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Implementation of SMED Methodology to reduce the Setup Time in a SMT Production Line

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Abstract:
The overall objective is to implement the Single Minute Exchange of Die (SMED) methodology to reduce the setup time (model change) in an electronics factory in Brazil. The research was carried out in the premises of a company in the electronics segment, located in the Industrial Pole of Manaus (PIM), with the cause and effects diagram it was verified that machines, labor, method and material are the main causes for the high setup time. The initial SMED action plan defines eleven actions related to machines, labor and method in order to reduce the line setup time. The application of the SMED method was implemented based on the original method presented by Shigeo Shingo (1985). The study has three stages, the identification of industrial wastes, the SMED analysis; and the action plan implementation. As a final result, the setup time was reduced in 64%, bringing a relevant productivity and efficiency in the SMT line studied.
Key Word*: SMED, SMT, Ishikawa diagram, Setup Time.*

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I. Introduction

Companies all over the world aim for high performance, flexibility and competitiveness and to achieve this they are working to identify and eliminate the industrial wastes. Industries that operate in large-scale production over the years have evolved by optimizing resources as a way to remain in the market, and recently new concepts of manufacturing competitiveness have been assumed by the main industrialized countries in the world. These companies are implementing lean processes and systems in order to add value to the product they deliver. However, for this it is necessary to improve the necessary process steps and at the same time eliminate those that do not add value (Alciatore and Histand, 2014).

21st century manufacturing is characterized by custom products. This led the industries to a complex planning and production control, making the mass production a big challenge. Many organizations faced difficulties in the new globally competitive markets. These factors pose the organizations to look for new tools and methods to continue climbing the ladder in this market landscape. While some organizations are continue growing based on economic constancy, others struggled due to a lack of understanding of changing customer mindsets and costing practices. To overcome this situation and become more profitable, many manufacturers have adopted the Lean Manufacturing culture (Bhamu and Sangwan, 2014). Lean manufacturing is arguably the most prominent manufacturing paradigm of recent times. The goal of LM is to be highly responsive to customer demand and reduce the industrial wastes. However, to do so, it must be established strategies to improve efforts in many areas, including reduce the production cost, improve quality, improve responsiveness, reduce delivery time and increase flexibility (Buer and Strandhagen, 2019). The Lean Philosophy (Lean Thinking, Lean Manufacturing or Toyota Production System) was developed by the Japaneses in the mid-1950s and is now used worldwide by companies. The term "Lean Thinking" encompasses a set of lean practices and was first addressed by Womack et al. (1992). From the advent of the Lean concept to the present day, the popularity of LM thinking has spread exorbitantly. Previous applications focus only on manufacturing companies (hence the designations used: Lean Manufacturing or Lean Production) (Leite and Vieira, 2015).

Gupta et al (2016) consider Lean Thinking as a methodology whose main objective is to create low-cost improvements based on waste reduction. Likewise, it can be said that the LM methodology provides a way to do more with less. In other words, better use of the organization's resources in which the strategy prioritizes flow efficiency over resource efficiency. Lean is about improving the processes to eliminate activities that do not add value (ie waste), generating a cultural transformation that changes the functioning of an organization. Thus, this case study deals with the implementation of the Single Minute Exchange of Die (SMED) methodology to reduce Setup time in a SMT line. In this context, this study seeks to analyze the causes and implement improvements in order to reduce the setup of this productive flow that can be impacted by machine, labor, method and material. Changes are faster than before and customer expectations in terms of products functionality and quality are constantly rising. Customers are also stimulated by an increasingly consumption-oriented society. To remain competitive in the modern market, companies must be able to expand their offer, but be flexible enough to adapt to market changes. Industries have been increasingly concerned with optimizing their processes, avoiding losses and waste during production, meeting market demand with speed and quality, producing more with fewer resources and reducing physical spaces, production time and stocks, all this through the LM.

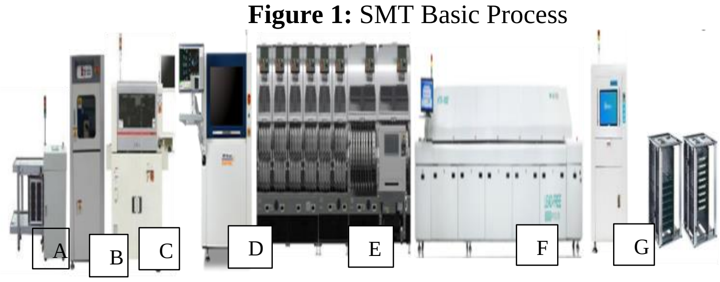
According to the Lean Institute Brazil (2022) Lean Thinking, as it is currently being called by some authors, is based on practices and concepts inspired by the Toyota Production System, whose principles aim to eliminate waste. Through Lean Thinking, organizations around the world have transformed their operations, becoming much more productive, profitable and efficient. The company studied produces around 25,000 assembled printed circuit boards daily, but despite being a large multinational and having been in the market for decades, it had never been concerned with production losses caused by the Setup time in the SMT lines. The purpose of this work is to measure the losses related to the waiting time during the model change, evaluate all the possible causes, raise an action plan for each cause, implement this improvement plan and evaluate if the expected results were achieved. For the academic community, through the application of research, the aim is to present results to prove that the usage of SMED and other Lean tools can indeed generate solutions and improve the results for the production process. The general objective of this article is to implement the Single Minute Exchange of Die (SMED) methodology to reduce Setup time in a SMT line. These are the specific objectives: to analyze the process of a company producing electronic products; identify the waste found in the production process, presenting the causes related to the high Setup time; implement the SMED methodology to optimize Setup time; and demonstrate the results obtained with the implementation of the improvement in the production process.

II. Material And Methods

Procedure methodology

The research was done at the premises of a company from electronics segment, located in the Industrial Pole of Manaus (PIM). This company manufactures monitors, TVs and electric meters, owning its own brands and producing to other brands in a OEM (Original Equipment Manufacturer) system also. It has four basic production processes, the Automatic PTH Insertion, SMT, Manual PTH Insertion and the Final Assembly. Our case study was focused in a SMT process, which has the configuration and layout shown in Figure 1. In order to better develop and understand, the basic elements of the SMT process are as follows: Solder Paste Printing; Solder Paste Inspection - SPI; Assembly; Solder Reflow; Component Inspection - AOI; Storage.

Figure 1: SMT Basic Process



Source: Autor (2022)

The Figure 1 presents the operation flow of the SMT line of the studied company, as exposed, it consists of 7 (seven) steps: 1st - Loader (A) automatically stores and feeds the boards in the Printer; 2nd - Cleaner (B) cleans the boards so that they pass through the paste printing without residues; 3rd - Printer (C) prints the solder paste on the board; 4th - SPI - Solder Paste Inspection (D) performs inspection of solder paste printing; 5th - SMT machine (E) assembles with precision the SMDs components on the boards, on the applied solder paste; 6th - Oven (F) has the function of melting the solder paste and soldering the components on the board; and finally, the 7th - Automatic Optical Inspection - AOI (G) verifies the quality of the welding and the quality of the assembly. After this process, the boards are stored or forwarded to the next production process.

