Application of the Value Stream Mapping tool to improve a productive process

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ABSTRACT: This dissertation approaches the optimization of an API (Active pharmaceutical ingredient) process, with the application of Value Stream Mapping tool. It was designed to identify process bottlenecks and to propose improvements to eliminate them. At the same time, it was intended to determine the maximum capacity of the current production line. Initially, the process was analysed, and data was collected. These data made it possible to calculate the maximum production capacity. Then, based on data, the value stream map of the current state of the company was elaborated. Analysing the elaborated map, the bottlenecks of the process were identified, and the drying process from the first process step was highlighted, which is the operation that determines the maximum capacity of the production. The maximum capacity can be increased with a standardization and implementation of PAT technology. Besides that, it was verified that one of the process bottlenecks could be overcome with the implementation of a new equipment and a new Nutsche filter. In addition, there is a variability of the process times of some operations that can be solved with a process standardization that includes synthesis scheduling and procedure changes. Finally, an ideal flow map was developed for the API process to be implemented, posteriorly, and to allow an optimization of the process.

Key words: API, optimization, value stream mapping, bottleneck

1. Introduction

Cipan - Industrial Company Producer of Antibiotics, is a company that is dedicated to the production of active pharmaceuticals ingredients (API).

This work was elaborated with the purpose of identifying the bottlenecks of an API process in Cipan and propose improvements to eliminate them, using the value stream mapping tool. Process bottlenecks are operations that delay all the production and zones where there is product accumulation, so it is important identify and solve them to increase the productivity. (Markgraf, s.d.)

2. Methods

2.1. Value Stream Mapping

Value Stream Mapping (VSM) is a Lean Six Sigma tool that consists in mapping the material flow and information flow of a process. Value Stream is the set of all necessary actions, whether they add value to the customer or not. (Rother & Shook, Junho 1999)

Current value stream map

Initially, the process must be observed in a flowchart prior to drawing the current value stream map and there is a symbology usually used to draw this map. To simplify the map, a process box is usually assigned to a production area that operates in a continuous flow and is interrupted to produce an accumulated product. Thus, between each process box there is a product stock, represented by a triangle with indication of the accumulated quantity.

Figure 1 shows an example of a process where the data boxes and the product stock are displayed. (Rother & Shook, Junho 1999) (Nishikawa Standard Company, 2009)

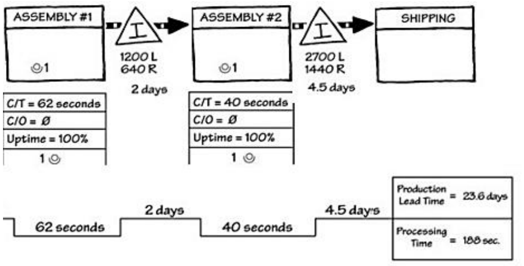

Figure 1 – Part of current value stream map

The data process boxes data depend on several factors, especially the type of industry involved, type of products, what is intended to be analysed and what is applicable to the facilities.

Subsequently, to complete the material flow described previously, the information flow is also represented in the value stream maps. This corresponds to the set of suppliers of raw material (upper left corner) as well as the customers of the product (upper right corner).

Lastly, in the bottom of the map there is a representation of a timeline like in Figure 1, which represents a synthesis of process times.

Future value stream map

Preparing a future value stream map is always necessary for any change in the company, because it allows to evaluate whether the change will solve the problem or create another. In this way, to help build a future map, there are questions that may help analyse the current value stream map and propose improvements (Rother & Shook, Junho 1999) (Nishikawa Standard Company, 2009):

• Where can continuous flow be used in the process?

• What improvements will be required to get a process with the future map specifications? (any new equipment or procedure)

• Where do you need pull systems and supermarkets?

After studying the improvements to optimize the process, all changes proposed in the current value stream map are marked red to elaborate the future value stream map, like in Figure 2.

