Line Balancing in assembly line. A case study.

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Abstract

In order to balance an assembly line one has to deal with different concerns as to the way to distribute operations to achieve takt times. Nowadays the complexity of assembly operations don't allow the company to maintain a work balance, which affects the inequity of the workstations' time and also generates non value added activities that is reflected in the total cycle time. The manufacturing plant of this study manually produces bus chassis, and has two assembly lines: urban chassis (UC) and foreign chassis (FC). The purpose of this research paper is to decrease the operator headcount 20% and to increase de value added to 59% in the assembly line. In order to achieve this paper's main objective, the research team used a Lean Six Sigma approach and DMAIC methodology. The activities completed were generating a balance proposal with the reduction or elimination of non value added activities through Kaizens. This paper is relevant for operations management professionals since it represents one of the most studied issues in manufacturing assembly lines, and provides an integrated approach combining different tools to solve this problem in a multinational company.

Keywords
Chassis, value added, line balancing, DMAIC, Lean Six Sigma.

1. Introduction

A value added activity is considered any activity which changes the physical form of the chassis and the non-value added activities are the ones that include any activity that presents itself in the form of a waste within the production process. Most of the non-value added activities are a part of the unbalanced utilization of the operators, in order to solve this problem, the investigation team worked with Kaizens, Six Sigma and projects and the line balancing. This particular methodology has been used in manufacturing enterprises, which have the same issue under different circumstances, for example having a high variability of the product. An unbalanced assembly line is a very common issue in manufacturing enterprises and it has been studied from different perspectives, but the common ground that each of them have is that they have is that they approach this issue through the elimination/reduction of the non-value added activities to then proceed to balancing the line. This project consists in the assembly of the crossbar of the chassis all the way through the assembly of the various harness and combustion lines, taking in consideration the first four work teams. Which will be named Team 1, Team 2, Team 3 and Team 4. And 11 work stations and 5 sub-assembly workstations.

2. Methodology

DMAIC (Define, Measure, Analyze, Improve and Control) is part of the Six Sigma approach. This process is very important in six sigma process because it is what helps bring a diverse team together. This is what helps them complete a process or model so that they can share their work and get the job done. (Patel Rumana &, Darshak A. Desai, 2014). Therefore, the research team used this methodology to develop an improvement in the process.

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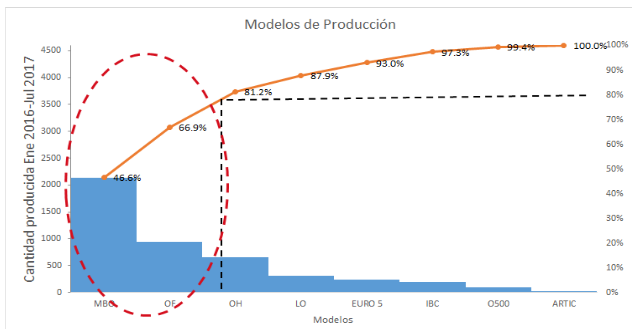
2.1 Define

This is the first stage of the DMAIC Methodology, in this stage the key points are established for the project development. Also, the identification of the main problem is done in this stage. In this case, the project problem discovered was that only the 43% of the activities of the production process add value to the final product. Currently, there is an operator template of 41 workers and an unbalanced workload causing an expense in overtime approx. $76,732 USD, by doing this the company could support the demand. Based on this problematic, the research team established a general objective and particular objectives which are: Increment the Value Added to 58% by balancing the production activities and the second particular objective is decreasing in 20% the current headcount.

2.3 Measure

In this phase of the project, the investigation team measured the time each operator takes to finalize his or her activities in their workstation. A stratified sample was done (shown in figure 1) and used to select the model on which the study was going to be done. After selecting the different model types that were going to be analyzed the videos were taken, and the result was a total of 348 videos.

