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Improvement model to reduce defective parts in the hinge line of a Peruvian metalworking SME using lean manufacturing tools

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Abstract*— There are immeasurable small and medium-sized companies distributed throughout the world that in some cases have certain occupational and financial limits. In turn, these contribute significantly to the economy of each country. Within the main sectors that make up, these so-called SMEs are metal-mechanic manufacturing. One of the main problems faced by these manufacturers is the production of defective parts in their production lines, this has a great impact on billing, whether monthly or annual. For this reason, this present investigation proposes an innovative solution attacking the aforementioned problem. This, using various analyzes related to the lean philosophy and its tools that help to counteract this dilemma. This study seeks to implement tools such as 5S, Poka-Yoke, Andon and TPM, in order to reduce defective production in the hinge line of a Peruvian metalworking SME. Through the investigation, a progress result of 29.83% to 13.24% was obtained in its defective production indicator, which is reflected in a margin of improvement of 16 percentage points.

Palabras clave*— Lean Manufacturing, 5s, Poka-Yoke, TPM, Andon, PDCA, productos defectuosos, pyme, metalmecánica.

I. INTRODUCTION

In the manufacturing sector, there is the metal-mechanic industry, which is an economic unit dedicated mainly to the transformation of materials with a series of manufactured parts or components, in order to obtain new products. Likewise, it takes advantage of metallurgical inputs for manufacturing processing based on the market control system [1]. In Peru, the manufacturing industries accumulated a growth of 39.3% of GDP, in a certain way, the sector positioned itself as the largest contributor to the growth of the Peruvian economy with 4.2 percentage points. Likewise, these manufacturing industries, both primary and non-primary, have emphasized with the global world of technologies to reach the competitive level of the market [2]. On the other hand, the gross added value of the metal-mechanic industry showed a decrease of -2.5%, according to the mystery of production, this was due to the reduced consumption by families and the negative behavior of exports [3].

The development of the Peruvian metal-mechanic industry has benefited thanks to the link with the mining industry and the massive investments they make in the country, but it is not the only one [3]. In addition, it has close relationships with companies in industries such as fishing, production, oil, gas and energy. This leads to a heterogeneous production from the basic metals industry, the manufacture of products to the construction of industrial plants and warehouses. In addition, an important factor in the field is the innovation that manage to build strong relationships with international companies with technology [4].

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The present object of study is a metalworking SME focused on the production of various products, one of them dedicated to the line of hinges. Said organization presents difficulties in the maintenance of the machines, since it does not have a quality standard, it has reduced spaces and little neatness to develop the efficient processing of the products they manufacture, this cause has generated the problem of defective products, bringing consequences to the industry such as cost overruns, imperfect parts and delivery complaints with end customers. Therefore, this problematic mishap generates a low competitive participation in the metal-mechanic market and they lose economic income. [5].

A defective or damaged production process that does not meet the requirements or production standards, also affects the quality of the product and is unlikely to be corrected, either due to the expense generated, the implications and/or tools to be used.

This research establishes a proposal for improvement in the production of companies in the metalworking sector through the application of Lean Manufacturing tools to reduce defective parts. It is worth mentioning that lean manufacturing or lean manufacturing is a continuous improvement system that originated in Japan, it began in 1927, based on the improvement of processes, this can be distinguished by the contribution to the following production systems which aims to chart the path to achieve positive results and eliminate all possible waste. [6].

The article will be classified in parts according to its development. In the first place, the introduction of the metal-mechanic sector and the object of study. Then, it will investigate different referential frameworks to contextualize our problem with the state of the art. It is worth mentioning that following this we will take and put together a model with the reference methodology to solve the main problem that afflicts the factory, which will have different phases to follow. Finally, we will test the model through validation by pilot tests and simulations. Which we will measure using the metrics already established as indicators, to conclude with the results that our research gives us.

