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Time and motion study applied to a production line of organic lenses in Manaus Industrial Hub

Produção de lentes orgânicas no Pólo Industrial de Manaus

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Abstract: This article presents a case study on the utilization of the time and motion technique applied to a production line of organic lenses in a multinational company located in Manaus Industrial Hub (PIM), Amazonas state, Brazil. The goal of this study is to enable insertion of five-minute breaks every production hour, maintaining productivity without changing the demand or increasing the operators' workload. Specifically, the main time and motion techniques were utilized in order to optimize operations, identifying value-added and non-value-added activities, and wastes. The case study describes the company's current scenario, proposed situation, data treatment, and results.

Keywords: Time and motion study; Organic lenses; Operation optimization; Wastes.

Resumo: *Este artigo apresenta um estudo de caso sobre a utilização da técnica de tempos e métodos aplicado em uma linha de produção de lentes orgânicas de uma empresa multinacional, localizada no Pólo Industrial de Manaus, Amazonas. O objetivo deste artigo é viabilizar a inserção de pausas de cinco minutos a cada uma hora de produção, mantendo a produtividade sem alterar a demanda ou aumentando a carga horária dos operadores. De forma específica, utilizou-se as principais técnicas de tempos e métodos para otimizar as operações, identificando atividades agregadoras ou não de valor, além de desperdícios. O estudo de caso descreve a situação em que se encontra a organização, a situação proposta, o tratamento de dados e os resultados obtidos.*

Palavras-chave: *Tempos e métodos; Lentes orgânicas; Otimizar operações; Desperdícios.*

1 Introduction

The competitiveness of the market develops a continuous search for improvement on processes, products and services in all organizations. In case a company doesn't focus on reducing costs and assuring the quality of what it provides, its survival on the market is compromised. In this context, the concept of lean manufacturing and its tools, which aim to reduce all types of waste within a company, is highlighted.

Lean manufacturing emerged within the Toyota Production System, with the goal of trying to eliminate the seven wastes: overproduction, waiting, transportation, incorrect processing, inventory, motion and defects. Through this philosophy, companies started classifying operations as value-added or non-value-added, always looking for process optimization. To help achieve this goal, auxiliary tools were developed, such as the time and motion study. This article is dedicated to the application of a time and motion study, by means of chrono-analysis and classification of tasks in value-added, non-value-added and waste in a line of organic lenses of a French multinational company located in Manaus Industrial Hub.

The present study is composed of introduction, theoretical foundation, methodology, case study and final considerations. Emphasizing the demonstration of the case study results after the application of the time and motion study, showing a comparison between the previous and the future situations, in order to show the effectiveness of the studied methodology.

2 Theoretical foundation

2.1 Lean manufacturing and the seven wastes

The lean manufacturing emerged in Japan after World War II. By that time, Toyota Motor Company was facing daunting challenges in terms of finances, technology and labor relations, like many other Japanese companies. Eiji Toyoda and the engineer Taiichi Ohno came to the conclusion that mass production would not suit Japan at that conjuncture.

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Therefore, they created a system that made virtue out of necessity. According to Werkema (2012), *Lean Manufacturing* is an initiative that seeks to eliminate waste, excluding what does not add value to the customer and transmitting speed to organizations.

The competitiveness of the market makes the price a variable controlled by the consumers. The consumer, more powerful than ever, has a large variety of choices, unprecedented access to information, and is demanding excellent quality at a reasonable price. Therefore, companies need to discover new ways to reduce their costs in order to be able to maximize their profits. For that goal, the Toyota Production System, as its main virtue, promotes intense attack to the wastes of the processes, always encouraging the involvement of employees in the improvement processes.

According to the principles of lean manufacturing, there are three types of work that can be identified in production or service provision processes:

a) Value-added: It's all work that modifies the product. In other words, it's work for which the end customer is willing to pay;

b) Non-value-added: It's work that does not modify the product, the customer does not pay for it, but it's necessary for the manufacturing and quality assurance of the product. It has to be minimized;

c) Waste: It's work that does not add value to the product, because the customer does not pay for it, and it's also not necessary for manufacturing and/or quality assurance. It should always be avoided.

According to Mayer et al. (2015, p. 180),

> The work can be divided into work that adds value and work that does not add value. The work that does not add value can be considered a waste. On the other hand, work that adds value is the one that involves processing to change or transform the product or the assembly thereof. It should also be considered that work that does not add value can be necessary, due to the characteristics of the machines and processes.

Also according to Mayer et al. (2015), the wastes are characterized as all the production elements that do not add value to the final product, increasing costs, being repetitive and unnecessary, and must be eliminated.

Toyota has identified the seven major types of non-value-added activities to business or manufacturing processes, which will be described below. They are applicable not only to the production line, but also to the development of new products, the making of orders and decisions, and to office activities:

a) Overproduction: Producing items sooner or in larger quantities than the customer needs. Producing sooner or in larger quantities than needed generates other losses, such as costs with excess personnel, storage and transportation due to excessive inventory. The inventory may be physical or a set of information;

b) Waiting: Workers serving merely as watchmen of an automated machine or having to wait for the next stage of processing or tool, supply, part, etc. Or, simply, not having work due to lack of inventory, processing delays, equipment downtime and capacity bottlenecks;

c) Transportation: Moving work in process from one place to another, even if it's only a short distance. Moving materials, parts or finished goods to stock or to withdraw them from stock between processes;

d) Incorrect processing: Performing unnecessary activities or tasks to process the parts. Inefficient processing due to poor quality of tools or product design, causing defects or unnecessary motion;

e) Excess inventory: Excess of raw material, work in process or finished goods, causing longer lead times, obsolescence, damaged goods, costs with transportation, storage and delays. In addition, the excess inventory hides problems, such as imbalances in production, delayed deliveries by suppliers, defects, equipment downtime and long setups;

f) Unnecessary motion: Any motion the employees have to make during their work period that do not add value to the part, such as locate, search or stack parts, tools, etc. In addition, walking is also a waste;

g) Defects: Production or correction of defective parts. Repair or rework, disposal, production for replacement and inspection mean waste of time, handling and effort.

Houts (2016) corroborates, emphasizing that the wastes are traditionally classified in seven: overproduction, waiting, transport, non-value-added processing, excess inventory, motion and defects.

The overproduction is considered the worst of the seven wastes, as it leads to most of the other types of loss. Producing sooner or in larger quantities than needed leads to formation of inventory at some later point in the process and/or the material waits to be processed in the next operation. According to Houts (2016), in addition to the seven wastes, an eighth waste can be added: underutilized people. Underutilized people are resources that have their time spent with inefficient processes or unnecessary waiting times.