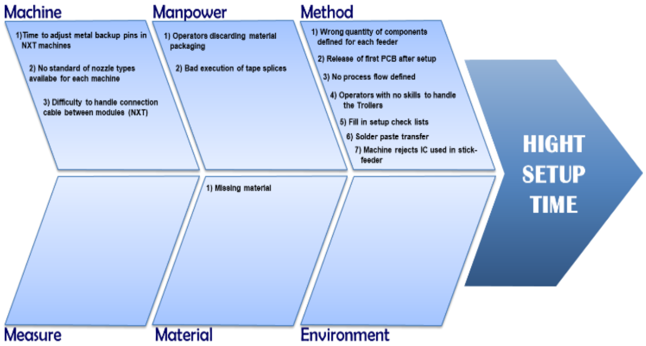
Identifying the industrial wastes

After analyze the SMT production process, it was observed that the setup was taking a very long time, since changing one model for another on the line was taking 1 hour, 08 minutes and 45 seconds, which could or should be less. Thus, the Engineering, Production, Quality and Materials Handling departments carried out an assessment of the time expended in each stage during the setup event in the production, as per mapped in Appendix A.

Cause and Effect Diagram

The Ishikawa diagram was used to identify the causes of the high setup time. The graphic structure of a fishbone illustrates the various causes that can affect the process for such an effect (high setup time).

Figure 2: Cause and Effect Diagram.



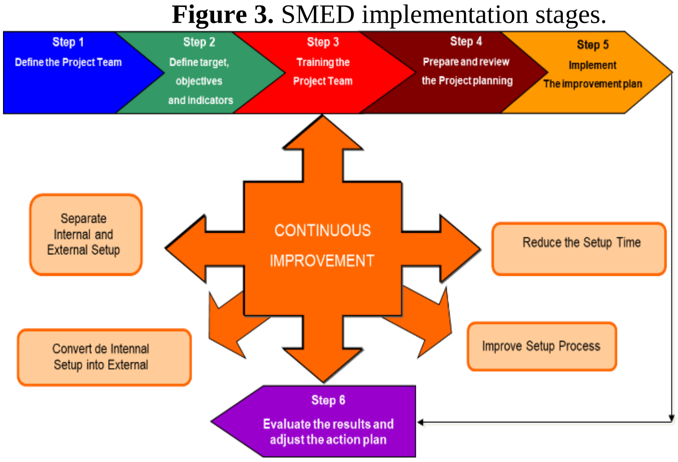
Source: Author (2022)

As shown in Figure 2, it was verified that machine, labor, method and material are the main causes for the high setup time. Regarding the Machine, the following items were listed: long time to place the metal backup pins in the NXT machines; There is no standard of nozzle types available for each machine; Difficulty to handle connection cable between modules (NXT). As for the labor item, it is affected because the operator is removing the residue during setup time and there are poorly made splices during kit closing. Related to the method, the following items were raised: error in the quantity of components per feeder; Long time to release of the first board after components placement; Lack of a flow for the Setup activity; Operators with no skills when handling trollers; no reports with process performance during Setup execution; Long time during solder paste transfer from current stencil to next one; and the machine rejecting ICs due to Stick-feeder device. And finally, related to the Material, the lack of material to close the kit.

Implementation of the SMED - Single Minute Exchange of Die

The SEMD methodology was implemented in order to reach a maximum time of 30 minutes. Figure 3 shows the steps for implementing this process.

Figure 3. SMED implementation stages.



Source: Author (2022)

Figure 3 shows the six stages of implementing the SMED methodology. The first is the definition of the project team, the second is the definition of the goals, objectives and indicators, the third is the training of the project team, the fourth is the construction and revision of the planning, the fifth is the implementation of the improvement actions, and the sixth, and last, is the evaluation of results and adjust the action plan.

Improvement Action Plan

Table 1: Presents the proposed improvement to reduce the setup time in the studied SMD line, proposed Improvement Action Plan

PROBLEM	ACTION
MACHINE	
Long time to place the metal backup pins	Replace metal pins by a softpin base
No standard of nozzle types available in machine	Standardize the nozzles
Difficulty to handle connection cable	Implement special connector
MANPOWER	
Operator is removing residue during setup time	Remove the residue after Setup
Poorly made splices during kit closing	Training to improve operator skills
METHOD	
Error in the quantity of components per feeder	Improve Feeder List format
Long time to release of the first board after components placement	Release the board after placement in each module for validation.
Lack of a flow for the Setup activity	Define a new setup operation flow and conduct training with the team.
Operators with no skills when handling trollers	Guide operators to complete forms after Setup.
Operators filling reports during Setup execution	Reports will be filled after Setup.
Long time during solder paste transfer	Improve process to transfer the solder paste.
Machine is rejecting ICs due to Stick-feeder	Change from stick-feeder to tray

Source: Autor (2022)

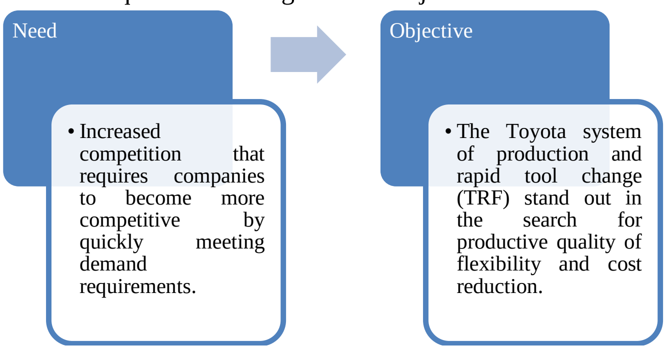
The initial SMED action plan defines eleven actions related to machines, labor and method in order to reduce line setup time.

III. Result

Analysis of the model change process

SMED is a methodology that can be translated into the rapid preparation of a production line configuration at the time of model change. It is proposed that the setups be carried out in a short period of time, considering that the tasks performed by the machine operator are rationalized.

Figure 4: Shows the need and purpose of implementing SMED. Competition between companies has turned quick tool change into an objective.



Source: Author (2022).

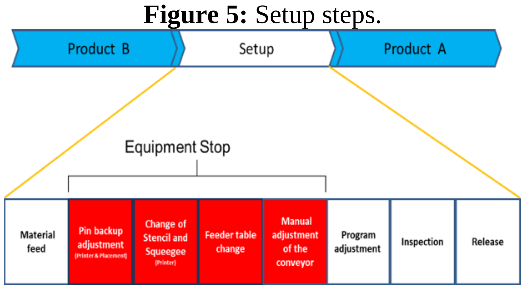
In view of the implementation of SMED, it appears that the tool aims to reduce the time of settings and adjustments, also known as setup time, in order to optimize production time. The setup is the configuration act to prepare a production line in the model change process. Furthermore, the setup time occurs from the output of the last unit produced in the previous setup to the first unit produced in the next setup. Figure 5 shows the model change process in the SMT line of the studied company. The initial stage consists of Material Feeding, in this stage the raw material is separated according to its allocation, each tape is identified with its respective feeder. After allocation, the feeders are fed with their respective materials and then these are fitted to the feeder table.

The positioning or adjustment of the backup pins is the positioning of the pins that support the board to avoid bulging, the pins are positioned on the Printer and on the SMT machines so that they have contact with specific points on the board with the help of a printed circuit board defined as a guide, this board prepared by engineering.

'In the Printer, in addition to backup pins, changing and adjusting the stencil and squeegee are crucial procedures for a setup. The Stencil is a metallic screen with holes that allow the solder paste to pass through applying it in a millimetric way on the islands of the plate. Changing the Feeder Table is done by replacing the feeder table of the previous model with the feeder table fed with the materials of the new model, as mentioned in the first stage of the setup process. Conveyor is the name given to the chain used to transport the slab during the process, each machine has a specific conveyor to carry out the slab transport system and as the slabs have different sizes, during setup Manual Conveyor Adjustment needs to be done on each fixture.