II. STATE OF THE ART

A. *Change management*

Growth in business organizations and their ability to remain profitable and competitive in the market depend on proper leadership that drives innovation and change management in them [7][8]. Likewise, leaders must be able to inspire employees to adapt to the necessary requirements by making certain changes in the company's organizational culture that favor process innovation [9]. In this regard, Professor J. Kotter developed a business innovation leadership model that consists of eight stages, which favor the creation of a culture of business innovation, as well as its deployment and development throughout the company, adapting to structural and organizational changes. transformation. By adopting a culture of business innovation, managers will be able to manage new innovation initiatives that allow the company to stay current and compete more efficiently, since the company will have developed an innovative brand, which means that employees will have adapted to corporate innovation policies and processes, as well as new employees will be able to quickly orient themselves to the progressive culture of the company [8].

B. 5S Methodology

5S is a technique that allows organizations to improve their workstations through the set of instructions or methods that are implemented to develop a cleaner, more organized and productive environment. This methodology aims to optimize the workflow thanks to its philosophy of reducing activities that do not add value and the coordination of the workplace to generate scalable production [10][11]. Likewise, the 5S tool is quite effective when it is implemented at the beginning of a lean transition, since it allows for a better organization of workspaces, thus serving as a starting point for the subsequent implementation of other lean tools that are more complex [12][13]. During the implementation of the 5S tool, difficulties may be found that prevent a correct development. According to this, it is pointed out that there are critical challenges for the implementation of 5S such as the participation of workers and the commitment of managers with the improvement proposal [14][15]. However, by overcoming the challenges of implementation, improvements in quality, productivity and occupational safety against accidents will be achieved [16].

C. Poka Yoke Tool

The Poka Yoke system is a way of working adopted by companies that seek to reduce human errors that occur in production, especially in those where quality policies in production lines are quite demanding [17]. Several studies adopted the production system under the Poka Yoke methodology, relying on computer or automated programs that allowed them to detect human errors that were overlooked, since

they were undetectable by the naked eye for the operators of the production lines [10][17]. In this regard, the main objective of Poka Yoke is to detect errors before products that do not meet quality requirements are generated in the manufacturing process and thus avoid being rejected by quality audits. quality or by customers, because today customers have adopted a more demanding position. For this reason, the Poka Yoke is called a production system with 0% defects [10][18].

D. Andon Tool

Wasted time in the industry means lost productivity and additional costs, which is why it is necessary to improve this situation. In this regard, Andon is based on the lean Jidoka principle to detect system failures or errors [19] [20]. We are presented with a technique that allows us to improve visual and sound communication by up to 85%, simplifying the problems that require a solution, so that the operators will know how to act in problematic situations that arise [21]. In this way, improvements in efficiency, quality, safety, communication, response times and production costs will be gained [20][21].

E. Total productive maintenance

TPM is a methodology that works best after the lean transition when applied on top of another lean methodology such as 5S [12]. Various studies have shown that the maintenance activities carried out in a successful implementation of TPM improve the general efficiency of the equipment by up to 50%, thus increasing productivity, quality, safety and reducing downtime. due to corrective maintenance activities such as operating costs, since there will be a greater availability of machines and equipment that will also operate with better precision and a low ratio of unplanned stops [21][22].

III. CONTRIBUTION

A. Methodology foundation.

The research reviewed for the development of this study proposal, as well as the consideration of the most important success cases, allowed the elaboration of a model for the present problem that allows to improve the current situation related to the exposed problem.

In this way, it was decided to combine the lean manufacturing tools in 4 phases. The first, Change Management; initial management tool that allows the proper introduction to the implementation of the other tools [8]. This will be extremely important, as it will serve as an initial link towards the continuous improvement that is sought to be obtained.