2.2 Standardized work, cycle time and *takt* time

Standardized work consists in the safer, easier and most effective way to perform a task. It is about creating a way to have the most consistent performance possible. According to Werkema (2011), the standardization is a very important tool in reducing the variability of a process, as tasks and procedures executed in a standardized way by all operators in a company reduce the chances of having an error in this task or procedure.

The main tools in establishing standardized procedures and processes are standardized work documents and lean manufacturing techniques. The standardized work documents help keep the process consistent, control the process and avoid variation. The lean manufacturing techniques allow the creation of a basis for evaluating tasks, and thus identify opportunities for improvement and avoid errors in the process. In addition to these characteristics, standardized work has other benefits:

1. Clear start and stop points in the process: enables us to easily determine the production condition;
2. Organizational learning: standardized work keeps the know-how and the experience. When an experienced operator leaves, his knowledge is not lost;
3. Training: standardized work provides a basis for the training of employees.

According to Marksberry et al. (2011), the standardized work is not only a documentation or training tool, but a work analysis tool.

Takt time is fundamental for standardizing work, as it defines with what frequency there should be a product output on the line. According to Sabet-Rasekh (2014), *takt* time is the production rate of a process. According to Wang et al. (2014), *takt* time is a function that determines how fast a process has to be in order to meet the customer demand. In terms of calculation, it is the time available to produce parts in a specific time interval divided by the number of parts demanded in that interval. For Sabet-Rasekh (2014), *takt* time is commonly associated to the cycle time. While the first is based on the customer's need, the second represents the production capacity of that process.

Generally, an operation balance chart is used to show how cycle times compare to *takt* times. It can be utilized to clarify doubts about process capacity. In case the cycle times of operations do not show great variation, it means the line's activities are well balanced and standardized.

2.3 Time and motion study

The time and motion study provides techniques to analyze in detail an operation or task, measuring which activities add value and how to minimize and eliminate the ones that don't add value or are considered a waste. Through time and motion study of a manufacturing process, it is possible to calculate its capacity and increase its efficiency and productivity, making the organization more competitive to the point of having lower production costs, offering a quality product at a lower price to the customer.

By utilizing the time and motion study, a better way to perform the operations of a process can be developed. To each operation, standard motions and times are assigned, which must be followed so that the organization finds better results in the market in which it operates. According to Souto (2002), Methods Engineering studies and analyses work in a systematic way, aiming to develop practical and efficient methods, seeking the standardization of the process.

The data processing for the standard time calculation follows 3 steps:

1. Sample size calculation - the ideal sample size is calculated through an equation, which will be exemplified in section 4.2.1 of this article;
2. The observed times are multiplied by the rating factor, and the value found is called normal time. The rating factor is determined by the observer himself, where:

   $V>100\%$ - Rating above normal;

   $V=100\%$ - Normal rating;

   $V<100\%$ - Rating below normal.
3. The normal times found are multiplied by the allowance factor of each operation - the allowance factor is a value corresponding to the existence of an allowance for personal needs, fatigue, waiting and break time.

There are several ways to calculate the rating and the allowance factors of an activity. To make the determination less subjective, the Westinghouse system, as seen on the Tables 1 and 2 below, is utilized.

The Westinghouse system analyses four conditions to determine the rating and the allowance factors:

skill, effort, environmental conditions a consistency. Thus, the factors are different for each operation of the production line.

2.4 Process flowchart

Process flowchart is a modeling and simulation tool that aims to list all phases of a productive process, allowing quick visualization and understanding, facilitating its analysis. According to Juran (1990), the flowchart is the most effective way to identify the customers and track the product and see what's affected by it.

For Paladini (2012), the flowchart makes it possible to create a common understanding, clarify the steps in a process, identify opportunities for improvement (complexity, waste, delays, inefficiency and bottlenecks), reveal problems in the process and reveal how it operates.

Table 1. Westinghouse rating factor system.

	Skill			**Effort**	
0.15	A1	Superskill	0.13	A1	Excessive
0.13	A2		0.12	A2	
0.11	B1	Excelent	0.10	B1	Excelent
0.08	B2		0.08	B2	
0.06	C1	Good	0.05	C1	Good
0.03	C2		0.02	C2	
0.00	D1	Average	0.00	D1	Average
-0.05	E1	Fair	-0.04	E1	Fair
-0.10	E2		-0.08	E2	
-0.16	F1	Poor	-0.12	F1	Poor
-0.22	F2		-0.17	F2	
	Conditions			**Consistency**	
0.06	A	Ideal	0.04	A	Perfect
0.04	B	Excelent	0.03	B	Excelent
0.02	C	Good	0.01	C	Good
0.00	D	Average	0.00	D	Average
-0.03	E	Fair	-0.02	E	Fair
-0.07	F	Basic	-0.04	F	Basic

Source: Adapted from Barnes (1977).

Table 2. Westinghouse allowance factor system.

	Physical effort	**Mental effort**	**Recovery**		**Monotony**	
			% Recovered time	**Factor B**	**Cycle duration (min)**	**%**
Effort	%	%	0-5	1	0 a 0.05	7.9
			6-10	0.9		
Very light	1.8	0	11-15	0.8	0.06 a 0.25	5.4
			16-20	0.71		
Light	3.6	0.6	21-25	0.62	0.26 a 0.50	3.6
			26-30	0.54		
Average	5.4	1.8	31-35	0.46	0.51 a 1.00	2.1
			36-40	0.39		
Heavy	7.2	3	41-45	0.32	1.01 a 2.00	1
			46-50	0.26		
Very Heavy	9	0	51-55	0.2	2.01 a 3.00	0.5
			56-60	0.15	3.01 a 4.00	0.2

Environmental conditions						
Thermal		**Atmospheric**		**Other**		
Temperature	**%**	**Local**	**%**			**%**
0 a 7 °C	3.6	Well-ventilated	0	Noise	Low level	0
8 a 15 °C	1.8	Poorly-ventilated or light smoke	2.4		Requires hearing protection	1.8
16 a 25 °C	0			Humidity	Dry and pleasant environment	0
26 a 34 °C	1.8	Heavy smoke or dust	5.6		High (> 25 ºC)	1.8
35 a 40 °C	3.6			Vibration	Ground or machine	1.8

Source: Adapted from Contador (1998).

According to Greef (2012), the flowchart consists of a momentary image of how the information pervades the functions of the mapped environment. There are several types of symbols utilized in process flowcharts, each one with a different characteristic that changes the way to analyze an activity, it's up to the professional to define which one best fits the studied process.

3 Methodology

3.1 Studied environment

The case study to be presented was performed on an assembly line of organic lenses of a French multinational company located in the city of Manaus, Amazonas. The Manaus plant is certified by ISO 9000 and 14000 and is considered the most productive in the world, with a production superior to 20 million lenses per year. This study took about two months to be performed and counted on the support of the quality and process engineering teams.

