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Application of Value Stream Mapping and Possibilities of Manufacturing Processes Simulations in Automotive Industry

Value Stream Mapping (VSM) is a commonly assessed method employed for the analysis of manufacturing processes. The principal asset of the method is its ability to identify wastes. Adopting lean manufacturing and lean management rules it is possible to eliminate such wastes. In the paper the case study of a manufacturing process of sleeves is presented. The current value stream map (CSM) and the future value stream map (FSM) of the sleeve manufacturing process are used. They are investigated with the help of Value Stream Analysis (VSA) that assists the process designer in identification and elimination of wastes. However, the authors think that, in order to take into account all the outcomes of the VSM, the analysis should be assisted by complementary tools such as computer simulations (CSs). CSs were implemented to analyse the data concerning a manufacturing process of the sleeve in order to use the results of VSA.

Keywords: *Manufacturing Processes, Wastes Elimination, VSM, VSA, Discrete Events Simulation.*

1. INTRODUCTION

Value Stream Mapping (VSM) is a method well assessed, together with all the tools used in value stream improvement [1, 2]. The method has been used in industry for many years [3], especially in the automotive industry [4, 5]. However, one can also find examples of VSM implementation e.g. in emergency room [6] or in the service sector [7].

The method can be implemented for manufacturing processes (MPs) [8,9,10,11], as well as for business [12] and administrative processes [13]. The implementation of the method in various groups of processes involves a few different ways of value stream implementation.

The method helps to improve manufacturing processes [14], assembly processes [15,16], processes concerning product development [17, 18] etc.

The main goal of VSM implementation is the waste identification and value stream improvement. In order to develop the value stream it is recommended to follow a set of rules [1]. These rules indicate different lean tools [19] which can be used to eliminate or at least decrease wastes in the value stream. While analysing a value stream map it is possible to identify problems to which the solution may allow the company to achieve better results. Sometimes the solution for the problems, which were discovered in the Value Stream Analysis (VSA), is apparent. Sometimes it is not so obvious which solutions are suitable in order to ensure the best performance. In such cases, it is helpful to carry out an additional analysis, namely the computer simulations (CSs). CS saves time and gives the possibility of having a deeper insight into the process performance. Examples of the simulations implementation, together with the value stream analysis, can be found in literature [20, 21]. However, preparing a model of a manufacturing system (MS) which will be analysed in CSs is also time consuming. That is why, the question is when we really need to carry out the simulations, and when it still is not necessary.

The paper presents a case study in which the production flow of a sleeve covered by rubber (vulcanized) is analysed with the use of VSA. The discovered problems are solved with the lean tools and suggested improvements. Then, the MS is modelled with the use of FlexSimTM program used in simulations. The solutions proposed in FSM are used in CSs. The authors try to answer the questions: whether the planned results can be achieved and whether the simulation was really necessary in the case.

The authors attempt to answer the question when it is useful to adopt CSs, assess time consumption as well as the question of which cases CSs can add value to the analysis.

2. METHODS OF VSM AND VSA

VSM used in MS analyses uses standard symbols to present elements of MS as well as the standard rules of VSA, described in literature [1].

VSM is implemented for a product family, which is a group of products that go through similar MP and over common equipment in downstream processes.

In order to develop CSM it is necessary to gather information concerning the client's demands, shipment quantity and frequency, processes engaged in products manufacturing, cycle times (*CT*s) of processes, which give information on how often the products are

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completed by processes; changeover times (*CO*s), the number of operators, materials delivery quantity and frequency, the quantity and places of inventories, working time, problems such as quality problems, machine failures and shutdowns, etc.

In VSA it is recommended to perform such calculations as the calculation of a daily client's demand (D_{CD}) – equation (1); available working time (A_{WT}) – equation (2); processing time (PT) – equation (3); inventory lead times (ILTs) – equation (4); manufacturing processes lead time (LT) – equation (5); takt time (TT) – equation (6); a required number of operators (R_{ON}) – equation (7).

$$D_{CD} = \frac{M_{CD}}{N_{WDM}}, \tag{1}$$

where: M_{CD} – monthly client demand [pcs/month], N_{WDM} – number of working days in a month [days/month].

$$A_{WT} = T_W - T_B, \tag{2}$$

where: T_W – working time a day [sec/day], T_B – break time [sec/day].

$$PT = \sum_{i=1}^{n} CT_i, \tag{3}$$

where: CT – cycle time [sec], n – a number of manufacturing processes.

$$ILT = \frac{IQ}{D_{CD}}, \tag{4}$$

where: IQ – inventory quantity [pcs], D_{CD} – daily client demand [pcs/day].