Program Adjustment is the change of programs of all the machines and equipment of the process, according to the model that is entering. In the Inspection activity, the operator reviews the first assembled board, visually comparing it with a standard board, confirming the correct assembly of the components. After the inspection, the release of production is carried out, thus concluding the Setup process. After the inspection, the release of production is carried out, thus concluding the Setup process.

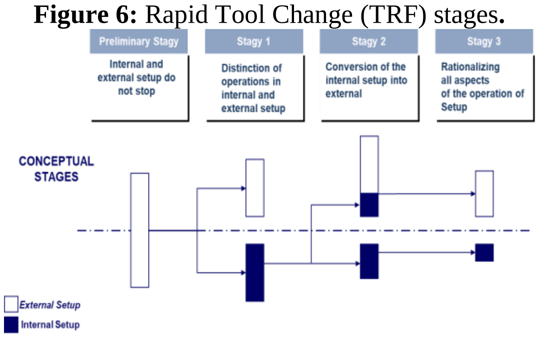
Figure 5: Setup steps.



Source: Author (2022)

It appears that to reduce setup time it is necessary, but not essential, to have knowledge of machines, equipment, tools and the ability to assemble, disassemble, adjust or calibrate. The setup time must be reduced to increase production capacity with a longer machine operating time during the working day, as well as for the production of smaller batches, increasing production flexibility. Figure 6 depicts the setup change stage.

Figure 6: Rapid Tool Change (TRF) stages**.**



Source: Shingo (2000, p. 98)

Figure 6 explains that the setup can be divided into two: The External, which considers the operations that can be performed before stopping the machine, in order to prepare the process of next part e.g. bring the raw material, tools and parts needed. And the Internal, which considers the operations performed while the machine is stopped, between the production of the last unit of the current model and the first unit of the model that is going into production. The conceptual stages and practical techniques of the quick tool change are:

- In the preliminary stage the internal and external setup is not distinguished.
- Stage 1 occurs separating internal and external setup.
- Stage 2 happens when the internas setup is converted into an external setup.
- Stage 3 focuses on systematically improving each basic operation of the internal and external setup.

Table 2 shows which are the points of attention in carrying out the Exchange of Setup when carrying out the analysis of the process.

Table 2: Attention points when performing the Setup change.

ACTIVITIES	DESCRIPTION
Transport (Setup Cart)	Standardized height with the height of the machines;
	Feeder fed on the correct location;
	Rollers and mechanical fittings previously checked;

Printer	Stencil availability (Clean / Inspected / Released in SFIS);
	Availability of Squeegee (Clean / Inspected / Released in SFIS);
	Welding Folder Availability (Finished defrost);
Placement (NXT & XP)	Stencil availability (Clean / Inspected / Released in SFIS);
	Availability of Squeegee (Clean / Inspected / Released in SFIS);
	Welding Folder Availability (Finished defrost);
	Program (In cases of PP);
Oven	Standardization or range that reduces many temperature adjustments;
AOI	Programs (In case of PP);
	Standard Plate Availability (Release);
	Availability of Magazines (Storage);
IM (Manual Assembly)	SOP at posts;
	Availability of

Source: Author (2022).

SMED analysis

Preliminary Stage: internal and external setup are indistinguishable.

The preliminary stage foyers only the initial time parameters of the activities carried out in the setup. To obtain the times of the activities, Shingo (1985) indicates the possibility of using a stopwatch, studying the method, interviewing operators or analyzing the footage of the operation. The author also indicates "[...] that observations and informal discussions with workers are generally sufficient" (Shingo, 1985). The result of the evaluation of the setup time in the preliminary stage, with the machine stopped, where there is no internal and external separation, it should be noted the lack of training and monitoring. The first two columns indicate the process and the activity, followed by the time duration of each activity.

Figure 7: Setup Time Assessment in Preliminary Stage.

PROCESS	ACTIVITIES	Start	End	Time
Vacuum Loader	Feed PCB	00:13:45	00:14:46	0:01:01
PCB Cleaner	Adjust Conveyor	00:14:46	00:15:46	0:01:00
Printer	Change Stencil and feed solder paste	00:15:46	00:24:46	0:09:00
Conveyor	Adjust Conveyor	00:24:46	00:25:36	0:00:50
SPI	Validate first PCB Inspection	00:25:36	00:27:36	0:02:00
Turn table	Adjust Turn Table	00:27:36	00:28:26	0:00:50
NXT	Change troller	00:00:00	00:13:38	0:13:38
	Adjust backup pins	00:05:09	00:22:16	0:17:07
	Validate feeder (pitch)	00:04:19	00:24:10	0:19:51
	Adjust feeder error	00:24:02	00:26:03	0:02:01
	Adjust clamp error	00:26:30	00:27:54	0:01:24
	Perform CHKKP check	00:31:16	00:39:10	0:07:54
	Validate first PCB	00:29:07	00:42:48	0:13:41
XP	Load Program	00:27:54	00:30:32	0:02:38
	Adjust backup pins	00:30:45	00:34:40	0:03:55
	Validate feeder (pitch)	00:37:11	00:41:27	0:04:16
	Perform CHKKP check	00:41:31	00:44:22	0:02:51
	Validate first PCB	00:45:13	00:54:58	0:09:45
Turn Table	Adjust Conveyor	00:44:22	00:45:01	0:00:39
Forno	Load Program	00:35:14	00:36:43	0:01:29
	Adjust Conveyor	00:36:59	00:37:25	0:00:26
	Visual Inspection	00:54:58	01:00:53	0:05:55
	Validate first PCB	01:00:55	01:07:06	0:06:11
AOI	Adjust Conveyor	01:07:06	01:07:56	0:00:50
	Load Program	01:07:56	01:08:50	0:00:54
	Validate first PCB	01:08:50	01:10:20	0:01:30
		TOTAL		**2:11:36**

Source: Author (2022).

Stage 1: Separating Internal and External setup.

This phase corresponds to the organization of activities, classifying and separating them as internal setup, those carried out with the machine stopped and external setup as being activities carried out with the machine running.

Figure 8. Evaluation of setup time in stage 1.

PROCESS	ACTIVITIES	Start	End	Time	CLASSIFICATION												
					Documentation	Software	Feeding	Manual Operation	Adjusts	Controls	Machine Setup	Cleaning	Wait	Transport	Inspection	INTERNAL	EXTERNAL
Vacuum Loader	Feed PCB	00:13:45	00:14:46	0:01:01				■								x	
PCB Cleaner	Adjust Conveyor	00:14:46	00:15:46	0:01:00				■								x	
Printer	Change Stencil and feed solder paste	00:15:46	00:24:46	0:09:00				■								x	
Conveyor	Adjust Conveyor	00:24:46	00:25:36	0:00:50				■								x	
SPI	Validate first PCB Inspection	00:25:36	00:27:36	0:02:00											■	x	
Turn table	Adjust Turn Table	00:27:36	00:28:26	0:00:50										■		x	
NXT	Change troller	00:00:00	00:13:38	0:13:38							■					x	
	Adjust backup pins	00:05:09	00:22:16	0:17:07							■					x	
	Validate feeder (pitch)	00:04:19	00:24:10	0:19:51					■							x	
	Adjust feeder error	00:24:02	00:26:03	0:02:01									■			x	
	Adjust clamp error	00:26:30	00:27:54	0:01:24									■			x	
	Perform CHKKP check	00:31:16	00:39:10	0:07:54											■	x	
	Validate first PCB	00:29:07	00:42:48	0:13:41										■		x	
XP	Load Program	00:27:54	00:30:32	0:02:38		■											x
	Adjust backup pins	00:30:45	00:34:40	0:03:55							■					x	
	Validate feeder (pitch)	00:37:11	00:41:27	0:04:16					■							x	
	Perform CHKKP check	00:41:31	00:44:22	0:02:51											■	x	
	Validate first PCB	00:45:13	00:54:58	0:09:45										■		x	
Turn Table	Adjust Conveyor	00:44:22	00:45:01	0:00:39				■								x	
Forno	Load Program	00:35:14	00:36:43	0:01:29		■										x	
	Adjust Conveyor	00:36:59	00:37:25	0:00:26				■								x	
	Visual Inspection	00:54:58	01:00:53	0:05:55											■	x	
	Validate first PCB	01:00:55	01:07:06	0:06:11										■		x	
AOI	Adjust Conveyor	01:07:06	01:07:56	0:00:50				■									x
	Load Program	01:07:56	01:08:50	0:00:54		■										x	
	Validate first PCB	01:08:50	01:10:20	0:01:30											■	x	
		TOTAL		**2:11:36**													