Since the organizational culture will choose to evolve by making certain changes that favor the culture of business

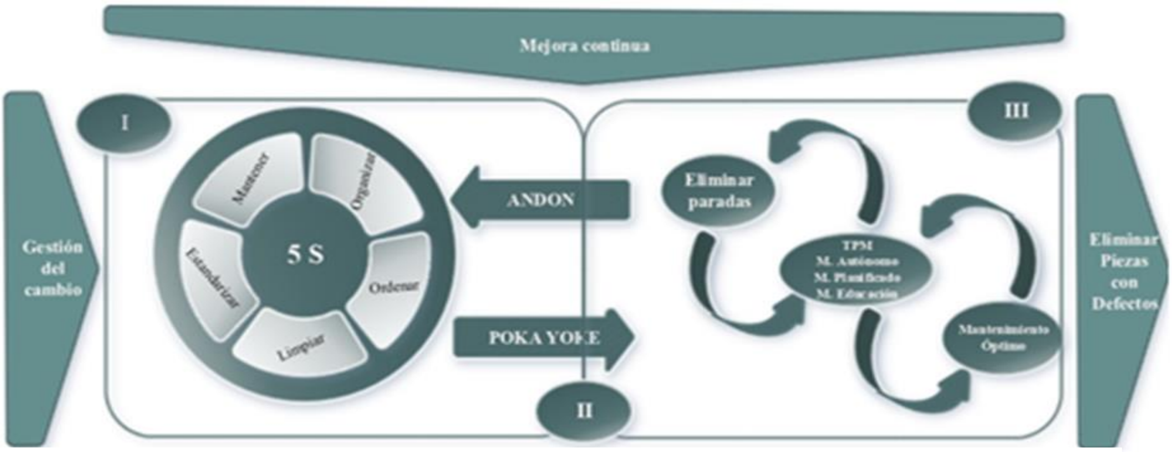

Fig. 1 Proposed improvement model. Adapted form de M.M. Shahriar et al. (2022); O. Bataineh et al. (2019).

innovation. Then, the 5S execution that allows establishing routines of order and organization in the company, establishing standards and codes of behavior that ensure compliance with the planning for improvement continue, in this way it is ensured

that the workstations are the most suitable for carrying out daily activities.

Third, the Implementation of Andon and Poka Yoke, tools that will facilitate the reduction of human errors in the production cycle thanks to its methodology based on the "zero defects" philosophy [17][20]. Finally, the TPM will be implemented, a tool that seeks to improve the efficiency of the equipment thanks to its autonomous and planned maintenance activities [21].

B. Proposed model.

The proposed model is made up of the phases already described, which includes the interactions of various lean manufacturing tools [13]. In addition, these have the objective of reducing the defective production of hinges in the production line of the company under study. In turn, this is complemented by the introduction of change management exemplified by Kotter [8].

This gives rise to the implementation of the 5S consistently with its components, to later implement the Poka Yoke and Andon tool that will solve the problems in the cutting and grinding stations. Finally, the TPM methodology that will solve the problems caused by unplanned stops is integrated into the model. Figure 1 shows the proposed model, which combines the four Lean tools.

C. Detail of the model.

1) Change management.

At this stage, the aim is to undertake the sense of organizational change in the company in order to give it the ability to assimilate the culture of continuous improvement, for this the first 6 steps will be used: establish a sense of urgency, form a powerful coalition, create a vision of change, communicate the vision, remove obstacles and achieve short-term victories, as shown in the following figure proposed by Kotter.

2) 5S implementation.

Next, the execution of the 5S tool continues, which will start with the training given to the staff, in this way they will be able to identify and classify the necessary and unnecessary elements in the work area, then they will be ordered according to their classification. and frequency of use with the use of a red card, this will provide greater ease of use through visual management.

To order, we will rely on shelves classified by yellow cards and the ordering will be done using an ABC chart to determine proximity by frequency of use. Subsequently, a team will be formed to be in charge of the order and cleaning schedule through Checklist. Finally, it seeks to standardize all the previous steps and adapt them as routine activities, in this way the necessary discipline is achieved to constantly apply the philosophy of continuous improvement.

As a means of control, the 5S radar diagrams will be used, in conjunction with a monthly audit. With this, it will be possible to monitor the progress and compliance of the 5S execution phase every month, identifying continuous improvement.

3) Implementation of Poka Yoke & Andon.