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

where: PT – processing time [days], ILT – inventory lead time [days], n – number of inventory kinds.

$$TT = \frac{A_{WT}}{C_D}, \tag{6}$$

where: A_{WT} – available working time [sec/day], D_{CD} – daily client’s demand [pcs/day].

$$R_{ON} = \frac{PT}{TT}, \tag{7}$$

where: R_{ON} – required number of operators, PT – processing time [sec], TT – tact time [sec].

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 implemented, in other case the Just in Time system with supermarkets and Kanban cards can be introduced to decrease the amount of inventories.

All the proposed improvements are collected and implemented in the FSM.

3. COMPUTER SIMULATIONS OF MANUFACTURING PROCESSES

Computer simulation of the product flow is a common design strategy used before launching a new production line [22]. The most frequently used simulation method is Discrete Event Simulation (DES) of the production, described as a queueing network. 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 [23]. The main drawback is obviously 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. VSM aims at identifying the unnecessary processes (with no added value) and tasks with average cycle times, while DES focuses on the queueing network and, therefore, requires cycle times distribution and interarrival times distribution. Nevertheless, there are several examples of simulations applied to VSM, especially in order to verify the outcomes of FSM [20, 24]. Obviously, it is necessary to acquire additional datasets with respect to the data provided by VSM.

The goal of the study was to analyse the CSM of the sleeves manufacturing process, to identify the existing wastes, to analyse the problems as well as the present suggestions for a value stream development on FSM.

In the research it was decided to apply VSM, VSA and CSs in order to see the added value of each tool. CSM and FSM are generated with Microsoft Visio Professional, while FlexSim^{TM} is employed for CSs.

4. SLEEVES’ MANUFACTURING

Rubber-metal sleeves (**Figure 1**) are an assembly element for a car frame (commonly named silent-blocks). The product is delivered to customer in two shapes. Orders are stable. A monthly customer's order amounts to 16,000 pcs equally divided between two types.

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. The containers are returnable. 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 i.e. another department in the factory. The supplier delivers internal and intermediate sleeves a few times a week.

The daily customer's demand (D_{CD}) can be calculated from equation (1) and it equals 800 pcs/day.

The company works 20 days per month, 5 days per week, 3 shifts per day and 8 hours per shift.

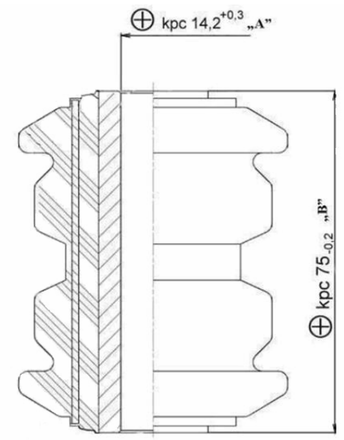

Figure 1. Section of a rubber-metal sleeve, type ZE1

Manufacturing of the sleeve consists of the processes presented in **Table 1**.

Table 1. Manufacturing processes realized in sleeves production

Process	Goal of the process
Degreasing	Degreasing of metal parts which can be made on a vibratory feeder. The process consists of the following operations: removing impurities, washing, drying.
Sand-blasting	The process aims at the surface cleaning with the use of abrasive material or at the surface forming by abrasive actions or grinding.
Phosphatizing	Chemical treatment to protect the product surface from corrosion. After the process the surface is prepared for adhesive coating.
Adhesive coating	Adhesive is warmed. The filings are eliminated in the machine.
Vulcanization	In the process metal elements are glued with rubber elements. 36 pieces can be in the process at the same time. The last operation of the process is products marking. Each product is marked with a blue dot.
Adhesion testing	Rubber adhesion is tested.
Control and Packing	The products are 100% visually controlled. Next, the products are packed to special containers according to the customer's requirements.
Shipment	Shipment to a customer is realized once a week. For shipments FIFO is applied.