Source: Author (2022)

Figure 8 shows the evaluation result of setup time in stage 1, in which the separation of internal/external preparation tasks and waste occurs, with machines down, this assessment should list and classify operations, check functions, time, and look for opportunities. The first three columns of the evaluation indicate the activity, the accumulated time and the individual time for each activity. The classification columns define the classification of the activity, that is, the type of activity and whether it is internal or external.

Steage 2: Convert ***Internal setup*** in ***External setup***.

In stage 2, the objective is to convert what was classified as an internal setup into an external setup. For the ongoing case study, the time reduction of the internal setup promoted by stage 2 is still not enough to reach the time goal proposed by the SMED, being necessary an analysis of the operations to verify if any of them were wrongly allocated within the internal setup and through a work convert these activities into external setup. Figure 9 shows the result of the evaluation of the setup time in stage 2, which occurs in the conversion of internal activities into external ones. The columns in green define what kind of action could be taken and how much time could be reduced in each activity to be improved.

Figure 9: Evaluation of Setup Time in stage 2.

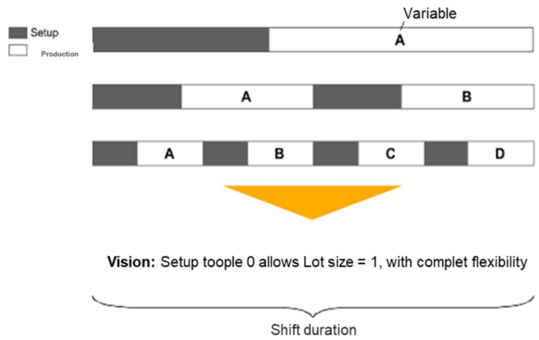
PROCESS	ACTIVITIES	Start	End	Time	CLASSIFICATION: Documentation	Software	Feeding	Manual Operation	Adjusts	Controls	Machine Setup	Cleaning	Wait	Transport	Inspection	INTERNAL	EXTERNAL	OPTIMIZATION: Eliminate	Combine	Redistribute	Simplify	INTERNAL	EXTERNAL
Vacuum Loader	Feed PCB	00:13:45	00:14:46	0:01:01				■								X						0:01:01	
PCB Cleaner	Adjust Conveyor	00:14:46	00:15:46	0:01:00				■								X						0:01:00	
Printer	Change Stencil and feed solder paste	00:15:46	00:24:46	0:09:00				■								X				■			0:09:00
Conveyor	Adjust Conveyor	00:24:46	00:25:36	0:00:50				■								X						0:00:50	
SPI	Validate first PCB Inspection	00:25:36	00:27:36	0:02:00											■	X				■			0:02:00
Turn table	Adjust Turn Table	00:27:36	00:28:26	0:00:50										■		X						0:00:50	
NXT	Change troller	00:00:00	00:13:38	0:13:38							■					X					■	0:07:38	
	Adjust backup pins	00:05:09	00:22:16	0:17:07							■					X					■	0:07:07	
	Validate feeder (pitch)	00:04:19	00:24:10	0:19:51					■							X					■	0:17:51	
	Adjust feeder error	00:24:02	00:26:03	0:02:01									■			X						0:02:01	
	Adjust clamp error	00:26:30	00:27:54	0:01:24									■			X						0:01:24	
	Perform CHKKP check	00:31:16	00:39:10	0:07:54											■	X				■			0:07:54
	Validate first PCB	00:29:07	00:42:48	0:13:41										■		X					■	0:08:41	
XP	Load Program	00:27:54	00:30:32	0:02:38		■											X			■			0:02:38
	Adjust backup pins	00:30:45	00:34:40	0:03:55							■					X							
	Validate feeder (pitch)	00:37:11	00:41:27	0:04:16					■							X							
	Perform CHKKP check	00:41:31	00:44:22	0:02:51											■	X				■			0:02:51
	Validate first PCB	00:45:13	00:54:58	0:09:45										■		X					■	0:07:45	
Turn Table	Adjust Conveyor	00:44:22	00:45:01	0:00:39				■								X						0:00:39	
Forno	Load Program	00:35:14	00:36:43	0:01:29		■										X						0:01:29	
	Adjust Conveyor	00:36:59	00:37:25	0:00:26				■								X						0:00:26	
	Visual Inspection	00:54:58	01:00:53	0:05:55											■	X					■	0:02:55	
	Validate first PCB	01:00:55	01:07:06	0:06:11										■		X						0:06:11	
AOI	Adjust Conveyor	01:07:06	01:07:56	0:00:50				■									X			■			0:00:50
	Load Program	01:07:56	01:08:50	0:00:54		■										X				■			0:00:54
	Validate first PCB	01:08:50	01:10:20	0:01:30											■	X				■			0:01:30
		TOTAL		2:11:36														TOTAL				1:07:48	0:27:37

Source: Author (2022).

Stage 3: Systematic improvement of each basic operation of the internal and external setup.

The improvement is not limited to the machine itself, but to everything related to it, such as improved storage and transportation. The pursuit of the single-minute (one digit) may not be achieved in the previous stages, requiring continuous improvement of each element, both the internal and external setup.

Figure 10: Result of the setup time evaluation in stage 3.



Source: Author (2022)

The setup reduction allows us to work with smaller production batches and thus reduce inventories and gain flexibility. The result of the evaluation of the setup time in stage 3, in the internal environment, allows to improve all aspects of the preparation operations. Thus, 5S must be carried out and the management and storage of utensils, tools and jigs improved. The result of the evaluation of the setup time in stage 3, in the external environment, allows to improve all aspects of the preparation operations. In this way, operations are carried out in parallel; functional fixtures; elimination of settings; and mechanization.

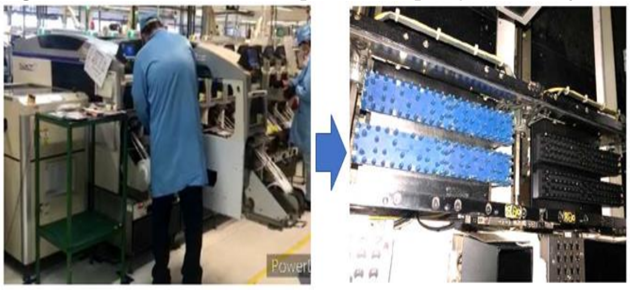
SMED implementation steps

The improvement proposal for the reduction of setup time implemented in the production flow of the studied SMT line occurred on the machines, labor, and method.

