Article

Applying the PDCA Cycle to Reduce the Defects in the manufacturing Industry. A Case Study

Arturo Realyvásquez-Vargas[1], Karina Cecilia Arredondo-Soto[2*], Teresa Carrillo[3*], Gustavo Ravelo[4]

[1] Department of Industrial Engineering, Tecnológico Nacional de México/Instituto Tecnológico de Tijuana, Calzada del Tecnológico S/N, 22414 Tijuana, Baja California, Mexico; arturo.realyvazquez@tectijuana.edu.mx

[2] Universidad Autónoma de Baja California, Calzada Universidad #14418, Parque Industrial Internacional, Tijuana, B.C., C.P. 22390; karina.arredondo@uabc.edu.mx

[3] Universidad Autónoma de Baja California, Calzada Universidad #14418, Parque Industrial Internacional, Tijuana, B.C., C.P. 22390; tcarrillo@uabc.edu.mx

[4] Department of Industrial Engineering, Tecnológico Nacional de México/Instituto Tecnológico de Tijuana, Calzada del Tecnológico S/N, 22414 Tijuana, Baja California, Mexico; guztavo27@gmail.com

* Correspondence: karina.arredondo@uabc.edu.mx

Featured Application: The tool of PDCA cycle, supported by other graphical tools, such as Pareto charts and flowchart, can be applied in the manufacturing industry to delete or reduce occurrence of defects.

Abstract: Defects are considered one of the wastes in manufacturing systems that negatively affect the delivery times, cost and quality of products leading to manufacturing companies facing a critical situation with the customers and to not comply with the IPC-A-610E standard for the acceptability of electronic components. This is the case is a manufacturing company located in Tijuana, Mexico. Due to an increasing demand on the products manufactured by this company, several defects have been detected in the welding process of electronic boards, as well as in the components named Thru-Holes. It is for this reason that this paper presents a lean manufacturing application case study. The objective of this research is to reduce at least 20% the defects generated during the welding process. In addition, it is intended to increase 20% the capacity of 3 double production lines where electronic boards are processed. As method, the PDCA cycle, is applied. The Pareto charts and the flowchart are used as support tools. As results, defects decreased 65%, 79% and 77% in three analyzed product models. As conclusion, the PDCA cycle, the Pareto charts, and the flowchart are excellent quality tools that help decrease the number of defective components.

Keywords: Lean Manufacturing, PDCA, defects, Pareto chart, flowchart

1. Introduction

Lean manufacturing is a philosophy applied to production systems [1–3]. This philosophy was developed in the Toyota Production System and rapidly it was stablished in the manufacturing industry around the world [4]. According to Botti et al. [4], the main features of lean manufacturing include just-in-time practices, work-in-progress, and wastes reduction [1–3], improvement strategies, defects-free production, and work standardization. The main goal of lean manufacturing is increasing the company's profits and adding value by deleting the wastes. It is by this reason that when companies seek improve the effectiveness and efficiency of their production process, they

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implement lean manufacturing [5, 6]. Regard the wastes, literature mentions that in manufacturing industry thy are classified into seven categories, they overproduction, inventory, transport, waiting times, movements, over processing, and defects [7]. All of these wastes negatively affect the delivery times, cost and quality of products [4, 8]. In the specific case of defects, several authors point out that defects are the main cause of damages in more advanced components [9–12]. Manufacturing companies transform the raw materials or components they receive from their providers, assembling them to obtain a finished product, which must be delivered to the customer at time and without defects [13]. However, even today, defective products and components are present in the manufacturing industry, and this is a critical situation that companies in this sector are facing. Even after proper care in the design, materials selection and product manufacturing, there are defective parts [14].

This is the case of a manufacturing company located in Tijuana, Mexico. In its manufacturing processes, this company use electronic boards, which must go through a welding process. This process is carried out in the Manual Finish area, and it begins with the placement of Thru-Holes components on the electronic boards. Next, this assembly (Thru-Holes and electronic boards) is placed on a fixture to weld the components in the wave soldering machine. After this, the assembly goes to the workstation of quality inspection, where the quality worker is responsible for checking the assembly does not have welding defects. Finally, once the assembly approves the quality inspection, it is sent to another production line, where more components will be placed on it. However, and due to the increasing demand on the products manufactured by the company, several defects have been detected in the welding process of electronic boards, as well as in the components named Thru-Holes. Among the defects that have been detected there are solder bridge, missing components, damaged component, lifted component, insufficient solder, and excessive solder. Therefore, all electronic boards that were released as products ready to be used are causing assembly and electronic test problems. Moreover, it is more difficult, and has a high cost, the fact of correcting all defects when electronic boards are already assembled with more final product components. This manufacturing company intends to comply with the requirements established by the IPC-A-610E standard for electronic components (see section 2.1). It is for all these reasons that this Project aims to reduce at least 20% the defects generated during the welding process in the Manual Finish area. In addition, it is intended to increase 20% the capacity of 3 double production lines where electronic boards are processed.