Figure 1, Pareto of different models



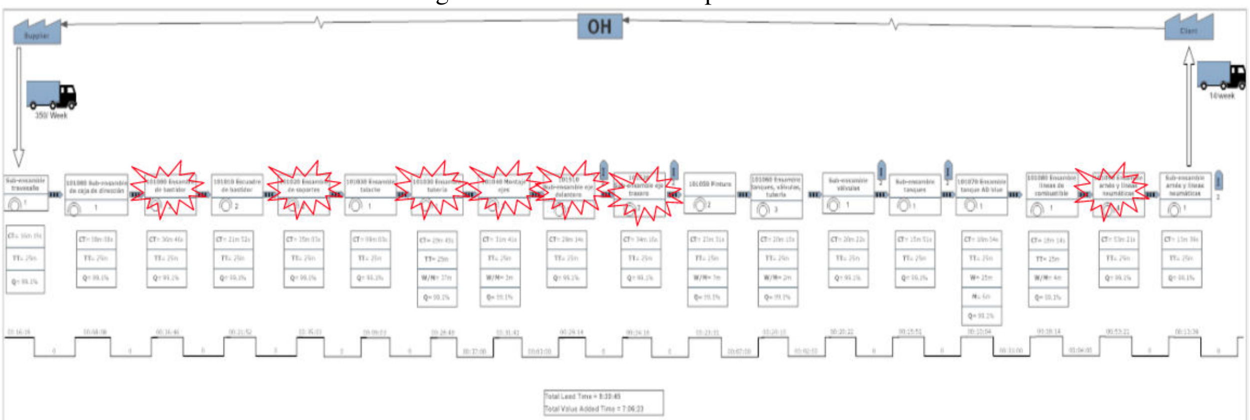
2.4 Analyze

One of the tools used for a correct and easier video analysis was the software: Timer Pro. This Software let the research team import videos and analyze the activities that the operator was doing during the video and determined which activities were Valued Added, Non Value Added and Non Value Added Necessary. As a final product the software develop a Yamazumi Chart that led to identify the various workload that the process has into the assembly line.

2.5 Value Stream Map (VSM)

In order to analyze the value flow in each workstation the research team used the *Value Stream Map* (VSM), with the objective to focus on the different problem situations that are present in the process of the chassis assembly right before the motor assembly starts. A VSM was done for each of the models of this study and the model with the highest Lead Time was the OH model with 8 hours, 39 minutes and 47 seconds, as it is shown in figure 2 and that there are 7 work stations which exceed the Takt Time of 25 min.

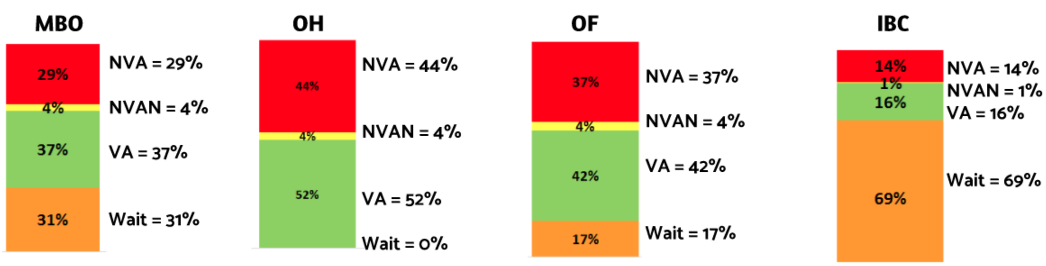
Figure 2: Value Stream Map OH model



2.6 VA, NVA, NVAN Analysis

The Timer Pro software was an advantageous lean tool that let us obtain the different Yamazumi charts of the assembly process. With this lean tool we could obtain the percentage of Value Added, Non Value Added and Non Value Added Necessary in each model.

