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ORIGINAL ARTICLE

Applying lean techniques to nougat fabrication: a seasonal case study

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Abstract Lean manufacturing has been increasingly applied by leading manufacturing companies throughout the world, led by the major automobile manufacturers and their equipment suppliers. The aim of this case study is to show the applicability of lean manufacturing's body of knowledge to a different environment: a seasonal food industry. Several techniques and analyses such as value stream mapping (VSM), overall equipment efficiency, spaghetti diagrams, work balance, and discrete event simulation were applied in this case study. Some of the improvement ideas resulting from the tools used were tested in the field to corroborate the findings. Finally, the future state VSM was mapped, where most of the improvement ideas identified throughout the project were consolidated. Whether the path to improvement is marked by increased spending on systems and machinery, human capital, or both, engineers and managers in the frontlines of food production recognize that improvement is a quest and not a destination. Although process industries need a special version of lean manufacturing tools, this case study shows how, with slight modification, several tools can be applied to the seasonal traditional craft industry.

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1 Introduction

Lean manufacturing, led by the major automobile manufacturers and their equipment suppliers, has been increasingly applied by leading manufacturing companies throughout the world [38]. It is a "system for the absolute elimination of waste" [23], where "waste" is defined as everything that increases cost without the creation of value for the final customer [37]. Since globalization leads to greater competition, lean production techniques are therefore an urgent prerequisite for producers everywhere.

In recent years, a wide range of literature associated with lean production has emerged since Womack et al. [55] studied the differences between mass production and lean production, highlighting the advantages of the latter. Several excellent books and reviews presenting the whole system or specific lean tools from a theoretical and practical perspective have since been published by authors such as [23, 27, 31, 44, 47, 52–54]. There is now a substantial body of research on lean, most of which focuses on highly automated, repetitive production environments [51].

However, there is still surprisingly little use of lean manufacturing techniques in the chemical and process industries [16, 34]. This is mainly due to the fact that the process industry needs its special version of lean manufacturing, since there are three critical differences between process manufacturing and mechanical manufacturing [16]. Firstly, the raw materials undergo a transformational change as they become a product, as opposed to the reconfigurational change that occurs in mechanical manufacturing. Secondly, the way that raw materials are transformed into products is often indirect, as opposed to the direct changes that occur in mechanical manufacturing. Finally, the transformation of raw materials in process manufacturing is frequently time dependent.

Moreover, this case study deals with a food industry and its production process, which has special characteristics compared to manufacturing industries, such as short shelf-life, heterogeneous raw materials, seasonality, and varied harvesting conditions. These factors greatly affect storage, conditioning, processing, packaging, and quality control, which makes quality improvement initiatives more complicated [13, 14]. Whether the path to improvement is marked by increased spending on systems and machinery, human capital, or both, engineers and managers in the frontlines of food production recognize that improvement is a quest and not a destination [21].

A few authors argue that lean approaches may not have universal applicability for all organizations [9]. So far, little has been written about the applicability of lean manufacturing to the food industry or to seasonal industries [13, 14, 29]. Moreover, little empirical evidence has been published on the implementation of lean practices and the factors that might influence them in small and medium enterprises (SMEs) [2]. Furthermore, findings of Dora et al. [13, 14] show that the deployment of lean manufacturing practice in food processing SMEs is generally low and still evolving.

However, there are a few antecedents in the food sector. Fuentes et al. [17] studied the applicability of lean production in the egg industry, concluding that it was indeed applicable. Zokaei and Simons [58] and Simons and Taylor [48] studied the implementation of lean in the red meat industry in the UK, while Perez et al. [39] presented lean application in the pork sector. Dora et al. [12] presented a successful application of lean sigma methodology in a medium-sized confectionary (ginger bread) company. Lehtinen and Torkko [29] presented a case study of a company operating as a contract manufacturer in the food industry. Finally, Jimenez et al. [26] presented the implementation of lean, particularly value stream mapping (VSM), to the wine production sector of Rioja.

Although the confectionary, chocolate, and meat sectors are more advanced than bakery, packaged fruits, and vegetable sectors, with respect to the implementation of quality management tools and techniques [11], no article related to the application of lean to the chocolate industry or nougat production was found in the literature.

Since little research on the application of lean in food industries is available in the scientific literature, the aim of this study is to expand lean manufacturing's body of knowledge, focusing on the applicability of lean tools to process industries, particularly in a seasonal chocolate industry. Consequently, several lean tools were applied to an important SME company from the chocolate industry in South America.

The structure of the paper is as follows. In Section 2, the theoretical background of lean manufacturing will be briefly introduced. A brief description of the methodology and the different methods used during the case study are presented in Section 3. The results from applying each of the lean techniques are presented in Section 4. A discussion of the results and conclusions are presented in Sections 5 and 6, respectively.

2 Theoretical background

Lean provides opportunities for a positive and fulfilling working environment for employees because of their involvement in and ownership of problem-solving and improvement activities, more diversified work functions requiring varied skills and abilities, and increased cross-functional and inter-organizational functions [55]. Furthermore, lean manufacturing is positively associated with market and financial performance [18, 24, 56].

Many of the tools and techniques of lean manufacturing have been widely used in manufacturing. However, applying all tools at once generally leads to only chaos and unsustainable efforts. The large set of lean tools is a collection of solutions for various problems that have accumulated over decades. The problem is that companies do not know the weight, the sequence, and the order in which to implement the lean changes [8].

In the next section, the theories behind the most important lean tools used in the case study are presented.

2.1 Value stream mapping

One of the latest contributions of the lean production movement is the development of the VSM technique [22, 45]. This is a visual tool that analyzes the complete material and information flow from the delivery of raw materials to the sales (or output) of the product, and it then analyzes the time used, the flow of information, and the percentage of time that adds value to the customer [42]. This analysis provides details of the current operational state within the enterprise as well as a framework for improvement activities. Through the analysis of its value stream (chain), a company can determine customer demand and provide value-added activities in order to meet customer demand.

The value chain is defined as the set of activities (both value added and those that do not add value) needed to move a product through the production flow, i.e., from raw material to the customer. There are three different types of flow within the value chain [42]:

1. Flow of materials, from the reception of raw materials from suppliers to the final delivery of the product to the customer;
2. Flow of information, which supports and directs the flow through the processes or operations from the processing of materials to the finished products;

3. Flow of people and processes, which support the other two flows. It is necessary for the other two flows to work and not stop production. The third type is generally examined through a motion study.

Unlike most process mapping techniques that often document only the basic product flow, value stream mapping also documents the flow of information within the system [49]. First, a visual representation is drawn of each of the processes in the material and information flow from the customer to the supplier. After that a "future state" map of how value should flow is drawn. The key benefit of value stream mapping is that it focuses on the entire value stream to find system wastes and tries to avoid the pitfall of optimizing some local situations at the expense of the overall optimization of the entire value stream [52].

Some applications of VSM have been published in the literature, though it is most frequently applied in highly automated process or in assembly environments [1, 3, 7, 20, 32, 33, 41, 43].

2.2 Overall equipment effectiveness

Overall equipment effectiveness (OEE) is an equipment efficiency indicator that was developed by Nakajima [36] and bases its values on three elements: quality, availability, and performance. The objective of the OEE is to numerically describe production effectiveness through a simple and clear overall metric. Managers appreciate such an aggregate metric rather than many detailed metrics [28].

OEE can be used for the value stream or individual workstations. Within the OEE, there are three key types of production losses: quality, availability, and cycle time. Nakajima [36] posited six main causes for a reduction in valid operating time: defects and reworks, start-up losses, idling and minor stoppage, speed reduction, breakdowns, and setups and changeovers. Figure 1 illustrates how these six main losses are grouped.

In addition, the preceding groups of losses define three basic indicators: availability, performance, and quality, which lead to an expression for the OEE.