Improvement – Machine

In the machine item, the first improvement made was the reduction of the time to adjust the pins of the NXT machines. The proposal consists of replacing the metal backup pins with a system called softpins, a system of pins that, because they are flexible, can make contact with any part of the board without any restrictions, supporting the board safely and efficiently. Figure 11 shows the before and after of the pin adjustment system.

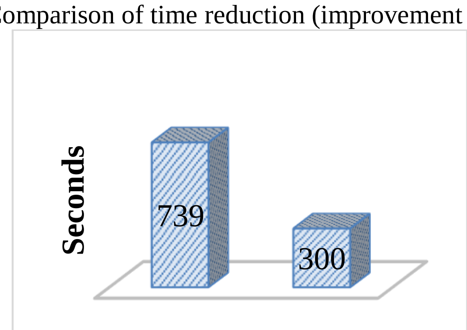
Figure 11: Before and after pins backup adjustment system.



Source: Author (2022)

After implementing the improvement in the operation of adjustments/change of metal pins, replacing the pins with the base of softpins, both productivity and quality improved. Changeover time reduced because all the activity of positioning each individual pin using the guide plate was replaced by the simple positioning of the base of softpins. Quality has been improved by eliminating the risk of incorrectly positioning a pin, which could cause the board to lack support during assembly, that is, an increase in the rate of poorly assembled components. Another risk eliminated by the softpin base is that of lifting the plate due to a poorly positioned pin which can cause the breakage of the head, part of the assembly machine with very high value and difficult to acquire due to the purchase process, in addition to the loss due to the stoppage of the line.

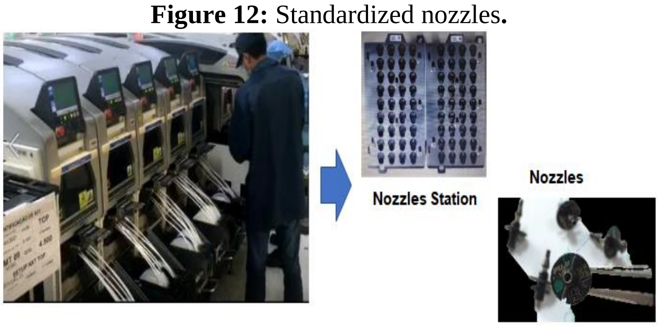
Graph 1: Comparison of time reduction (improvement 1 - Machine)



Source: Author (2022)

Graph 1 denotes a reduction of 59.40% (439s) in the time to adjust the backup pins, since initially 00:12:19 (739s) was spent for the individual positioning of the pins, and after implementation of the sofpins base the same activity is performed in just 00:05:00 (300s). The second improvement was due to the lack of standardization of the nozzles in some modules, the non-availability of some types of nozzles due to the lack of standardization of the nozzle kit it made the machine operator waste time looking for these nozzles in other modules or other production lines. Figure 12 shows the before and after standardization of the nozzles.

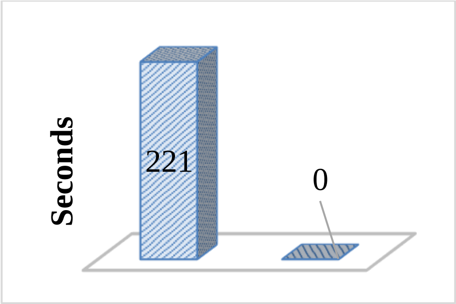
Figure 12: Standardized nozzles**.**



Source: Author (2022)

Before and after Figure 12 shows the "before", which is the lack of standardization of the nozzles where the operator wasted a lot of time looking for the missing nozzles in other places, and the "after" after the implementation of the no nozzle station in each module, making available what was needed to change the model in each NXT module. Graph 2 demonstrates the comparison of time with the development of this improvement.

Graph 2: Comparison of time reduction (improvement 2 - machine).



Source: Author (2022)

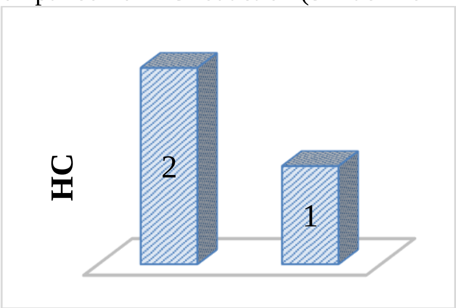
Graph 2 shows a 100% reduction in time, because initially the time spent looking for nozzles that were not available in any of the modules was 00:03:41 (221s) and after the action of standardize all modules with a standard kit this waste of time has been eliminated, therefore increased productivity. Improvement 3 was carried out by replacing the machine modules connection cable (NXT), a special connection cable was implemented that allowed easy connection, avoiding breaking the cables, figure 13 shows the improvement made.

Figure 13: Connection cable between modules 1 and 8.

Source: Author (2022)

Graph 3 presents a comparative reduction in people (HC-Headcount) after the implementation of the new connection cable. With the development of the improvement, it is observed that there was a reduction of 1 person in the process. In view of this, productivity increased, there was a reduction in losses in the process, and a reduction and standardization of operations.

Graph 3: Comparison of HC reduction (3-machine improvement).

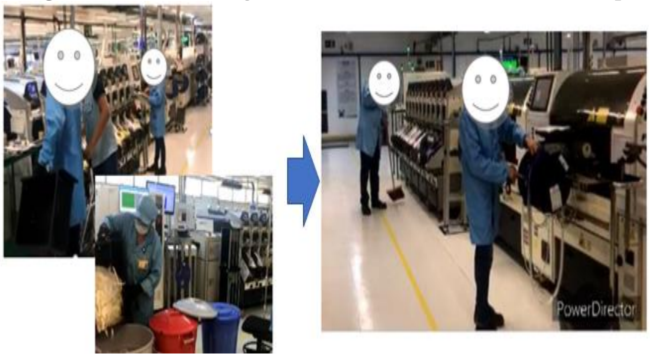


Source: Author (2022)

Improvement - Labor

In the Labor item, the first improvement consists of removing the packaging residue from the components only after the setup and not during, so the operator was instructed to remove the residue after the setup, figure 14 shows the realization of the majority.

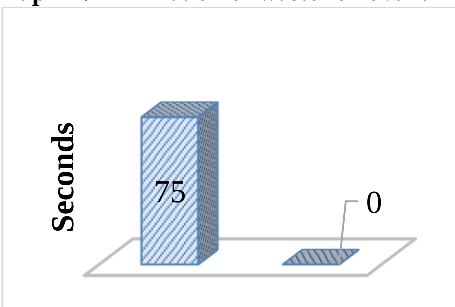
Figure 14: Removing residue from the rollers after setup.



Source: Author (2022)

Graph 4 shows the change in activity from internal to external, after defining the new process for removing waste from component rolls after setup. It is possible to visualize the elimination of the time used 00:01:25 (75s) in the waste removal activity, due to its transfer to after or before the setup.

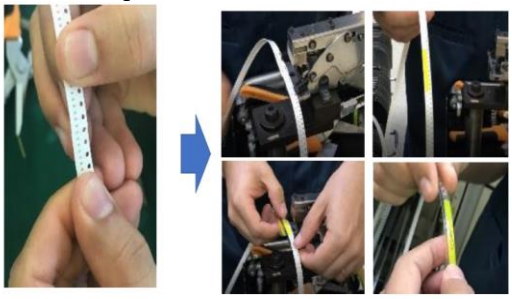
Graph 4: Elimination of waste removal time.