To reduce or delete the wastes, such as defects, in a manufacturing company, lean manufacturing provides 25 methods, techniques or tools. Some of them are 5S, just-in-time, Kaizen, and Plan-Do-Check-Act (PDCA) cycle [15]. In the present Project only the PDCA cycle is used.

The rest of the document is organized as follows. Section 2 offers a recent literature review on the PDCA cycle and the supporting tools applied, it means: Pareto charts and flowchart. Section 3 describes the case study, the context research and the methodology applied. Section 4 presents the results obtained once the methodology was applied. Finally, section 5 contains the conclusions and recommendations derived from the case study.

2. Literature review

2.1 IPC-A-610E standard to acceptability of electronic assemblies

Accepted in all the world as the key manufacturing standards for the industries of manufacture of printed boards and electronic products, the IPC standards are related to most of the development cycle stages of electronic products. From the design and the purchase to the assembly and packaging, the IPC standards help to guarantee a better quality, reliability and consistence on the electronic assemblies that are part of an electronic product. Among the IPC standards are the following: IPC-A-630, IPC-A-600, IPC-4101, IPC-A-610E, and others. All IPC standards are accredited by the American National Standards Institute (ANSI).

With regard to the standard IPC-A-610E, it is a collection of visual quality acceptability requirements for electronic assemblies. In this standard, quality acceptability criteria are not focused

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define processes to perform assembly operations or authorize the repairing/modification or change of final product. In the specific case of the components named Thru Holes, the quality acceptability criteria of welding are the following:

- There are no cavities or imperfections on the surface.
- The terminal and the track have good wet conditions.
- The terminal is discernible.
- There is a 100% welding filament around the terminal.
- The solder covers the terminal and forms a smooth finish with thin edges on the conductor tracks.
- There is no evidence of raised filament.

In this way, all electronic components that go through a welding process must meet these criteria [16, 17].

2.2 PDCA cycle

The PDCA cycle, also known as Deming cycle or Shewhart cycle [18], is a lean manufacturing methodology that was developed in 1930, when there was no more exclusive products and a more quality management focusing competitiveness raised in the global market [19, 20]. According to several authors, the creator of the original PDCA cycle was an American statistician named Walter A. Shewhart [20, 21]. However, William Edward Deming was who, in the 1950s, developed this method, which, today, is one of the most worldwide known and applied. In its beginnings, the PDCA cycle was used as a tool to quality control of products [20, 22]. However, rapidly it was highlighted as a method that allowed developing improvements in process at organizational level [20, 22, 23]. Currently, the PDCA cycle is characterized by its continuous improvement approach [24] and it is recognized as a logic program that allows improving the activities [22, 25].

Several authors state that the PDCA cycle is much more than a simple lean manufacturing tool. Instead, they mention that the PDCA cycle is a processes continuous improvement philosophy introduced in the organizational culture of companies [26] that is focused in the continuous learning and the knowledge creation [22, 27]. Following rows describe the four stages of the PDCA cycle [28]:

- Plan: In this phase improvements opportunities are identified, and later priorities are assigned to them. En esta fase se identifican las oportunidades de mejora, y posteriormente se les asignan prioridades. Likewise, the current situation of the process to be analyzed is defined by means of consistent data, the problem causes are determined and possible solutions are proposed to solve it.
- Do: In this phase it is intended to implement the action plan, select and document the information. Also, unexpected events, learned lessons and the acquired knowledge must be considered.
- Check: In this step the results of the actions implemented in the before step are analyzed. A before-and-after comparison is performed verifying if there were improvements and if the stablished objectives were achieved. To this, several graphic support tools, such as Pareto chart or Ishikawa diagram, can be used.
- Act: This phase consists in developing methods aimed to standardize the improvements (in the case objectives had been reached). In addition, the proof is repeated to obtain new data and re-test the improvement (only if data are insufficient or circumstances had changed), or the project is abandoned and a new one is begun from the first stage (in the case the implemented actions did not yield effective improvements).

To perform these steps in an effective manner, other quality tools can be required to be used. These quality tools can help mainly to analyze the problem and define the actions to be implemented [20]. According to several authors [20, 29], among the quality tools most used by the companies, and that serve as support to the PDCA cycle, are the 5S, Failure Mode Analysis and Effects (FMEA), 5W1H o 5W2H, brainstorming, benchmarking; statistical process control (SPC), checklists, Ishikawa diagrams and the Pareto chart, Quality Function Deployment (QFD), the flowchart, histograms,

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SMED, Poka Yoke, Servqual, times quality and Six Sigma. In this project the graphical tools of Pareto chart and the flowchart are used.

2.3 Pareto chart

The Pareto chart is a special type of bars chart in which each bar represents a different category or part of a problem [30]. It raised when the Italian scientist named Wilfredo Pareto found that 80% of the wealth was received by 20% of people in Italy [31]. This type of chart illustrates the distribution frequency of descriptive data classified in categories. These categories are placed on the horizontal axe and the frequencies on the vertical axe [30, 31]. Talking on categories, they must be in descendent order from left to right, whereas the accumulated percentage of frequencies is represented by a line. The highest bars represent the most contributing categories to the problem. Pareto charts help identify how much some specific factors influence on a problem in relation with other factors, i.e., Pareto charts help identify the best improvement opportunities [32]. It is recommended to use Pareto charts in the following cases [30]:

- To decompose a problem into categories or factors.
- To identify the key categories that contribute the most to a specific problem.