This stage begins with training on the Andon and Poka Yoke tools, since the aim is for the operator to know how to deal with the situations that arise at this stage. Based on the training, the operator will be fully informed about the improvement actions that he must carry out and put them into practice, in this way, it will be possible to achieve the reduction of human errors in the production process. Regarding the Andon and Poka Yoke tools, we propose the implementation of anti-error objects that control and attack the cutting and grinding problem that the company presents.

For this, the device Figure 2 was designed. This has folding and fixed metal handles of 2.5x2.5 cm and 2.5x7.5 cm, with which the fastening of the steel plate does not move in the mentioned processes. In addition, this table has the specific measurements of the plate inscribed and forged on its side support so that it can only be accommodated with the fasteners and the required dimensions are marked with a chalk and the power machine can circumscribe without problems. Thus giving a fairly comfortable operating margin and providing the operator with security when carrying out the process following the Law peruvian number 29783 regulations. In the case of Andon, it is proposed to implement an Andon traffic light with 4 lights on the work table, green if the piece is compliant, yellow if there is an error in grinding, red if there is an error in cutting and blue to call the area supervisor [19]. Thus strengthening the communication of errors. In addition, to be able to provide directives to be able to act when the problem occurs at the moment.

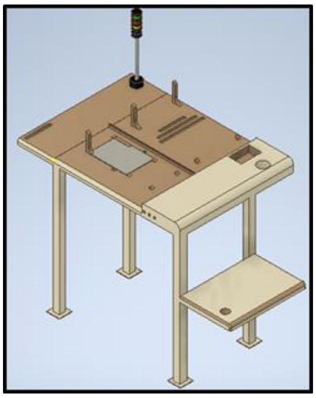

Fig. 2 Poka Yoke & Andon table

4) TPM execution.

The final phase will also begin with the training given to the operating personnel. Once the staff is informed and trained, the formation of the TPM team will continue. This equipment will be important to implement the education pillar, since in it the main objectives to be achieved are set out, in addition, training and education of effective maintenance techniques will be provided. With autonomous maintenance, the aim is for operators to be able to carry out basic and essential maintenance activities, activities that do not require great skill to carry them out. Finally, planned maintenance will be carried out by drawing up maintenance schedules, taking into consideration historical data on breakdowns and previous repairs of machines.

This stage seeks to reduce stoppages due to breakdowns or corrective maintenance, in this way, there will be a more fluid and active production line to achieve the results proposed in this model.

D. Model indicators.

Eventually, all the phases already described in the application to the case study require indicators and/or metrics that can measure the functional evaluation of the proposal, these must be linked to the improvement objectives set throughout the diagnosis and the design that we have proposed to eliminate the difficulty presented by the SME. Therefore, we have proposed four indicators that assess this.

a. Defective production rate

It represents the percentage of defective products with respect to production. There is a record that the sector manages a percentage of 15%. [22].

$$D.Production = \frac{Defective\ products\ (units)}{Total\ production\ \ of\ hinges\ (units)}$$

b. 5S qualification audit.

There are precedents that the sector handles a percentage of 74%. [13].

$$Audit\ 5S = \ \Sigma\, Qualification\ of\ \ each\ pillar$$

c. Defective production related to a bad cutting process.

It represents the defective products with a bad cut. There are precedents that the sector handles a percentage of 9%. [17].

$$Cutting\ error\ rate = \frac{Hinges\ with\ defects\ in\ the\ cut\ (unit)}{Total\ production\ \ of\ hinges\ (units)}$$

d. Overall Equipment Effectiveness (OEE).

There are precedents that the sector handles a percentage of 60%. [21].

$$OEE = Availability\ \times\ Performance\ \times\ Quality$$

IV. VALIDATION

In order to validate our proposed model, a pilot plan will have to be implemented and a process simulation designed in the Arena software, with which we will define how optimal and sustainable it is depending on the impact of the solution that is provided along with the proposed tools.

This is based on the state of the art and supporting our indicators with each of the items defined in the theoretical framework [17][21][22].

