VALUE STREAM MAPPING OF A UNIQUE COMPLEX PRODUCT MANUFACTURING PROCESS

Mapowanie strumienia wartości procesu produkcji niepowtarzalnego wyrobu złożonego

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A b s t r a c t: Value stream mapping is a method used for wastes' identification in manufacturing systems as well as in other processes realized in the companies. The method is well known and applied in different areas and industries. However, as each process is different, every time when the method is used, some unexpected problems in its implementation can appear or the method has to be applied in a specific way. In this paper, the value stream mapping method is applied in order to analyse a manufacturing system in which unique complex products are manufactured. The paper discusses important issues which have to be taken into consideration while the method is applied in the circumstances similar to these presented in the analysed case study. In the work, on the basis of the collected data, the current state of a value stream map was developed. Then, the problems existing in the manufacturing system were identified and analysed. Finally, on the basis of the suggested solutions for the problems, the future state of a value stream map was proposed. The paper emphasizes the aspects important in the value stream mapping of a unique complex product manufacturing process.
K e y w o r d s: Value stream mapping, unique complex product, problems analysis, pull system

S t r e s z c z e n i e: Mapowanie strumienia wartości jest metodą stosowaną do identyfikacji strat w systemach produkcyjnych, a także w innych procesach realizowanych w przedsiębiorstwach. Metoda ta jest dobrze znana i stosowana w różnych obszarach i branżach przemysłu. Ponieważ jednak każdy proces jest inny, za każdym razem, gdy stosowana jest metoda mapowania strumienia wartości, mogą pojawić się nieoczekiwane problemy z jej implementacją lub metoda musi być zastosowana w określony sposób. W niniejszym artykule zastosowano metodę mapowania strumienia wartości do analizy systemu produkcyjnego, w którym wytwarzane są niepowtarzalne produkty złożone. W artykule omówiono ważne kwestie, które należy wziąć pod uwagę, gdy metoda jest stosowana w okolicznościach podobnych do przedstawionych w analizowanym studium przypadku. W pracy, na podstawie zebranych danych, opracowano mapę strumienia wartości stanu aktualnego, a następnie zidentyfikowano i przeanalizowano problemy występujące w systemie produkcyjnym. Następnie, na podstawie zaproponowanych rozwiązań problemów zaproponowano mapę strumienia wartości stanu przyszłego. W artykule podkreślono aspekty ważne w mapowaniu strumienia wartości procesu wytwarzania niepowtarzalnego produktu złożonego.
S ł o w a k l u c z o w e: Mapowanie strumienia wartości, niepowtarzalny produkt złożony, analiza problemów, system ssania

Introduction

The organization of a manufacturing process of a complex product is challenging. Especially, if the product changes in time and if it is a little bit different with every new customer's order. The situation is better when a product is composed with standard components and has a modular structure. However, there are cases in which it is impossible. Thus, the components are a little bit different every time. This makes the work organization more difficult and the production must be realized on the basis of a received order. A manufacturing process cannot begin in advance. If, in this case the lead time *(LT)* of a manufacturing process is longer than the delivery time *(DT)*, a company has problems. In consequence, it has to work on additional shift(s), has to work overtime if possible, or has to find other solutions in order to prevent delivery delays.

Therefore, the company must ensure that the lead time is shorter than the delivery time *(LT < DT)*. Hence, the lead time that is too long is the biggest problem in the company which manufactures unique complex products. In order to analyse the organization of manufacturing processes, the literature proposes a value stream mapping *(VSM)* method. Although in the work [2] the authors claim that there is no significant correlation between VSM and the defined by them operational performance measures such as e.g. quality, speed, flexibility, cost etc., other publications prove the usefulness of this method [8]. For example, in the work [9] the authors present how it was possible to decrease *LT* in manufacturing processes with the use of VSM. In the analysed lock manufacturing process *LT* was decreased by 62.74%. In the work [6], which analyses the process of car parts manufacturing, *LT* was decreased by 140%. In the work [7] the authors obtained the improvement of a manufacturing process productivity by almost 11%. Moreover, the literature also presents a positive and significant influence of the VSM implementation on the OEE indicator [5]. Furthermore, in the papers [4, 12] the way of the implementation of VSM, improving process efficiency and decreasing the costs was presented.

In the work [11], it is shown how the VSM method can be applied in complex product manufacturing processes. However, the VSM methodology is usually applied for repetitive production. In this work the problem is not only connected to the product complexity but also with to the product uniqueness. In the work [1] the authors apply VSM in a low volume production. Therefore, the mentioned studies are a good starting point for the analyses.