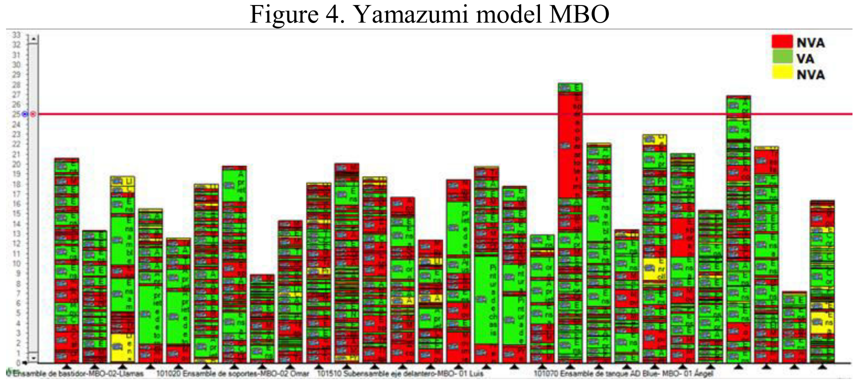
Figure 3. VA, NVA, NVA by model



2.6.1 VA, NVA, NVAN ANALYSIS: MBO

The first model that was analyzed is from the urban line: MBO. In this model the Yamazumi chart shows that 37% of the activities add values, while 29% are non value added activities, versus 4% of these activities don't add value, but are necessary, and 37% of the rest of the activities are wait. This type of wait comes from the difference of the total takt time minus the sum of the total operation time.

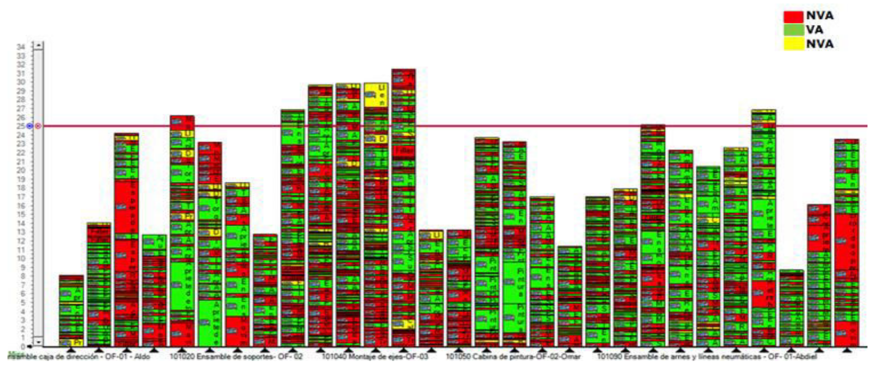
Figure 4. Yamazumi model MBO



2.6.2 Analysis VA, NVA, NVAN: OF model

The second model analyzed is the OF model. From this model, it was obtained that the Yamazumi (Figure 5) showed the following results:

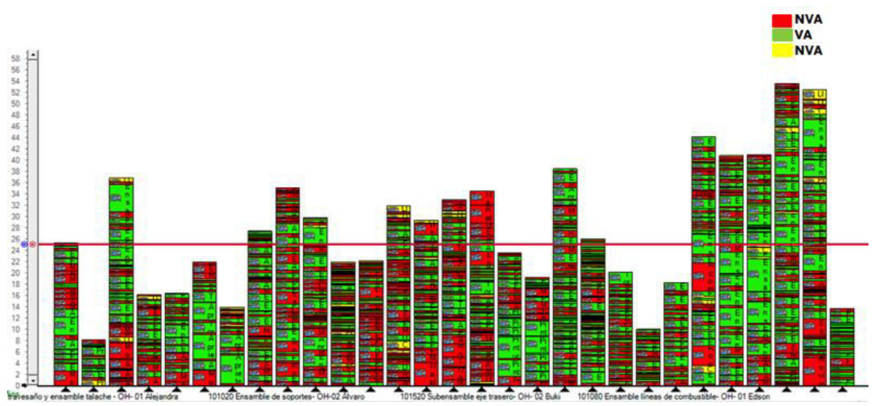
Figure 5. Yamazumi OF model



2.6.3 VA, NVA, NVAN Analysis: OH Model

The last model that was analyzed was the OH. Despite of having the longest operation time this model contains the most value added activities.

Figure 6. Yamazumi model OH



2.6.4 VA, NVA, NVAN Analysis: IBC Model

The IBC model, that represents a 16% of value added activities, a 14% of non value added and a 1% of non value added but necessary activities. This model shows a red flag in the waiting percentage due to the fact that 66% of the process is wait and Takt Time exceeds the operator time. Shown in figure 7.

