the entry to the exit, see Table 2
Average Changeover time (CO) for each process	[s]	In	time needed to make a workstation ready to perform another manufacturing process.
Available working time (A_{WT}) on each workstation	[s]	In	normal working time minus planned breaks
Availability of a workstation (a machine)	[s]	In	percentage of time in which a workstation can be utilized for manufacturing
Number of working days in a month (N_{WDM})		In	Average number of working days in a month
Number of shifts for each workstation		In	Number of shifts for each workstation can be different
Number of products ordered by customers		In	Average number
Number of products in a shipment		Par	Average number, product dependent
Frequency of shipments	[1/s]	Out	Average number
Frequency of deliveries	[1/s]	Par	Needed for each supplier
Processing time (*PT*)	[s]	Out	Time needed to perform a process
Inventory lead time (*ILT*)	[s]	Out	How long a product has to wait in inventory before being processed.
Lead time (*LT*)	[s]	Out	time from entry to exit into MS.
Takt time (*TT*)	[s]	Out	Average time between unit productions, when production starts are set to match the rate of customer demand.

The calculation of the VSM variables is performed by using the following relations:

$$D_{CD} = \frac{M_{CD}}{N_{WDM}}, \quad (1)$$

$$A_{WT} = T_W - T_B, \quad (2)$$

$$PT = \sum_{i=1}^{n} CT_i, \quad (3)$$

$$ILT = \frac{IQ}{D_{CD}}, \quad (4)$$

$$LT = PT + \sum_{j=1}^{n} ILT_j, \quad (5)$$

$$TT = \frac{A_{WT}}{C_D} \quad (6)$$

$$R_{ON} = \frac{PT}{TT} \quad (7)$$

The analysis highlights bottleneck workstations, excessive inventory levels and unnecessary frequent shipments.

Then, it should be analysed whether the MS is balanced. If possible, the flow should be improved, otherwise Just in Time with supermarkets and Kanban cards can be introduced to decrease the size of inventories.

3. Building the CS

Computer simulation of the product flow is a common design strategy used before launching a new production line (Gershwin, 1989). The most frequent simulation method, used to describe production processes, is Discrete Event Simulation (DES), that is numerical solution of queueing networks. The main benefits of DES are the understanding of the system behavior before building it, the discovery of unexpected nonconformities, the possibility of investigating different uses of case scenarios (Kellner et al., 1999). The main drawback is related to the extent to which the simulation can be made compatible with the current system.

This drawback is particularly significant when DES is applied to a process model described by VSM. The goals of the two methods are different, and that is reflected in the kind of data collected by VSM which are different from the data needed by DES. The main difference is the use of stochastic variables. In order to build a DES the variables described in Table 2 are necessary.

Table 2. Definition of the variables necessary to build the DES model and whether they can found in the VSM.

Concept	Attribute	Values	VSM
Process			
	Action	Seize / Delay / release	Y
	Delay time	Probability distribution	-
	Resource seized	Type and number	Y
Resources	Type	Machine / Operator	Y
	Number		Y
	Processing	batch size	Y
	Initial state	Busy / Idle	-
	Failure	MTBF / MTTR	-
Entity	Type	Item / Tote / Pallet	Y
	Arrival rate	Probability distribution / schedule	-
	Travel	batch size	Y
Queue	Type of Entity	-	Y
	Queue size	-	Y
	Service discipline	FIFO / LIFO / priority rules	-
Clock			
	Total time	Total simulation time	Y
	Event list	Schedule	-

Nevertheless, there are several examples of simulations applied to VSM (Abdulmalek and Rajgopalb, 2007, De Carlo et al., 2013). Obviously, it is necessary to acquire additional datasets with respect to the data provided by VSM. As an example, VSM reports the average arrival rate of items, while DES needs the schedule of each arrival (or the probability distribution).

The goal of the study is to show as CS uses different sets of data and produces different outputs. Many results are common between the two analysis but there are some significant differences. Whenever CS is used to verify the FS of a VSM, using the same data of VSM it will probably replicate the same results. If additional data are added, like machine failures or process time variability, CS will produce other outputs that could give a different viewpoint on the process. It must be noted otherwise that the kind of additional data, required to perform a more faithful simulation of the process, are not easy to find, as FS is referring to a proposed new production organization that is at the moment only on paper.

4. Discussion

VSM aims at identifying three types of activities in the production flow: 1-non value added; 2-necessary but non value added; 3-value added. There are seven sources of waste: overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion, defects (Hines and Rich, 1997). The rationale is to eliminate 1 and to shorten the time spent by 2, or even reorganize the flow in order to avoid the necessity of type 2 activities. The activities are tagged by their LT.