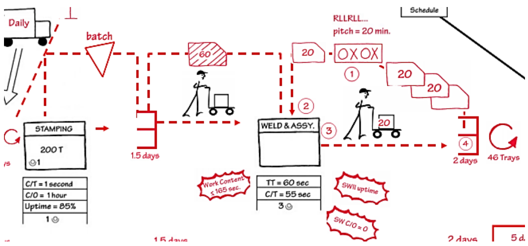

Figure 2 – Part of future value stream map

3. Results and discussion

The first products to be produced in Cipan were oxytetracycline and tetracycline by fermentation, however, later, other tetracyclines began to be produced.

The API process under study is complex and comprises 5 steps. The process is by batches in which product A, product B, product C and API are formed.

The production of API in Cipan is performed for 24 hours daily with 4 shifts of 10 operators, each working for 8 hours at three different schedules, 00h to 08h, 08h to 16h and 16h to 00h.

3.1. Process times

The mapping of the API process requires the collection of different process times. The times collected must be strictly objective and clear, so that they can be interpreted by anyone. In this type of industry, the times required for the application of the Value Stream Mapping tool are described below.

The operation time (OT) is the time between the first step in the procedure and the transference of the resulting product.

The waiting time (WT) corresponds to the time when no operation step is occurring.

The operation processing time (OPT) is the operation time if there is no waiting time. This time is calculated by the difference between in operating time and pause time.

The cycle time (CT) corresponds to the time between the end of a batch and the end of the next batch. This time is conditioned by the bottleneck of the process.

The value added time (VA) to the customer is the steps times of the operation that modify a compound, resulting in a product with greater value for the customer, with the specifications that it intends.

The non-value added time (NVA) to the customer corresponds to all the steps which the customer would not pay, whether they are expendable (NVAD) or indispensable (NVAI).

The batch processing time (BPT) is the time from the first charging to weighing the final product.

Both times were collected from the first 20 batches of 2018, from all operations and for each step of the process.

Exemplifying with a filtration in API process, the operating time begins at the cleaning check of the equipment to be used and ends at the discharge of the same. This operation does not distinguish the pause time since it is the same time that dispensable non-value added time. Due to that, the sum of value added time and non-value added time indispensable results in the operation processing time.

The value added time to the customer in the filtration operation, corresponds to all the filtration of the solution. In this operation occurs a purification of an intermediate product by eliminating undesired impurities in the product specifications. it is the purification of the product formed in this step. The non-value added time indispensable encompasses the necessary activities to the realization of the operation, like the discharge of the product which is an essential activity, as well as the solvent charges.

In Figure 3, the times mentioned was represented.

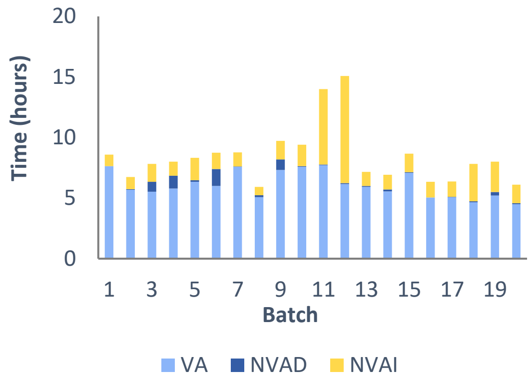

Figure 3 – VA, DNVA and INVA times of filtration operation in API process.

Eliminating the non-value added times indispensable in this operation it is visible a greater discrepancy between the operation processing times, so the filtration would be one of the operations to be analysed in the production zone and must be improved.

As for the batch processing time, for the first 20 batches of 2018 of each product, the time from the first loading to the weighing of the final product was collected. The minimum, average and maximum times are in the table 1.

Table 1 – Batch processing times of products.

	Batch processing time (BPT)			
	Prod. A	**Prod. B**	**Prod. C**	**API**
Min.	2,04	1,25	1,23	2,38
Average	2,60	1,85	1,42	2,86
Max.	3,91	3,01	1,62	4,34

3.2. Maximum production capacity

The maximum production capacity of API depends on the means required for its production, the facilities and availability of raw material.

Starting with the production of product A, activities that limit the cycle time of the process are the occupation of the RAP3377 equipment, which is used in two operations (8,4h) and the filtration in FC3302 (8,5h).

In the production of product B (2nd step), the operation with the longest duration is the drying (15,5h) which determines the beginning of the next batch.