2.4 Flowchart

A flowchart is a visual tool that shows the workflow for a specific work process, facilitating the understanding, standardization and improvement of such process. More precisely, a flowchart is a picture that contains the steps of a work process. It uses different symbols to represent different types of activities of a process. For instance, it uses boxes or rectangles to represent the activities or steps of the process or task, ovals or circles to indicate the beginning and the end of the process, diamonds to indicate that decision must be made, as well as arrows to indicate the sequence of said steps. The flowchart provides the following advantages [32, 33]:

- It allows identify the sequence of necessary steps to perform a task.
- It allows identify the relationships among the steps.
- It highlights the transferences, i.e., the places from where the process flows from a person to another one.
- It allows detect problem in the analyzed work process.

Although the necessary steps to perform a task can be identified by means of a list, a flowchart is easier to interpret, follow and remember. Moreover, a flowchart allows identify the process to be analyzed, the total steps in the process, and the beginning and the end of the process [33].

3. Case study

3.1 Context research

The present case study was performed in a manufacturing company lacated in Tijuana, Mexico. This company is dedicatd to the production telecomunications equipments, such as the following:

- Analog signal amplifiers of cable television.
- Transmitters of digital signals by optical fiber.
- Digital fiber optic receivers.
- Optical Modem.
- Analogue modem.
- Video transmitters by internet protocol (PI).

In its production process production processes, this company uses electronic boards. However, it has been detected that these components have present different defects, which has negatively affected finished products and also has delayed the delivery times to the customers. Then, in this case study, the PDCA cycle was applied to decrease the percentage of defects. Following subsection describes the methodology applied to achieve this.

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3.2 Methodology

The PDCA cycle was used to perform the present project. As mentioned above, the PDCA cycle comprises four phases: 1) Plan, 2) Do, 3) Check y 4) Act. Following subsections describe how each PDCA phase was applied in this project.

Phase 1. Plan

In this phase, the current situation of the wave welding process in the Manual Finish area was identified. To do this, a flowchart and a layout of the Manual Finish area were developed. Later, data on the number of defects in the last five months were obtained by means of the Flight Control platform of the company. Figure 1 shows the Flight Control platform screen. Once the defects presented in the Manual Finish area were known, the next step was to find those that have occurred in higher amount. This step was done by means of a Pareto chart. Finally, the defects were saved in a database to identify the models of products that had presented more defects and at the same time had the highest demands by customers, and therefore, the highest production levels. On this way, opportunities for improvement were identified and prioritized.

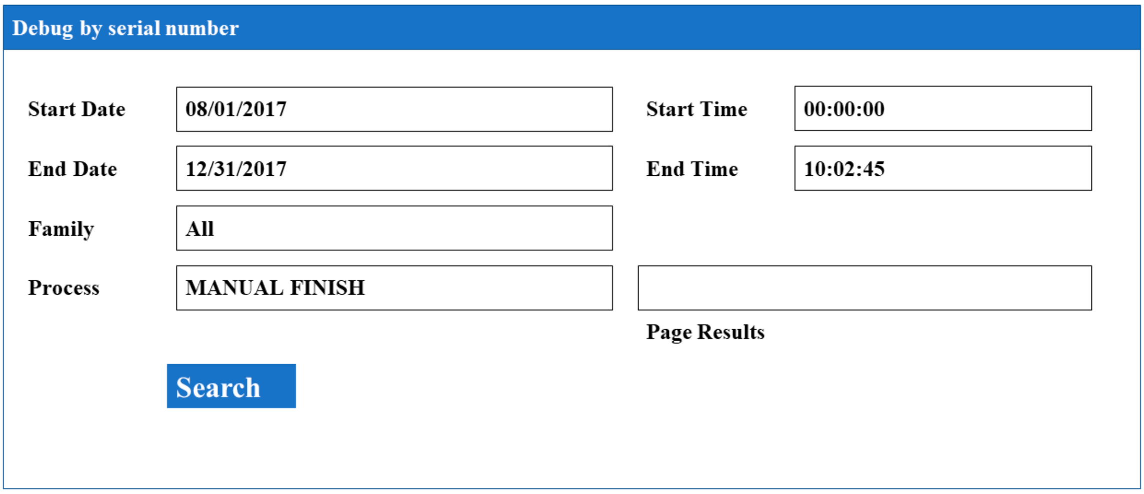

Figure 1. Flight Control platform screen.

Phase 2. Do

In this phase, the improvements opportunities detected in phase 1 were implemented. Among the implemented improvements were the following:

- Update of the process sheets for the set of electronic boards.
- Adjustment of parameters (temperature, speed, and other ones) for different product models.
- Evaluation and improvement of the design and conditions of the fixtures.