The effectiveness of VSM relies on its usual application to nearly deterministic production processes, as happens in the large automotive assembly plants. Indeed, VSM was originated in Toyota as part of the Toyota Production System. In a deterministic process, buffers do not increase the throughput but obviously increase the WIP that is linked to non-value added activities. Frequently, the strategy proposed by VSM analysts to generate the FS is the introduction of Just in Time (JIT) strategy, with the use of supermarkets to put a limit threshold for the inventory levels. This strategy is effective if the production is deterministic or little variable. In presence of large variability, the strategy could still work if the plant capacity is far from saturation.

The buffers that are seen by VSM as non-value added activity become necessary to contrast the variability due to randomness. Among the most typical variability sources are CT randomness of manual processes, demand variability and pre-emptive outages: machine failure, consumables shortage, power outages.

If buffers are allowed in the production, variability leads to increasing the time in queue, ILT. Conversely, if buffer size is capped, variability will affect directly the throughput.

The design of a production line is a problem of resource allocation. This assertion explains why DES is frequently employed as a design support tool.

The design of a production line should be based on the optimization of several performance measures. The most used performance measures are: the throughput, the average inventory level in buffers (queue length and staytime), the lead times. All of them can be calculated both with VSM or DES. Additional performance measures are: utilization rate of machines, starving time for the machines downstream to the bottleneck machine and blocking time and probability for the upstream machines, starving and blocking times after machine failures. These latter measures can only be calculated by DES but require several more data to be obtained.

In the following section, VSM and CS are applied to a case study to highlight the added value of each tool and conversely the arguments of disagreement. VSM is generated with Microsoft Visio Professional, while CS is implemented in FlexSim^{TM}.

5. Application to the case study

The case study is a Polish company that produce rubber-metal sleeves for the automotive market (better known as silent-blocks). The process consists in the surface treatment of the inner and the outer sleeve and in their joining during the vulcanization of the rubber filler (Stadnicka, 2015).

Orders are stable and well below the plant capacity. The orders are loaded on the supplier's MRP system (SAP). The production orders are generated monthly, and the weekly orders or shift orders go to each work stand.

Products are delivered in containers of 2,000 pcs. Sleeves are shipped once a week. The customer sends a monthly forecast and a weekly order. Materials needed for manufacturing are delivered from an internal supplier.

In Table 3 the list of processes is presented. The collected input data are reported in Table 4.

Large inventories are present before degreasing processes (DIS, DES), vulcanization (VLC) and adhesive testing (AT) as they are usually slower than the upstream processes. TT is calculate from the equation (6). The calculations gives TT equals to 98 sec. CT is lower than TT for all the processes, the maximum value is VLC with 34.6 CT. Wastes are operators waiting for work, processes stoppage, materials waiting to be processed and products waiting to be shipped to a customer.

Table 3. List of manufacturing processes in the sleeve production.

Symbol	Process	Additional data
DIS	Degreasing of internal sleeve	Automatic process
SIS	Sand-blasting of internal sleeve	Automatic process
PIS	Phosphatizing of internal sleeve	Automatic process
AIS	Adhesive coating of internal sleeve	Automatic process.
DES	Degreasing of intermediate sleeve	Automatic process
SES	Sand-blasting of intermediate sleeve	Automatic process
PES	Phosphatizing of intermediate sleeve	Automatic process
AES	Adhesive coating of intermediate sleeve	Automatic process
BM	Building of the mixture	Manual process
VLC	Vulcanization	Semi-automatic process
AT	Adhesion testing	Mechanized process
SP	Shipment	Ready for shipment

Table 4. Variables concerning processes and operators for use in VSM.

Symbol	*CT* [s]	CT_{batch} [s]	LT [s]	*CO* [h]	R_{ON}
DIS	6	2 544	2 544	0	1
SIS	5.4	2 290	2 290	0	1
PIS	11.4	4 766	4 766	0	1
AIS	8.11	3 408	48.7	1.5-2	2
DES	5	2 124	2 124	0	1
SES	9.8	4 090	4 090	0	1
PES	11.4	4 766	4 766	0	1
AES	4.91	2 062	343.7	1.5-2	1
BM					
VLC	34.6	1 248	1 248	8	2
AT	12.2	439.2	439.2	0.25	1

The flow of material during sleeve manufacturing is described in Fig. 3 as a CS map. From the CS it is possible to identify several problems: underuse of plants, very large WIP, long queues and queue times, VLC bottleneck machine much slower than other machines making the line unbalanced, long COs measured in adhesive coating processes (AIS, AES) and in VLC, eventually wrong workload assignment.