Proceeding for the production of product C (3rd step), hydrogenation is the operation that delimits the interval of time between batches. The H3391 equipment is occupied on average 8,41h.

Finally, in the production of API (4th step), the drying operation is the operation with the longest duration, lasting 22 hours.

Process bottlenecks define ideal cycle times with current installations, thus, including margin for additional handling. In table 2 are presented the current and ideals cycle times.

Table 2 – Ideal and current cycle time (CT)

	Current CT (h)	Ideal CT (h)
Prod. A	16,0	9,0
Prod. B	18,0	16,0
Prod. C	17,0	9,0
API	38,4	22,5

By analysing the results obtained, it is possible to produce 30 batches of API with the facilities. To produce 30 batches of API, 54 batches of product A and product C and 45 batches of product B are required. In this way, it is concluded that the maximum amount of API production is defined by the installations of the 2nd step. To produce the maximum amount, 53 batches of product A and product C, 43 batches of product B are necessary.

Figure 4 shows the maximum number of finished lots in a month, using the maximum production capacity of each lot and the maximum number of finished lots producing a specific amount of API, which is the company's current objective.

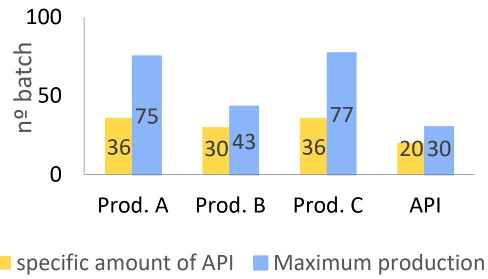

Figure 4 – the maximum number of finished lots in a month

3.3. Current value stream map

In figure 5, is represented the current value stream map of the API process, which relates the flow of information to the flow of material.

In the information flow it is observed on the left side the current suppliers and the quantities ordered for 2018. Customers are represented on the right corner. This company has several customers, so a batch of final product with 500 kg (maximum quantity of a batch) was selected as an example. These 500 kg of product will be sold to 3 different customers, 410 kg for customer A, 40 kg for customer B and 50 kg for customer C.

In the material flow, the API process was divided by zones, each ending in accumulated product. The value of the accumulated product was presented in kilograms and days (duration of the quantity).

The process data are the times referred as well as the quantity produced on a batch average (Q.Batch), the OEE (Overall Equipment Effectiveness) parameter that can be calculated for any equipment, however, this tool is usually applied to evaluate the performance of equipment that limits the production capacity, so the bottlenecks of the whole process. This parameter is the combination of 3 factors, availability, performance and quality.

The cycle times presented are the values of the current state, however these times may be shorter.

Finally, in the value stream map we see the number of operators in each zone of the process and it varies between 2 and 3 operators, meaning that although in general, the operations present 2 necessary operators, to produce a batch there are times when 3 operators are needed, in the beginnings of syntheses and when parallel operations occur.

At the end of the time line, the values of the total times, which correspond to the sum of the times of each zone, are presented. As for the production time, this corresponds to the time from the raw material to the shipment.