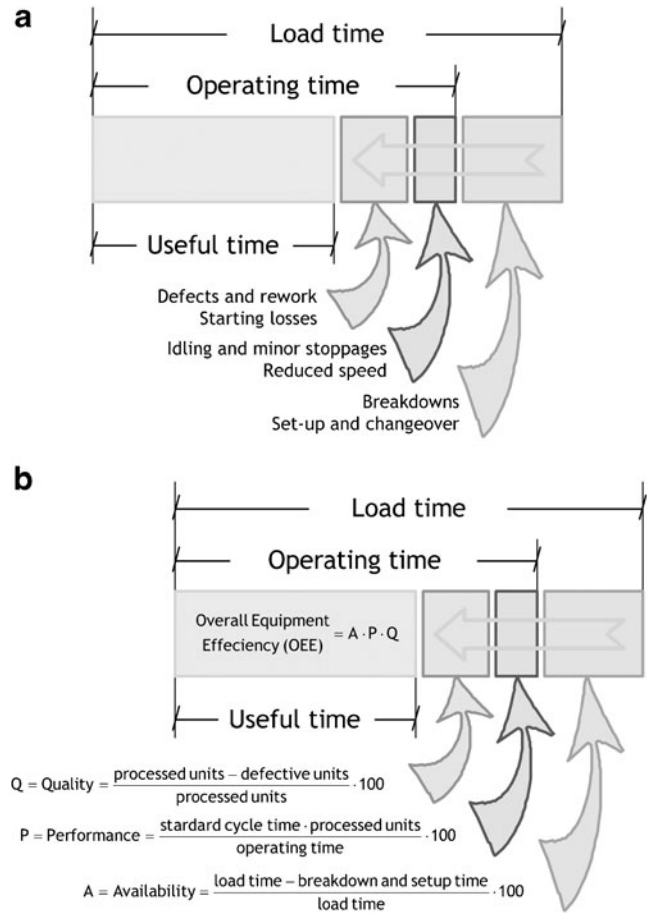


Fig. 1 Grouping causes to obtain the useful time (**a**) and the three main rates (**b**)

2.3 Work balance and time study

Work balance involves balancing the assignment of operations to workstations so that idle time and the number of people working on the line are minimized [32]. A prerequisite for a line balancing analysis is to know the standard amount of time necessary for each task, which is generally obtained through a time study. A time study can be defined as the methodology used to determine the amount of time a qualified operator needs to carry out a specific task, working at a normal pace throughout a day [44]. The time standard is essential management information that applies to manufacturing and office work [57]. A time study provides information that can be used to minimize idle time and balance the production line. Defining standard time can be useful for scheduling production, setting a standard for incentive systems based on worker productivity, comparing different work methods, optimizing the number of workers required to follow a schedule, and meeting production costs [44].

2.4 Spaghetti diagram

The spaghetti diagram is a simple yet powerful tool for visualizing movement and transportation [52]. Such diagrams are a well-established tool that looks for more effective layouts [6]. When the transportation paths are plotted, it is often easy to spot opportunities to reduce waste in movement. In this case study, the spaghetti diagram was used to follow and draw worker movements in order to try to find unnecessary movements that could be eliminated. Moreover, analyzing the current situation may be useful for comparing it with proposed improvements.

3 Case study

A case study was carried out at an SME chocolate company in the Mercosur region.[1] The aim was to improve the productivity of their nougat production processes through the application of lean tools in the plant. The production process has a seasonal nature, since the products are consumed only for a few days a year, during Christmas period. The project was carried out over a period of 6 months, during which time several initiatives using lean tools were undertaken.

The tools used in the project were selected according to their immediate usefulness to the company. Therefore, commonly implemented tools such as Poka-Yoke and single-minute exchange of die (SMED) were discarded since they did not address the top issues of the company. The tools that were applied in this case study were VSM, OEE, work balance, time study, spaghetti diagrams, and discrete event simulation.

We decided to start with a VSM since it shows an overview of the nougat production value chain and helps identify opportunities for improvement. Then, the OEE metric was chosen because the VSM showed that the bottleneck was located at the cartoner, a machine that could not reach the expected efficiency levels. The OEE helped identify the causes of this problem, which was useful for helping the company determine what element had low efficiency and consequently take action to mitigate it. Afterwards, an analysis and time study was applied in the kitchen area (where the nougat is produced) because the bottleneck in the production line moved there once the efficiency of the cartoner improved. Some of the improvement ideas resulting from the tools used were tested in the field to corroborate the findings. Finally, a future state VSM was developed. Since the future VSM state cannot be easily evaluated in some situations, Abdulmalek and Rajgopal [1] recommend forecasting the future situation with simulation. Therefore, discrete event simulation was used. Although this is not strictly a lean tool, in the present case it was considered useful for modeling and studying the behavior of the potential improvements in the nougat production before their actual implementation. In this way, the options that did not exhibit the desired characteristics could be ruled out without having to test them in practice, saving the costs and complications they would have entailed [33]. The simulations were also used as a means of verifying the results of the experiments carried out during the case study.

3.1 Value stream mapping application

The first tool that was applied was a "door to door" VSM of the nougat production process. The entire nougat production process can be considered as a single product family, since it goes through similar processing steps and is used with common equipment in the downstream processes [7]. We decided to start with VSM since it shows an overview of the nougat production value chain and helps identify opportunities for improvement. The purpose of VSM is to identify process improvement at the system level.

Figure 2 shows the VSM resulting from the analysis of the current (initial) nougat production situation.

The current state VSM shows the following process: The nougat dough obtained from the pot is then used in the so-called kitchen so that after several processes nougat bars are obtained. It is cooled to ambient conditions, and then, it can be dipped in chocolate and directly packaged by flowpack machines. After this, the nougat bar is placed inside a cardboard case. The latter two processes are carried out with machinery, while the processes in the kitchen are manual.

These processes have different levels of inventory, both in terms of raw materials and packaging materials, as well as nougat in various stages of production. These inventories were expressed in days by dividing the number of items over daily demand. Converting process and inventory into a time measure makes it possible to construct the time line included at the bottom of Fig. 2, which is strictly related to the lean concept of takt-time. This German word refers to precise cycle time, rhythm, or interval, and it also refers to a conductor's baton moving in time with the music. Takt-time is calculated by dividing customer demand into available working time per shift.

There were several explanations for the high levels of inventory in this company. For example, much of the raw material had to be purchased in large quantities so as to supply the entire season with a single order because providers cannot provide smaller amounts to better fit this SME's needs. Because of this, inventory reduction of the raw materials and packaging material was not emphasized. However, the reduction of work-in-process (WIP) and finished product was within the scope of this project, and therefore, we aimed to reduce it.

A metric that measures the efficiency of a company in delivering value added, the work cycle efficiency (WCE), is easily obtained from the VSM [5]. WCE can be defined as the amount of value-adding time divided over the total cycle time.

Leaving the stocks of raw materials aside, the WCE for the situation at the beginning of the study was extremely low, 1.12 %. This means that the rest of the time, that is, 98.87 %, did not add value to the final product. This metric also indicates where attention should be directed in order to significantly improve the percentage of value-added time. Consequently, the value stream map allowed us to identify the major nonvalue-added steps and conclude that the days of stock of nougat bars generated prior to running the stock through the cartoner machine have the most influence on the

[1] Economic and political agreement among Argentina, Brazil, Paraguay, Uruguay, and Venezuela.

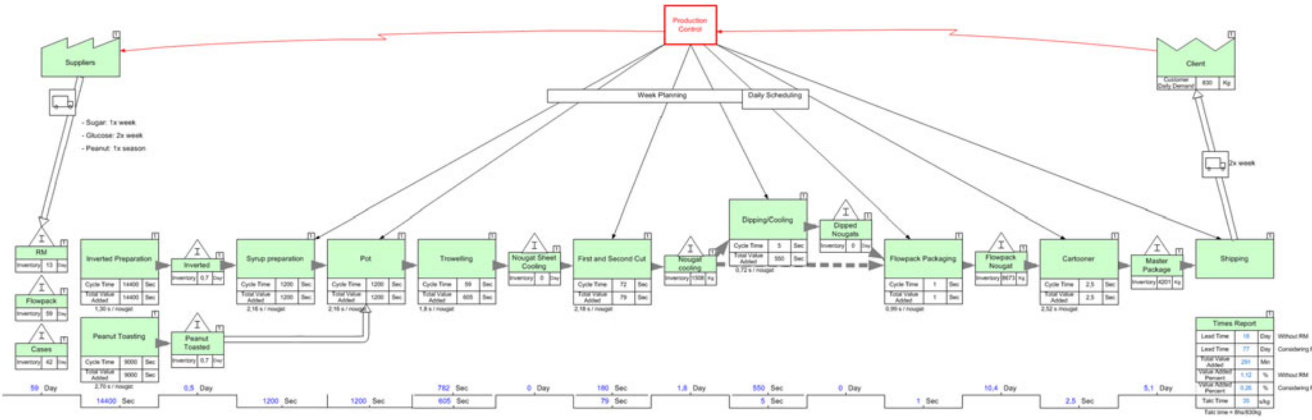


Fig. 2 Current state VSM

WCE. Moreover, as mentioned by Singh et al. [49], the VSM was useful in identifying the bottleneck, since the existence of high levels of nougat bar stock that accumulated prior to the cartooning stage was evidence that the bottleneck was at the cartoner. Therefore, an analysis of this machine was done.

3.2 Analyzing the cartoner with overall equipment effectiveness

Due to the high inventory levels prior to the cartoner machine detected in the VSM, we decided to run a more in depth study of the cartoner to find the root causes. The company was aware that there were some problems with this machine and they were interested in knowing its real productivity. To study the efficiency of the cartoner, the OEE metric was used.