A. Initial Diagnosti..

For the implementation of the phases defined in the proposed solution, the objective values of the test metrics related to the model indicators are determined. In this way, you can get not only a quantitative argument, but also how much the current initial situation of the company has improved. Since the company has a wide range of products in the field of technology, we work based on historical information and information collected during 1 year of the company under study. This generates increases in the probability that the project will be successful.

In general, there is a general indicator that is the one that measures the proportion of defective products in relation to the population of hinges produced. In relation to this indicator, four more underlie. The number of parts that at the end of their assembly process have paint or grease, which during the 2021 period have an incidence rate of 8.55%, this is related to poor organization and cleaning of the workplace. Then, there are products that after the cutting process present different problems such as a more finished grinding and a poor finish in the cutting process. The indicator averages the number of pieces that incur in this aspect, reaching a ratio of 3.10% in errors in grinding and 6.10% in cutting defects. Taking into account that these data are taken by quality control daily. Finally, there are dimensional errors that occur in the assembly and coupling of the hinge. So, we have the following table.

TABLE I
Current situation.

Indicator	2021
Defective production rate of the hinge line.	29.83%
Index of defective products with presence of grease.	8.55%
5S qualification audit	21.60%
Defective production related to poor grinding.	3.10%
Defective production related to a bad cutting	6.10%
OEE	48.86%
Defective production related to sizing.	7.42%

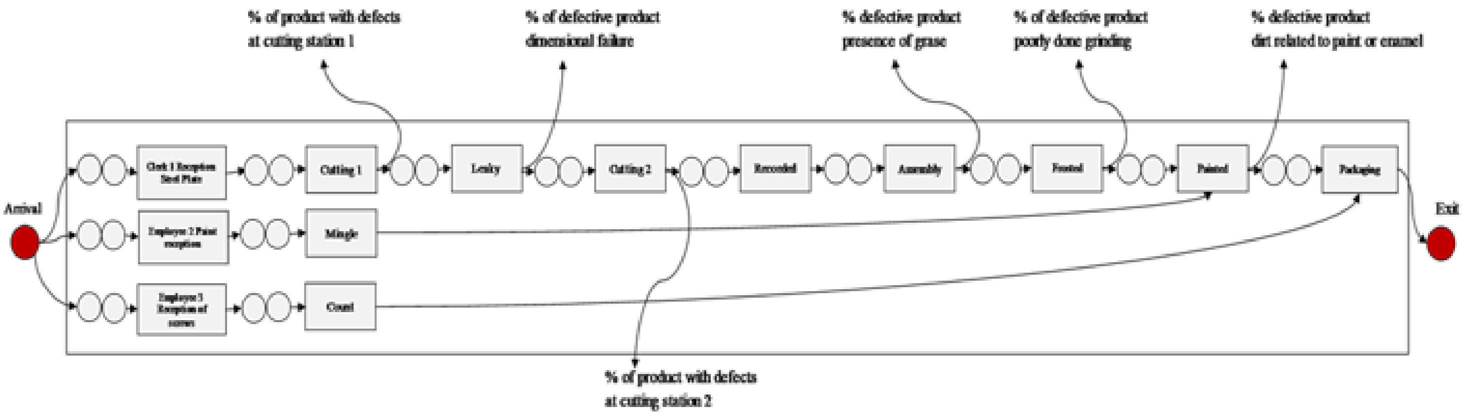

Fig. 3 System representation.

B. *Validation design.*

1. *Pilot test.*

For the calculation of the pilot test, it is considered to use the formula of the finite population. The population size was considered to be the 7101 hinge pieces manufactured during the year 2021, the confidence level at 95%, the probability of success and failure at 50% using the plugin as error. Likewise, the calculation was made using the finite population formula, resulting in approximately 1 month, but for reasons of greater reliability, 3 months will be used.


Fig. 4 Pilot test.

Each one of the tools was developed during the months indicated in the previous paragraph, each one of these was monitored and inspected by the operators and immediate heads of the production line.