Research problem and goal

The problem which is analysed in this paper concerns long *LT* of the manufacturing process of a unique complex product. A unique complex product is defined as a product which is unique and complex. The uniqueness of the product means that each product (which can be still ordered by a customer in a small batch) is a little bit different from the previous one ordered by a customer. Consequently, the manufacturer never knows in advance what will change. Therefore, *LT* cannot be longer than the delivery time. The product complexity is connected to a large number of parts which have to be manufactured and then assembled into a ready product. The complexity also concerns a manufacturing process in which the product components can be manufactured in parallel. In the analysed case study the situation is even more complicated because there is a necessity of using subcontractors' services. This creates an additional risk of delivery delays. To summarize, the following factors influence difficulties with the VSM implementation: product uniqueness, product complexity, parallel manufacturing of components and engagement of subcontractors. The goal of this paper is to analyse a case study manufacturing process organization and propose solutions to decrease *LT* to an acceptable value. The project presented in the case study was initiated because the company had a problem with on time deliveries and the employees had to work on additional shifts or overtime in order to prevent delivery delays. However, it was not always possible.

Work methodology

The work methodology, which was applied in this paper, is based on the value stream mapping (VSM) method presented in [10]. However, the VSM application for a complex product is not so simple as presented in the mentioned work. Therefore, the VSM adapted to a complex products manufacturing system analysis, presented in the work [11], was taken into consideration in the analyses and calculations. Nevertheless, in the cited work, a collaboration with external service providers was not investigated. In the case study, presented later in this work, it is necessary to include external service providers in a value stream map. This is a novelty, in relation to the aforementioned work. Moreover, the uniqueness of a product requires additional attention when setting value stream mapping targets. Therefore, the following main steps of the work methodology are realised:

Step 1. Identifying a product family and choosing a representative of the product family. In the presented case study the analysis was performed for a product family representative that is an expansion tank. For the product, which is a complex product, a product structure was developed.

Step 2. Setting the value stream mapping goals which take into consideration customer's requirements connected to the delivery time, bearing in mind that the manufacturing process concerns the production of unique products.

Step 3. Identifying the material and information flow and data collection. The data were collected with the use of a time study and discussion with the employees engaged in the process.

Step 4. Developing the current state of a value stream map (CS-VSM). The value stream maps were developed with the use of Visio Professional software. The lead time *(LT)* for the current state was calculated.

Step 5. Identifying and analysing problems. The problems were analysed and the suggestions for the problem elimination were presented.

Step. 6. Developing the future state of a value stream map (FS-VSM). The FS-VSM presents the proposals which can improve the flow. The *LT* for the future state was calculated. The obtained results were assessed.

Step. 7. Assessing the improvements. The improvements were assessed with the use of the *LT* improvement *(LTI)* and of value-added activities improvement *(VAI)* indicators.

The listed steps were applied. That is presented later in this work.

Description of the product

The product which is manufactured on the analysed manufacturing line is an expansion tank used in vehicles, and it is considered as a complex product [3]. Figure 1 shows ready products. The structure of the product is presented in Figure 2. The product consists of the components which are manufactured in the company, delivered by a customer or bought. In order

Figure 1. A photo of ready products

to manufacture the components, the company uses the following materials, i.e. round bars, stainless steel and seamless pipes. Table 1 presents a list of components, units and materials indicating their origin and quantity.

The structure of the product shows its complexity. The uniqueness is not presented here. The products are differentiated by size or number of certain product components. This can influence the processing time.

Communication with customer and suppliers and working time

A customer orders 32 pcs of ready products which have to be delivered in 6 weeks. The products have to be delivered in containers. One container includes 4 pcs of ready products. 32 pcs of ready products are delivered to a customer every 6 weeks. The next order will concern a product of a different structure. The client orders products 8 weeks before the planned shipment. Therefore, the lead time cannot be longer than 8 weeks.

Materials are delivered by the suppliers every 2 weeks. Additionally, the customer delivers some parts which are assembled to a ready product.

The company works 20 days in a month on two shifts (Production Department, Quality Department) and one shift (Design and Technology Department, Logistics Department and Marketing Department). One shift lasts 8 hours with a 30-min-break. Therefore, the available working time per shift is 27,000 seconds.