In order to calculate performance for the cartoner, a theoretical cycle time had to be established, which was defined as 2.4 s per nougat. This value was based on information provided by the company, which stated that the expected cycle time was 25 nougat bars per minute.

In order to calculate the OEE in this situation, certain criteria had to be defined. It was assumed that planned production time equals the difference between the first and last time that an operator was allocated to the machine by his supervisor. Another assumption had to be taken into consideration because the nougat case supplier printed on the carton fiber in the wrong direction, and the cartoner had problems with its conformation. As a result of this, the carton had to be prefolded by hand as it was found that it helped the conformation in the machine. The time spent at the beginning of the day preparing the machine and at the end of the day putting the work area into order was considered to be preparation and therefore reduced availability. The time spent changing the product or batch is considered a stop, which also reduces availability.

Figure 3 shows the evolution of the cartoner's OEE.

The average values for the period were Q=98.9 %, P=64.0 %, and A=89.9 %, while the world class values defined by [36] are Q=99 %, P=95 %, and A=90 %. It can be seen that both the quality and availability of the machine are close to target levels. However, performance is the element that is detrimental to the OEE. Therefore, we decided to analyze this indicator in greater depth in order to determine the main causes of this initial conclusion.

3.2.1 Further analysis of cartoner performance

Initially, the effect of case quality and the number of operators on the performance metric was studied, obtaining a 20 and 28 % effect respectively, as explained later. However, we decided to study how production was affected by these two factors together. A general linear model (GLM) was used to analyze this issue.

Taking the OEE performance metric as the dependent variable, the following independent variables were analyzed through GLM:

- Day: Chronological number of day, i.e., from days 1 (first day of casing) to 34 (last day)
- Workers: Amount of workers for the cartoner (two or three operators). The extra operator was generally included to prefold the cases.
- Case quality: Cases were classified into three categories that took the abovementioned printing issue into consideration. Poor quality cases were called 1, brand X were called 2, and good cases were called 3.

A first model that included first- and second-order interactions was obtained with Minitab® using these variables, considering "day" as a covariate. In order to improve this model, interactions were eliminated since interactions were highly insignificant. Consequently, a second model without these interactions was obtained (Table 1). Finally, residuals were checked by obtaining the usual graphs (Fig. 4).

Results presented in Table 1 confirm that case quality and the number of workers do have a significant impact on the performance metric. However, since no significant interaction exists on their impact on performance, it can be

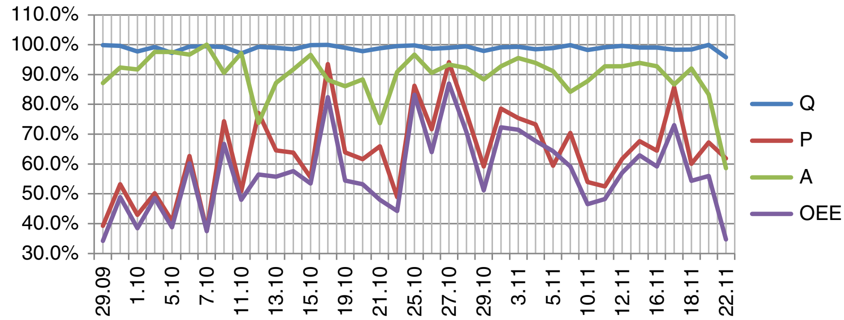


Fig. 3 Evolution of OEE

assumed that both effects can be added linearly. This means that the improvement in performance due to the presence of three workers (20 %, obtained from the preliminary study) may be added to the improvements of using good cases (28 %, obtained from the preliminary study). Therefore, the use of good cases and three operators means an improvement of about 48 % compared to the performance when using two operators and bad quality cases. These improvements significantly improve the performance metric and consequently the overall equipment efficiency.

3.3 Kitchen analysis

In a chain, there can only be one weakest link in each independent network, and this determines how much the network can produce [40]. Gains made in OEE, while important and ongoing, are insufficient. It is necessary to focus one's attention beyond the performance of individual tools and towards the performance of the whole factory [35]. Efforts to reduce waste can in itself be a waste, which is something of even greater importance in SMEs [40]. Once the cartoner was analyzed and improved, the results were soon apparent since the WIP upstream decreased and the bottleneck moved to the kitchen production process. This calls to mind the fifth step of the theory of constraints [19], "If the constraint has been broken up, go back to identify the new system constraint." A formal analysis that considered the productivity of both the cartoner and kitchen processes confirmed the hypothesis that the cartoner was no longer the bottleneck and that it had moved to the kitchen.

Therefore, the production in the kitchen needed to be studied, starting with an analysis based on the information obtained from the production control registers. A GLM was applied to the production information, and the analysis was carried out with Minitab® software.

The number of kilograms produced daily was defined as the response (dependent variable). The factors included in the analysis were:

- Total hours: Covariate that represents the total amount of workforce hours dedicated to production on that day, e.g., if only there were two workers that day, and one worked 6 h and the other worked 7 h, the total hours equal 13;
- Day of the week: Categorical variable to deal with the day of the week. 1=Monday, 2=Tuesday, 3=Wednesday, 4=Thursday, 5=Friday;
- Nougat size: Categorical variable that considers the different products produced according to size (or weight). The company offers three different sizes: 1=Small, 2=Medium, and 3=Large. Large nougat bars were not considered in the analysis, since their production is minimal and there were no data for large nougat production for each day of the week.

A first model that included first- and second-order interactions was obtained with these variables, taking "Total hours" as a covariate. Results are shown in Table 2, and analysis residuals are shown in Fig. 5.

In the graph in the lower right part of Fig. 6, an increase in the residuals can be observed as time increases. Because of

Table 1 GLM analysis for performance (*P*) metric

Source	DF	SS	SS adjusted	MS adjusted	*F*	*P*
Day	1	0.03949	0,01317	0.01317	0.35	0.555
Workers	1	0.70571	0,79226	0.79226	21.20	0.000
Quality	2	0.67196	0,67196	0.33598	8.99	0.000
Error	66	2.46615	2,46615	0.03737		
Total	70	3.88331				
S=0.193303		R^2=36.49 %		R^2 (adjusted)=32.64 %		
Term		Coefficient	Coefficient of EE	*T*	*P*	
Constant		0.68153	0.05114	13.33	0.000	
Day		−0.001482	0.002496	−0.59	0.555	

DF degrees of freedom, *SS* sum of squares; *SS* adjusted; *MS* mean sum of squares adjused

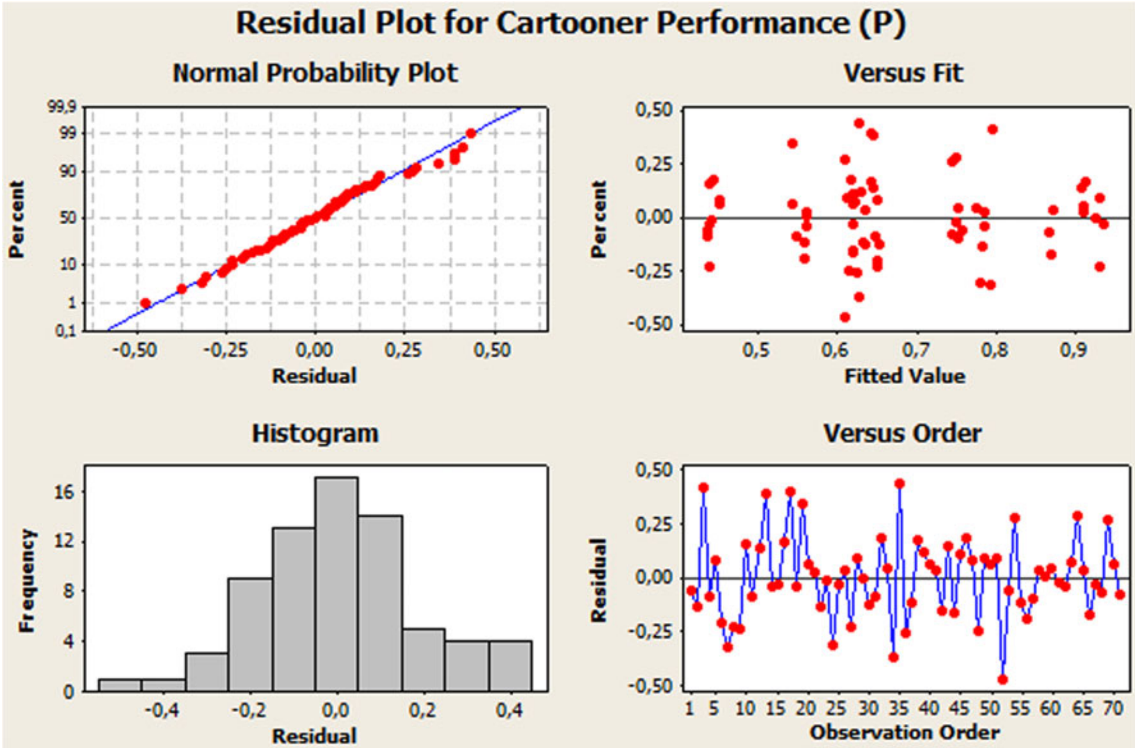


Fig. 4 Residuals

this trend, we decided to add a new variable to the analysis, the "Time" effect. This ordinal variable represents the days, where 1 is the first day of production and 86 the last day. This effect could be initially explained by workers learning their tasks, with productivity increasing as they gain experience.