The product consists of two metal elements (internal sleeve and intermediate sleeve). They are treated in different processes. Data concerning the processes are presented in **Table 2**, **Table 3** and **Table 4**. The number of operators on the production line is 12. The workflow is presented in **Figure 2**.

The inventory in time units (ILT) have been calculated from equation (4).

The full CSM visible in the whole MS and in the warehouse, as well as *ILT*s are presented in **Figure 3**.

Table 2. Manufacturing processes of internal and intermediate sleeves and additional data concerning the processes

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	Partly automatic and partly manual process
AT	Adhesion testing	Mechanized process
SP	Shipment	Inventory of products ready for shipment

Table 3. Times concerning manufacturing processes and number of operators

Symbol	Cycle time for one piece *CT* [sec]	Cycle time for a batch *CTs* [sec]	Lead time of the process [sec]	Setup time *CO* [h]	Number of operator N_o
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
VLC	34.6	1 248	1 248	8	2
AT	12.2	439.2	439.2	0.25	1
Accessibility of all work stands is 100%,					

Table 4. Size of batches in sleeves manufacturing line

Symbol	Size of a transportation batch to the process [pcs]	Size of a transportation batch after the process [pcs]	Number of pieces in the process at the same time
DIS	420	420	420
SIS	420	420	420
PIS	420	420	420
AIS	420	36	6
DES	420	420	420
SES	420	420	420
PES	420	420	420
AES	420	70	70
VLC	36	36	36
AT	36	36	1

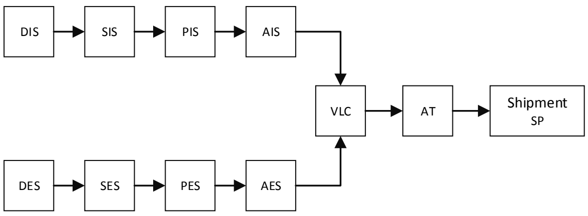

Figure 2. Workflow

We can see huge inventories before degreasing processes (DIS, DES), vulcanization (VLC) and adhesive testing (AT). It means that these processes are usually slower than the upstream processes.

5. ANALYSIS OF CURRENT STATE AND PROBLEMS IDENTIFICATION

In order to identify problems in the current state of a value stream, first of all, it is necessary to calculate *TT* from the equation (6). The calculations are presented in equation (8).

$$TT = \frac{3\ \text{shifts/day} \cdot 26\,100\ \text{sec/shift}}{800\ \text{pcs/day}} = 98\ \text{sec}/\ pcs \tag{8}$$

We already know that *TT* equals 98 sec. We can compare *CT*s of MPs in order to assess if a bottleneck process exists in the production line. The analysis of cycle times for the analysed case is presented in **Figure 4**.

On the basis of the performed time analysis it can be said that there are no undersized processes and the company shouldn't have any problems with deliveries to a customer, because the *TT* (*TT* = 98 sec) is much higher than *CT*s of the processes. Furthermore, the utilization rate (UR) of the processes is very low. In this situation the company could probably increase the production rate safely.

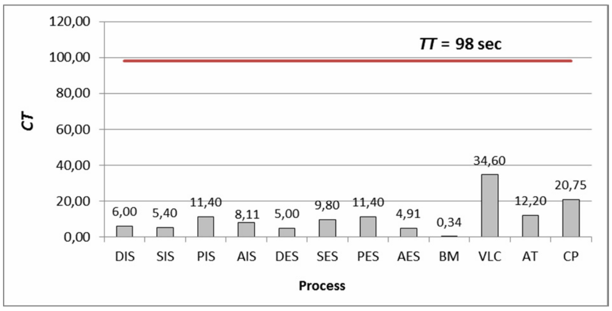

Figure 4. Analysis of cycle times

From VSM it is apparent that the manufacturing line is not balanced. VLC process takes much more time than other processes. This is the slowest process in the MS and it decreases a throughput rate (TR).

The required number of operators for the line (R_{ON}) can be calculated from equation (7) in 1.32, i.e. 2 operators.