Source: Author (2022)

The second improvement relates to poorly prepared splices during the component roll (tape) feedback process, mainly at the output of the model in production, when many rolls are feedback to close the production order. Training was carried out with all machine operators so that the splices could be carried out in the best way, as shown in figure 15.

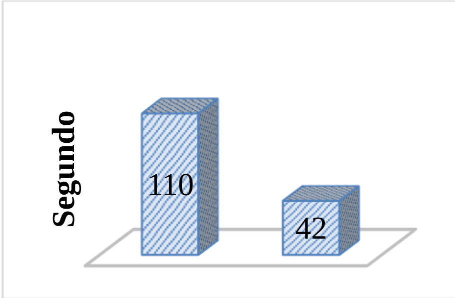
Figure 15: Roller kit closure.



Source: Author (2022)

Graph 5 tabulates the reduction in time used to correct poorly prepared splices by operators of SMT machines when feeding new Components. As shown in the data in Graph 5, there was a reduction of 61.8% (68s) in the time after the improvement, as before, 00:01:50 (110s) was used, that is, in 1 minutes and 50 seconds, for if you correct amendments and after implementing the training, time0 was reduced to 00:00:42 (42s).

Graph 5: Reduction of losses with amendments.

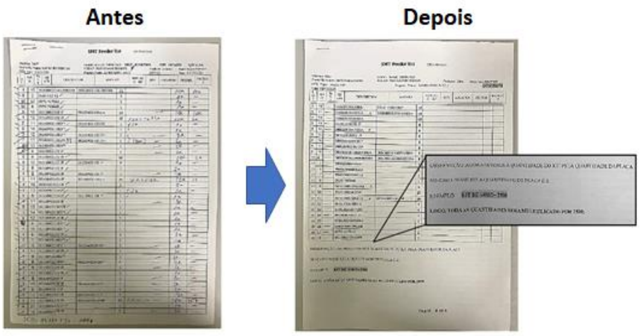


Fonte: Autor (2022)

Improvement – Method

In the Method item, the first improvement was in the supply list, which had errors in the quantities of components, which directly impacted the closure of production of the current model, and the proposed improvement was to define the correct quantities of components used in each feeder instead of an estimated number. Figure 16 shows the modification of the list format considering the exact definition of the quantity of components in each feeder, this improvement leads to a reduction in the number of material feedbacks since the quantity of components defined in the list was in line with reality.

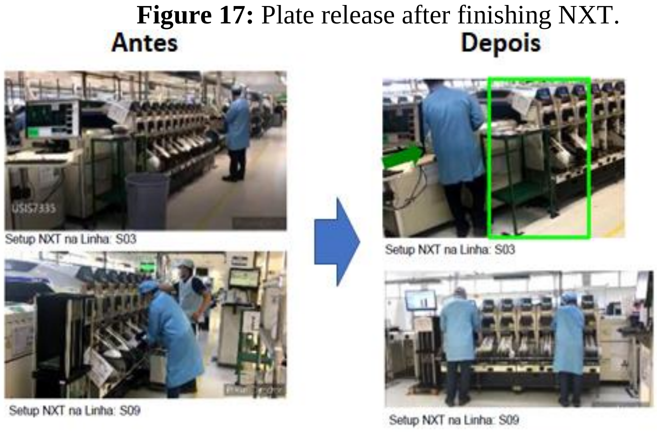
Figure 16: Feed list.



Source: Author (2022)

The second improvement was in the release of the first plate after completion of assembly. In the improvement proposal, the release occurs after finishing each module of the SMT machine, as shown in figure 17.

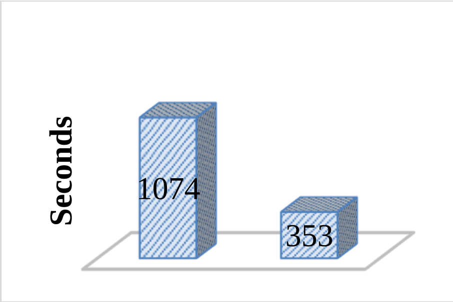
Figure 17: Plate release after finishing NXT.



Source: Author (2022)

Graph 6 quantifies the data after implementing the improvement, a reduction of 67.1% (721s) of time is obtained, since before it was used 00:17: 54 (1074s), that is, in 17 minutes and 54 seconds, and became 05 minutes and 53 seconds (353s).

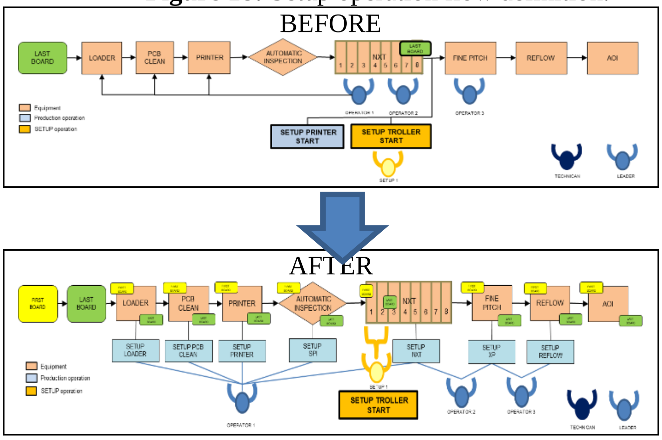
Graph 6: Optimization to release the first board



Source: Author (2022)

The third improvement is related to the lack of definition of the setup operation flow, in the proposal a new setup operation flow was defined and training with the team, as shown in figure 18.

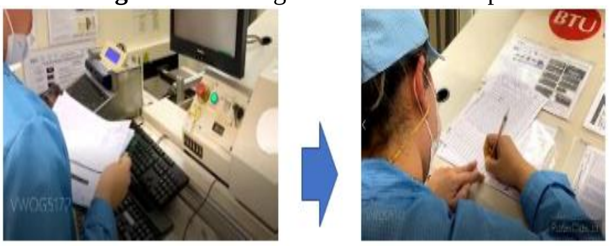
Figure 18: Setup operation flow definition.



Source: Author (2022).

The improvement implemented, as shown in figure 18, the new setup operation flow (see Appendix C) generated an increase in productivity, a reduction in process losses as well as the training and leveling of operators. The fourth improvement occurred in the form of filling out forms during setup, as the proposal made was oriented to operators to fill in forms after setup, as shown in figure 19.

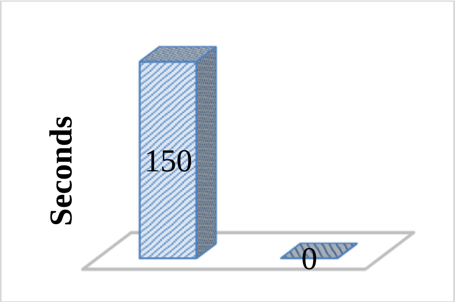
Figure 19: Filling in forms after setup.



Source: Author (2022)

After guiding operators on filling out forms after setup, the data was tabulated in seconds. Graph 7 shows the 100% reduction in the time that was used in this activity, 00:02:30 (150s) was previously used after the change in the process, this time was transferred from the internal setup to the external one.