Therefore, a new GLM model was obtained by considering first- and second-interactions and by considering "Time" and "Total hours" as covariates. In order to improve this model, highly insignificant interactions (p value>0.1) were eliminated. Consequently, a second model without these interactions was obtained (Table 3). Finally, the residuals shown in Fig. 6 present no clear pattern, thus validating the results.

To sum up, from this analysis we can firstly conclude that the experience/training of operators has a visible effect on production because the number kilograms produced per day increases over time. It was also observed that the size of the nougat (small and medium) bar appears to have no significant effect on production.

3.3.1 Work balance

From the aforementioned results, it was observed that there is a strong correlation between production (kilograms) and operator performance. In order to increase productivity at the bottleneck, a more study in depth was needed to analyze the inefficient processes of each worker involved in the kitchen area in order to balance work and production.

Work balance refers to a situation where all the operators along the production line require the same length of time to perform their tasks. In an ideal situation, the work content is distributed evenly between workstations in a way that meets the takt-time.

The first step in a balancing study is to study the work of each operator in greater detail and design a time study. Once the time study is carried out, a balancing diagram can be constructed with these data, as shown in Fig. 7. Once the balance chart is constructed three things can be seen at a glance [52]: how much time is wasted, the degree of balancing achieved, and the bottleneck for the section studied. In this case study, we considered only value-added activities and those standardized and planned nonvalue-added activities (NVA). Therefore, only necessary NVA, mainly workers movements, were included.

From Fig. 7, we can see that there is a huge percentage of worker cycle time that is wasted, since the real cycle time is greater than the foreseen bottleneck. Most of this waste is from waiting for the previous process to be finished. In particular, we detected a significant waiting time for between-batch intervals at activity 1.

3.3.2 Spaghetti diagrams

While the time study was carried out, spaghetti diagrams of the main operations in the kitchen were drawn. Making spaghetti diagrams consists of getting a layout diagram of

Table 2 ANOVA for production (kilograms), utilizing SS adjusted for tests

Source	DF	SS	SS adjusted	MS adjusted	*F*	*P*
Hours	1	239,7670	132,924	132,924	2.35	0.130
Day	4	143,082	494,405	123,601	2.18	0.080
Size	1	8,738	59,171	59,171	1.05	0.310
Day × hours	4	149,718	362,723	90,681	1.60	0.184
Size × hours	1	10,204	66,416	66,416	1.17	0.282
Day × size	4	595,633	595,633	148,908	2.63	0.042
Error	68	3,848,284	3,848,284	56,592		
Total	83	7,153,328				
S=237,892	R^2=46.20 %		R^2 (adjusted)=34.34 %			
Term	Coefficient	Coefficient of EE	*T*	*P*		
Constant	320,2	350.6	0.91	0.364		
Hours	5,330	3,478	1.53	0.130		
Hours × day						
1	4,052	5.090	0.80	0.429		
2	2,906	3,200	0.91	0.367		
3	3,052	2,896	1.05	0.296		
4	−2,388	2,969	−0.80	0.424		
Hours × size						
1	−3,524	3,253	−1.08	0.282		

DF degrees of freedom, *SS* sum of squares; *SS* adjusted; *MS* mean sum of squares adjusted

the area and tracing the physical flow of the products (or workers) in question on the diagram. This allows the movements made by each operator to be studied, which in turn shows opportunities for improvement. Figure 8 shows the spaghetti diagrams for two different workers doing the first cut and trowelling activity.

Through the analysis of this diagram, it was concluded that several of these movements could be reduced by

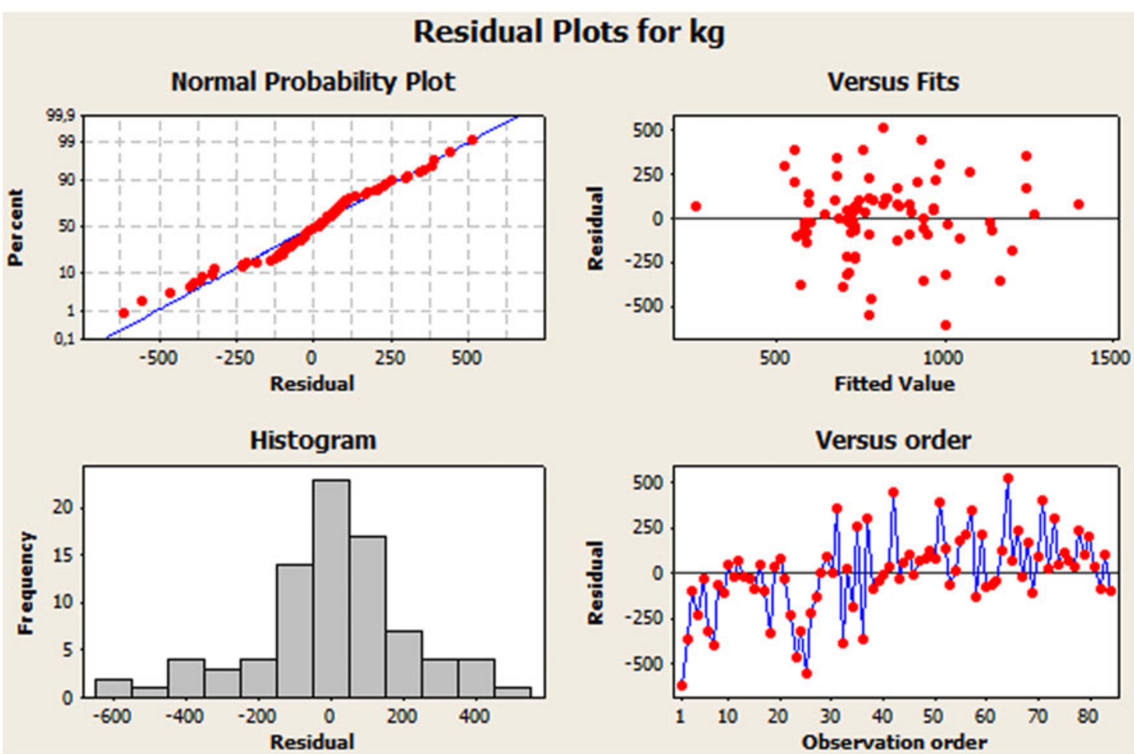


Fig. 5 Residuals

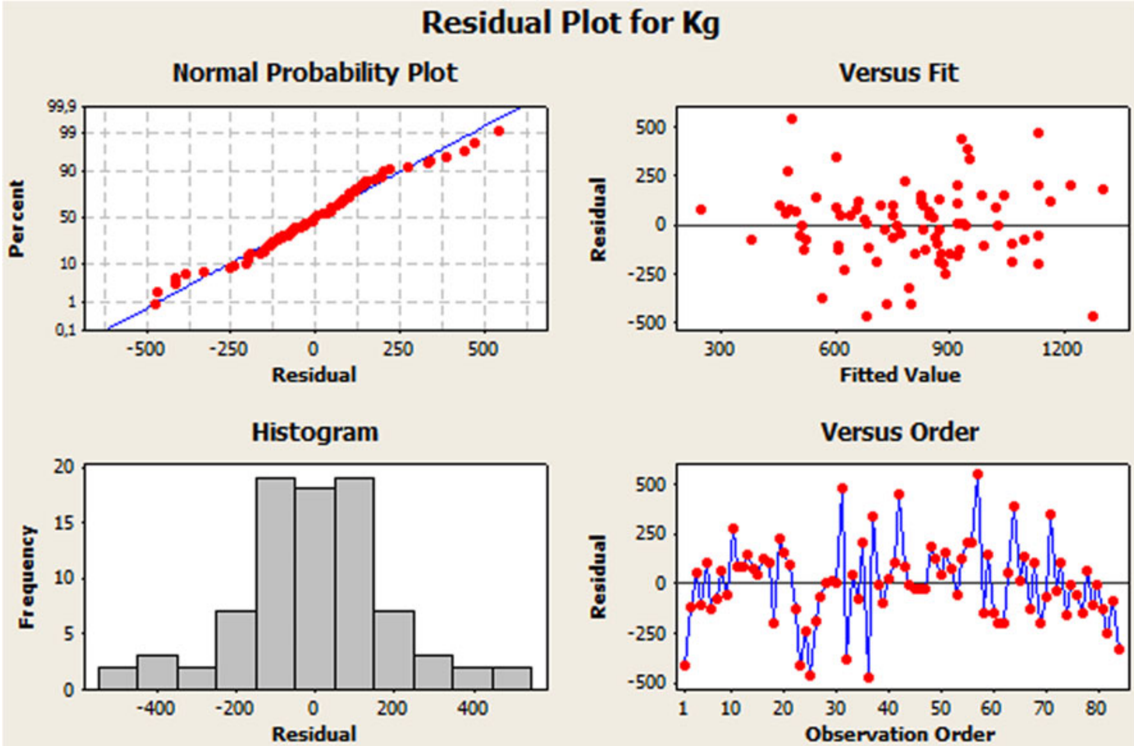


Fig. 6 Residuals

improving the layout. A new layout was proposed and tested in the experimentation stage.