In the current situation it would be enough to engage 2 operators to perform the work on the production line. We observe different kinds of wastes such as operators waiting for work, processes stoppage while waiting for semi-products, materials waiting to be processed and products waiting to be shipped to a customer. We also see long COs in the adhesive coating processes (AIS, AES) and in VLC.

In order to decrease inventories and to improve the flow in MS a FSM was proposed. It is presented in **Figure 5**. It was decided to produce DIS and DES on one work stand only as both have a low utilization level. It is possible because a changeover is not needed while the production changes from DIS to DES.

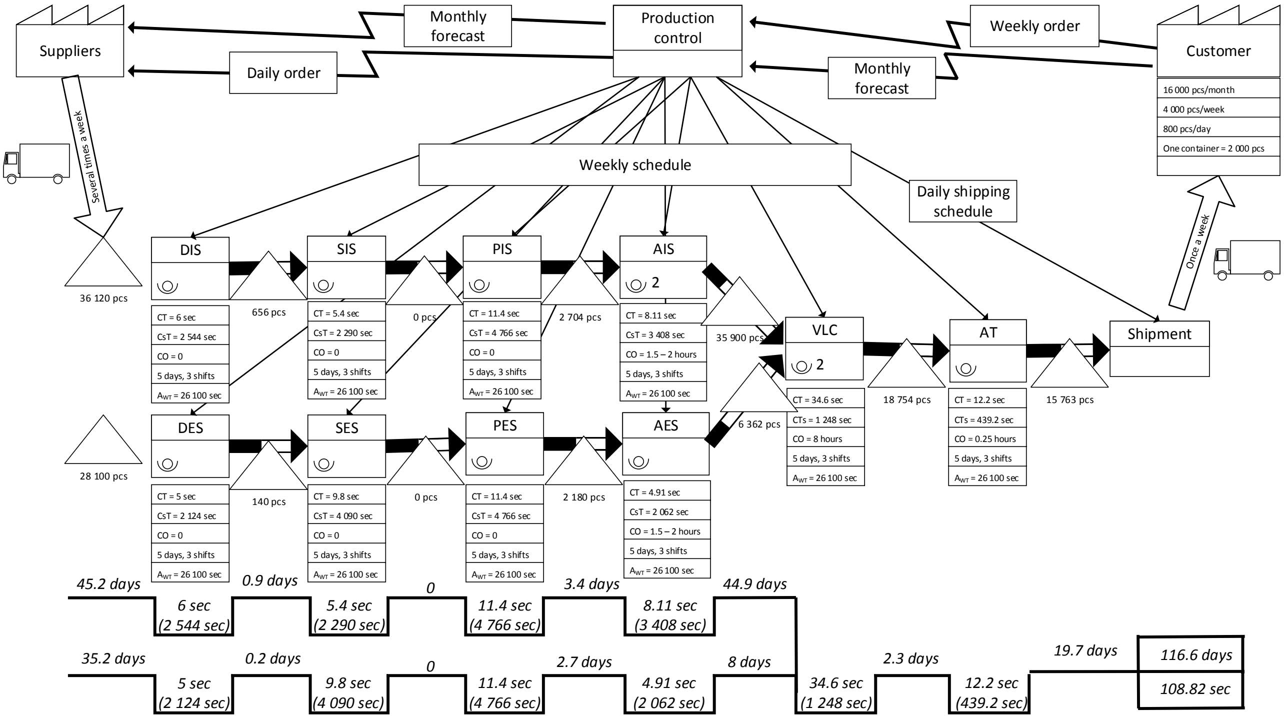

Figure 3. Current state map

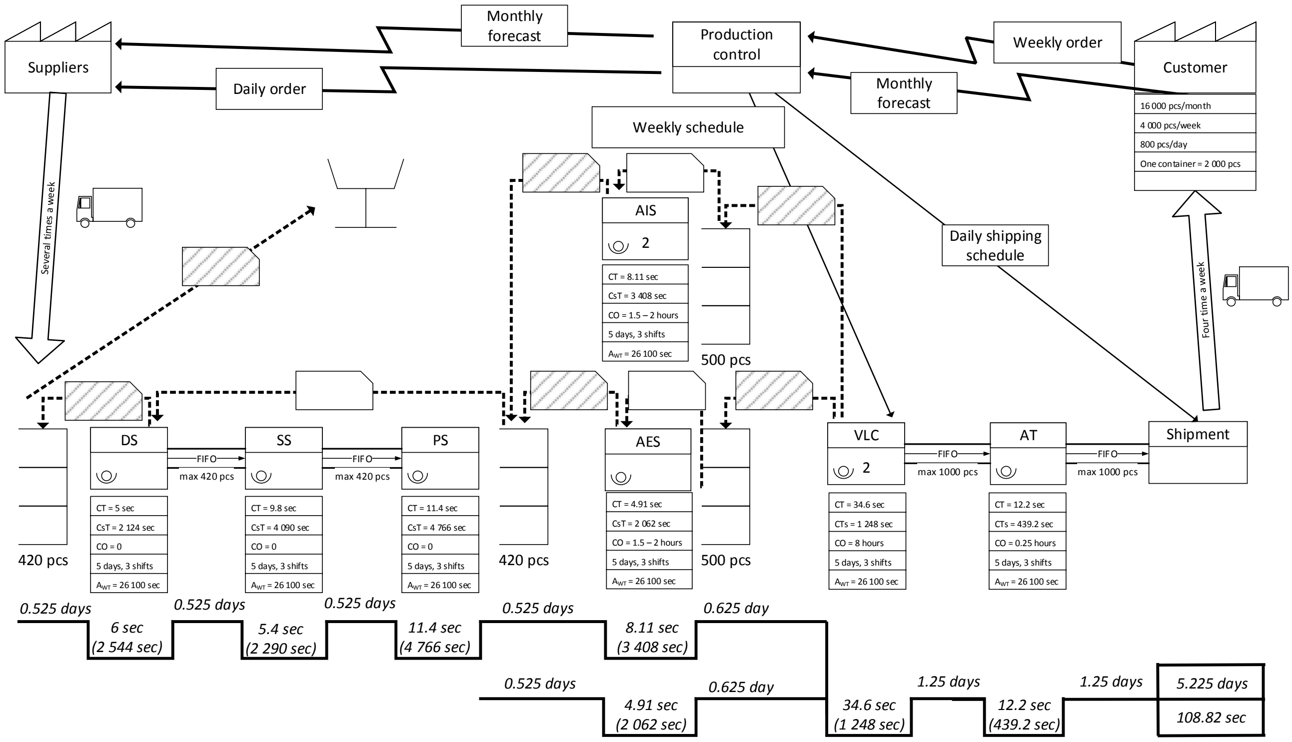

Figure 5. Future state map

Additionally, *CT*s are the same for both, internal and intermediate sleeves. The similar situation occurs between SIS and SES as well as between PIS and PES. However, *CT* of SES is almost as twice long as *CT* of SIS. AIS and AES have to be realized on different machines because the processes for internal sleeves and intermediate sleeves are different, and adhesive coating process of both can't be realized on the same machine – not on any of the existing machines. In the FSM it is also proposed to implement supermarkets with Kanban cards and FIFO lanes in order to decrease inventories. After the implementation of the solutions presented in FSM, it will be possible to decrease *LT* of the production process. In CSM *LT* equals 116.6 days, while in FSM it is only 13.31 days.

6. GENERAL DISCUSSION

VSA 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 [19].

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 *LT* could be the time allotted for the processing by managers or the actual average time measured in practice.

As VSM was originally applied to the factories that followed the Toyota Production System paradigm, the choice of not considering the process variability but only the mean time was not seen as a vice. Toyota Production System aims at eliminating every source of variability as the main cause of Muda.

Nevertheless, the large success of VSM extended its application to many small and medium enterprises as well as to several production and services sectors, where Toyota Production System cannot be applied directly. This is the case of the present enterprise.

In order to correctly estimate the amount of non-value added time, in the presence of variable process times, it is necessary to calculate the average waiting time on a line. The queueing theory, for a Markovian process with Markovian arrivals, and a First in First out (FIFO) queue policy says that the average time in a queue t_{queue} is calculated from equation (9).

$$t_{queue}(M/M/1) = \frac{UR}{1-UR} \cdot t_e \qquad (9)$$

where:
t_e is the effective mean process time.