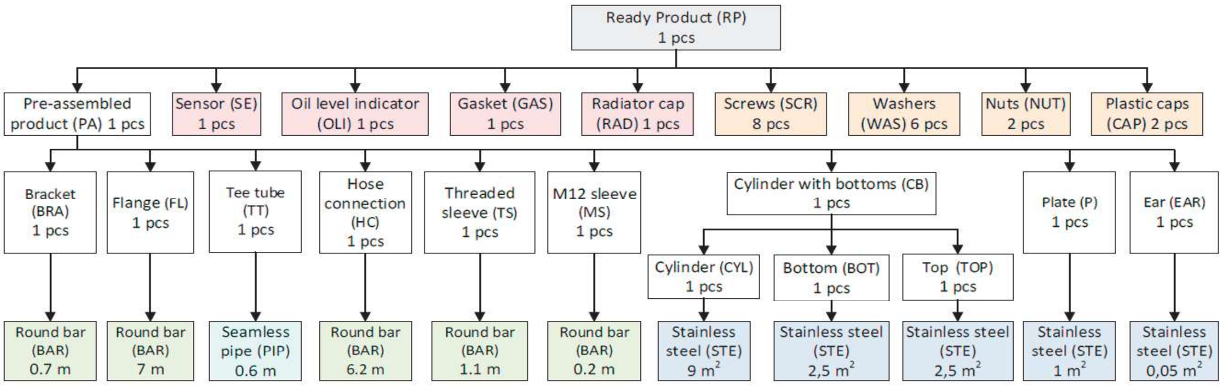


Figure 2. The structure of the product

Table 1. Components and materials needed to manufacture one expansion tank; MB – material bought, DC – delivered by customer, M – manufactured in the company, RP – ready parts bought

No	Component/material	Origin	Symbol	Qty	No	Component/material	Origin	Symbol	Qty
1	Bracket	M	BRA	1 pcs	13	Pre-assembled Product	M	PAP	1 pcs
2	Tee Tube	M	TTU	1 pcs	14	Round bar	MB	BAR	15.2 m
3	M12 sleeve	M	MSL	1 pcs	15	Stainless steel	MB	STE	15.05 m2
4	Threaded Sleeve	M	TSL	1 pcs	16	Seamless pipe	MB	PIP	0.6 m
5	Hose connection	M	HC	1 pcs	17	Sensor	DC	SE	1 pcs
6	Flange	M	FL	1 pcs	18	Oil level indicator	DC	OLI	1 pcs
7	Cylinder	M	CYL	1 pcs	19	Gasket	DC	GAS	1 pcs
8	Bottom	M	BOT	1 pcs	20	Radiator cap	DC	RAD	1 pcs
9	Top	M	TOP	1 pcs	21	Screws	RP	SCR	8 pcs
10	Ear	M	EAR	1 pcs	22	Washers	RP	WAS	6 pcs
11	Cylinder with bottoms	M	CB	1 pcs	23	Nuts	RP	NUT	2 pcs
12	Plate	M	PLA	1 pcs	24	Plastic caps	RP	CAP	2 pcs

Table 2. Manufacturing processes; CT – cycle time, CO – changeover time, AVA - Availability

No	Input	Process	Output	CT [s]	CO [s]	AVA [%]
1	BAR	Deburring I	BRA	180	0	80
2	BRA	Bending	BRA	60	480	90
3E	BRA	External service I: Hot dip galvanizing	BRA	Batch size: 4 pcs Lead time: 1 day		
4	BRA	Deburring II – after galvanizing	BRA	120	0	100
5	PIP	Shipment to a subcontractor	TTU	3 600	0	80
6E	TTU	External service II: 3D laser burning	TTU	Batch size: 4 pcs Lead time: 1 day		
7	TTU	Turning I – universal lathe	TTU	360	600	90
8	BAR	Cutting I – band saw (33 pcs)	MSL TSL	78	1 800	70
9	MSL TSL	Turning II – CNC lathe (33 pcs)	MSL TSL	2 073	7 860	80
10	BAR	Cutting II – cut-off machines	HC FL	2 040	0	100
11	HC FL	Turning III – CNC lathe	HC FL	2 190	4 140	80
12	HC	Turning IV – universal lathe	HC	90	1 800	100
13	FL	Milling – Centrum VZ-700	FL	960	2 160	80
14	STE	Deburring III	EAR PLA CYL BOT TOP	510	0	80
15E	CYL	External service III: Coiling	CYL	Batch size: 4 pcs Lead time: 1 day		
16	CYL BOT TOP	Welding	CBT	2 100	0	90
17	TTU MSL TSL HC FL EAR PLA CBT	Assembly of components	PAP	7 500	0	100
18E	PAP	External service IV: Passivation	PAP	Batch size: 4 pcs Lead time: 1 day		
19	BRA PAP SCR WAS NUT CAP	Final assembly + Pressure test	RP	6 300	7 200	100