3.4 Experimentation

The improvements observed from the time study and spaghetti diagrams were implemented as a trial. The improvements to be tested in the trial experiment had to be chosen so that they could be implemented with the available resources, i.e., without introducing any new equipment or making major modifications. It must be remembered that since the production is seasonal, the experiment was carried out near the end of the production timeline. Ideally, given that the main concept underlying improvement suggestions is that the product should flow (preferably in a U type), the product should move rather than the workers. However, this solution would have required changes to equipment, and the fact that making such big changes would have delayed the experiments and been physically impossible given the production timeline, the extent of the improvements that could be implemented were limited. Given the above constraints, two improvements were tested. The first was a change in

Table 3 ANOVA for production (kilograms), utilizing adjusted SS for tests

Source	DF	SS	SS adjusted	MS adjusted	*F*	*P*
Time	1	964,223	1,008,841	1,008,841	22.46	0.000
Total hours	1	2,443,714	1,768,861	1,768,861	39.37	0.000
Day	4	153,009	311,067	77,767	1.73	0.153
Size	1	731	38	38	0.00	0.977
Day × size	4	356,992	356,992	89,248	1.99	0.106
Error	72	3,234,658	3,234,658	44,926		
Total	83	7,153,328				
S=211,957	R^2=54.78 %		R^2 (adjusted)=47.87 %			
Term	Coefficient	Coefficient of EE	*T*	*P*		
Constant	−184.2	142.8	−1.29	0.201		
Time	4.4196	0.9326	4.74	0.000		
Total hours	8.564	1.365	6.27	0.000		

DF degrees of freedom, *SS* sum of squares; *SS* adjusted; *MS* mean sum of squares adjused

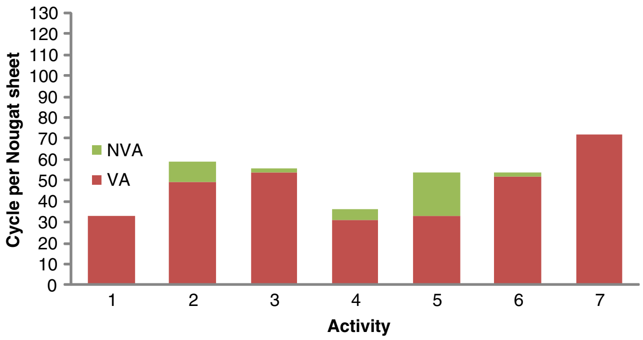


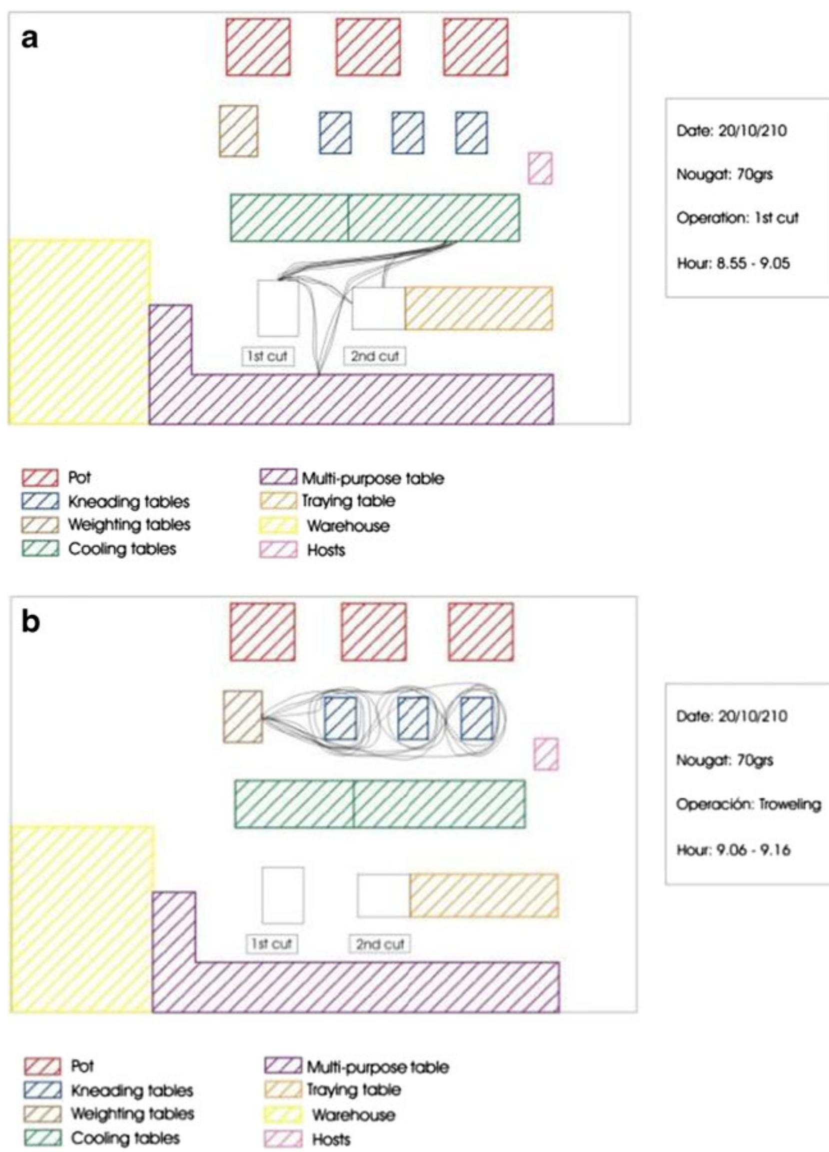
Fig. 7 Work balance diagram

the distribution of work among operators (work balance), and the other consisted of a change in layout in order to reduce worker transit. Each improvement was examined separately.

The first improvement was to have the worker who assigned to the first cut also be doing the weighing activity (activities 1 and 4 in Fig. 7). The worker released from activity 1 was allocated to the bottleneck section (second cut). As a result of this first experiment, a 56 % improvement in cycle time was observed. Theoretically, 17 % of this improvement can be attributed to the transfer of the bottleneck to an activity that has a smaller cycle time. Another cause of the improvement could be the fact that the workers' pace increased because they knew they were being observed and probably felt anxiety because one of them had been relocated. An increase of 33 % could be attributed to this cause [44].

In the second experiment, we changed the layout of the kitchen section. Figure 9 shows the flows for the initial layout and the proposed layout. This change sought to increase productivity by reducing transport times and increasing flexibility with the U-shaped flow.