3.2 Research characterization

The research consists of a case study, as stated in the previous section. For Gil (2010), the case study is characterized by a deep and exhaustive study of one or a few objects, in order to allow broad and detailed knowledge of it, a practically impossible task to accomplish with other types of design considered. The theoretical foundation was developed through books, scientific articles, magazines and texts published about the subject.

The research's approach is both qualitative and quantitative. According to Llewellyn & Northcott (2007), the qualitative approach focuses on identifying the characteristics of situations, events and organizations. For Terence & Escrivão-Filho (2006), quantitative research allows the researcher to measure opinions, habits, attitudes and reactions through a statistical sample that represents the researched universe.

In regard to its nature, the research is classified as applied, as it has immediate purposes, causing direct effects to the process. Regarding the goals, it's identified as exploratory for having the purpose of obtaining more knowledge about a subject and guiding objectives and methods. As instruments during the research were utilized mainly videos and interviews with people responsible for the process studied. The Table 3 represents a summary of research classification.

4 Case study

The research presented in this article has the goal to show the capacity to increase the productivity of a continuous flow production line by means of a time and motion study of all line operations. Through this research we analyze the *takt time* calculation of a production line, occupation rate of operators, how to identify production bottlenecks, macro and microanalysis of times and proposal of alternatives to eliminate waste.

The case study is divided into three main steps:

1. Identification of the current situation;
2. Increase the line productivity through micro motion study;
3. Increase the production capacity after adding two operators.

The realization of this time and motion study emerged as an opportunity for the company to increase its productivity, reducing the operators' fatigue and effort, and also to adjust to the norms of the Public Prosecution in regard to working time and the number of mandatory breaks per worked hour. Thus, in addition to the points already mentioned, the change in the production schedule with the addition of new breaks during the work time and the manner in which data collection was performed at each station will also be shown.

4.1 Process of manufacturing organic lenses

To manufacture organic lenses, we need: two molds (one concave and one convex), a clip, a plastic gasket and manomer. The organic lenses assembly line works on a pulled and continuous production system, with a standardized work method for each operation. The line operates with two sides, each with its respective conveyor belt, with duplicate stations. It has a total of 22 employees, distributed through its nine operations:

Table 3. Research's characterization.

The research in regard to	Classification of the methodological procedure
Technical procedures	Case Study
Goals	Exploratory
Nature	Applied
Approach	Qualitative and quantitative

Source: Own authorship (2015).

1. Unclipping – The operator removes a tray from a metal structure located inside one of the process ovens, places it on the table, removes the clip from the mold and places it on the conveyor belt. After removing the clip from the mold, he puts it on a holder located above his table, when the holder is full, the operator takes it to the clipping station and empties it, bringing the empty holder back to his workstation. This station has two operators, each working on one of the conveyor belts;

2. Gasket removal machine – This station consists of just an automatic machine. It's responsible for removing the plastic gasket from the mold the operator placed on conveyor belt. There are two gasket removal machines, each located at one of the conveyor belts;

3. Brushing – In this station, the operator receives the mold already without the plastic gasket, holds four molds at a time and, utilizing a simple brush, brushes them to remove the excess monomer that may have leaked from the molds. After brushing, the operator places the mold again on the conveyor belt;

4. Gasket feeding – The operator checks the programming of lenses that will pass through the line, verifies the product reference and supplies the line with a new gasket, next to the respective mold;

5. Assembly – This station is marked by the removal of the lens from the mold. The operator removes the mold and the gasket that has just been fed from the conveyor belt, cleans the gasket with compressed air, removes the lens from inside the mold, inspects the lens placing it against an inspection lamp to check its recording. In case it is identified as a product mixture, it is segregated, in case it isn't identified, it is put back on the conveyor belt. Then, the operator fits the gasket into the mold from which he has removed the lens and puts it back into the process. Composed of four operators, two on each conveyor belt of the assembly line;

6. Inspection – Inspection occurs on 100% of the lenses in the process. The operator removes the lens from the conveyor belt that's passing in front of him at that moment, places it against the inspection lamp located in front of him and checks whether the product is compliant or not. In case it is compliant, the operator places it back on a second conveyor belt positioned next to the one from where the lenses and molds have arrived. In case it's not compliant, the operator removes it from the process and registers the type of defect in the system. The molds conveyor belt goes to the clipping station, while the lenses conveyor belt goes to the organization station. Each inspection station is composed of two operators, each responsible for inspecting one side of the line;

7. Clipping – The operation consists in putting the clips removed from the molds back on them. The operator removes the mold from the conveyor belt, puts the clip back on the mold and puts the mold back on the conveyor belt;

8. Filling – After the mold has the plastic gasket and the clip back, the operator receives it and places it in the filling machine, where monomer is injected into the mold. The operator then places the mold on a tray and when it is full, it returns to the water ovens. There are two filling machines on each side of the line;

9. Lens organization – At the lens organization station, the operator collects the lenses from the process, checks if there is product mixture, registers the quantity of each group in the system and organizes the lenses in trays or baskets.

Below, Figure 1 is a schematic representation in the form of a flowchart with all operations described above.

4.2 Data collection

After describing the operations that make up the organic lenses manufacturing process, the next step is the data collection, where the timing of the cycles of each task will be done and the average times, normal times and standard times will be determined. After the times are calculated, a table is created with the data, taking into consideration the allowance and the rating factors. In addition to the time measurements, information is also collected on the production demand of every shift, number of breaks per shift and their duration.

Chrono-analysis was performed through the use of a recording camera. It is important to emphasize that the use of a camera was preferred instead of a timer because the camera provides a more accurate time analysis, since it is possible to measure time according to the operator's motion. While utilizing the timer, the operation is only observed during the moment in which the time is being measured, besides the greater possibility of errors in the operation of the timer and the time interval lost between the pressing of the button and the end of the operation.

The recordings were adjusted so that one second of recording was composed of 30 frames, thus making the analysis more detailed. The analysis of each cycle was performed in the following way: a table was created with fields to be filled with the frame count when the activity started and when it ended, then the subtraction is divided by 30, giving the final information in seconds. The table also identifies which activities add value to the product and which don't. Initially, seven cycles of each operation were recorded, but only five of each were used, because, normally, one or two measurements that may contain a foreign element in the operation are discarded. Below, the Chart 1 shown model utilized.

Through programming documents, interviews and meetings with those responsible for the production line of organic lenses, it has been identified that it has two shifts with a demand of 9700 lenses. The operators' schedule was also collected and the time worked by the operators was confirmed in practice.

4.2.1 Determination of the number of cycles

After timing the operations, the number of cycles actually required for the time and motion study was calculated using the Equation 1, adapted from Martins & Laugeni (2006).