Phase 3. Check

In this phase, the results that were obtained when implementing the improvements of the previous phase were analyzed. For instance, the performance effect of the new fixtures on the number of defects was analyzed. Similarly, the assemblies released from the stations of manual assembly and Touch up were analyzed. Also, data from the last month (June 2018) were collected once the proposed changes were implemented in stage 2.

Phase 4. Act

In this phase, general results that were obtained with the changes made in the process were presented to managers. Based on the analysis performed on phase 3, some changes were standardized in the wave welding process.

4. Results

4.1 Results of phase 1

Figure 2 shows the layout and flowchart for the Manual Finish area. As can be seen, the production of electronic boards was performed in eight tasks: 1) Manual in, 2) Manual assembly, 3) Wave soldering machine, 4) Touch up, 5) Hand soldering, 6) Inspection, 7) Finish out, y 8) Quality assurance (Q.A.). Improvement opportunities were detected in the tasks of Manual assembly and Wave soldering machine. The results obtained from these improvements are presented in section 4.2.

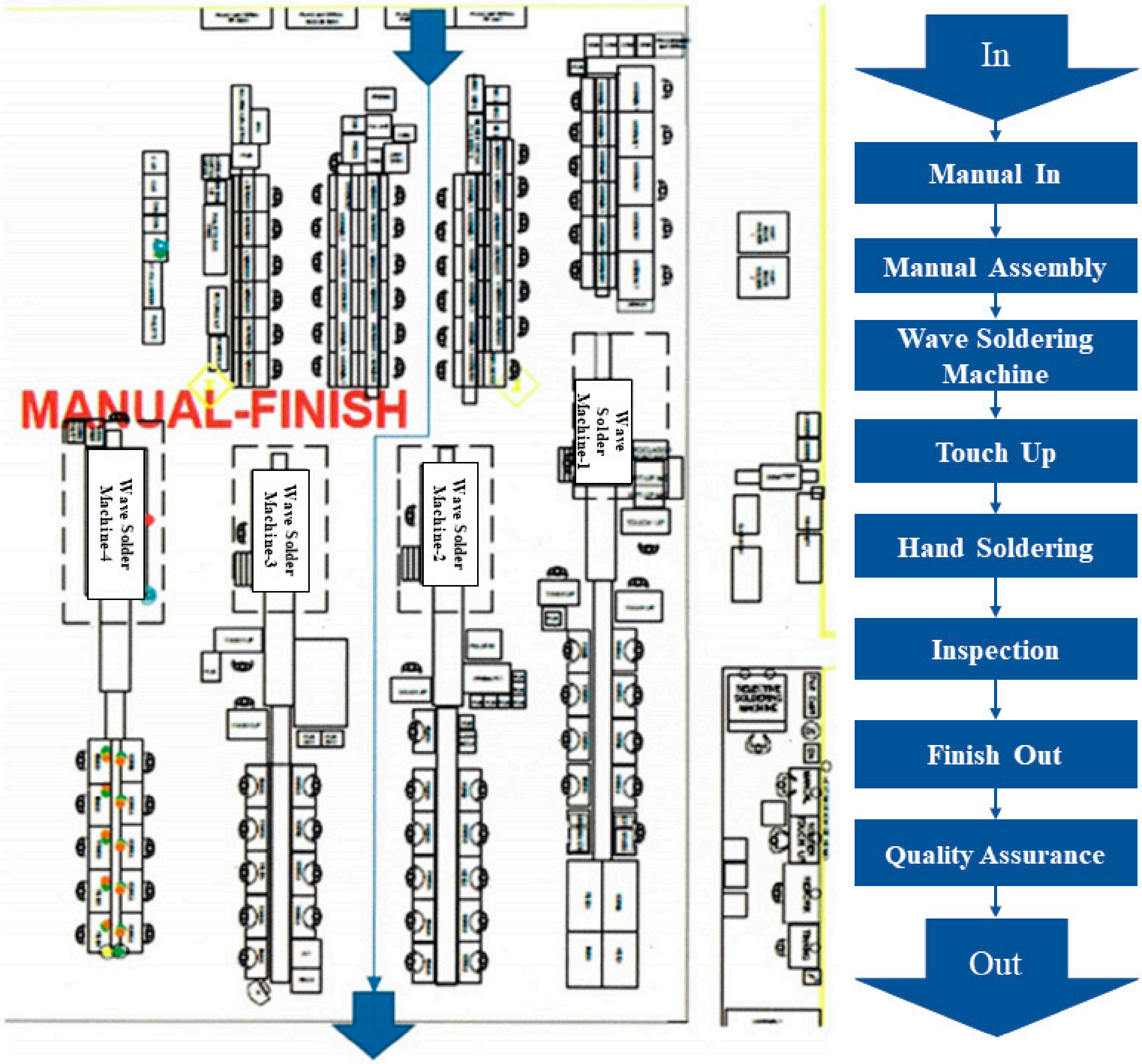

Figure 2. Layout and flowchart for the Manual Finish area.