Fig. 8 Spaghetti diagram. **a** First cut. **b** Trowelling



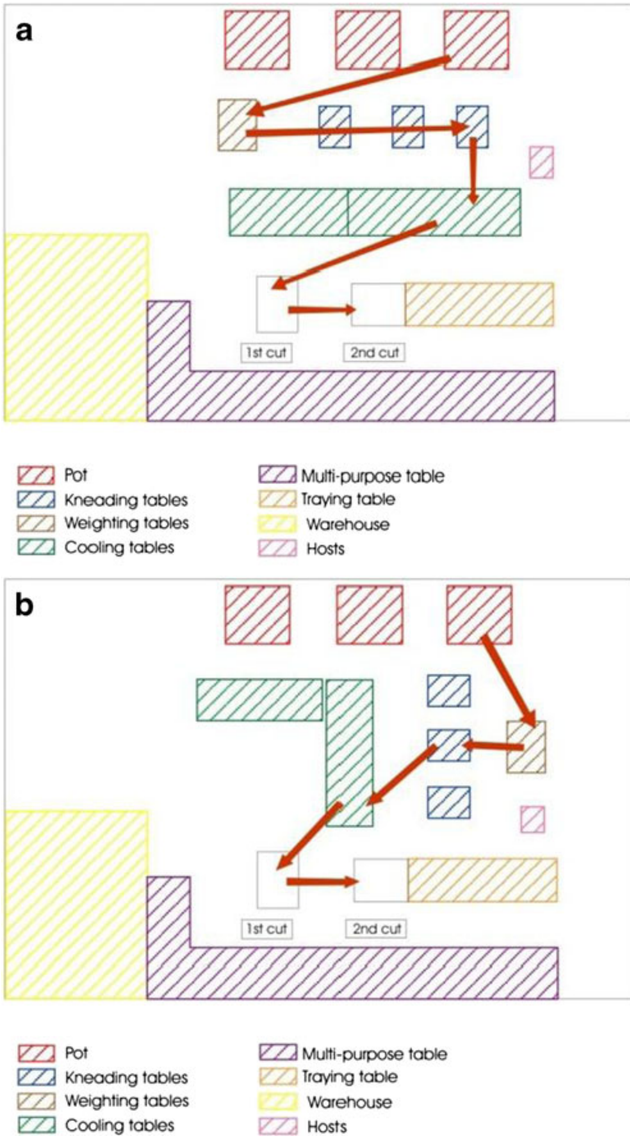


Fig. 9 **a** Initial layout. **b** Proposed layout

The experiment resulted in a 40 % improvement in productivity. As shown in Figure 9, the flow changed from being a zigzag path to being more similar to a U-shaped path. To improve the U-flow, it was proposed that the raw materials warehouse, located at the bottom left of the diagram, be moved. Unfortunately, it was not possible to make this change during the experimentation.

Throughout the experiment, it was observed that with the proposed layout operators had to move less. Anecdotally, a worker noticed a decrease in the distance and told another worker that "it was good to walk less." Another important effect was that due to the new layout an operator could provide support to the bottleneck, reducing cycle time. Figure 10 shows the spaghetti diagrams for the two activities under study, where the improvement provided by the new layout can be appreciated (see Fig. 8).

In the experimental setup for the first cut worker (Fig. 10a), it can be observed that the distances that the operator must repeatedly travel are fewer. The worker's movements are to take the nougat "sheet," cut it, and then take it to the second cutter. With the change in layout, the decline in travel is mainly due to the relocation of the cooling table. According to an MTM table, a reduction of 2 m per cycle time in the new layout could reduce the cycle of this activity by more than 1 s.

In the initial spaghetti diagram of the trowelling activity (Fig. 8b), it can be seen that the movements to the weighing table are frequent since the operator must carry the dough from weighing table to the kneading table. These distances are particularly long for the table furthest from the weighing table. To remedy this, it was proposed that the three tables be moved so faced the weighing table, thereby reducing the

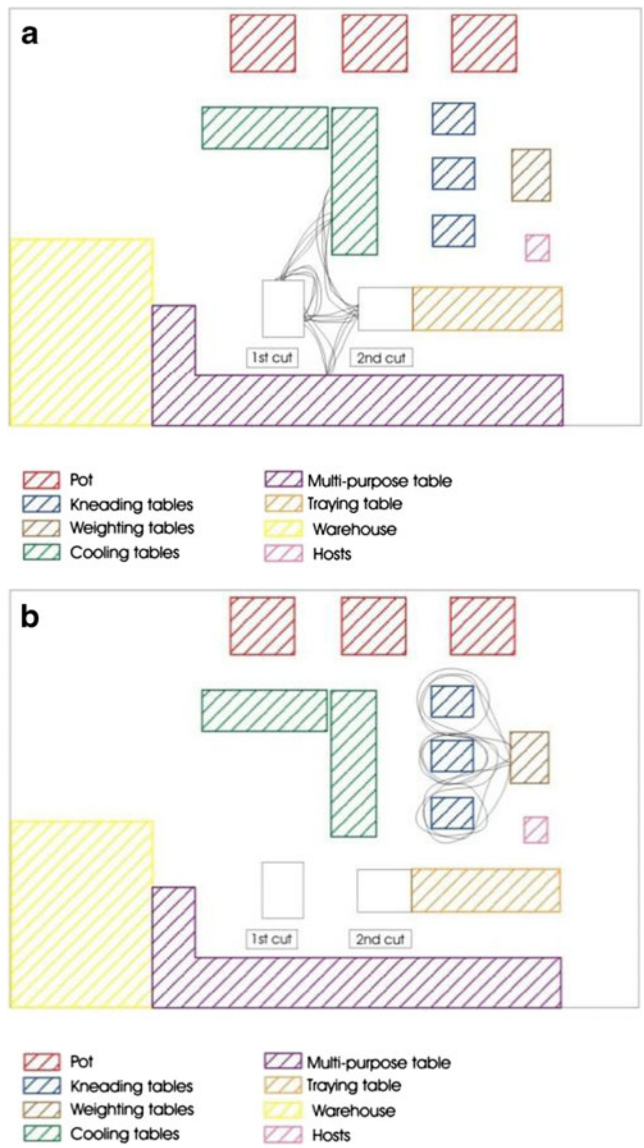


Fig. 10 Experiment spaghetti diagram. **a** First cut. **b** Trowelling

distances. Considering the case of the more distant operator, we can approximate that the distance traveled from the weighing table to the kneading table is about 6 m. With the new layout, it is estimated that this distance decreased to 2 m. This means that in the case of trowelling on the farthest table, the cycle time could be reduced by about 2.5 s. Spaghetti diagrams were drawn for other activities, but no clear improvements in distances could be observed.

To sum up, from the results of these two experiments it cannot be concluded that by implementing these improvements productivity levels will invariably increase to 40 or 56 %. However, there will be a significant increase in productivity, since the bottleneck will move to an activity with lower cycle time and operators will have more opportunities to collaborate and product movement will become more efficient.

3.5 Simulation of nougat production in the kitchen

Considering the seasonality of the process, in order to verify the results obtained above, the nougat production process was simulated with Arena® discrete event simulation software. A model for the initial system was first modeled, and it was later modified to model the proposed future state. This simulation allows for the handling of uncertainty and the creation of dynamic views of intermediate inventory levels, machine efficiencies, and the different time measures [1, 46]. Enhancing VSM with simulation is important for providing information that cannot be provided by using VSM alone given its static nature [30, 33].

The data obtained from the time study were used as input for the duration of each activity. Normality tests were performed with Minitab® software, and they showed that the durations of the different activities follow a normal distribution.

The number of kilograms produced daily in the simulation differed from the real values by 6 %. The cycle time value obtained from the simulation is 23 % less than the value calculated from the production data. The differences could be explained by the fact that the average cycle time calculated from the production data includes inefficiencies and production stops. It was estimated that the nougat spends about the same amount time waiting that it spends in adding value activities. Another interesting result is that the average processing time per nougat is 32 min. As the results from the simulator are quite close to reality, it can be considered that the model sufficiently replicated the real system.

3.5.1 Simulating the experiments

Once the initial systems were modeled, we validated the results from the experiments carried out in the kitchen. Remember that, due to seasonality, it was possible to experiment only during a limited period of time. Therefore, both of the improvements described in Section 3.4 were introduced into the model and evaluated with the same parameters as in the real experiments. This approach provides quantification of the expected benefits that could be obtained by implementing the proposed improvements.

In comparing the cycle time that was calculated using the model with the baseline, for the first experiment the improvement was 19 %. In the second experiment, productivity improved by 27 %. It can be concluded from the results of the simulation that the improvements obtained in the experiments are reasonable and that the model confirmed the improvements. Some possible explanations for the differences between the trails and the simulation are that it was not feasible to introduce certain inefficiencies into the model and that the effect of observing workers was not present in the simulation.

4 Results

The future state VSM is presented as a summary of all the improvements identified (Fig. 11):

Comparing future state lead time with the current state VSM, an expected decrease from 18 to 3 days can be observed. This significant improvement of 15 days is mainly obtained through lower WIP inventories before reaching the cartoner and lower finished product inventories waiting for delivery. This reduction in lead time could easily translate into lower financial costs and lower inventory management costs. Moreover, the future state VSM shows a major improvement, though not yet sufficient, in the WCE metric. Since the value added time remained constant and lead time was reduced, the improvement in WCE went from the initial 1.12 to 6.23 %

As shown in Fig. 11, several improvement initiatives were selected and stated in the future state VSM. Firstly, in order to reduce finished product inventories, we proposed daily shipments of the finished product to customers, so the stock would decrease from 5 to 0.5 days. This should not change transports cost, since the daily necessity of nougat and other products is greater than truck capacity.

Another improvement aimed at reducing inventory levels is to define customer sales earlier on and therefore define the packaging and products needed to fulfill requirements. This idea is feasible, since most sales in the seasonal product industry are based on the previous year's consumption. This improvement will allow the nougat bars to be put in their casing previously, without generating the excessive flowpack WIP that was observed at the initial status of the company.