The design constraints for the optimization are to reuse the same machines and accomodate demand increases.

To decrease inventories and to improve the productive flow, FS map is proposed (Fig. 4). DIS and DES are produced on the same work stand as both of them have a low utilization level. This change is admissible because changeover is not needed to process DIS or DES. Additionally, CTs are the same for both, internal and intermediate sleeves.

Similar situation occurs between SIS and SES as well as between PIS and PES. AIS and AES are executed on separate machines because of different processes. The most important improvement in FS is the adoption of supermarkets with Kanban cards and FIFO lanes to decrease inventories. The VSM allows to make an estimate of the new LT by calculating a reduction from 116.6 days to 13.31 days.

6. Verification of the FS through CS

The simulation of the process needs data that are not known and not available as the FS is still in the proposal stage.

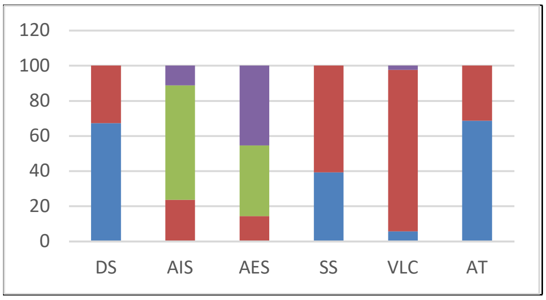

Fig. 1. Staytime on selected machines.

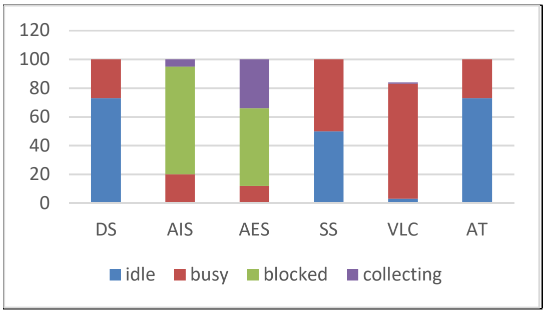

Fig. 2. Staytime on selected machines in presence of VLC failures.

It is possible to assume the same time distributions as in actual production and that the plant is working to its maximum throughput. Time distributions are assumed as exponential. Experiment is executed by introducing in the model the possibility of preemptive outage in the VLC.

The goal of present experiment is to show how much performances are degraded in a JIT production system with an increase of variability. As variability source it has been chosen a failure of the bottleneck machine (VLC). Performance measures are reported in Fig. 1 and 2 for the most significant machines. The blocked time for AIS and the starving time for AT show a large increase.

7. Conclusions

VSM analysis allows to identify the management problems due to an excess of non-value added activities and to long LT. The proposed FS map presents many great improvements and is estimated to optimize most of the performance measures. Simulation need additional, unavailable data but provides a different analysis, showing that the new work organization could become, not only sub optimal, but even worse than the actual process. The conclusion is that CS should be combined with VSM not so much for verification as for sake of a different picture of the investigated MS.

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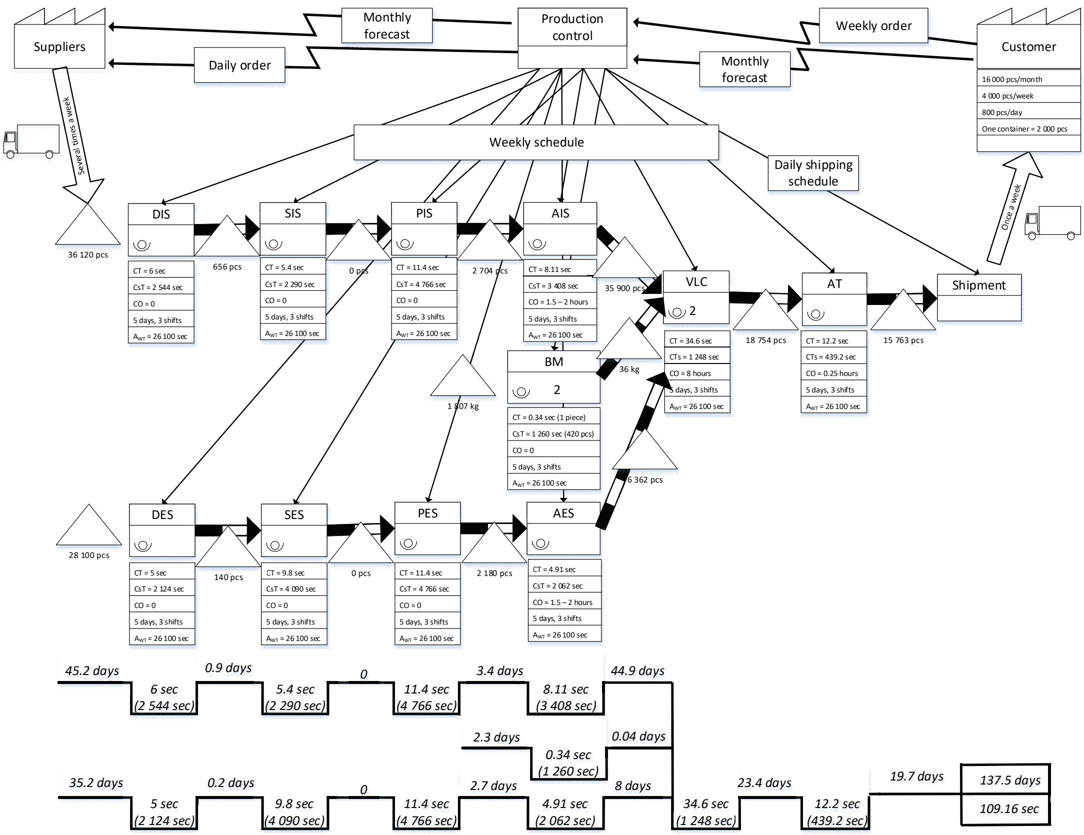