The main defects detected in the wave welding process, and that represented the 80.8% of all defects, were solder bridge, damaged component, missing component, wrong component, lifted component, excessive solder, reversed component, insufficient solder, and pin damaged. Figure 3 shows the results in a Pareto chart for the defects detected in the Manual Finish area during the period of August to December 2017. Similarly, Figure 4 shows a Pareto chart with the product models that had the highest number of defects. These models were 595407-XXX-00, 595310-001-00, and 595481-00X-00. On the other hand, Table 1 shows the shows the projected demand for one year (February 2018 to February 2019) for the three models mentioned above before carrying out the present project. Note that for the three models, the projected demand is more than 21,000 units (row of Total). Based on the fact that these models were the ones with the greatest number of defects and also the highest demand, they were the ones that were dealt with in this project. Figure 5 shows the defects detected in the model 595407-XXX-00. Similarly, Figure 6 shows the defects detected in the model 595481-00X-00. Finally, defects detected in the model 595310-001-00 are shown in Figure 7.

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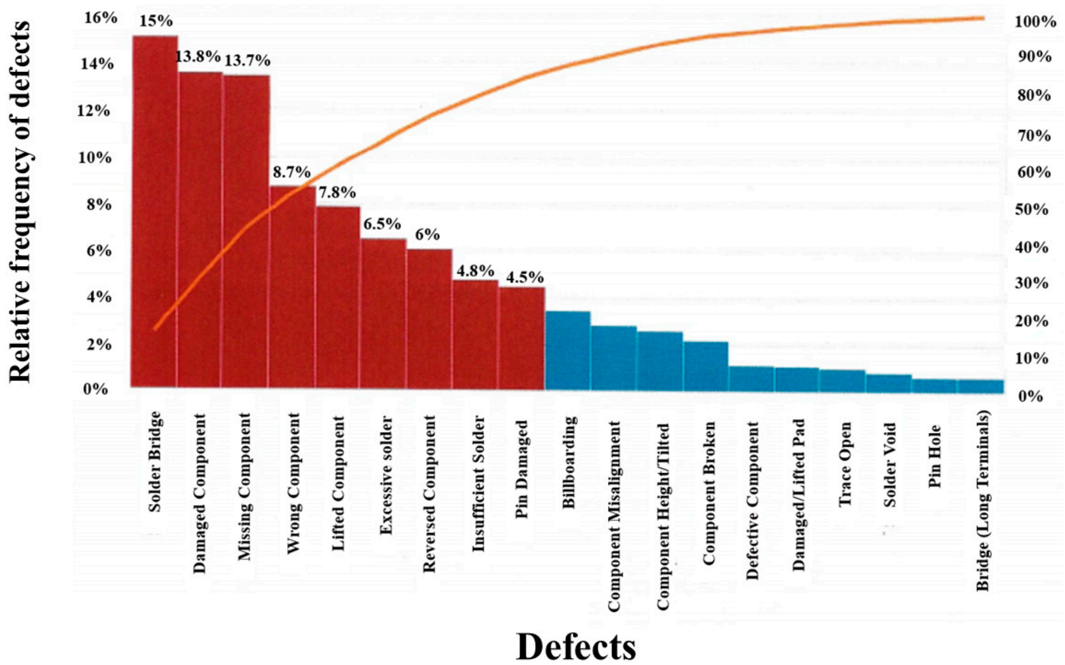

Figure 3. Pareto chart for the defects detected in the Manual Finish area.

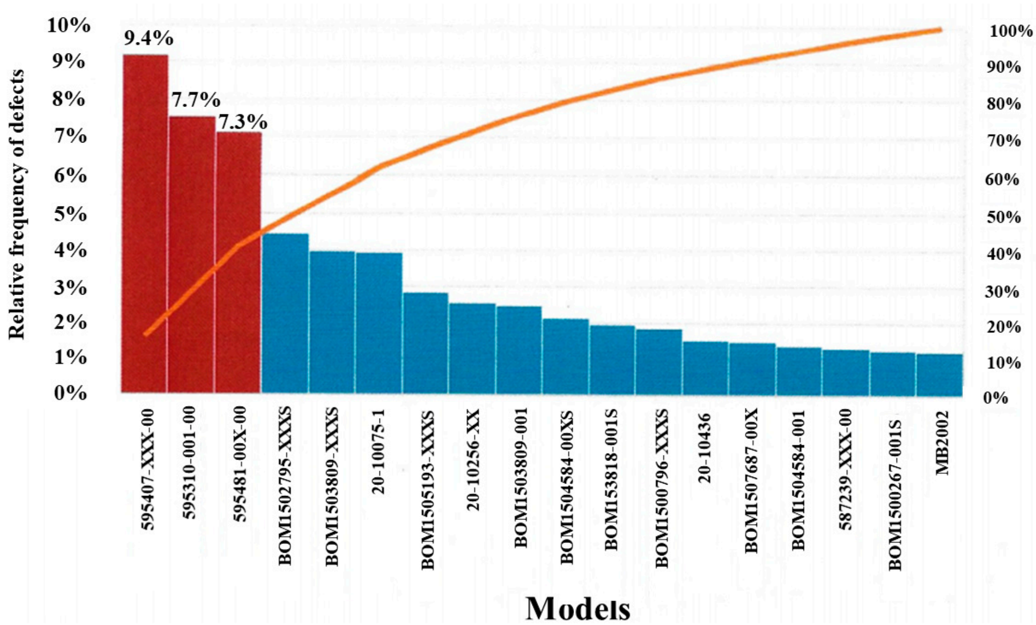

Figure 4. Pareto chart for the model with more defects.