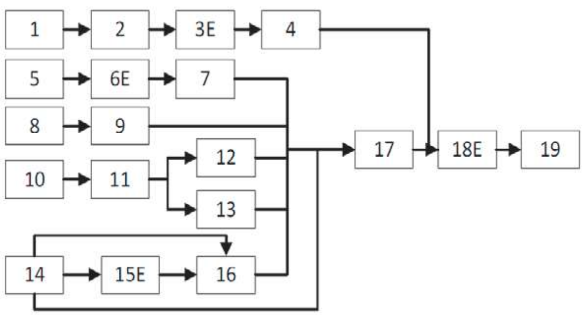


Figure 3. The structure of the manufacturing process

Manufacturing process description

Manufacturing is implemented within the processes presented in Table 2. One operator works in each process. Some processes are realized in co-operation and these are: Hot dip galvanizing (3E), 3D laser burning (6E), coiling (15E) and passivation (18E). Table 2 presents the data concerning the processes i.e. cycle time (CT), changeover time (CO), workstation/machine availability (AVA). Moreover, the information concerning inputs and outputs for each process is presented. In two processes (8 and 9) one additional piece is manufactured. This is due to the poor quality of the processes. Therefore, the need to produce one additional piece is determined in advance. The structure of the manufacturing process is presented in Figure 3.

On the basis of the present manufacturing process structure (Fig. 3) and the data presented in Table 2, CS-VSM was developed and it is presented in the next part of this work.

Current state of the value stream map development and problems identification

The current state of a value stream map (CS-VSM) is presented in Figure 4. The scheme shows that some components are delivered from the outside of the company, directly to the assembly process, and some of them are manufactured in the company. Manufacturing processes of different components are realized in parallel. In the presented case study a time line is divided into a few parts. That is different from what was presented in the work [11]. The time line is situated directly under the processes. The authors consider that the map is easier to read this way.