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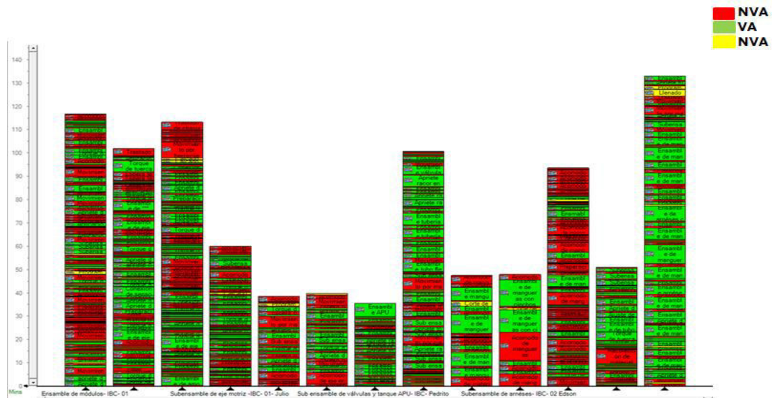
Figure 7. Yamazumi model IBC



2.7 Root Causes

For the identification of the root causes, an Ishikawa diagram was made, with a negative effect of 57% of the activities that do not add value in the process. They were also collected from a list of symptoms, both qualitative and quantitative, and with the operators, the production area and operations area, they were placed in the diagram depending on the area, be it material, labor, machine, environment, or method.
From the previous analysis with the Ishikawa diagram and based on its methodology, the 3 root causes identified were:

- The activities of the production lines are not balanced to the Takt Time of 20 future units
- There is bad distribution of the location of equipment (materials and tools) in the work area
- There are not defined how many operators are needed per workstation

2.8 Improve

Continuing with the DMAIC Methodology, the next stage is "Improve", in this stage the solution design was made. This solution was based in the root causes. With a detailed analysis the research team could determine which solutions would be best fitted to eradicate the present root causes and impact the general objective of the project. The key points to do this were the elimination of wastes and the balancing of the line, and this process was divided in 2 stages: 1. Preparation for Kaizen and 2. Determination of the pilot.

Stage 1: Preparation for kaizen:
Step 1: Team Meetings
Step 2: Non value added percentage analysis

Stage 2: Determine the pilot model
Step 1: Pilot´s precedence model diagram (OH)
Step 2: Balancing Proposal
Step 3: Simulating the balancing proposal

For the Step 2 of balancing proposals, beginning with team 3, they where made final groups of jobs in team 3, the main change was that each sub assembly would be done in the sub assembly area and the headcount was reduced from 6 operator to 5. In team 2 there were several improvements that would have a direct impact in the total time of each job, by doing this all of the activities will be align with the takt time and the headcount will be the same. For team 1 all the activities were balanced in order to reduce the headcount from 9 operators to 8 operators.
To validate the balance proposals that were determined by the research team, a simulation was done with all of the models and their respective times. This simulation was done with a period of 8 hours (1 day shift). The results were

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9 chassis with an average time in the system of 5.12 hours compared to 8 hours of the highest average time in the system.

3. Kaizens

To do Kaizens in the company, the dates were first established to perform the various Kaizens in the work area, then with a work team, the possible improvements for each of the teams were determined, those of greater impact were selected, all this through a brainstorming. Once these proposals were established, they were distributed to each team and their respective managers. Finally, the realization of each of them was continued.

Team 2:

Table 1. Improvements implemented Team 2

Implemented Improvements	Operation Time (min)		Tools	
	Before	After	Before	After
Lifting complete chassis for axle assembly	29.8	22.08	-	-
Missing tools	-	-	10	23
Height of table / support for axes	34.47	20.33	-	-
TOTAL	**64,27**	**42,41**	**10**	**23**

Team 3:

Table 2. Improvements implemented Team 3

Implemented Improvements	Walking distance (m)		Operation time (min)		Inventory	
	Before	After	Before	After	Before	After
AD Blue Car	-	-	6	3.5	24	4
Tube sub-assembly table	15	0	2	0	-	-
Tube car	40	16	-	-	-	-
Relocate serpentine rack and connectors	10	4	-	-	-	-
Car for subassemblies	95	48	1.10	0.40	-	-
IBC tank car	13	2	0.43	0.09	-	-
Modify IBC cars	-	-	5.23	3.59	-	-
Material of tubes supports	40	15	11	9	-	-
Modificación de área de subensamble	27	5	-	-	-	-
Tank Rack (IBC)	66	24	1.4	0.6	-	-
Excess of IBC tubes	-	-	5.9	0.66	7	5
Subassembly material	10	0	-	-	-	-
TOTAL	**316**	**114**	**33,06**	**17,84**	**31**	**9**