Table 1. Projected demand for one year (February 2018 to February 2019) for the three models analyzed.

Model	Period													Total
	2018											2019		
	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dic	Jan	Feb	
595481-004-00		814	912	772	494	552	630	462	552	630	462	552	522	**7354**
595481-003-00	1450	2570	969	956	919	912	1046	771	912	1046	771	912	865	**14,099**
595481-002-00	206													**206**

Total														**21,659**
595407-003-00	238	9771	6490	3260	3509	3552	4072	3000	3552	4072	3000	3556	3383	**51,455**
595407-002-00	177	837	2727	2299	698	673	769	569	673	769	569	668	640	**12,068**
Total														**63,523**
595310-001-00		18916	12130	8432	7456	7296	8388	6198	7296	8388	6198	7296	6930	**110,756**
Total														**110,756**

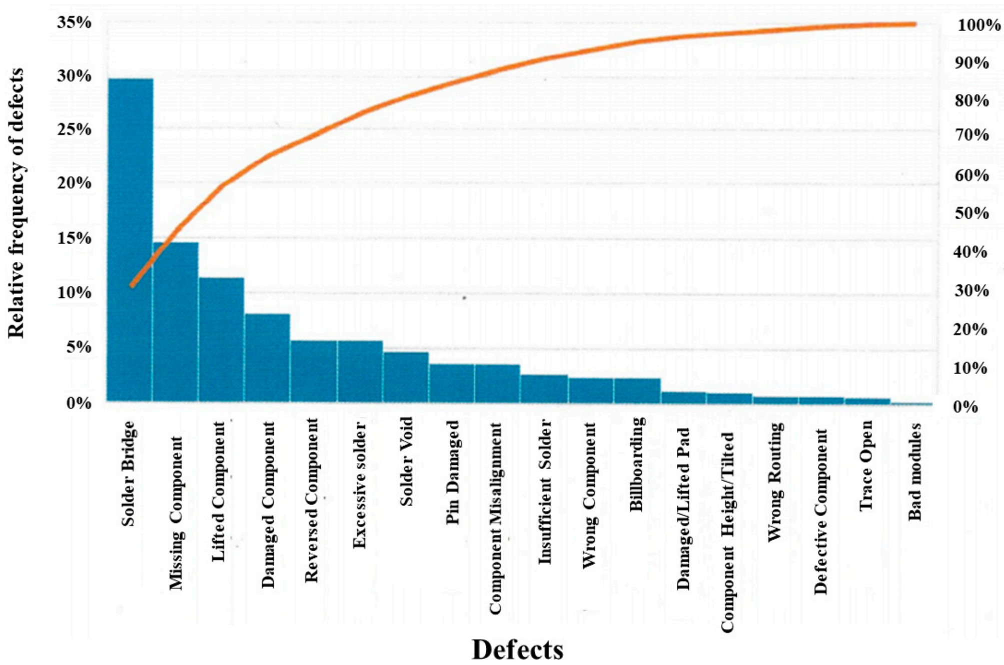

Figure 5. Pareto chart for the defects detected in the model 595407-XXX-00.