Graph 7: Comparison of time reduction (improvement 4- method)



Source: Author (2022)

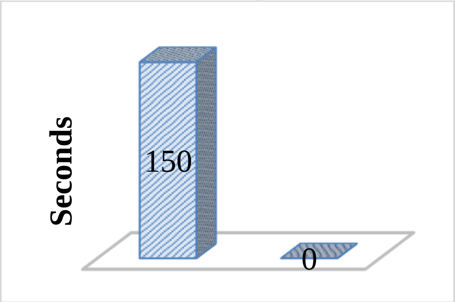
The fifth improvement carried out was in solder paste overflow, since, to optimize time, training was given to operators on the correct method of carrying out solder paste overflow, as shown in the figure 20.

Figure 20: Solder paste overflow.

Source: Author (2022)

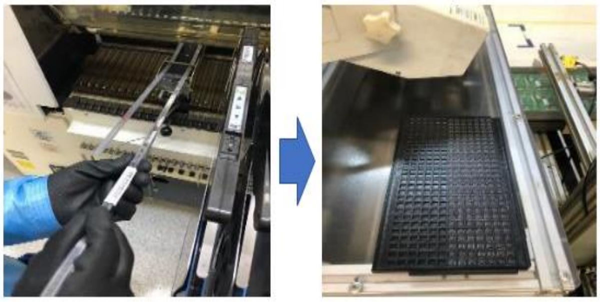
After conducting operator training on the most efficient method of carrying out solder paste overflow, the time was reduced to zero, as shown in Graph 8. Graph 8 shows the 100% reduction in the time used to carry out this activity, since it was previously performed at 00:03:00 (n= 180). In view of this, productivity was increased, standardized and losses reduced in the process; and redistributed the operation to external setup. The sixth improvement implemented was in the components in rod (stick) that became in tray, as shown in figure 21.

Graph 8: Elimination of solder paste overflow time solder.



Source: Author (2022)

Figure 21. Tray components.



Source: Author (2022)

The improvement in the exchange of the rod for the tray occurred because the rod (stick) is fed very frequently, the pick-up has a reduced speed, and components fall during the pick-up. After using the tray components, feeding no longer needed to be as frequent as before, the pick-up started to be done with greater speed and there were no more falls during the pick-up. This change increased productivity, reduced losses in the process and time to close production of the current model. The seventh improvement was related to the handling of feeder tables, also known as trollers. The lack of skill in handling the trollers caused in some setups an unplanned loss of time when fitting them to the STM machines. Figure 22 shows the training carried out with the operators to increase their ability to handle the trollers.

Figure 22: Training with machine operators.

Source: Author (2022).

IV. Discussion

One of the most important objectives of SMED is the reduction of setup times, by eliminating waste related to changing tools. Thus, what is intended with SMED is to try to separate the internal operations - namely the Exchange of Matrixes or the assembly of the equipment, which have to be carried out with the machine turned off from the external operations, namely those carried out with the machine in normal operation mode as is the case with tool preparation. (Moreira and Parents, 2011). The application of the SMED method was implemented based on the original established procedure presented by Shigeo Shingo (1985). However, in the initial stage, the waste found in the production process was identified, and as exposed the main problem identified was the high setup time (as presented in the cause and effects diagram).

Setup reduction is an extremely powerful tool that improves a plant's ability to provide customer satisfaction by making better use of its own assets (Albuquerque, 2017). SMED is an alternative to make production more flexible and increase productivity, by reducing failures and, mainly, setup time. The search for the elimination of waste generates the difference between companies, which provides survival and the guarantee of profits in the organization through the flexibility of existing processes. The SMED implementation must take into account the following factors: used material, machines, people involved and provision of machines and materials (Trombeta et al., 2020). SMED is done by changing activities or activities that can be changed from internal activities to external activities to save configuration time. Next parallel or combine external activities to simplify and shorten the configuration time (Kusrini and Parmasari, 2020). To learn more about the implementation of the SMED technique, it is necessary that the industry and executives become familiar with the factors in order to consider them and lead to accelerate the implementation of the SMED, or not (Hashemzadeh et al., 2014).

In the second moment, the SMED analysis took place, in which all the production process was timed to identify which stages the setup was greater. There are several approaches that can be used to study the configuration process. Using a stopwatch can give a good approximation of setup times. Being on the shop floor allows you to gain insights that are difficult to obtain from a secondary view, such as by videotape In the development of the SMED the entire team is tasked with proposing ideas to improve configuration operations. After the situation as this was evaluated, SMED is implemented (Pellegrini et al., 2012).

It was proposed to improve the exchange time in the classic SMED implementation method. The objective was to design a systematic way to reduce the time needed to perform a tool change in order to achieve the best possible results. The SMED methodology is applied through the application of a six-step process. First, the entire configuration is measured in the current state. The configuration is then analyzed to identify internal and external configuration elements, including calculating individual configuration elements. Then, the elements are analyzed and whenever possible, internal operations are converted into external operations. The time for the necessary internal and external configuration activities is reduced and, finally, the new exchange procedure is standardized (Lopes, 2019). SMED is a set of techniques used to reduce and improve machine preparation times and raw material preparation to be used in the next process, in order to change molds or equipment to make a production line in less than 10 minutes (Trombeta et al., 2020).

Application of the SMED methodology reduces waste to achieve efficient setup, The reduction is defined as the time required to change a process from the last part of the previous product to the first good part for the next product execution (Thomaz and Chiroli, 2016). SMED is developed to improve, process, labor, machine tools, and can be implemented in various production processes (Trombeta et al., 2020). The implementation of the rapid tool change was carried out on the machines, labor, and the method was carried out in eleven steps. In the machine environment, the first improvement made was the delay in the mechanical pinning adjustment system at NXT, in which the proposal was to replace the equipment's metal pins. Improvement in the operation of adjustments / metal pin exchange increased productivity because it reduced losses in the process; eliminated metal pins in NXT I and II, reduced setup time and eliminated the use of the mask board in NXT; and avoided head damage due to wrong positions. With the improvement there was a reduction of 59.40% (n = 300 seconds) of time, because initially 12 minutes and 19 seconds were spent and after implementation the same activity is carried out in 5 minutes.

The second improvement was made due to the lack of standardization of the nozzles (2 last modules), in view of this the nozzles (2 last modules) were standardized. Figure 12 shows the before and after standardization of the nozzles. Before the improvement, the operator performed the activity manually, and after it was implemented in the nozzles station. Thus, after there was a 100% reduction in time, because initially the time spent on the activity was 3 minutes and 68 seconds and after the implementation of the activity improvement was eliminated, therefore, increased productivity, there was a reduction in losses in the process, and standardization of activity. The third improvement was made in the handling of the connection cable between modules 1 and 8 (NXT), so a connection cable between modules 1 and 8 (NXT) was implanted. With the development of the improvement, there was a reduction of 1 HC in relation to the improvement in the connection cable between modules 1 and 8. In view of this, productivity increased, there was a reduction in losses in the process, and a reduction and standardization of operations. In the labor environment, the fourth improvement was made as the operator removing the residue during the setup of the rollers containing the SMD microcomponents, thus, the operator was instructed to remove the residue after the setup. It is observed that there was a reduction of 100%, for 1 minute and 25 seconds were used, and after the activity it was performed at a time that did not impact the setup activity, so it impacted the increase in productivity.

The fifth improvement made was poorly made amendments during kit closure of the rollers that feed the SMD machines, so the operators were trained to be carried out in the best way. With the implementation there was a reduction of 61.82% (n = 68 seconds) of the time after the improvement, since before 1 minute and 50 seconds were used, subsequently, a stop of 1 minute and 10 seconds was obtained, thereby increasing productivity, reducing losses in the process, and there was a standardization. In the method environment, the sixth improvement was in the supply list received with an error in the number of components impacting the closure, and the proposal made was a power list in a new component division format. With the improvement of the power list in a new component division format productivity increased, a reduction in losses in the process, in the time of kit closure, and of unscheduled operations is obtained.