It was then established that the flowpack packager must work twice a day for nougat production, generating two batches that the cartoner machine can handle in half a day.

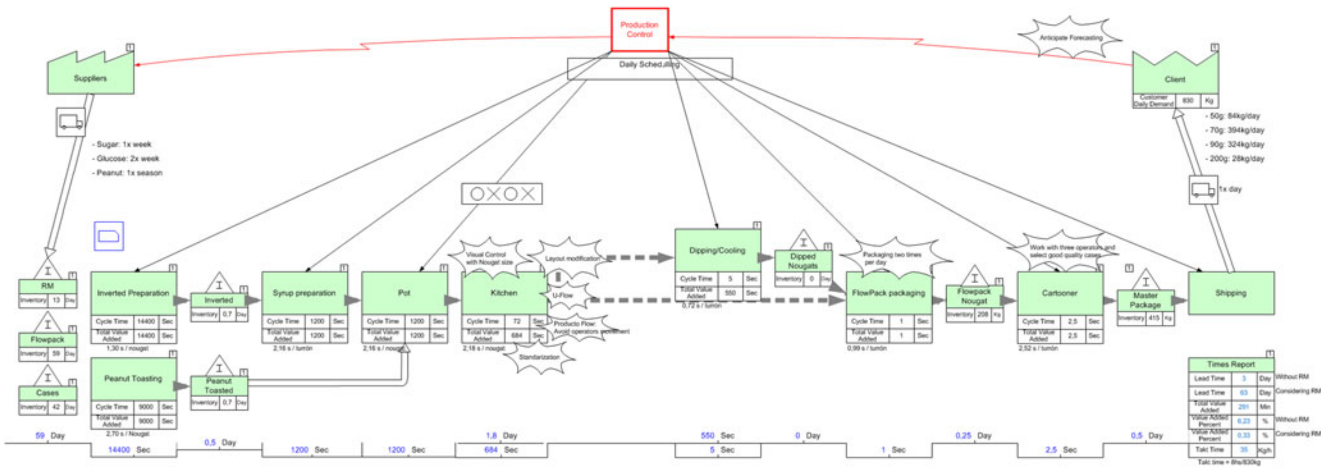


Fig. 11 Future state VSM

Thus, the inventory of nougat bars in the flowpack could fall from 10.4 to 0.25 days on average.

As a result of the time study carried out in the kitchen, we can conclude that the variability in the processes is very high, so their standardization through a method study or automation is recommended. Another point that should be improved is the flow between the pot (where the nougat dough is made) and the subsequent processes. It turns out that the entire line must stop on a regular basis because there is no nougat dough to work with, causing great losses in productivity. To overcome this, it was suggested that neural networks be introduced, which could help solve the problem through an efficient control of the pot and thus avoiding discontinuities in flow.

From the time study and the experimentation, it can be seen that it was possible to improve productivity by reallocating labor and improving layout. Ideally, the process flow would form a "U," thus providing greater flexibility in adapting to changes in demand or in producing the nougat in the case that operators are absent, something that is particularly important to this company where absenteeism rates are high. Thus, they must find the way to move the product and not the workers. This could be done mechanically by using rails to move the tables. The advantage would be that the operators would walk less and they would work at the pace imposed by the line. It was also observed from the time study and spaghetti diagrams that the amount of time dedicated to movement is considerable and that it could be reduced in a variety of ways, such as decreasing the distances as well as making the nougat move (instead of the workers).

Regarding the cartoner, it can be concluded from various studies that it is necessary to solve the problem of the quality of the carton used for the cases since they have an effect on the efficiency of the machine. It was also concluded that a third operator working at the cartoner has a real effect on performance improvement.

5 Discussion

VSM has proved to be an original and practical tool, with many attributes for improving production systems [45, 49], namely simplicity, systemic vision, bottleneck detection, and the possibility of being the starting point of a strategic improvement plant, among many others. Moreover, the DBR (drum–buffer–rope) method used in the theory of constraints is an interesting area, as shown in this case study, that could contribute to VSM enhancement [45].

Several improvements were identified, and most of them are from a theoretical perspective of rapid deployment and low cost. However, it should be clarified that their application in practice can prove difficult. This is because in many cases the improvements involve a change in the way people work, unlike other types of improvements that are rarely resisted, such as the purchase of new machinery. These types of changes are often resisted at various levels of the company and therefore must be applied with conviction so as to not abandon them and fail in their implementation, which is a common problem in lean implementations [15]. Companies often make the mistake of implementing lean, thinking that it is only a method of production, but it will not work unless it is used as a general management system [15]. The transformation to a lean enterprise should be a strategic approach that is intended to allow an enterprise to outperform its rivals, based on the manner in which it plans, organizes, and executes its activities [8].

There is a gap between the theory as proposed in VSM and the level of usage in real word applications. Serrano et al. [45, 46] state that VSM theory should be strengthened in certain areas. In the case study, several difficulties were encountered in implementing VSM. Firstly, it was necessary to decide which units to use, since VSM requires expressing each of the processes in a single measure. For this reason, when evaluating the various tasks that are involved in the value chain, it was observed that each used a unit of measure that was different from previous or subsequent tasks. Another important factor for the graphic representation of the initial state of VSM is to be able to quantify the time required in each of the tasks. The tool used for this was the time study, which was essential to accurately quantify the duration of each of the tasks. One of the particularities of this VSM is the bifurcation that occurs when the nougat is dipped in chocolate. This is something that is not normally present in the VSM, where the value chain is usually always linear. As suggested by McDonald et al. [33], a critical path was used to analyze VSM. Finally, the VSM future map was analyzed through computer simulations. Since VSM is a static tool that cannot describe dynamic behavior and cannot handle either complexity or uncertainty [30], introducing simulation for the future state should help to overcome these difficulties in several applications.

Furthermore, while large enterprises are able to provide the necessary resources and expert know how to configure and implement lean, SMEs lack these essential resources for organizational, technological, and workforce-related changes [2, 10, 11, 25, 47]. Even if companies know that they need to improve their operations, they may not know where to start the lean journey [50]. The key barriers encountered by food SMEs in the implementation of lean manufacturing practices results from the special characteristics of the food sector [13, 14]. However, several aspects of SME organizational characteristics can be seen as positive for a lean initiative, such as the great flexibility and high impact of the individual on company performance [4].

In order, to select a lean toolbox for seasonal process industries, companies should focus on the five lean principles mentioned by Womack and Jones [54]:

1. *Specify value*: There is a critical need for lean firms to rethink value because this is often the key to finding more customers, and the ability to find more customers and sales quickly is crucial for success. Value can only be defined by the final customer. TRIZ and value analysis through Gemba walks could be used as tools for this purpose.
2. *Identify the entire value stream*: Tools are oriented to distinguish value from waste. The real purpose of mapping is to design the future state, since mapping and analysis without action is waste. Several tools are useful, including seasonal process for mapping and assessment of process [6], while value stream mapping is the most common one.
3. *Make the remaining value-creating steps flow continuously*: Make value flow. While flow thinking is easy to see in conventional discrete-product manufacturing, similar principles could be applied to any activity. In the process industry, material flow is determined by the batch size and it is not possible to propose a one-piece flow in the same conditions as is done for assembly lines, although companies must continuously seek to reduce their batch size and any obstacles in the way. Therefore, there are many movements, involving workers that can be analyzed by using tools such as spaghetti diagrams, 5S, motion study, visual management, etc.
4. *Let customers pull value from the enterprise*: Pull refers to the short-term response to customer rate of demand, and not over producing. In demand chains, this should be the final customer, not distorted by the intermediate “bullwhip” effect. There are several mechanisms for pull: Kanban, Conwip, DBR, etc.
5. *Seek for perfection*: Perfection does not mean only defect free: it means delivering exactly what the customer wants, exactly when the customer wants, at a fair price and with minimum waste [6]. Lean is a never-ending journey of continuous improvement. The main set of tools that focus on increasing effectiveness and efficiency, tools such as SMED, Poka-Yoke, TPM, and Jidoka, any of which could be applied in any type of company.

Consequently, applying lean manufacturing to process industries is not straightforward. Inevitably, effective application and utilization of lean manufacturing within SMEs will be delayed or may not be achieved at all unless SMEs restructure their focus to becoming more receptive and capable of absorbing new ideas [2]. Considering seasonal food production adds a new constraint to lean tools, but mainly in solution implementation. Therefore, the modifications introduced to lean manufacturing tools mentioned in this case study should be useful for helping managers overcome those difficulties in their companies.