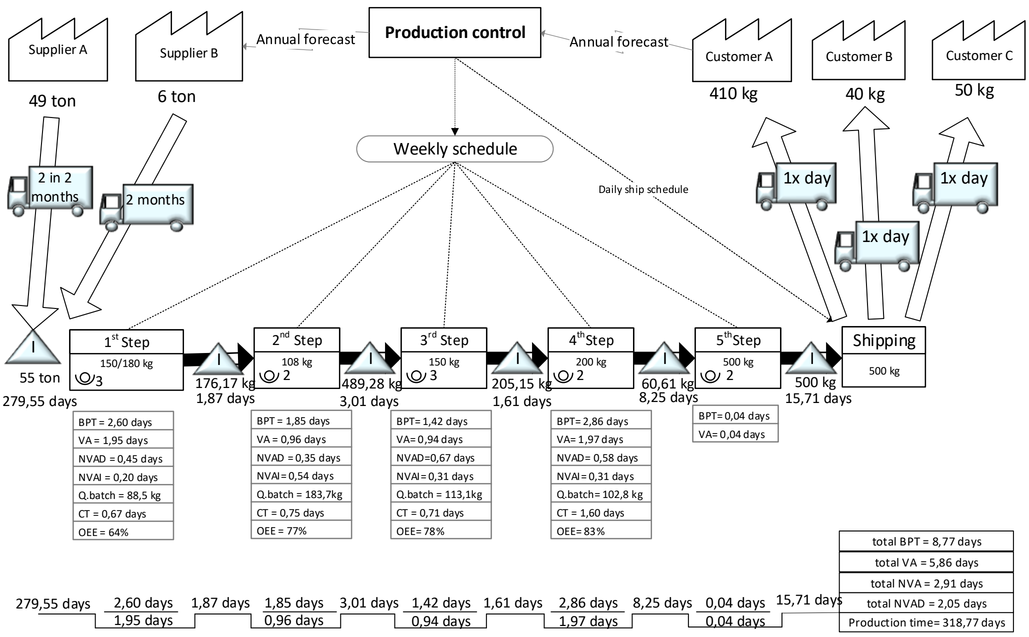

Figure 5 – Current value stream map of the API process

3.4. Process bottlenecks

There are several types of bottlenecks, bottlenecks for equipment capacity, bottlenecks for the duration of operations, bottlenecks for batches size, among others. (Investopedia, 2018)

In the value stream map, it is possible to identify the bottlenecks of a process.

Analysing the different stocks of the process, the product B stock (2nd step) corresponds to the greatest waste of inventory (3,01 days). This waste is mainly due to the lack of a technician on the weekends to realize tests that are necessary for the consumption of this product.

Proceeding to analyse the operation processing times, the 4th step present a higher BPT (2,28 days) and a higher cycle time, 1.6 days. This zone does not define the entire production of API, since it is the last step for its production.

The second highest BPT is in the 1st step (2,15 days). Contrary to the previous zone, it defines all the production by the high operation processing time and the batch size is not enough to produce a batch of the following product. When a batch was not approved, it was reflected a delay in production, proving the existence of this bottleneck.

The maximum capacity of the 2th step determines the monthly amount of API produced because it has the highest cycle time compared to the other products.

After a global perspective of the process and an identification of the limiting points, the operations belonging to each zone of the process were studied. In the production of product A, the limiting equipment is the RAP3377 and the FC3302. In the production of product B, the bottleneck in this step is the drying in DLF3311 / 2/3. In the production of product C the limiting operation is the hydrogenation in the hydrogenator H3391. Finally, in the production of API the limiting equipment is the DV3301 and DV3302.

There are still other operations that need to be standardized like the filtration in the FP3396 and FF3361, however, the limiting operations are priority in optimization process because allow to increase the production.

In addition to the process times, the OEE parameter indicates the possibility of improvement in the critical points of the process through several factors (world class value is 85%), especially in the 1st step. In this step the quality factor in the start month (month that was analysed) is low due to batches that have not been approved.

3.5. Study of improvements

3.5.1. Operation standardization

The standardization of operations allows the optimization of the times of the process and avoid delays in the production through changes to the procedure and schedule of the syntheses. With the standardization of operations, the batches variability decreases, and in turn, the quality of the product increases.

3.5.2. Nutsche Filter

A Nutsche filter is an equipment where you can filter and dry a product. This equipment is shown in Figure 6. (Interphex, s.d.)

Figure 6 – Nutshe filter

In a Nutsche filter a batch filtration occurs which uses vacuum and / or pressure in an enclosed tank. This technique of filtration and drying presents some advantages such as the reduction of the risk of product contamination, minimal operator exposure, low product handling and environmental protection against solvent vaporization. In addition, the Nutsche filter / drier is GMP compliant and is used in the pharmaceutical industry. (May, 2014) (Pfaudler, 2018)

The Nutsche filter is the ideal equipment for two critical zones of the process. Firstly, in 1st step, the filtration and drying, could be replaced by the Nutsche filter because the filtration is a bottleneck in the production of product A and this product is determinant for the rest of the syntheses. Second, in 4th step, the Nutsche filter could be used instead of the filter and dryer DV3301 / 2. In this step, drying is the operation with the longest processing time of the operation and should be improved.