It is clear that the time wasted in a queue is not a function of the mean process time only, but it strongly depends on UR. When UR approaches the unity, the time in a queue tends toward infinity.

Therefore, in a real factory producing small batches with a changing demand volume, the queue time is not constant but it increases nonlinearly with the demand growth. This effect could be overlooked by VSM. The increase in the demand is observed only in terms of the reduced takt time (*TT*). Because of queue explosion it is possible that the production cannot meet the demand even if *CT* is well below *TT*.

Let us assume that we are not able to eliminate all the queues before the processes. If this is the case, VSM would yield misleading recommendations unless not supported by a classic process simulation by the means of a queueing theory.

7. COMPUTER SIMULATIONS OF PRODUCTION LINE WORKING

In the present case study the process is simulated with exponential process time distribution, neglecting the time increase due to preemptive outages.

On the basis of the data gathered from MS and presented in previous tables, the model of MS was developed.

Then the simulation of work for the current state (CS) and future state (FS) was performed. The simulation covers one week. The experiment was conducted by assuming different scenarios with the increasing arrival rate of raw materials. In the first scenario, S1, the arrival rate is equal to the observed rate, in the fourth scenario, S4, the rate is quadrupled, as shown in **Figure 6**.

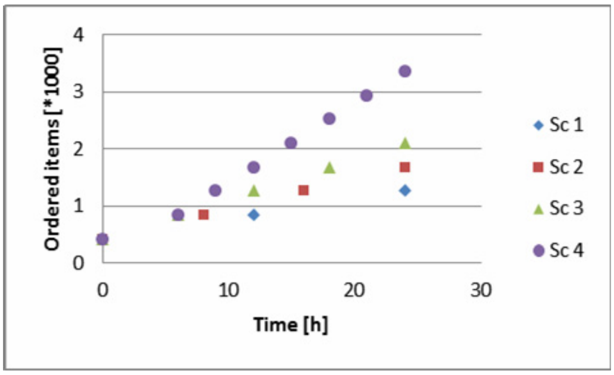

Figure 6. Cumulative production orders vs. time for four different scenarios

The model of a production line is presented in **Figure 7** and the simulations results are presented in **Tables 5-11**.

It is possible to show how the arrival rate influences Work In Progress (WIP), throughput rate (TR) and utilization rate (UR) of the vulcanization workstation in the different scenarios.

The forth scenario deliberately stresses the production line above its capacity. In S4, VLC has an UR equal to 1 and, therefore, WIP explodes, while TR is bounded to the bottleneck rate, i.e. VLC's capacity.

Table 5. WIP [pcs] – CS

	Mean (90% Confidence)					Sample Std Dev	Min	Max
S1	2327	<	2330	<	2332	8.1	2316	2350
S2	2609	<	2612	<	2614	8.9	2599	2633
S3	4352	<	4360	<	4369	28	4320	4424
S4	16969	<	16977	<	16985	25	16941	17033

Table 6. WIP [pcs] – FS

	Mean (90% Confidence)					Sample Std Dev	Min	Max
S1	2906	<	2908	<	2910	6.5	2901	2934
S2	2714	<	2716	<	2719	8.7	2701	2742
S3	4708	<	4717	<	4726	28	4685	4814
S4	17121	<	17132	<	17142	34	17080	17230

From **Tables 5** and **Tables 6** we can draw conclusions that WIP in CS and FS are similar in each simulation (**Figure 8**). This is counterintuitivebecause in FS most inventories are strictly bounded to contain 1 batch.

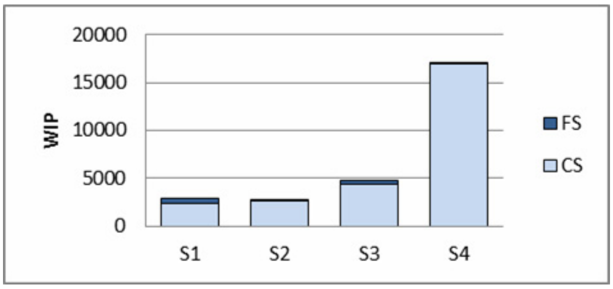

Figure 8. Graphical comparison of WIP in the 4 scenarios between CS and FS

The reason is that the inventories in the internal and intermediate sleeve production line are hardly ever used as the UR of the corresponding workstations is very low and, therefore, only the inventories supplyingthe VLC are actually used.