Team 4:

Table 3. Improvements implemented Team 4

Implemented Improvements	Walking distance (m)		Operation time (min)		Inventory		5s
	Before	After	Before	After	Before	After	
Harness reel	20	5	15.01	1.27	-	-	-
Cars (6)	75	15	2.13	0	-	-	-
Table and racks battery cables	25	12	2.23	1.14	-	-	-
Relocate crimp	62	0	2.5	0	-	-	-
Harness basket	-	-	1	0	-	-	-
Rearrangement of racks material	-	-	3.18	0	-	-	
Sub-assembly supports	-	-	-	-	-	-	
Inlet tube rack	-	-	-	-	12	6	-
Rack CKD	-	-	2.12	0.24	25	15	
Rack sub-assembly hoses	-	-	-	-	50	35	
Rack sub-assembly table	9	8	0.15	0.12	-	-	
TOTAL	**191**	**40**	**28,32**	**2,77**	**87**	**56**	

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3.1 NVA impact by Kaizen

Once Kaizen was developed in each workstation into the production line, the research team could obtain wastes reduction and/or wastes elimination, depending the situation presented into the workstation. The reductions were measured taking as a consideration the database taken during the analysis phase. Coming up next the results obtained are presenting:

In the Team Number 3, 3,394.73 minutes were from NVA activities and with the improvement we could obtain a time to 2,865.78 minutes; it means that with the improvements there were a reduction of 15.58% about NVA time. In the team 2, there was a reduction of 6,349.31 minutes to 4,351.63 having a decrease of 31.46% of NVA time, produced by the Kaizen made in this area. In the team 4, there was a reduction of 63.7% decreasing the time to 5,424.99 to 1,969.22 minutes of NVA activities.

4. Pilot Model

In order to verify the feasibility of the balancing proposal, a pilot model was taken in which 3 different takes were validated of the processes. The pilot model chosen was OH due to its complexity, as previously mentioned. After implementing all the improvements for Team 3, three tests were done and the times are shown in Table 4.

Table 4. Pilot model tests Team 3

Jobs	Test 1 (min)	Test 2 (min)	Test 3 (min)
Painting and assembly of tanks	37:14	31:56	28:46*
Painting and assembly of valves	27:12	24:53	24:37
Subassemblies	28:31	23:41	23:16
Subassembly valves	18:02	18:01	17:58
Tube assembly	26:27	21:03	20:49

In Team 4, the biggest changes were made in the processes, due to their high operations times in the analysis stage, the times obtained in the tests performed are shown in Table 5.

Table 5. Pilot model tests Team 4

Jobs	Test 1 (min)	Test 2 (min)	Test 3 (min)
Installation of main harnesses 1	28:54	27:38	27:08*
Installation of main harnesses 2	29:42	25:16	23:37
Installation of main harnesses 3	28:33	26:42	24:58
Routing harnesses and brake installation 1	34:12	30:54	28:38*
Routing harnesses and brake installation 2	30:34	28:34	26:19*
Armed lines and rods	26:37	24:54	23:21
Fuel lines	29:24	26:12	24:58
Subassembly	14:01	13:58	13:56

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In Team 2, tests were done with a different way of lifting the chassis to assemble the front and rear axles, the times that were obtained from these tests can be seen in Table 6.

Table 6. Pilot model tests Team 2

Jobs	Test 1 (min)	Test 2 (min)	Test 3 (min)
Assembly of axes 1	25:42	24:04	22:08
Assembly of axes 2	24:38	23:56	23:09
Assembly of axes 3	26:49	26:11	24:01
Front axle subassembly	26:48	25:22	24:11
Rear axle subassembly 1	25:14	22:49	20:33
Rear axle subassembly 2	20:17	18:41	16:22