The filtration and drying time in the Nutsche filter should be less than the filtration rate currently in order to overcome the bottleneck. However, the quality of the product may suffer improvements which will lead to an increase in capacity.

3.5.3. Installation of a new equipment

The production of product A is a critical step and presents two equipment that limit the maximum capacity of this product, RAP3377, because it is occupied in two different operations and FC3302 used in filtration, that has a duration similar to the time that the equipment is occupied.

Regarding the FC3302 problem, the filter Nutshe was suggested. As the problem of RAP3377 is occupation, it would be appropriate to install an equipment for one of the two operations in RAP3377.

3.5.4. PAT (Process Analytical Technology)

The FDA defines PAT (Process Analytical Technology) as a system for designing, analysing, and controlling production through spot measurements of critical quality attributes, always ensuring product quality. (Parris, Airiau, Escott, Rydzak, & Crocombe) (FDA, 2004)

PAT technology is applied to various equipment, including fluidized bed dryers. This type of dryer is used in the drying of the 2nd step. This operation has to be optimized, because has large variations of the operation processing times. In addition, it is a controlled operation with the NIR analysis of samples taken over time. These samples are taken manually and are analysed by Near Infrared Spectroscopy (NIR), a technique frequently used for moisture analysis of a process. (Mattes, Root, & Birkmire, 2005) However, real-time measurement using PAT technology is possible. Thus, the drying process can be monitored without manual intervention, allowing control and determination of the end of the operation. (Metrohm).

For the operation under study, it is suggested the analysis of the composition of the gases in the vapor phase that has several advantages such as its use in different types of dryers and that do not require direct contact of the probe with the API. Direct contact with the probe may result in incorrect results due to a blocking of the probe with poorly representative material. Figure 7 shows the evolution of NIR and temperature in drying operation, obtained with an example of monitorization (Morris, et al., 2010)

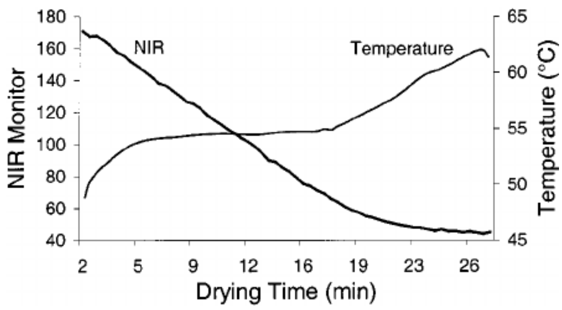

Figure 7- NIR evolution and temperature in drying operation, obtained with an example of monitorization.

3.6. Future value stream map

After analysing the current state value stream map of the company, the ideal value stream map is elaborated, which corresponds to the future state that is intended to be reached. Ideally, the future state would be in the situation of API production with maximum capacity, however, currently the company's goal is to produce a specific amount of API. So, this is the state we are trying to achieve today. This quantity is defined according to the demand for API in the market.

Further in the calculation of takt time (production rhythm), it was considered a customer demand of 20 batches. Considering that the production operates daily without pauses, the takt time is 1,5 days. Thus, every 1,5 days a batch of API should be started.

The elaboration of the future value stream map is made from the value stream map of the current state of the company. After a syntheses schedule, it was possible to obtain the optimal quantities of stock levels, as well as cycle times.

In the future state, times that do not add value to the process and are unnecessary should be eliminated and thus the batch processing times acquire the values of the ideal batch processing times. As for the cycle time, this represents the maximum interval time between each batch and must be updated with the synthesis schedule to produce a specific amount of API.

In the value stream map, all the improvements described previously are marked as shown in figure 8.

Figure 8– Kanban sign that allows identification of possible improvements to be adopted

Between each stage of the process, supermarkets were placed for product storage because with the variation of batch size and batch processing time, it becomes necessary to store the product that is withdrawn in the next step. The First in First Out (FIFO) was considered but the batch sizes are not the same, leading to the use of different batch parts to produce a batch of the next product. Therefore, the use of supermarkets is the best option. (Roser & Nakano, 2015)

Figure 9 represents the symbology used between the stages of material flow in the future state value stream map.