TR is the same in all simulations in both cases (CS and FS) (**Figure 9**), and in the last two scenarios it is saturated to the bottleneck rate that is 105 items/hour.

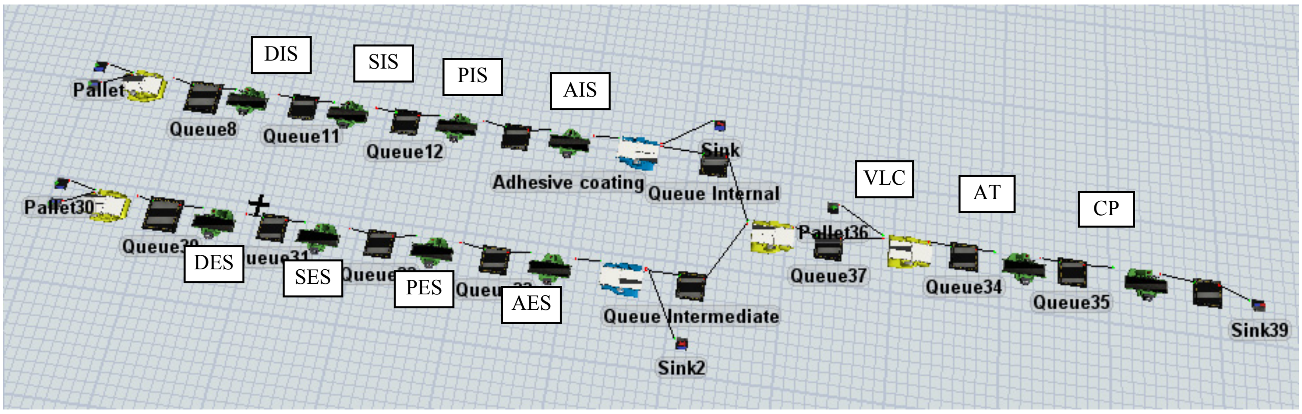

Figure 7. A model of production line in FlexSim

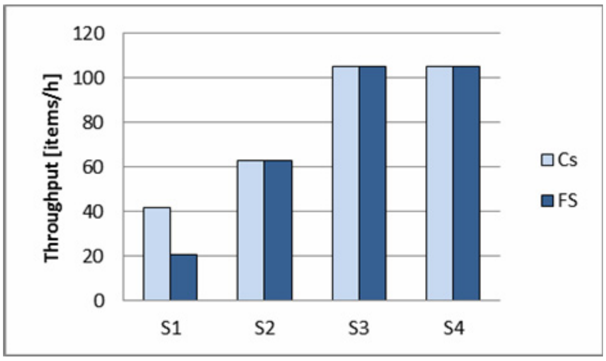

Figure 9. Graphical comparison of TR in the 4 scenarios S1-S4 between CS and FS

Table 7. *LT* [ks] – CS

	Mean (90% Confidence)					Sample Std Dev	Min	Max
S1	119.8	<	120	<	120	0.60	18.8	121
S2	92.2	<	92.3	<	92.4	0.43	91.5	93.3
S3	104	<	104	<	104	0.95	103	106
S4	337	<	338	<	338	1.06	333	340

Table 8. *LT* [ks] – FS

	Mean (90% Confidence)					Sample Std Dev	Min	Max
S1	169.8	<	170.1	<	170.3	0.8	168.9	172.8
S2	97.8	<	97.9	<	98.0	0.3	97	99
S3	110	<	111	<	111	1.0	110	115
S4	180	<	181	<	181	1.0	179	183

Table 9. UR of VLC machine [%] – CSM

	Mean (90% Confidence)					Sample Std Dev	Min	Max
S1	38.4	<	38.52	<	38.55	0.099	38.33	38.62
S2	55.8	<	55.96	<	56.04	0.257	55.31	56.58
S3	N/A	<	100.00	<	N/A	0.00	100.00	100.00
S4	N/A	<	100.00	<	N/A	0.00	100.00	100.00