Likewise, the Poka Yoke and Andon were put to the test in a magical way to assess the incidents that occurred with the tool working in the work area. The 5S and TPM tools were launched along with the established indications and standards. Thus, obtaining the following results shown in Figure 5 where we can visualize the comparison of each indicator versus its peer in 2021. It is very important to take into account that these results present a substantial improvement.

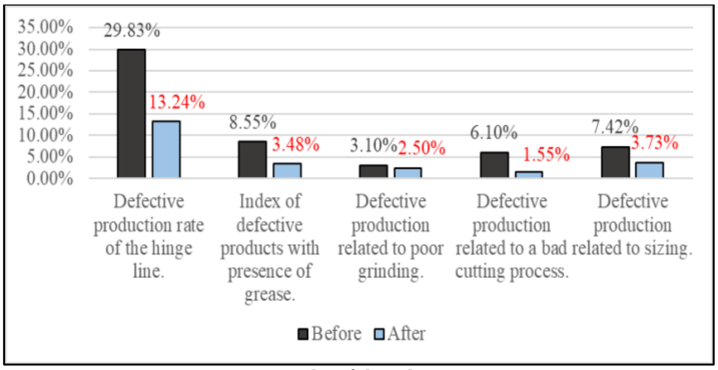

Fig.5 Results of the pilot test.

2. *Arena simulation system.*

As a complement to the execution of the pilot plan, the application of a simulation of the entire creation process is of hinges with the purpose of corroborating the standards already applied during a certain period of time. With this, the graphic representation of the current process that is carried out in the company was made. See figure 3.

For the elaboration of the hinges, it is shown below in figure number 6. Of which there are different processes that interact with each other and the percentages of waste are the percentages found in the company, these are quite similar to reality. There is a project process whose main task is to simulate the system with the improvement percentages in order to validate the proposed solution. For this reason, starting initially from a sample of 250 observed time data at each station involved, the calculation of the optimal sample will begin.

Then, we proceed to calculate the amount necessary for the estimation and collection of this data. It is important to mention that for this process the formula for the optimal number of samples to be analyzed was used.

Likewise, for this simulation system we will take the initial percentages related to the variance of the times taken for the stations involved, it is important to be clear that the stations that are part of the system are reflected in the graphic representation of the system. These are comprised of the processes for receiving the plate and production order, receiving the paint, receiving the screws, the cutting process 1 and 2, mixing, counting screws, drilling, engraving, assembly, grinding, painting and packed. Taking into account the initial percentages of each indicator related to the defect of parts with grease or paint, design defects and dimensional defects. As stated in the foundation of the model. We proceed to find and design the model in the Arena software. For this, it is considered to find the optimal number of runs that it will have for the current simulation system and the simulation with the implementation made. Having these data we will be able to evaluate if the system is suitable for our study. Next, the mapped system is inserted into Arena. After finishing the configuration of the first run that is made in the software. The first replication is carried out to assess whether the quantities provided by the simulator correspond to the historical data we have for the year 2021. Afterwards, having the quantity, it will be possible to validate the optimal number that is needed to be able to use the information with the greatest possible reliability. The first run is executed giving us an initial amount of 7353 units. We proceed to evaluate the error of the first runs.

TABLA II
Results to the simulator

Situation	Parts	Defective	% Defects
Current	7353	2109	28.68%
Improvement	11589	1494	13.01%

With the results obtained, a preliminary calculation of the error calculation is made, taking the production of 2021 as a reference. As the percentage is less than 5%, it can be said that the error is within the margin, therefore, the simulator can be used to make the projections with the percentages found in the pilot plan. Likewise, the optimal number of accounts that the percentages in the indices improved has the following information.

As shown in table number three, the percentage of the current situation is quite close to the percentage calculated in 2021 of 29.83%. Regarding the improvement, there is a percentage of 16.82% of defective production in the first year, exceeding the 15% that we want to reach, giving us a fairly optimistic scenario with respect to the study.

V. CONCLUSIONS

After putting into practice the model that contains the lean manufacturing tools presented in the case study and comparing results with studies of various categories that present a similar problem, the following conclusions were reached.