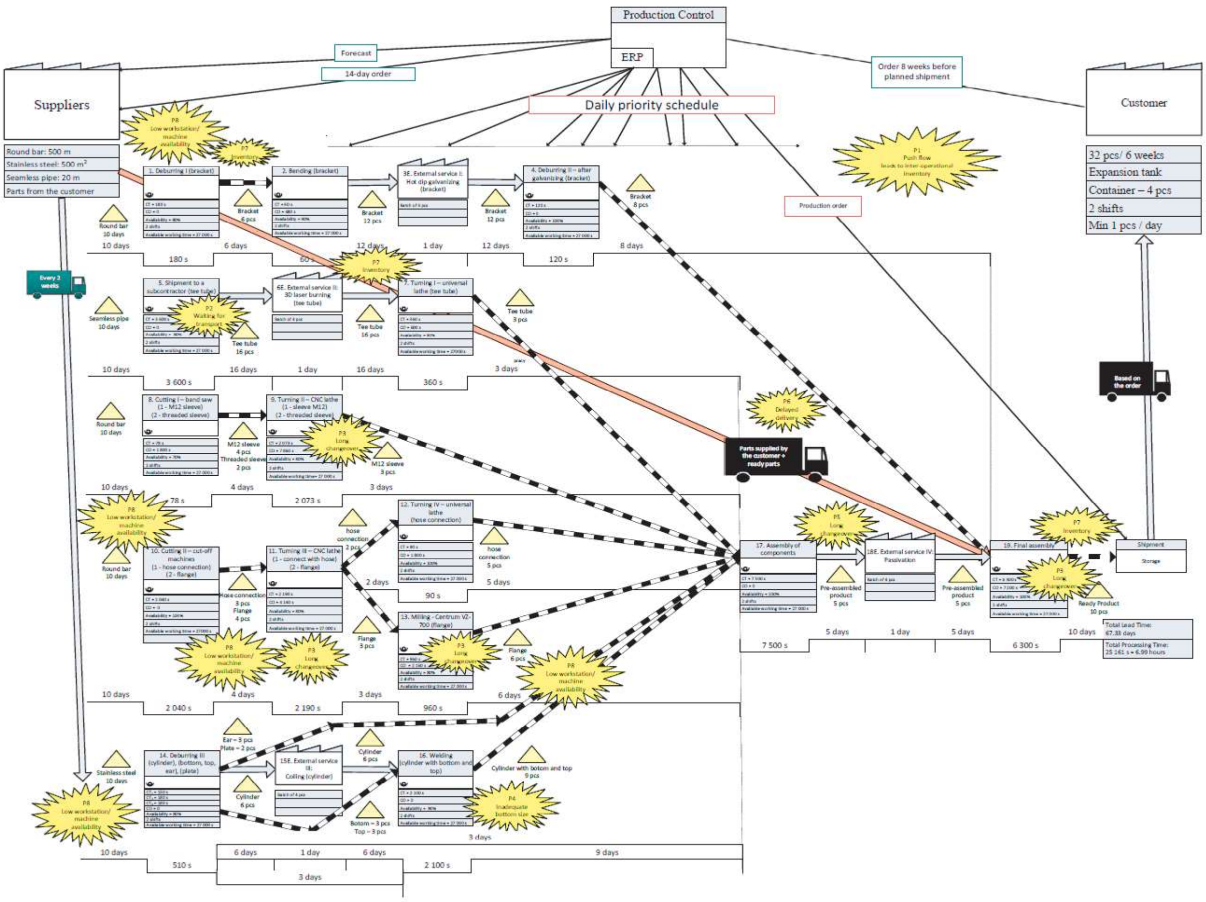


Figure 4. CS-VSM of an expansion tank manufacturing process

The lead time was calculated based on a time line (Fig. 5). For each parallel manufacturing process the lead time (*LTP*) was calculated (equation 1). A critical path defines the length of *LT*, and it was calculated with the use of equation (2).

In the presented case study, in the current state, the lead time LT_{CS} equals 67.33 days. The processing time equals to 28 161 s (469.35 min = 7.82 h). It is too long for *LT* considering that the processes are realized in parallel. Moreover, 67.33 days is too long taking into account that the company has 8 weeks to manufacture the products, i.e. it can start production at the earliest 40 days before delivery. Therefore, it is impossible to deliver the products on time without any problems despite the fact that the takt time (*TT*) equals to 15 hours and CT_s of all processes are shorter than 15 hours.