Table 10. UR of VLC machine [%] – FSM

	Mean (90% Confidence)					Sample Std Dev	Min	Max
S1	N/A	<	34.57	<	N/A	0.00	34.57	34.57
S2	55.81	<	55.87	<	55.9	0.21	55.43	56.35
S3	98.9	<	98.93	<	99.0	0.25	98.11	99.40
S4	N/A	<	100.00	<	N/A	0.00	100.00	100.00

Analysing the data from **Table 7** and **Table 8** we can realize how large is LT in each simulation. FS always shows larger *LT* than CS. This is expected as the number of parallel lines has been reduced. The increase is not as high as to worry about system stability, and the advantages in the reduction of non-necessary machines outweigh it. This is a kind of information that can increase the insight about the system, helping VSA. In the scenario 4 the line is blocked. The kanban based management of FS results in a consistent LT cutback with respect to the CS.

The simulation allows us also to obtain the data concerning URs of machines. As we know from VSA, the slowest process is VLC. That is why, the data concerning these processes are analysed. UR of VLC machine is presented in **Table 9**, while FS is showed in **Table 10**. In FS, UR is slightly better than in CS. Namely, in S3 the workstation has not yet reached the full utilization, avoiding the concurrent blocking of the upstream line; while in the CS blocking has already occurred. The reason is that the supplyingstrategy of FS, slowing down the upstream line (the same line has to produce both internal and intermediate sleeves), guarantees the more uniform feeding of the VLC avoiding unnecessary waiting to collect parts to be assembled.

In FSM some processes such as Degreasing, Sand Blasting and Phosphatizing are planned to be performed on the same machine. **Table 11** presents the simulation results of scenario 3 concerning Phosphatizing process before (PIS and PES) and also after (PS) changes.

In CS it is possible to utilize only 36.61% of the time in PIS, and 36.33% of time in PES. In FS this value obviously increases to 71.84%.

Table 11. UR from S1 – CSM (PIS, PES) and FSM (PS)

	Mean (90% Confidence)					Sam. Std Dev	Min	Max
PIS	36.13	<	36.61	<	37.10	0.84	35.50	37.89
PES	36.11	<	36.33	<	36.56	0.38	35.76	37.03
PS	71.30	<	71.84	<	72.37	0.92	70.22	73.12

8. CONCLUSIONS

When analysing CSM we can identify places in MS where excessive inventories occur. These facts derive from real MS. We can also see how high are ILTs in each area. Additionally, we have the whole overview of the system with the data concerning COs, LT and PT. FSM is the map which presents the possible MS and the level to which, in this situation, LT can be decreased. CSs can provide additional data such as WIP, TR and UR of each machine. With CSs we can assess the results of changes which we want to implement in MS in order to find the best solution.

In conclusion, we can say that CSs give a real added value to VSA and can help in the decision making process concerning a manufacturing system development.

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ПРИМЕНА МАПИРАЊА ТОКА ВРЕДНОСТИ И МОГУЋНОСТИ СИМУЛАЦИЈЕ ПРОИЗВОДНИХ ПРОЦЕСА У АУТОМОБИЛСКОЈ ИНДУСТРИЈИ

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Мапирање тока вредности је уобичајени метод процењивања који се користи за анализу производних процеса. Основна предност овог метода је његова могућност одређивања губитака. Усвајањем правила lean производње и lean управљања могуће је елиминисати губитке. У раду је приказана студија случаја производног процеса чауре виљушке. Актуелна мапа тока вредности и будућа мапа тока вредности производног процеса чауре виљушке се користе у раду. Истраживање мапа су урађене помоћу анализе тока вредности која помаже пројектанту процеса у идентификацији и елиминацији губитака. Међутим, аутори сматрају, да би се узели у обзир сви резултати мапирање тока вредности, да код примене мапирања тока вредности анализа треба да укључи комплементарне алате као што су компјутерске симулације. Компјутерске симулације су у раду коришћене за анализу података о производном процесу чауре како би се искористили резултати анализе тока вредности.