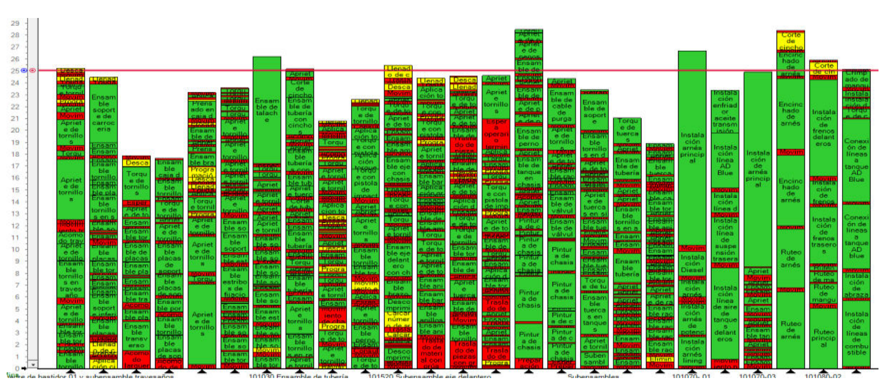
For the last Team, the rolling test was done with 8 people instead of 9 that were previously, the times obtained in these tests can be seen in Table 7.

Table 7. Pilot model tests Team 1

Jobs	Test 1 (min)	Test 2 (min)	Test 3 (min)
Subframe crossmember and frame bracket	26:12	25:49	24:56
Sub-assembly of steering box and frame assembly 1	27:37	25:57	24:03
Frame Assembly 2	24:41	20:18	17:52
Frame Assembly 3	22:43	19:10	17:46
Frame bracket 2	27:21	25:22	23:34
Assembly of supports 1	27:11	25:06	24:03
Assemble supports 2	29:37	27:28	26:21*
Assemble tubes	28:03	26:13	24:45

From the tests carried out and with the help of the TimerPro software, the following Yamazumi was obtained where the change in the OH model is seen. Where the LeadTime was reduced to 5.7 hours, assuming it was a continuous sequence, and the added value for this model increased from 52% to 75%

Figure 9, Yamazumi balanced activities model OH



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4.1 Objectives Compliance

The general objective of this project is to increase the percentage of the Value Added activities from the 43% to 58% and reduce the headcount by 20%. Which would be fulfilled by means of the fulfillment of the particular objectives that are the balancing activities in the production of the models: MBO, OF, OH and IBC and determine the necessary headcount for the production of 20 chassis per shift. Both particular objectives are shown in the balancing proposal for each model. In addition to the balancing of the activities and the reduction of the headcount, the improvements made of Kaizens, are a factor that helped to increase the added value, increasing from 43% to 48% with the implementation of the improvements and the balancing of activities for the OH pilot model, achieving a 59% value added when implementing the improvements in the remaining models. In the same way, when carrying out the balancing for the OH model, it was possible to reduce the headcount of the company by 20%, from 41 workers to 32.

5. Control

5.1 Control Tools

Standard Work Instruction (SWI)
As part of the activities documentation about the activities involved into the process, the research team used the control tool named for the company as Standard Work Instruction (SWI)

Internal Audit
As a part of the compliance implementation of the new process, the research team implemented a new control process named internal audit. This audit must be taken one time during the month with the objective to ensure that the improvements implemented are taking a correct way and do not need to be moved in the four workstation studied. The people included in the audit process will be the responsibilities of the compliance of the process control, these people are: The team leader, Continuous Improvement Coordinator, and the Process Owner; taking as a consideration the next points: Takt Time Compliance, Operator template compliance for each workstation (based on the balancing proposal), Process compliance, based on the balancing proposal, Revision of the operator walking into their workstation.

6. Conclusions

The line balancing is fundamental for a manufacturing company because by equalizing the work times in all the stations, different benefits can be obtained. During this project, different tools of the Lean Six Sigma methodology were carried out that helped to reduce or eliminate the waste founded in the line and then achieve the balancing of all the activities. By implementing Kaizens for each of the teams, the reduction of 28.06% of the activities that were not adding value within the line was achieved, in the same way, with the software of TimerPro, a comparison was made with the previous analysis established, where the Yamazumi for the OH pilot model showed favorable results, as the reduction of times in jobs that were outside the Takt Time from 16 to 6, a decrease in Lead Time to 5.7 hours, increase of added value and a reduction of the headcount in a 20%. For the missing models, a balancing proposal was made. After implementing the improvements for the models and making the implementation of the balancing proposal for the pilot model, the general objective was completed, reaching a percentage of value added of 59% and a headcount reduction of 20%.

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