6 Conclusions

This case study showed that although process industries need a special version of lean manufacturing tools, there are several lean manufacturing tools that can be applied in the traditional seasonal craft industry without special modification. The aim of this project was to study the applicability of lean tools to the chocolate industry, rather than implementing lean in the whole company. During the case study, several techniques and analyses were applied and performed, i.e., VSM, OEE, spaghetti diagrams, work balance, and discrete event simulation. This case study presented promising improvements primarily in lead time and work cycle efficiency.

Although this paper presented a novel case study at a SME in the food sector and in a seasonal process industry, one important limitation of this research and its findings is that is based on a single case study experience.

There are several areas for future research and applications that build on the work described here. One is to apply and implement further lean manufacturing in process industries and thus discover which adaptations are necessary for the management system. Another is to develop a lean toolbox in order to increase lean application in process industries, especially those dealing with seasonal production. Finally, further theory is needed to understand the difficulties SMEs can face when implementing lean and, in particular, within VSM to deal with the dynamic behavior of production processes and to encompass their complexity.

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References

1. Abdulmalek F, Rajgopal J (2007) Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study. Int J Prod Econ 107(1):223–236
2. Achanga P, Shehab E et al (2006) Critical success factors for lean implementation within SMEs. J Manuf Technol Manag 17(4):460–471
3. Alvarez R, Calvo R et al (2009) Redesigning an assembly line through lean manufacturing tools. Int J Adv Manuf Technol 43:949–958
4. Bakas O, Govaert T et al (2011) Challenges and success factors for implementation of lean manufacturing in european SMES. 13th International Conference on the Modern Information Technology in the Innovation Processes of the Industrial Enterprise. Tondheim, Norway, NTNU Engineering Series 1
5. Ballis JP (2001) Managing flow: achieving lean in the new millennium to the gold. Brown Brooks, Dallas
6. Bicheno J, Holweg M (2008) The lean toolbox. PICSIE Books, Buckingham
7. Braglia M, Carmignani G et al (2006) A new value stream mapping approach for complex production systems. Int J Prod Res 44(18–19):3929–3952
8. Cil I, Turkan Y (2013) An ANP-based assessment model for lean enterprise transformation. Int J Adv Manuf Technol 61:1113–1130
9. Cox A, Chicksand D (2005) The limits of lean management thinking: multiple retailers and food and farming supply chains. Eur Manag J 23(6):648–662
10. Chiarini A (2012) Lean production: mistakes and limitations of accounting systems inside the SME sector. J Manuf Technol Manag 23(5):681–700
11. Dombrowski U, Crespo I et al (2010) Adaptive configuration of a lean production system in small and medium-sized enterprises. Prod Eng Res Dev 4:341–348
12. Dora M, Kumar M et al (2012) Lean sigma implementation framework for food processing SMEs: the case of a Belgian confectionary. 6th International Conference on Decision Sciences for Performance Excellence, Hyderabad, India
13. Dora M, Kumar M et al (2013) Application of lean practices in small and medium sized food enterprises. Br Food J (in press)
14. Dora M, Kumar M et al (2013) Food quality management system: reviewing assessment strategies and a feasibility study for European food small and medium-sized enterprises. Food Control 31(607–616)
15. Emiliani B (2007) Real lean: understanding the lean management system. The Center for Lean Business Management, Wethersfield
16. Floyd RC (2010) Liquid lean: developing lean culture in the process industries. Taylor and Francis, New York
17. Fuentes J, Rodríguez C et al (2007) Designing food supply chains: an application of lean manufacturing and lean supply chain paradigms to the Spanish egg industry. European Association of Agricultural Economists, Innsbruck-Igls
18. Fullerton RR, Wempe W (2009) Lean manufacturing, non-financial performance measures and financial performance. Int J Oper Prod Manag 29(3):214–240
19. Goldratt E, Cox J (1992) The goal. North River Press, New York
20. Grewal C (2008) An initiative to implement lean manufacturing using a value stream mapping in a small company. Int J Manuf Technol Manag 15(3–4):404–417
21. Higgins K (2006) State of food manufacturing: the quest for continious improvement. Food Eng 78(9):61–68
22. Hines P, Rich N et al (1998) Value stream management. Int J Logist Manag 9(1):25–42
23. Hoeft S (2010) Stories from my Sensei. Productivity Press, New York
24. Hofer C, Eroglu C et al (2012) The effect of lean production on financial performance: the mediating role of inventory leanness. Int J Prod Econ 138(2):242–253
25. Huang B, Li C et al (2013) Cloud manufacturing service platform for small and medium-sized enterprises. Int J Adv Manuf Technol (in press)
26. Jimenez E, Tejeda A et al (2012) Applicability of lean production with VSM to the Rioja wine sector. Int J Prod Res 50(7):1890–1904
27. Kumar CS, Panneerselvam R (2007) Literature review of JIT-KANBAN system. Int J Adv Manuf Technol 32:393–408
28. Kuo Y, Lin K (2010) Using neural network and decision tree for machine reliability prediction. Int J Adv Manuf Technol 50:1243–1251
29. Lehtinen U, Torkko M (2005) The lean concept in the food industry: a case study of contract a manufacturer. J Food Distrib Res 36(3):57–67
30. Lian Y-H, Van Landeghem H (2007) Analysing the effects of Lean Manufacturing using a value stream mapping-based simulation generator. Int J Prod Res 45(13):3037–3058
31. Liker J (2004) The Toyota way. McGraw-Hill, New York
32. Liu C-M, Chiang M-S (2009) Systematic lean techniques for improving honeycomb bonding process. Advanced concurrent engineering. Springer, New York, pp 267–269
33. McDonald T, Aken EM et al (2002) Utilising simulation to enhance value stream mapping: a manufacturing case application. Int J Logist Res Appl 5(2):213–232
34. Melton T (2005) The benefits of lean manufacturing: what lean thinking has to offer the process industries. Chem Eng Res Des 83(A6):662–673
35. Muthiah K, Huang SH et al (2008) Automating factory performance diagnostics using overall throughput effectiveness (OTE) metric. Int J Adv Manuf Technol 36:811–824
36. Nakajima S (1988) Introduction to TPM: total productive maintenance. Productivity Press, New York
37. Ohno T (1988) Toyota production system. Productivity Press, New York
38. Pattanaik LN, Sharma BP (2009) Implementing lean manufacturing with cellular layout: a case study. Int J Adv Manuf Technol 42:772–779
39. Perez C, de Castro R et al (2010) Development of lean supply chains: a case study of the Catalan pork sector. Supply Chain Manag Int J 15(1):55–68

40. Piratesh RM, Fox RR (2011) Profitability with no boundaries. ASQ Quality Press, Milwaukee
41. Ramesh, Kodali (2012) A decision framework for maximizing lean manufacturing performance. Int J Prod Res 50(8):2234–2251
42. Rother M, Shook J (1999) learning to see: value stream mapping to add value and eliminate MUDA. The Lean Enterprise Institute, Cambridge
43. Sahoo AK, Singh NK et al (2008) Lean philosophy: implementation in a forging company. Int J Adv Manuf Technol 36:451–462
44. Santos J, Wysk R et al (2006) Improving production with lean thinking. Wiley, New York
45. Serrano I, de Castro R et al (2009) Extent of the use of Lean Concepts proposed for a value stream mapping application. Prod Plan Control 20(1):82–98
46. Serrano I, Ochoa C et al (2008) Evaluation of value stream mapping in manufacturing system redesign. Int J Prod Res 46(16):4409–4430
47. Shah R, Ward P (2003) Lean manufacturing: context, practice bundles, and performance. J Oper Manag 21:129–149
48. Simons D, Taylor D (2007) Lean thinking in the UK red meat industry: a systems and contingency approach. Int J Prod Econ 106:70–81
49. Singh B, Garg SK et al (2011) Value stream mapping: literature review and implications for Indian Industry. Int J Adv Manuf Technol 53:799–809
50. Srinivasaraghavan J, Allada V (2006) Applications of mahalanobis distance as a lean assessment metric. Int J Adv Manuf Technol 29:1159–1168
51. Stone K (2012) Four decades of lean: a systematic literature review. Int J Lean Six Sigma 3(2):112–132
52. Wilson L (2010) How to implement lean manufacturing. McGraw Hill, New York
53. Womack J, Jones C (2005) Lean solutions: how companies and customers can create value and wealth together. Free Press, New York
54. Womack J, Jones D (2003) Lean thinking: banish waste and create wealth in your corporation. Free Press, New York
55. Womack J, Jones DT et al (1990) The machine that changed the world: the story of lean production. Free Press, New York
56. Yank MG, Hong P et al (2011) Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms. Int J Prod Econ 129:251–261
57. Zandin KB (2001) Maynard's industrial engineering handbook (5th edn). McGraw-Hill, New York
58. Zokaei K, Simons D (2006) Performance improvements through implementation of lean practices: a study of the UK Red Meat Industry. Int Food Agribus Manag Rev 9(2):30–53