The seventh improvement was in the release of the first plate after finishing the NXT, and in the proposal the release occurs on the first plate after finishing each module of the NXT. The improvement implemented with the first board after finalizing each NXT module. With the improvement, a reduction of 67.13% (n = 721 seconds) of time is obtained, since it was performed in 17 minutes and 54 seconds before and became 5 minutes and 53 seconds, increasing productivity and a reduction in process loss was achieved. The eighth improvement was in the absence of definition of setup operation flow, in the proposal a new setup operation flow was defined and training with the team was carried out. The improvement had an impact on the setup operation, in the proposal a new setup operation flow was defined and productivity increased, process losses reduced, new definition of method and flow of operation, as well as the training and leveling of operators.

The ninth improvement occurred in the form of filling out forms during setup, because in the proposal made, operators were instructed to complete forms after setup. The change made reduced 100% of the time that was used in this activity, since previously 2 minutes and 30 seconds were used, improving operational performance. The tenth improvement made was in the transfer of solder paste, since, to optimize the time, training was carried out with operators on the correct method of transhipping solder paste. The improvement optimized 100% of the time that was used to perform this activity, since it was previously developed in 3 minutes. In view of this, productivity was increased, standardized and reduced losses in the process; and redistributed the operation to an external setup. The eleventh, improvement implemented were those of the (stick) components, which became a tray. The improvement in the exchange of rod per tray occurred because in the rod (stick) there were failures due to constant feeding, pick up with reduced speed, component drop during pick up or due to the component by vibration, and pick-up variation. After using the components in the feed tray does not have to be constant, the pickup is at high speed, there was no more drop during pick-up and the vibration process, and no variation in pick-up was recorded. Such a change increased productivity, reduced process losses and closing time, and offered a new tray design.

The latest improvement was related to the handling of feeder tables, also known as a troller. The lack of skill in handling trollers caused some unplanned time losses in some setups when they were fitted to the STM machines. With the implementation of the proposed actions, a setup reduction of 1 hour, 8 minutes, and 45 seconds is obtained, that is, a reduction of 44 minutes and 45 seconds in the product exchange team produced in the beautiful SMT studied. In many investigations, SMED, as a tool or technique, is considered a primary key factor in maintenance, total preventive maintenance, the process of continuous improvement to achieve production (Hashemzadeh, et al., 2014). The implementation of the SMED eliminates all unnecessary movements required of the person, reduces the time spent on transportation with unnecessary activities. That is, it maximizes all the general effort for a more efficient setup (Silva, 2019). Establishing precise procedures for the operator to work in the transition process is necessary to show a precise sequence of operations in which the operator is needed to perform the operation. Standardized work instructions detailing the new transition process will be developed and posted on workstations. In addition, operators will be trained in the new transition procedures to ensure that the benefits of the new method are realized. The benefits of standardizing configuration procedures are documentation of the correct process for all shifts, reductions in variability, easier training for new operators and a baseline for improvement activities (Desai and Rawani, 2017).

SMED will be used as a tool to analyze configuration activities that can be reduced or eliminated to reduce overall configuration times. This will be accomplished and documenting in relation to the existing change process. The process will be evaluated and improved to include process improvements that will help to reduce setup times including a strategy to reduce the number of operators needed, reduce performance activities, improve machinery and other productivity (Santos, 2015). Training is a key element in the success of setup reduction efforts. Operators should be informed about the rapid exchange and informed about the reasons why they are being examined. A common trap is that the operator perceives configuration monitoring as an individual performance assessment tool, rather than a general improvement process. The result is that, when observed, he becomes nervous and starts to follow different procedures and operates at a different pace than usual, thus producing unreliable and biased data (Pellegrini et al., 2012). It can be seen that managerial support and technological capabilities are the most influential for successful implementation of SMED to reduce the risk of failure. In addition, managers must accurately assess the organizational condition for implementing this system. This increases certainty in the successful implementation of this system, identification of opportunities for improvement and review (Hashemzadeh et al., 2014).

The results of this study prove that setup time and reduced tool change time is an effective tool that can be applied to improve the manufacturing organization's ability to improve customer satisfaction through better use of assets. Therefore, it is concluded that the modification of practices results in a significant reduction in the configuration and tool change time, improving productivity (Desai and Rawani, 2017). In view of the results presented, it is pointed out that the implementation of rapid exchanges allows manufacturers more flexibility to adjust to changes in demand levels or to changes in demand for different products. Shorter setup times increase production capacity. When the current capacity is almost filled, being able to reduce the setup and convert that time into productive time is an alternative to using overtime or making capital goods acquisitions to increase capacity.

V. Conclusion

The implementation of lean principles in any process will bring good results for any industry. Great results can be achieved by eliminating activities that do not add value. If these principles are applied in all departments of the organization, they will bring considerably good results. The lean manufacturing approach using the SMED technique can be used effectively in any type of manufacturing machine, as it is a world-class manufacturing tool. The basic approaches to applying the SMED method, which were defined by Shigeo Shingo, were described in this dissertation. The SMED method is mainly used to optimize the exchange process and to eliminate negative impacts by carrying out the activities of the internal and external setup. It is concluded that when implementing the SMED technique, productivity can be achieved, and waste can be eliminated.

The application of the SMED method was implemented based on the original established procedure presented by Shigeo Shingo (1985). In this project, it was carried out in three stages that were identified by the waste found in the production process, and as exposed, the main problem identified was the high setup time; SMED analysis in which all the production process was timed to identify which stages the setup was greater; and the implementation of 11 (eleven) improvement based on the SMED methodology on the machines, labor, and method. With the implementation of the proposed actions, a setup reduction of 1 hour, 8 minutes and 45 seconds to 24 minutes is obtained, that is, a reduction of 44 minutes and 45 seconds in product change time produced in the beautiful SMT of the studied company.

Those with data mentioned above conclude that a new proposed process has a significant productive increase, achieving better productive efficiency in the sector, in addition to reaching new productive levels and also reducing the cost of labor, which was responsible for manual speed change. Therefore, the electronics company obtains significant gains in relation to the increase in productivity to reduce labor costs and setup time. The critical success factors in implementing the project are the costs involving equipment and labor that are necessary for its realization, which, if too expensive, makes them unfeasible. Another factor that prevents its realization is organizational, because when analyzed by the company's top management, it appears that the project is not favorable for the electronics company. Finally, another variable that makes the project not beneficial for the company is quality, as increased productivity can affect the quality of the pet bottle transport process, affecting the quality of the product. Then, before the final implementation of the project, testing and training was carried out before its final installation to confirm the reliability of the process.

Applied research has achieved its objective of reducing the setup time of the SMT line, above all it has competitive advantages, besides being one is a way to increase the competitiveness of a company, produce more with less, that is, maintain the same production with a smaller number in a leaner process. Besides that, it is recommended that management needs to create a training plan for the operator to familiarize himself with the new procedure and develop the inspection measures to ensure that the procedure is actually implemented, thus obtaining the positive results presented. As future directions for the project, some developments are presented below: the implementation of this improvement in other production processes in order to make the company efficient and fast and, consequently, therefore, offering its most quality and effectiveness; and carry out an analysis of the company's other organizational production processes in order to verify the possibility of SMED implementation to reduce the time of the exchange process, in order to achieve continuous organizational improvement.

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