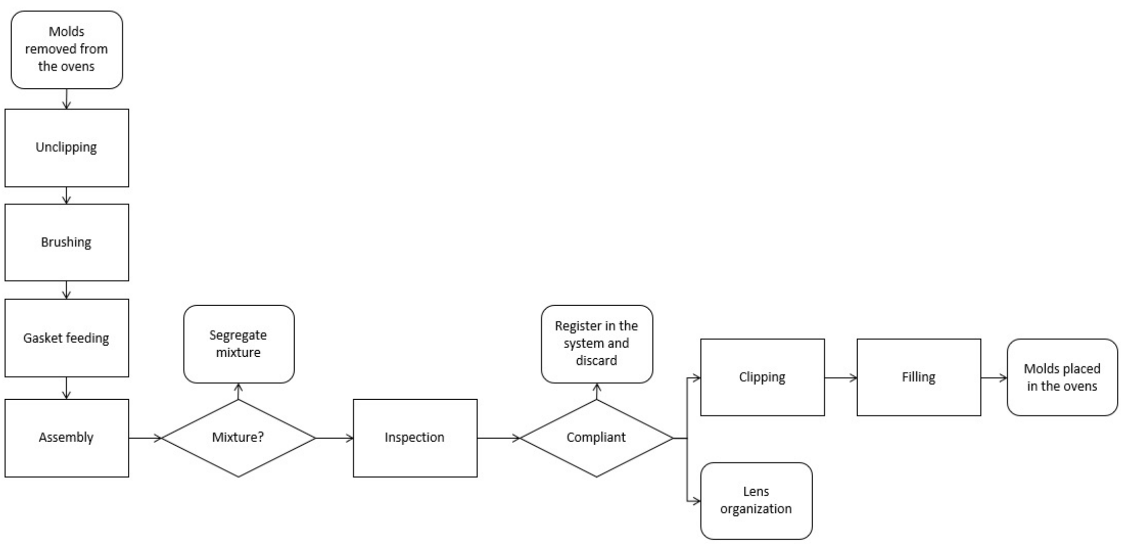

Figure 1. Organic lenses line flowchart. Source: Own authorship (2016).

Chart 1. Operations timing model.

F/S	Cycle time analysis	Value	Cycle 1		
30	**Video name:**	**VA: 1 NVA: 0**	**First**	**Last**	**Frames**
1	Operation 1	0	x1	y1	y1-x1
2	Operation 2	0	x2	y2	y2-x2
3	Operation 3	0	x3	y3	y3-x3
4	Operation 4	0	x4	y4	y4-x4
5	Operation 5	0	x5	y5	y5-x5
6	Operation 6	1	x6	y6	y6-x6
7	Operation 7	0	x7	y7	y7-x7
8	Operation 8	1	x8	y8	y8-x8
9	Operation 9	1	x9	y9	y9-x9
10	Operation 10	0	x10	y10	y10-x10
	Total				Sum

Source: Own authorship (2015).

$$N = \left(\frac{z \, X \, R}{Er \, X \, d2 \, X \, \bar{x}} \right) \quad (1)$$

where: N = number of cycles to be timed; Z = normal distribution coefficient for a given probability; R = sample range; Er = relative error of measurement; d2 = coefficient as a function of the number of preliminary timings; $\bar{x}$ = average value of the observations.

For each operation, the average and the range were calculated, and after that, the number of cycles to be timed (N) was calculated considering a confidence interval of 95% (z = 1.65) and relative error of 5%, due to the high precision of timing allowed by the recording camera. The coefficient as a function of the number of preliminary timings used was 2.326 (five observations), the average and the range of each operation were calculated and are shown on the Chart 2 below.

4.2.2 Normal time and standard time calculation

To calculate the normal time of each activity, it's necessary first to determine the rating factor (V). The rating factor was defined for each operation according to the observations of the director of the time and motion study, being determined, as well as the calculation of the normal time (TN) on the Chart 3 below.

After calculation of the normal time, the allowance factor (FT) of each operation is identified, based on the break time provided by the company per shift and working conditions (fatigue, atmospheric conditions, skill and consistency), in order to calculate the standard time (TP) of each activity. In this case, the company provides 35 minutes of break between the 460 minutes worked. It's important to state that the gasket removal machine's cycle does not enter this calculation, since it has no rating nor allowance factor, as there's no fatigue or the other circumstances considered for the other operations. Thus, the normal cycle time is equal to the standard cycle.

The allowance factor calculation was performed according to the following Equation 2, adapted from Martins & Laugeni (2006).

$$F = \left(\frac{1}{1 - p} \right) \quad (2)$$

where: FT = allowance factor; P = Permissive time.

Below, the Chart 4 with the allowance factor calculated for each of the line operations.

After the allowance factor is calculated for each operation, they are multiplied by their respective normal times in order to obtain the standard time required to perform each activity as can be seen in Chart 5.

Chart 2. Cycle times per operation.

Cycle time analysis (in seconds)									
#	Video:	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Average	R	Ideal number of cycles
1	Unclipping	1.57	1.60	1.40	1.47	1.57	1.52	0.20	5
2	Brushing	1.70	1.99	1.81	1.97	1.90	1.87	1.17	5
3	Gasket feeding	1.72	1.34	1.60	1.71	1.74	1.62	0.80	12
4	Assembly	2.50	2.28	2.49	2.58	2.56	2.48	1.29	3
5	Inspection	1.59	1.33	1.53	1.39	1.30	1.43	0.58	8
6	Clipaping	1.25	1.58	1.50	1.68	1.58	1.52	0.83	16
7	Filling	1.74	1.41	1.43	1.50	1.46	1.51	1.33	10
8	Lens organization	1.96	1.94	2.22	2.06	2.04	2.04	0.56	4

Source: Own authorship (2015).

Chart 3. Calculation of the normal time of operations.

Cycle time analysis (in seconds)				
#	Video:	Average	V	TN
1	Unclipping	1.52	0.01	1.54
2	Brushing	1.87	0.06	1.98
3	Gasket feeding	1.57	0.05	1.65
4	Assembly	2.42	0.04	2.52
5	Inspection	1.46	0.18	1.72
6	Clipping	1.55	0.03	1.60
7	Filling	1.54	0.05	1.62
8	Lens organization	2.05	0.04	2.13

Source: Own authorship (2015).

4.3 Previous situation

From the information on demand and duration of the shift, it was possible to calculate the *takt* time of the line using the Equation 3 and build a diagram with the operators' times, relating the working hours to the break times shown in Figure 2. The operators work about seven hours and forty minutes per shift, have one hour for lunch and 35 minutes divided between gymnastics (five minutes), meetings (ten minutes), and two intervals for personal needs (ten minutes each).

$$Takt\ time = \frac{worked\ time}{demand} = 2.85 \quad (3)$$

With the *takt* time result, it's possible to build a chart with the standard time of each station and verify the production situation at the time of the study, according to Figure 3 below.