The general percentage of defective production rate in the line and hinges went from 29.83% to 13.24% according to the pilot plan executed for 8 weeks, giving an improvement percentage of 12.91% according to our simulator. The index of defective production with the presence of fats went from 8.55% to 3.48%. Likewise, with respect to the 5S audits, after the implementation of the pilot plan, the percentage of compliance went from 21.60% to 75%, through the monthly follow-ups that were carried out. Regarding the OEE in the critical machines, there was a percentage of 48.86% after the implementation, there is a 63.80% compliance with respect to this indicator.

Regarding the index of defects related to cutting and grinding, it went from 6.10% to 1.55% and 3.10% to 2.50% respectively.

Regarding the defective production index related to sizing, an overall improvement of 3.69% was obtained in relation to this indicator. In conclusion, it can be said that the best one is efficient and achieves its objective in broad strokes.

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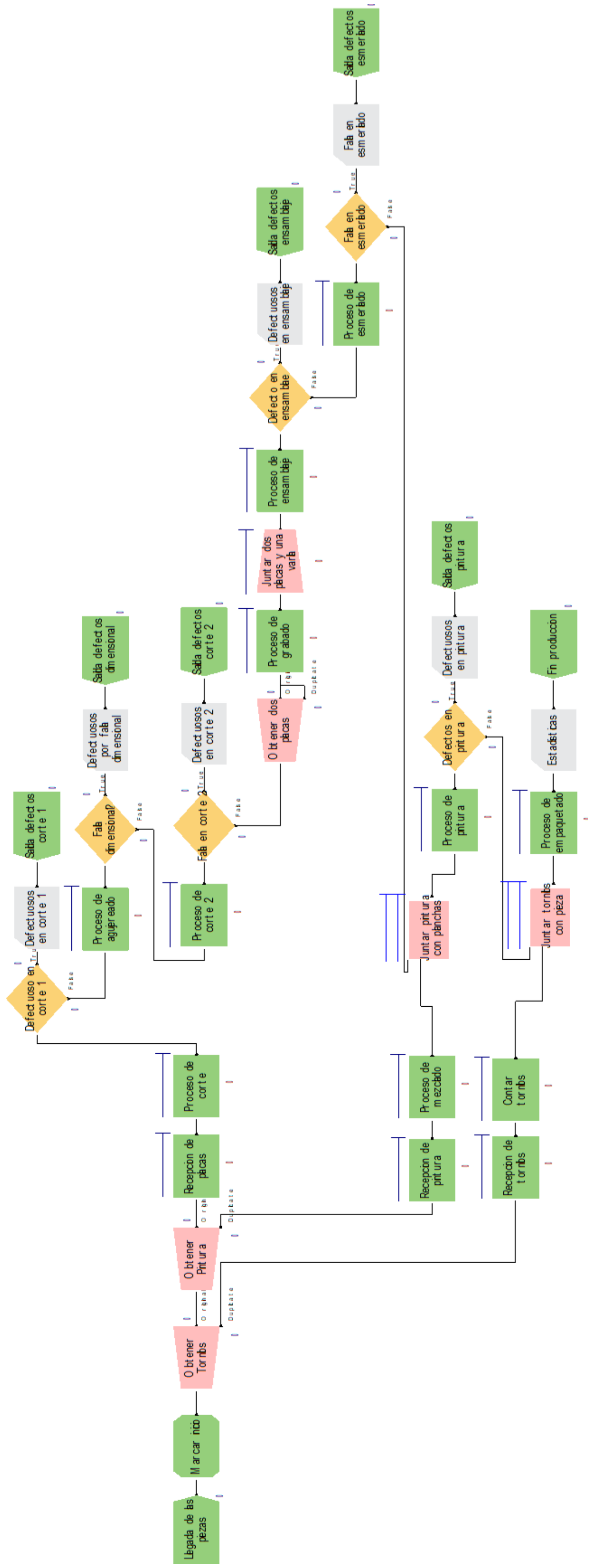

Fig. 6 Improvement simulation model.