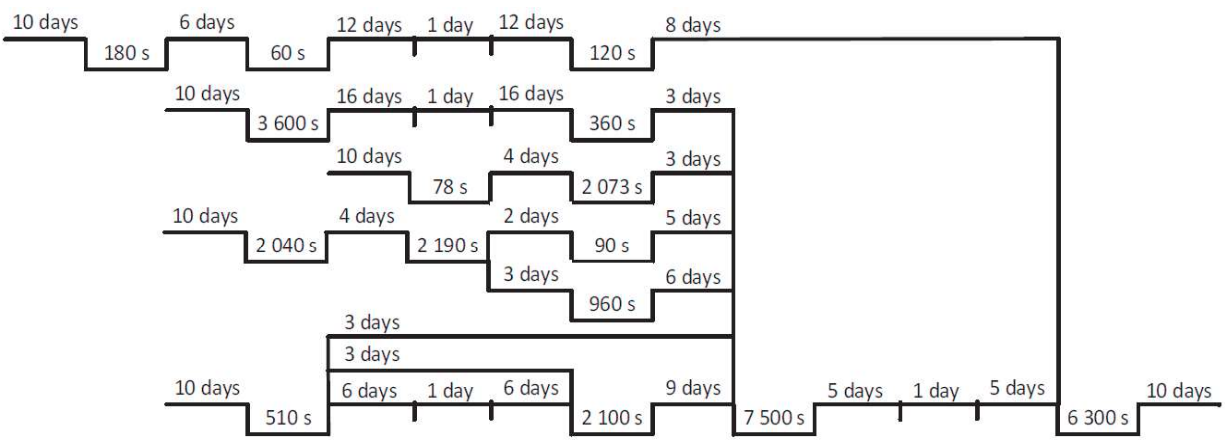


Figure 5. CS-VSM of an expansion tank manufacturing process time line

$$LT_{P-CS} = \begin{bmatrix} \sum_{l=1}^{r} ILT_{1l} + \sum_{l=1}^{v} CT_{1l} \\ \sum_{l=1}^{m} ILT_{2l} + \sum_{l=1}^{s} CT_{2l} \\ \dots \\ \sum_{l=1}^{p} ILT_{kl} + \sum_{l=1}^{q} CT_{kl} \end{bmatrix} = \begin{bmatrix} LT_{P1} \\ LT_{P2} \\ \dots \\ LT_{Pk} \end{bmatrix} = \begin{bmatrix} 59\ days + 6\,660\ s \\ 67\ days + 17\,760\ s \\ 38\ days + 15\,951\ s \\ 42\ days + 18\,120\ s \\ 44\ days + 18\,990\ s \\ 34\ days + 14\,310\ s \\ 43\ days + 16\,410\ s \\ 53\ days + 16\,410\ s \end{bmatrix} = \begin{bmatrix} 59.12\ days \\ 67.33\ days \\ 38.29\ days \\ 42.33\ days \\ 44.35\ days \\ 34.27\ days \\ 43.30\ days \\ 53.30\ days \end{bmatrix} \quad (1)$$

where: *ILT* – inventory lead time, *CT* – cycle time, *LTP* – lead time for a path, *l* – a number of process steps, *k* – a number of paths

$$LT_{CS} = \max\{LT_{Cs1}, LT_{Cs2}, \dots, LT_{Csn}\} = 67.33\ days \quad (2)$$

The current state was studied and the following problems were discovered. The problems were analysed and proposals for improvement were offered.

Problem 1. Push system. In the current state the push system was applied. It was because different kinds of tanks being in the same product family were ordered by customers in different time periods. This way, in one period of time only one kind of expansion tanks was manufactured. Therefore, the company decided to push production to obtain this product which was ordered first to be ready. This way, the Lead Time (*LT*) was long. The implementation of a pull system with the introduction of FIFO lanes and supermarkets with kanbans can be the solution then.

Problem 2. Waiting for transport to collaborators and long preparation time. The manufacturing process cannot be realized fully in the company. Therefore, the company uses external services. This concerns four processes (3E-Hot dip galvanizing, 6E-3D laser burning, 15E-Coiling and 18E-Passivation). Components and products have to be sent to collaborators. Sometimes it causes problems of waiting for transport and this, in turn, increases the inventory of the products waiting to be sent to collaborators who are currently responsible for the transport process. The solution proposed is that the company takes the responsibility for the transport process and an additional training for the employees who prepare transport in order to decrease the preparation time. The training additionally decreased the processing time of process 5 from 3 600 s to 600 s.

Problem 3. Long changeover time. The next problem concerns a long changeover time in the processes: Bending (2), Turning (7, 9, 11, 12), Cutting (8), Milling (13) and Final assembly (19). In order to decrease a changeover time the SMED method was recommended for the implementation.

Problem 4. Inadequate components waiting for a process. Another problem which was discovered was connected to inadequate components (e.g. bottoms) which were waiting for an assembly process. In order to solve this problem, 5S method is the best solution to be introduced. Other solutions of this problem include visualization or Poka Yoke implementation.

Problem 5. Long processing time. Long processing times (*PT*) in the last processes (17). Assembly of components – 2.1 hours and 19. Final assembly – 1.75 hours) are much longer than PT_s of other processes, what additionally increases *LT*. In these processes two operators could possibly work. That might shorten the processing times by half.

Problem 6. Component delivery delays. Delayed deliveries of components from the customer were another problem. The customer does not deliver the components together with an order but later, not always on time. Therefore, the company has to wait with the assembly process for the delivery. The implementation of supermarkets for the components from the customer should solve this problem.

Problem 7. High inventories. The problem is caused by the existing push system and the lack of the implementation of inventory limits. The solution is to introduce a pull system, supermarkets, and/or FIFO lanes.

Problem 8. Low workstations/machines availability. The last identified problem concerns workstations/machines availability. However, because the takt time (*TT*) is much longer than CT_s. Currently, this problem does not influence the manufacturing process. The problem can become serious if the production volume increases. Therefore,