The chart shows the times for all operations of the studied line, it is noted that all cycles are in accordance with the takt time needed to meet the demand determined by production shifts. It means that the production of 9700 lenses should be met provided there are no unforeseen events, since with the maximum cycle time of 2.80 lenses per second, it's possible to produce a total of 9857 lenses in one shift.

4.4 Proposed situation

The management proposal, to improve fatigue and decrease the effort of operators during the working hours, was that there should be five-minute intervals

Chart 4. Calculation of the allowance factor of operations.

Cycle time analysis (in seconds)						
#	**Video:**	**Average**	**V**	**TN**	**P**	**FT**
1	Unclipping	1.52	0.01	1.54	8%	1.091
2	Brushing	1.87	0.06	1.98	6%	1.065
3	Gasket feeding	1.57	0.05	1.65	8%	1.089
4	Assembly	2.42	0.04	2.52	7%	1.076
5	Inspection	1.46	0.18	1.72	8%	1.082
6	Clipping	1.55	0.03	1.6	8%	1.087
7	Filling	1.54	0.05	1.62	7%	1.078
8	Lens organization	2.05	0.04	2.13	5%	1.058

Source: Own authorship (2015).

Chart 5. Calculation of the standard time of operations.

Cycle time analysis (in seconds)						
#	**Video:**	**Average**	**V**	**TN**	**FT**	**TP**
1	Unclipping	1.52	0.01	1.54	1.091	1.67
2	Brushing	1.87	0.06	1.98	1.065	2.11
3	Gasket feeding	1.57	0.05	1.65	1.089	1.80
4	Assembly	2.42	0.04	2.52	1.076	2.71
5	Inspection	1.46	0.18	1.72	1.082	1.86
6	Clipping	1.55	0.03	1.60	1.087	1.74
7	Filling	1.54	0.05	1.62	1.078	1.74
8	Lens organization	2.05	0.04	2.13	1.058	2.26

Source: Own authorship (2015).

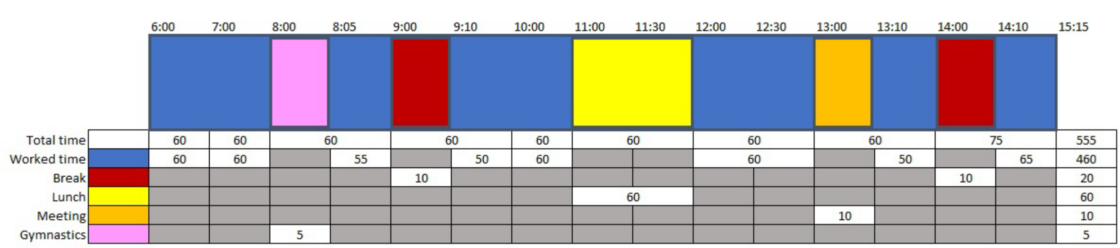

Figure 2. Organic lenses line chronogram. Source: Own authorship (2015).

for each hour of the production shift. Without eliminating the lunch interval in order not to fail to comply with article 70 of the CLT (consolidated labor laws), keeping the five-minute gymnastics break and the daily meeting would take place on one of the breaks. This situation would increase the interval duration from 35 to 40 minutes, reduce the *takt* time of the line from 2.85 to 2.81 parts per second and the maximum production capacity would be 9750 lenses per shift. This way, it would still be possible to meet the production demand during the normal working time, provided no unforeseen events happened during the shift.

Ten-minute intervals for each one hour of the production shift were adopted for caution, since there may be delays in returning from such intervals. This adaptation in the management proposal increases the total interval time to 70 minutes, divided into seven ten-minute breaks (one of them being the daily meeting) and one five-minute break for labor gymnastics. The measure decreased even more the *takt* time of the line, going from 2.85 to 2.65, as can be seen below in chart of Figure 4 and in in the diagram of Figure 5.

Through the chart, it is noticed that the cycles of the operations of removing the gaskets from the molds and the assembly surpass the *takt* time of the line.

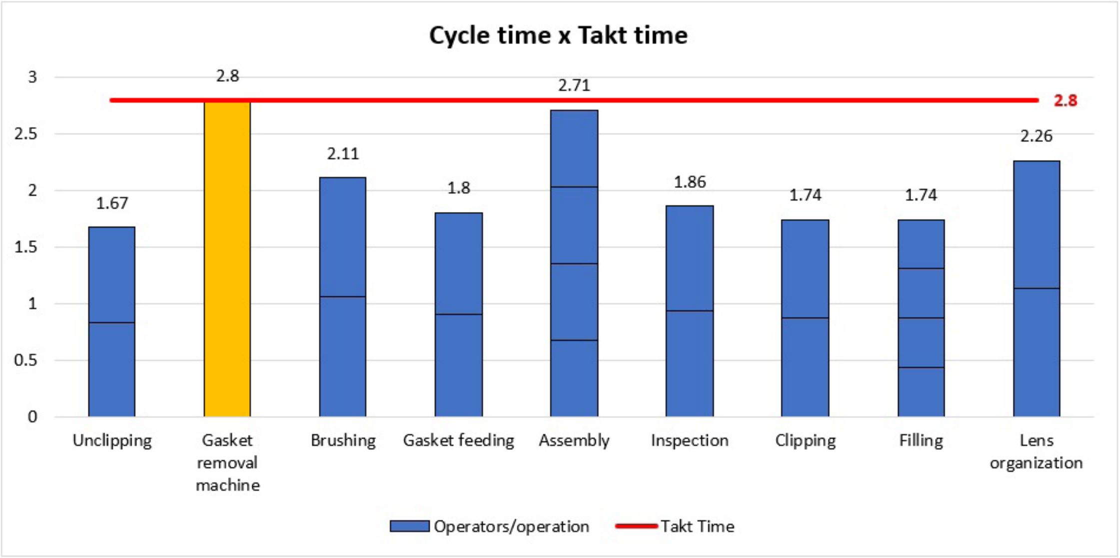

Figure 3. Operation balance chart. Source: Own authorship (2015).