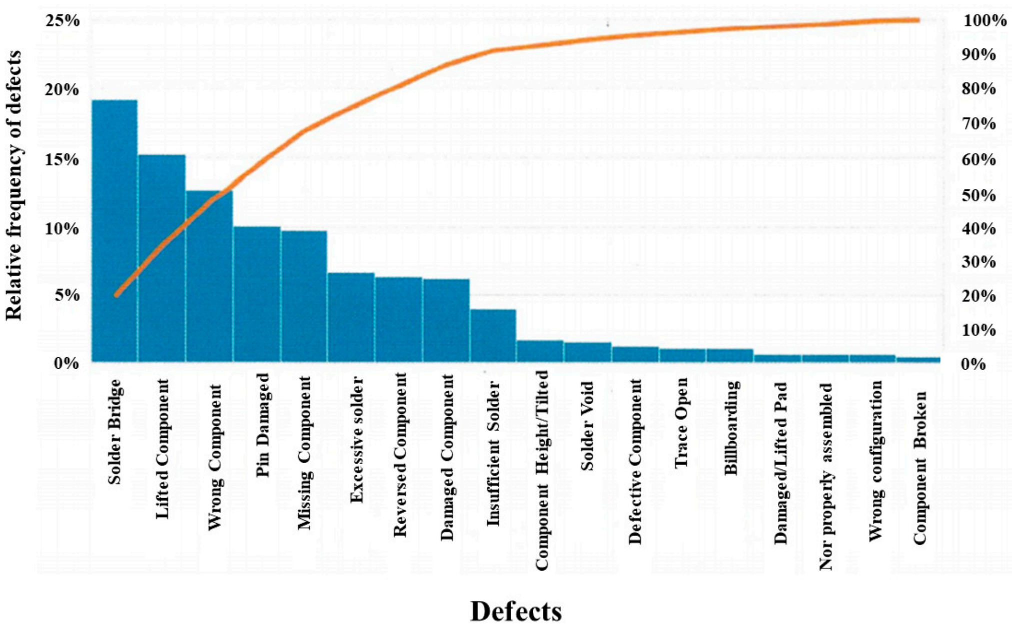

Figure 6. Pareto chart for the defects detected in the model 595481-00X-00.

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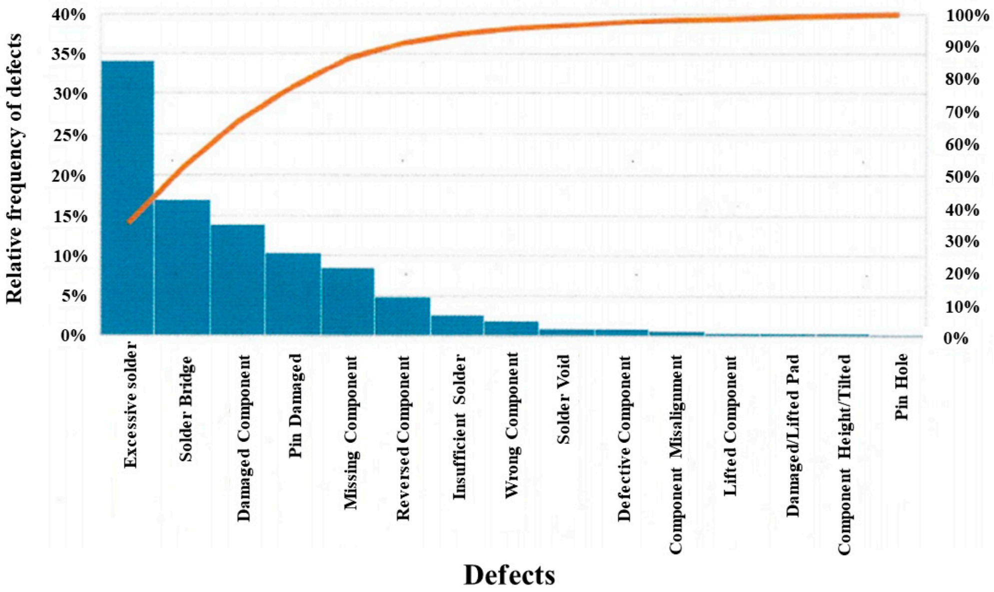

Figure 7. Pareto chart for the defects detected in the model 595310-001-00.

Regarding the fixtures used to perform the welding process, it was detected that several of them were damaged. This condition favored the appearance of defects. Therefore, new fixtures were purchased. These new fixtures presented a new design, since an improvement opportunity was detected in this issue. Table 2 shows the number of fixtures for each model in the company before the project was carried out, how many of them were damaged, how many had to be purchased, and the total cost, in American dollars (USD), to obtain them.

Table 2. Number of fixtures for model, damaged fixtures, optimal number of fixtures, fixtures to be purchased, and total cost.

Model	Fixtures before the project	Damaged fixtures	Optimal number of fixtures	Fixtures to be purchased	Price by fixture (USD)	Cost for total fixtures (USD)
595407-XXX-00	6	4	7	5	$220	$1,100
595481-00X-00	6	3	6	3	$240	$720
595310-001-00	7	3	9	5	$480	$2,400
					Total cost (USD)	$4,220

4.2 Resultados of phase 3

Based on the improvements implemented in phase 2, results indicated that all necessary fixtures were purchased for each model (see Table 2). In the wave welding process, these new fixtures helped to decrease the number of defects in comparison with the old fixtures. Other results indicated that the workstations of Manual Assembly did not have defective parts. Similarly, in the Workstation of Touch up there was an instant improvement, since the touch up process time had a decrease.

Regarding the defects of the analyzed models, results showed that the percentage of defects significantly decreased on the three models, having all of them less than 5% of all defects among all the models. Figure 8 shows the percentages (in red) of defects for the three models during the month of June 2018 (after the project was concluded). More precisely, the percentage of defects for the model 595310-001-00 decreased 65%. Similarly, the defects for the model 595407-XXX-00 were reduced in 79%, whereas the defects of the model 595481-00X-00 decreased 77%.