Fig. 3. Current State - VSM.

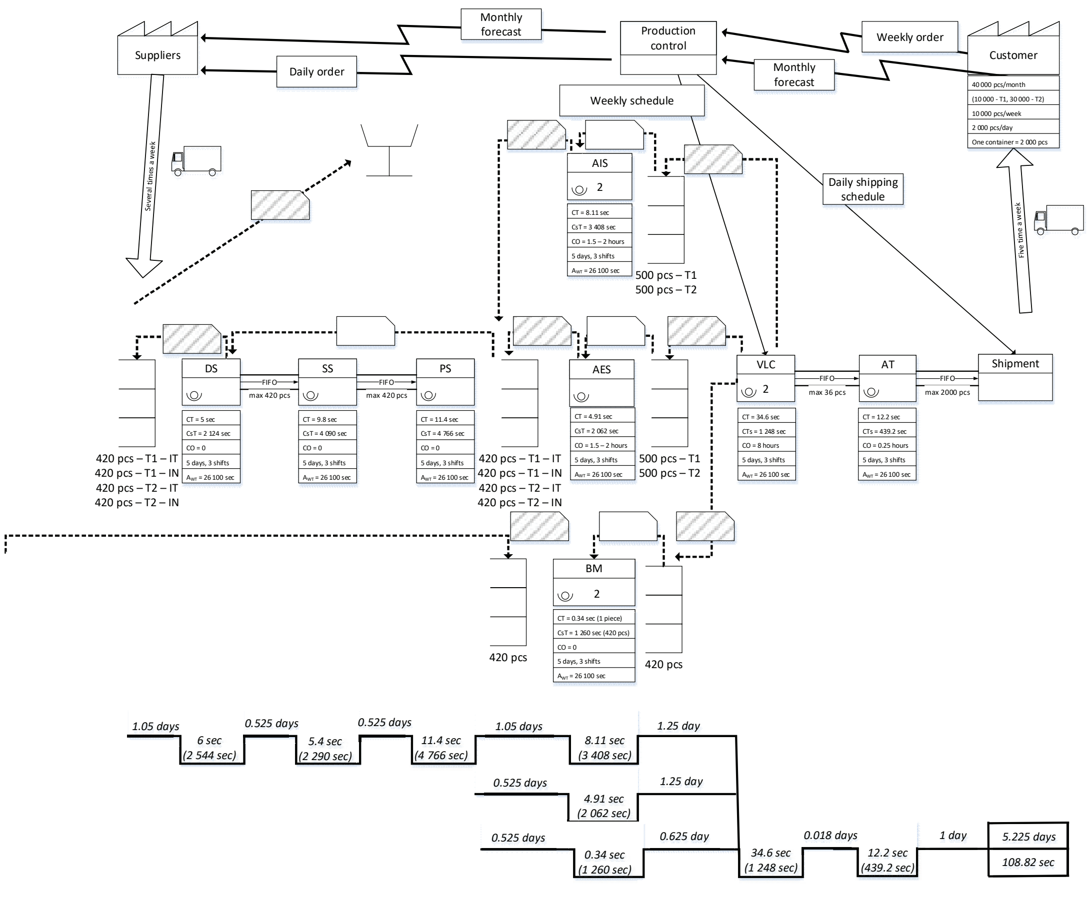

Fig. 4. Future state - VSM.