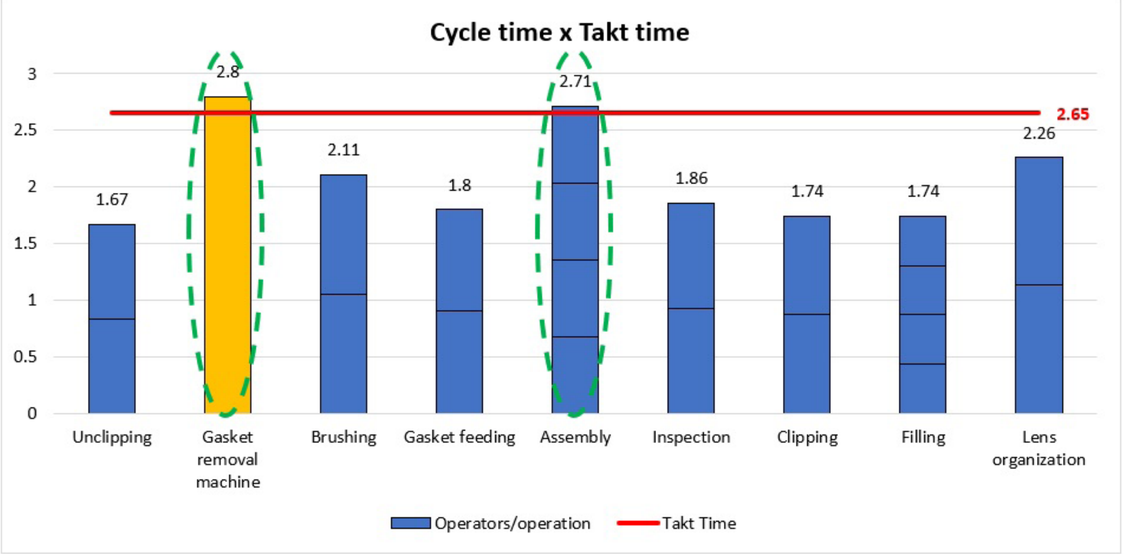

Figure 4. Operation balance chart after *takt* time reduction. Source: Own authorship (2015).

The task of removing the gaskets is performed by an electromechanical machine that has an adjustable cycle, therefore, to reduce the operation time it suffices to modify the machine settings utilizing its software. However, to reduce the assembly time, it's necessary to study the motion of operators, identifying activities that do not add value to the product and/or wastes, and find ways to minimize or eliminate them.

4.5 Micro motion study

The micro motion study of the assembly operation was performed utilizing the recording camera and the table presented in section 4.2 of this article. Three videos were utilized, as indicated by the equation of ideal number of cycles to be timed already calculated previously, and all micro motions of the operator during the task were analyzed. Data was inserted in Chart 6 below.

In the measurement table, the frame average of the three analyzed videos, average time per operator and per part, and the amount of time classified as value-added or non-value-added, are computed. It is important to emphasize that the computed times are not the standard times for performing the activity, but the times measured through the recordings. Through the analysis, it is noticed that only three activities performed by the operator add value to the product: disassemble the mold, assemble the concave side of the mold and assemble the convex side of the mold. It doesn't mean the other activities can be eliminated, though they do not add value to the product, they required for the progress of the production.

However, two of the operator activities are highlighted: raise the lens and inspect the lens. As described in section 4.1 of this article, the operator raises the lens to place it against the inspection lamp and identify mixtures. However, after this station, there is the inspection operation, where the operator inspects

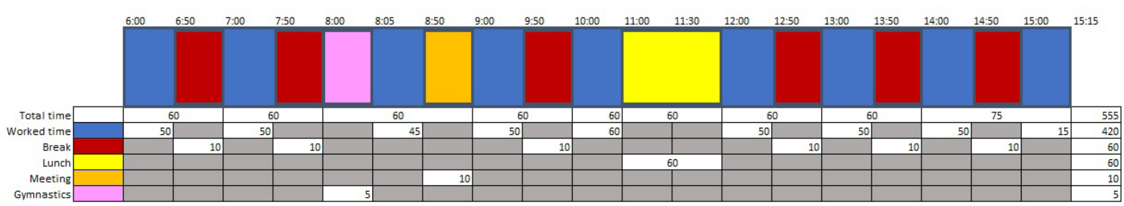

Figure 5. Line chronogram after *takt* time reduction. Source: Own authorship (2015).

Chart 6. Micro motion study of the assembly operation.

F/S	Cycle time analysis	Value	Current state of cycle time				
30	**Video: Assembly**	**VA: 1 NVA: 0**	**Frame average**	**Time per group**	**Time per unit**	**VA**	**NVA**
1	Remove the mold and the gasket from the conveyor belt	0	13	0.11	0.43		0.43
2	Clean the gasket with compressed air	0	18	0.15	0.60		0.60
3	Place the gasket on the holder	0	11	0.09	0.37		0.37
4	Raise the mold	0	8	0.07	0.27		0.27
5	Clean the mold with compressed air	0	22	0.18	0.73		0.73
6	Place the mold on the holder	0	13	0.11	0.43		0.43
7	Disassemble the mold	1	26	0.22	0.87	0.87	
8	Clean the concave side of the mold with compressed air	0	40	0.33	1.33		1.33
9	Assemble the concave side of the mold	1	38	0.32	1.27	1.27	
10	Raise the lens	0	17	0.14	0.56		0.56
11	Inspect the lens	0	8	0.07	0.28		0.28
12	Place the lens on the conveyor belt	0	10	0.08	0.33		0.33
13	Clean the convex side of the mold	0	28	0.23	0.90		0.90
14	Assemble the convex side of the mold	1	23	0.19	0.77	0.77	
15	Place the assembled mold back on the conveyor belt	0	16	0.13	0.53		0.53
	Total		290	2.42	9.67	2.91	6.77

Source: Own authorship (2015).

100% of the lenses that pass on the conveyor belt, searching for defects in the product, and takes action provided by this activity. Therefore, this inspector is also able to identify the recordings on the lenses and segregate process mixtures as much as or even more than the assembly operator, since his main activity is product verification. From this conclusion, adding the product segregation to the inspector when he finds a mixture, both micro motions performed by the assembly operator are classified as waste. After all, they do not add value to the product and are not necessary for the assembly operation and should be eliminated as can be seen in Chart 7.

Eliminating waste, the cycle time of the activity drops from 2.42 to 2.21. Next, the normal time and the standard time of the operation are calculated shown in Chart 8. With the cycle time of the gasket removal machine adjusted to the same value as the assembly (2.47 seconds), the line has a production capacity of 10202 lenses per shift.

4.6 Results

The time and motion study of operations allowed the redistribution of breaks during the organic lenses production shifts, reducing the fatigue of operators and increasing the line's production capacity, even with a reduction in *takt* time. By analyzing the chart of Figure 6, it is noticed that the line became more balanced after adjusting the cycle time of the gasket removal machine and eliminating lens inspection during the assembly.

Chart 7. Micro motion study after waste elimination.