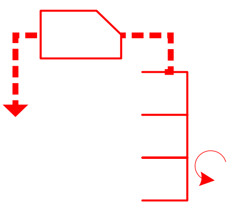

Figure 9 - Symbology used between stages of the material flow, in the value stream map of the future state.

Finally, after the production of the final product batch, it takes 15,71 days to be shipped. This value is currently determined by reviewing the batch production record and releasing documentation. Therefore, releasing documentation should be more synchronized with the production.

In Figure 10, is represented the value stream map of the future state.

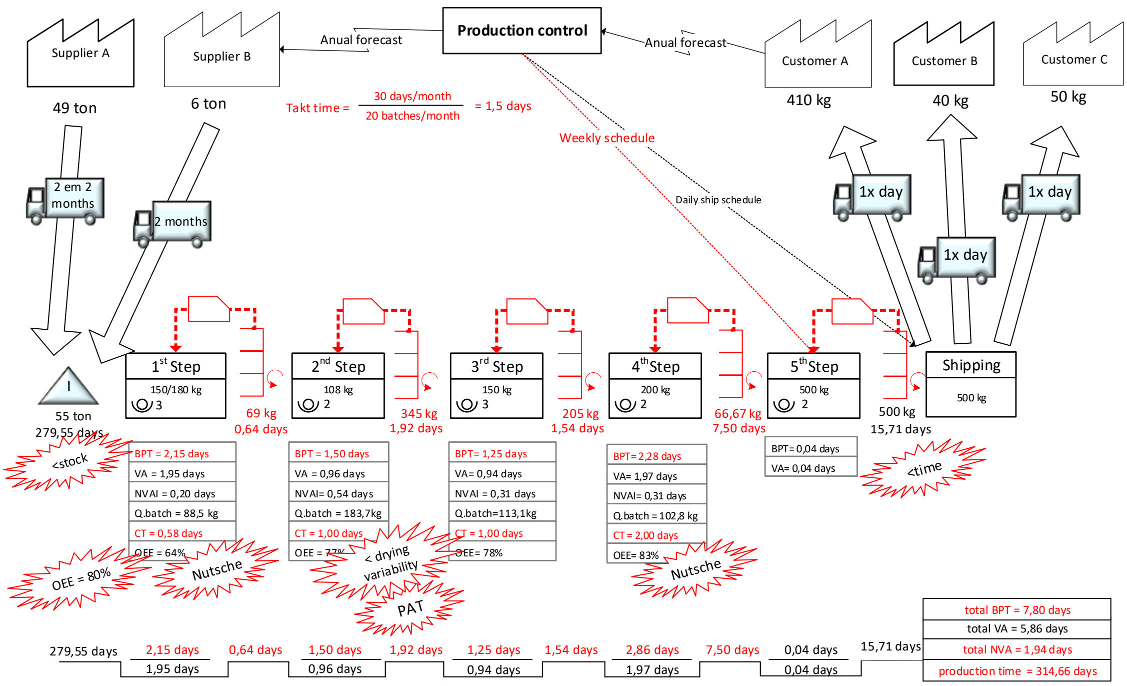

Figure 10 – Future value stream map of the API process

4. Conclusion

By looking at the current state value stream map of the company and the data collected from both process operations, it has been concluded that there are numerous operations that can be improved. Regarding the improvement of the process it is suggested the installation of new equipment, implementation of new technologies and operations standardization.

Starting with the production of product A, it currently has a duration of 2,60 days, but with the elimination of waiting times can last for 2,15 days.

The production of product B has a duration of 1.85 days, but with the elimination of waiting times this value would be 1,50 days. This step requires special attention because it constitutes a process bottleneck that determines the maximum capacity of the process. In addition, the production of product B is limited by the electricity rate adopted and per tests that are necessary to the consumption of product B.

Proceeding to the production of product C, this lasts for 1,42 days and could be 1,25 days with the elimination of times that do not add value to the customer and are unnecessary.

Finally, the production of API lasts 2,86 days but could last for 2,28 days.

For critical equipment, OEE (Overall Equipment Effectiveness) was calculated and both result values are below world class values. However, the results show that product A production has a greater margin for improvement and this is due to the quality factor. In the starter month the quality factor has a low value due to batches that have not been approved.

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