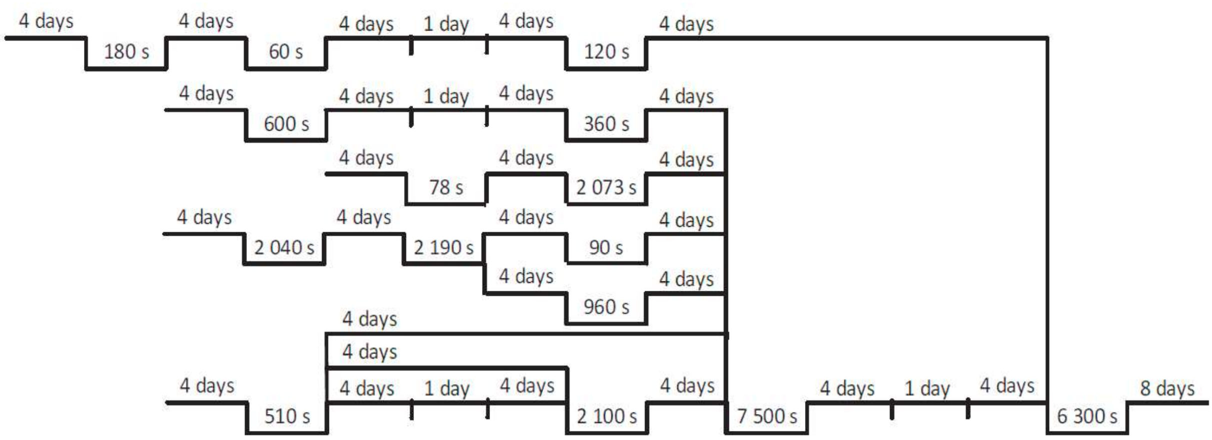
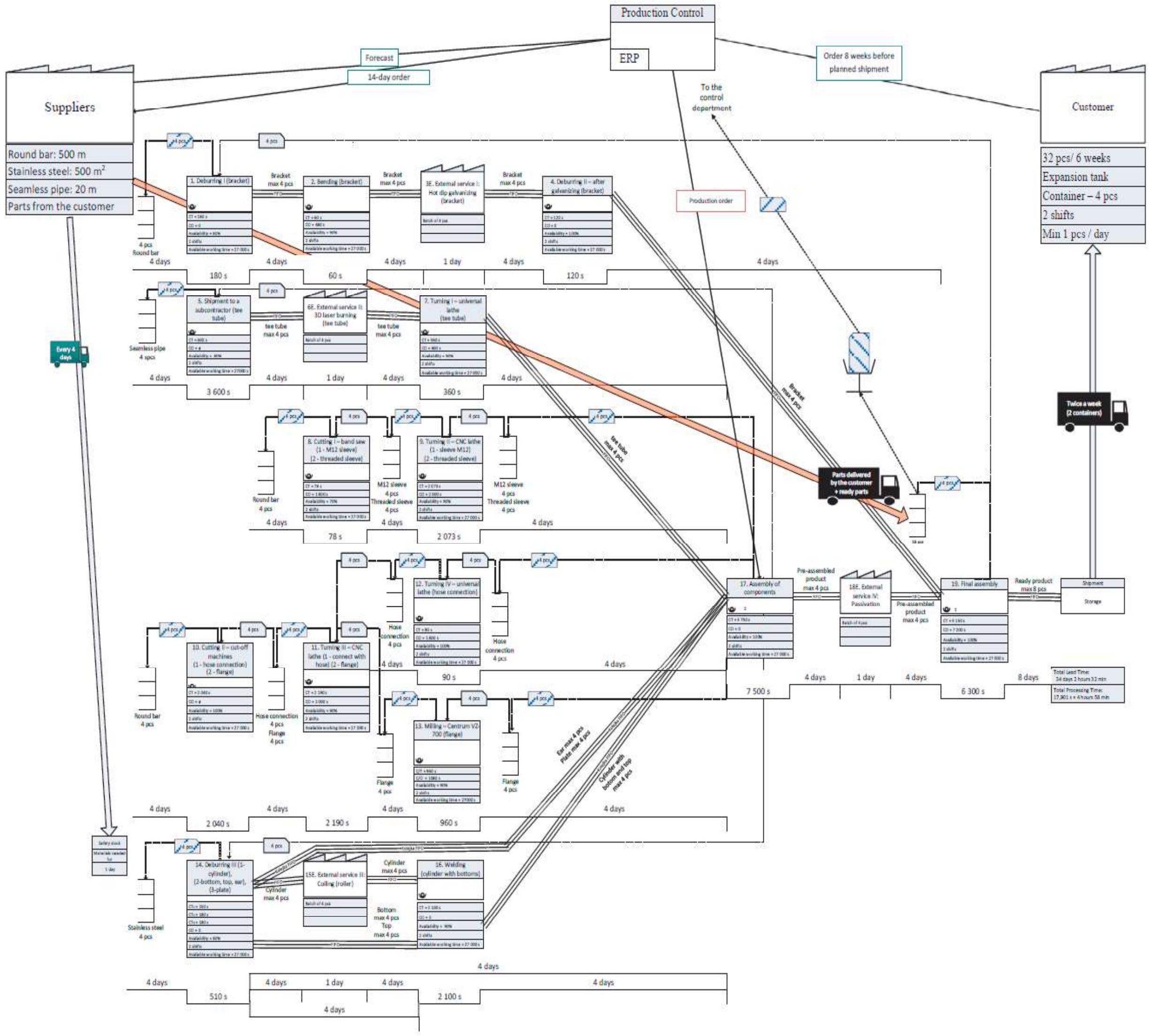