F/S	Cycle time analysis	Value	Future state of cycle time			
30	Video: Assembly	VA: 1 NVA: 0	Time per group	Time per unit	VA	NVA
1	Remove the mold and the gasket from the conveyor belt	0	0.11	0.43		0.43
2	Clean the gasket with compressed air	0	0.15	0.60		0.60
3	Place the gasket on the holder	0	0.09	0.37		0.37
4	Raise the mold	0	0.07	0.27		0.27
5	Clean the mold with compressed air	0	0.18	0.73		0.73
6	Place the mold on the holder	0	0.11	0.43		0.43
7	Disassemble the mold	1	0.22	0.87	0.87	
8	Clean the concave side of the mold with compressed air	0	0.33	1.33		1.33
9	Assemble the concave side of the mold	1	0.32	1.27	1.27	
10	Raise the lens	0	0.00			
11	Inspect the lens	0	0.00			
12	Place the lens on the conveyor belt	0	0.08	0.33		0.33
13	Clean the convex side of the mold	0	0.23	0.90		0.90
14	Assemble the convex side of the mold	1	0.19	0.77	0.77	
15	Place the assembled mold back on the conveyor belt	0	0.13	0.53		0.53
	Total		**2.21**	**8.83**	2.91	5.93

Source: Own authorship (2015).

Chart 8. Normal and standard time calculation after eliminating waste.

Cycle time analysis (in seconds)						
#	Video:	Average	V	TN	FT	TP
1	Unclipping	1.52	0.01	1.54	0.091	1.67
2	Brushing	1.87	0.06	1.98	0.065	2.11
3	Gasket feeding	1.57	0.05	1.65	0.089	1.80
4	**Assembly**	**2.21**	**0.04**	**2.30**	**0.076**	**2.47**
5	Inspection	1.46	0.18	1.72	0.082	1.86
6	Clipping	1.55	0.03	1.60	0.087	1.74
7	Filling	1.54	0.05	1.62	0.078	1.74
8	Lens Organization	2.05	0.04	2.13	0.058	2.26

Source: Own authorship (2015).

However, even after the time and motion study, the greatest cycle time is still in the assembly operation. Nevertheless, it's still possible to shorten its duration by redoing the micro motion study and finding ways to avoid waste and reduce the times of activities that do not add value. Another viable possibility is to configure the line so that you have three assemblers on each side, thus dividing the assembly time by six rather than by four, as demonstrated in Chart 9. After that, the next step would be to recalculate the normal time and the standard time of the operation and build the new cycle time Chart 10 and the new graph in Figure 7.

Adding one more assembly operator to each side of the line, the operation ceases to be the bottleneck and becomes the second lowest time, leaving the line even more balanced. The production capacity becomes 11004 lenses per shift. The lens demand may be increased without overloading the operators, in case the production management finds it necessary.

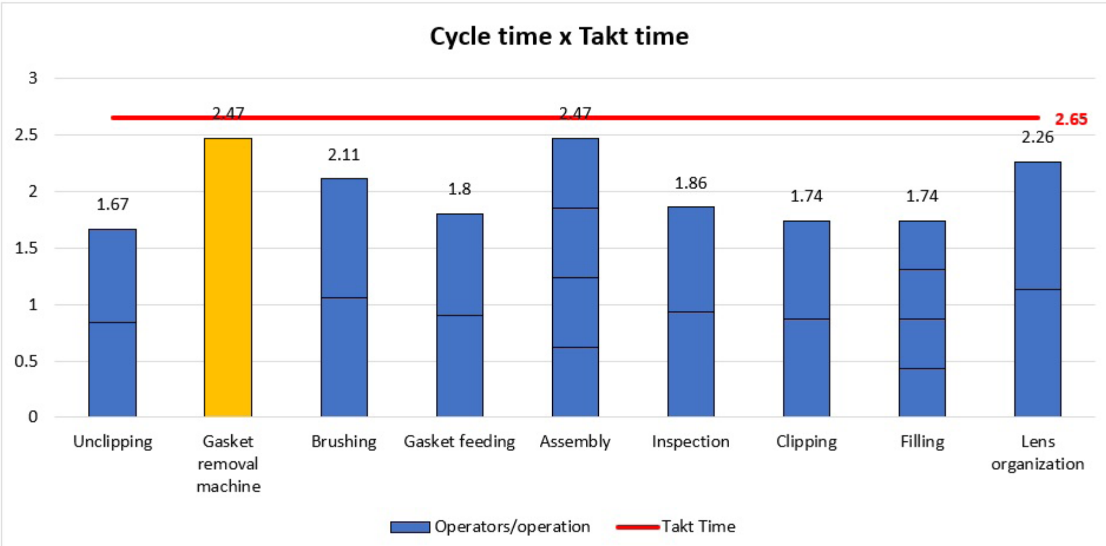

Figure 6. Operation balance chart after eliminating waste. Source: Own authorship (2015).

Chart 9. Micro motion study after adding two operators.

F/S	Cycle time analysis	Value	FUTURE STATE OF CYCLE TIME			
30	Video: Assembly	VA: 1 NVA: 0	Time per group	Time per unit	VA	NVA
1	Remove the mold and the gasket from the conveyor belt	0	0.07	0.43		0.43
2	Clean the gasket with compressed air	0	0.10	0.60		0.60
3	Place the gasket on the holder	0	0.06	0.37		0.37
4	Raise the mold	0	0.04	0.27		0.27
5	Clean the mold with compressed air	0	0.12	0.73		0.73
6	Place the mold on the holder	0	0.07	0.43		0.43
7	Disassemble the mold	1	0.14	0.87	0.87	
8	Clean the concave side of the mold	0	0.22	1.33		1.33
9	Assemble the concave side of the mold	1	0.21	1.27	1.27	
10	Raise the lens	0	0.00			
11	Inspect the lens	0	0.00			
12	Place the lens on the conveyor belt	0	0.06	0.33		0.33
13	Clan the convex side of the mold	0	0.15	0.90		0.90
14	Assemble the convex side of the mold	1	0.13	0.77	0.77	
15	Place the assembled mold back on the conveyor belt	0	0.09	0.53		0.53
	Total CT		**1.47**	**8.83**	2.91	5.93

Source: Own authorship (2015).

Chart 10. Normal and standard time calculation after adding two operators.

Cycle time analysis (in seconds)						
#	Video:	Average	V	TN	FT	TP
1	Unclipping	1.52	0.01	1.54	0.091	1.67
2	Brushing	1.87	0.06	1.98	0.065	2.11
3	Gasket feeding	1.57	0.05	1.65	0.089	1.80
4	**Assembly**	**1.47**	**0.04**	**1.53**	**0.076**	**1.64**
5	Inspetion	1.46	0.18	1.72	0.082	1.86
6	Clipping	1.55	0.03	1.60	0.087	1.74
7	Filling	1.54	0.05	1.62	0.078	1.74
8	Lens organization	2.05	0.04	2.13	0.058	2.26

Source: Own authorship (2015).