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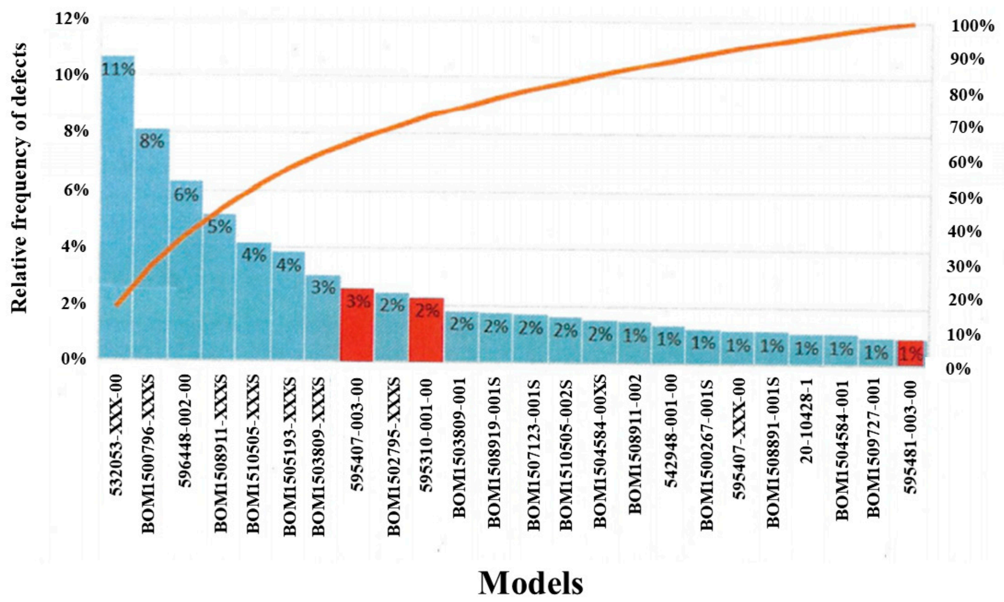

Figure 8. Relative frequency of defects for each model after finishing the project.

At the same time, these results led to an increase in the product quality, since the number of times the electronic boards were retouched was decreased, which in the beginning caused them to wear out, was reduced. Likewise, an increase in production was obtained in the three analyzed models, since the average times in the Touch up stations were reduced. For the model 595310-001-00, the average time in the Touch-up station decreased from 2.1 to 0.73 minutes; for the model 595407-XXX-00, from 2.54 to 0.53 minutes; and for the model 595481-00X-00, from 3.1 to 0.71 minutes. Table 3 shows the monthly capacity of the Touch up station before the project was carried out.

Table 3. Monthly capacity of the Touch up station before the project was carried out.

Parameter	Number
Shifts per day	2
Hours per shift	9
Hours of rest	1
Double production lines	3
Net time per day (hours)	96
Days worked per week	6
Weeks worked per month	4
Net time per month (hours)	2304

Table 4 shows the hours earned by model at the Touch Up station once the project was completed.

Table 4. Hours won by model at the Touch Up station once the project was completed.

Model	Times of the Touch up (Hours)			Hours earned per month
	Before	After	Difference	
595310-001-00	0.035	0.012	0.023	212.28
595407-XXX-00	0.042	0.009	0.033	174.68
595481-00X-00	0.052	0.012	0.04	67.36
			Total	454.33

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Based on the differences presented in Table 3 and Table 4, results indicated an increase of 19.72% in the capacity of the Touch up station. In economic terms, this percentage represents a saving of $ 21,027 USD projected to one year, since the cost per operator was $ 3.87 USD per hour.

4.3 Results of phase 4

At this stage, results were presented to the managers who approved to standardize some changes in the wave welding process. Some of the standardized changes were the use of fixtures with the new design, the update of visual aids with real photos of the electronic boards, in which notes for the electronic boards with polarity were added, specifying the correct positioning of the board. Similarly, some parameters (temperature, fan speed, wave speed, conveyor speed, conveyor width, flux amount) were changed and standardized for the three models.

5. Conclusion and recommendations

In general terms, it is concluded that the PDCA cycle is a tool that facilitates the detection of improvement opportunities, as well as the development and implementation of the same in lean manufacturing projects. This can be further simplified by the application of support tools, as in this case study were the Pareto charts and the flowchart. Together, the three tools help to globally increase the competitiveness of manufacturing companies, as in the case of the case study shown in this project.

Respect the objectives proposed in this project, it is concluded that the objective of reducing, at least 20%, the defects generated by the wave welding process in the models with the highest sales volume in the Manual-Finish area was achieved, since the number of defects on the three analyzed models decreased by 65%, 79% and 77%. On the other hand, with regard to the objective of increasing the capacity in the 3 double production lines of the electronic boards by at least 20%, it is concluded that also this objective was achieved, since the result was 19.72%, which had a difference of 0.28%, which it is considered non-significant. Finally, these results allow the company to be closer to complying with the IPC-A-610E standard, since a high percentage of the electronic boards of the analyzed models managed to meet the criteria established by that standard.

Based on the results in this case study, it is recommended to replicate PDCA cycle in the other models, present more defects, such as 532053-XXX-00, BOM1500796-XXXS, and 596448-002-00, to name a few.

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