Figure 6. FS-VSM of an expansion tank manufacturing process time line

Figure 7. FS-VSM of an expansion tank manufacturing process



the problem was not analysed in this work. Moreover, in the current calculations some simplifications were made. Namely, an available working time for each process was assumed as 27 000 s.

Future state of the value stream map

The presented solutions allowed proposing the future state of a value stream map (FS-VSM).The implementation of the FIFO lanes and supermarkets allowed to decrease *LT*. A lead time for the future state was calculated based on a time line (Fig. 6). FS-VSM is presented in Figure 7.

For each parallel manufacturing process a lead time (*LTP*) was calculated (equation 3). The critical path defines the length of *LT*. It was calculated with the use of equation (4).

$$LT_{P-FS} = \begin{bmatrix} 29\ days + \ 6\,660\ s \\ 34\ days + \ 14\,760\ s \\ 29\ days + \ 15\,951\ s \\ 33\ days + \ 18\,120\ s \\ 33\ days + \ 18\,990\ s \\ 25\ days + \ 14\,310\ s \\ 29\ days + \ 16\,410\ s \\ 34\ days + \ 16\,410\ s \end{bmatrix} = \begin{bmatrix} 29.12\ days \\ 34.27\ days \\ 29.29\ days \\ 33.33\ days \\ 33.35\ days \\ 25.27\ days \\ 29.30\ days \\ 34.30\ days \end{bmatrix} \quad (3)$$

$$LT_{FS} = \max\{LT_{Cs1}, LT_{Cs2}, \ldots, LT_{Csn}\} = 34.30\ days \quad (4)$$

The pull system with kanbans, supermarkets and FIFO lanes, proposed in FS-VSM, allowed decreasing *LT* to LT_{FC} that equalled 34.3 days. Since the customer is asked to make an order 8 weeks (40 working days) before the shipment of a product, it is enough time to deliver the products on time. Finally, the improvements were assessed with the use of *LTI* (equation 5) and *VAI* (equation 6).

$$LTI = (LT_{CS} - LT_{FS})/LT_{CS} = (67.33\ days - 34.3\ days)/67.33\ days = 0.49 \quad (5)$$

$$VAI = (PT_{CS} - PT_{FS})/PT_{CS} = (28\,161\ s - 25\,161)/\,28\,161\ s = 0.1 \quad (6)$$

On the basis of *LTI* and *VAI* it can be concluded that *LT* decreased by 49% and the processing time decreased by 10%. It is known that the processing time of the current state (PT_{CS}) equals to 28 161 s and the processing time of the future state (PT_{FS}) equals to 25 161 s. In order to achieve this improvement, the presented proposals for the problem elimination have to be implemented. If not, the achievement might not be obtained or it might be smaller.

Summary

In the presented case study the manufacturing process of an expansion tank was analysed. On the basis of the collected data, the current state of a value stream map was developed and then analysed. The identified problems were discussed and some solutions were proposed. Next, the future state of a value stream map was created taking into account the proposed solutions. The lead times for CS-VSM and FS-VSM were calculated. The goals set for the work have been achieved. *LT* for the future state equals to 38.52 days and it is lower than the maximal (40 days).

The presented work has some limitations. In the calculations, the workstations/machines availability was assumed as 100%. It means that the time of 27,000s was taken as an available working time for each process. However, in reality the availability was lower and equalled, in the presented case study to 100%, 90%, 80% to even 70% in case of a cutting process (7). The availability reduction was not taken into consideration because in the analysed case study *TT* was much higher than CTs of the manufacturing processes. However, in other cases the decreased availability has to be considered and it will be discussed in the future studies.

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