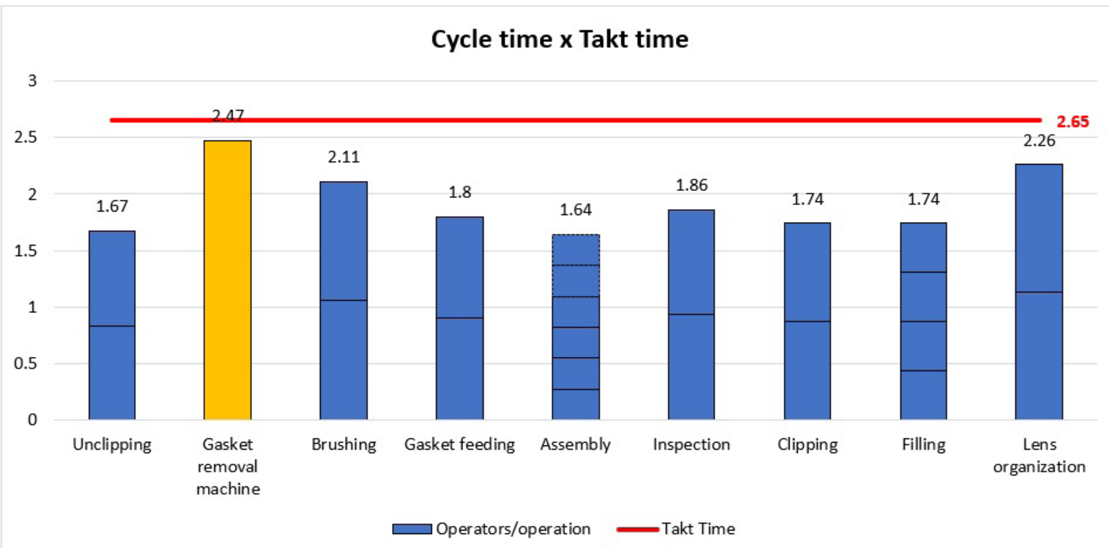

Figure 7. Operation balance chart after adding two operators. Source: Own authorship (2015).

Despite the positive results, if there's still an intention to increase the line's production capacity, it suffices to repeat the same steps for the lens organization operation.

5 Final considerations

The time and motion study allows the development of continuous improvement within organizations. A technique that emerged along with the Lean Manufacturing philosophy, in the Toyota Production System, it allows the optimization of production processes, guaranteeing flexibility, lower costs, and faster delivery of products to the customer.

This article addresses a case study performed in a lens factory, where the utilization of time and motion study allowed an increase in production capacity with a reduction in the line's *takt* time and in the cycle times of each operation. The article has three main steps: the analysis of the situation before the study was performed, the reduction through the micro motion study and the result after adding two operators in the line's bottleneck operation.

The studied situation showed that the operators had only three breaks during the entire work shift, one of them used for the daily meeting rather than personal needs. The initial goal was to add five-minute breaks for every one hour of work. In order to achieve that goal, the cycles of each operation were studied before and after adding the breaks, and the line's conditions were verified. After performing the mentioned chrono-analysis, two operations were identified as bottlenecks.

The application of the time and motion study proved effective, once utilized it was possible to identify activities considered not only as non-value-added, but also considered waste, and eliminate them from the production line, reducing the line's bottleneck and increasing production capacity.

Through the micro motion study of the assembly operation, an opportunity to leave the line more balance was found, by adding two operators to this task. Thus, besides achieving the goal of adding breaks during the work shift, the line had its production capacity increased and no longer the assembly operation as bottleneck.

References

Barnes, R. M. (1977). *Estudo de movimentos e de tempos: projeto e medida do trabalho*. São Paulo: Edgard Blucher.

Contador, J. C. (1998). *Gestão de operações: Engenharia de Produção a serviço da modernização da empresa*. São Paulo: Edgard Blucher.

Gil, A.C. (2010). *Como elaborar projetos de pesquisa* (5. ed.). São Paulo: Atlas.

Greef, A. (2012). *Lean office: operação, gerenciamento e tecnologias*. São Paulo: Atlas.

Houts, L. (2016). Minimizing the seven wastes at Betts Spring Manufacturing. *International Journal of Business and Applied Social Science*, 2(4), 23-28.

Juran, J. M. (1990). *Na liderança pela qualidade*. São Paulo: Pioneira.

Llewellyn, S., & Northcott, D. (2007). The "singular view" in management case studies qualitative research in organizations and management. *International Journal*, 2(3), 194-207.

Marksberry, P., Rammohan, R., & Vu, D. (2011). A systems study on standardized work: a Toyota perspective. *International Journal of Productivity and Quality Management*, 7(3), 287-302. http://dx.doi.org/10.1504/IJPQM.2011.039349.

Martins, P. G., & Laugeni, F. P. (2006). *Administração da produção* (2. ed.). São Paulo: Saraiva.

Mayer, P. C., Maciel, A. C., Baggio, D. K., & Siedenberg, D. R. (2015). Implantação de metodologia de análise do valor agregado em uma indústria metalúrgica de produtos sob encomenda. *Gestão da Produção, Operações e Sistemas*, 10(1), 177-195.

Paladini, E. (2012). *Gestão da qualidade* (2. ed.). Rio de Janeiro: ABEPRO.

Sabet-Rasekh, A. (2014). *Design of a lean manufacturing system for the production of compliant wind at sparton electronics* (Master thesis). Embry-Riddle Aeronautical University, Daytona Beach, Florida.

Souto, M. S. M. L. (2002). *Apostila de engenharia de métodos*. João Pessoa: Curso de Especialização em Engenharia de Produção, UFPB.

Terence, A. C. F., & Escrivão-Filho, E. (2006). Abordagem quantitativa, qualitativa e a utilização da pesquisa-ação nos estudos organizacionais. In *Anais do XXVI Encontro Nacional de Administração*. Fortaleza: ENEGEP. Recuperado em 12 de dezembro de 2015, de http://www.abepro.org.br/biblioteca/ENEG EP2006_TR54 036 8_8017.pdf

Wang, W., Lu, Z., & Zhu, Q. (2014). The integration of group technology and simulation optimization to solve the flow shop with highly variable cycle time process: a surgery scheduling case study. *Mathematical Problems in Engineering*, 2014, 1-8. http://dx.doi.org/10.1155/2014/547485.

Werkema, C. (2011). *Lean Seis Sigma: introdução às ferramentas do lean manufacturing* (2. ed.). Rio de Janeiro: Elsevier.

Werkema, C. (2012). *Criando a cultura Seis Sigma* (3. ed.). Rio de Janeiro: Elsevier.