Applying Lean Maintenance to Optimize Manufacturing Processes in the Supply Chain: A Peruvian Print Company Case

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Abstract—High competitiveness forces are used to reduce costs and optimize processes throughout the supply chain. One of these supply chain processes is manufacturing, where the objective may be that machines work at their maximum efficiency and capacity. This study proposes to increase the effectiveness of the printing process by improving the maintenance by applying the Lean concepts. This research will serve as a guide for other companies in the printing industry that seek to increase their production based on the effectiveness of their equipment focused on maintenance processes, which is an important component in their supply chain manufacturing.

Keywords—*Supply Chain Management, Supply Chain, Lean Supply Chain, Lean Maintenance, Peru.*

1. Introduction

In today's world, companies are always looking to increase their competitive advantages in order to grow customer's demands [38]. Companies must continually seek to optimize the products and services they offer, and one way to increase competitive advantages is to optimizethe supply chain (SC) processes [17]. The management of the SC is a set of methods that allow for efficient value creation processes, from the suppliers to the final client [28]. The increase in efficiency and productivity can achieved by using the principles of Lean in any process SC of the industry [15].

Currently, many industries worldwide are using Lean Manufacturing to reduce their costs and make better use of their resources. In the same way, Lean Manufacturing helps improve the quality and response time to customer demand [3] and increase their Operational Excellence; The latter gives companies competitive advantages in terms of costs, quality of service and on-time delivery. As a result, defects are reduced, customer value flows are optimized, inventories are reduced and delivery times are improved [54].

An SC consists of all the activities from the supply of raw material to the final product delivered to the customer [43]. For manufacturing industries, it is important that the SC meets customer demands by providing quality products at the right time and in the right place [40]; to achieve this, the proper functioning of the equipment must be guaranteed through proper maintenance management [25].
Therefore, the maintenance of the equipment is considered indispensable in a production organization, because it impacts on the performance of the equipment and, consequently, on the quality of the final product [58].

The objective of this investigation is to improve the operational effectiveness of the printing process of a print company, which has an impact on an improvement in the SC as explained by the industry experts. Lean tools focused on maintenance processes will be used to measure line productivity, identify losses, and detect maintenance needs [22],[32].

2. Theoretical framework

2.1. Lean Manufacturing

Lean Manufacturingstarts with the reduction of costs and elimination of waste through the techniques of quality assurance [15]. According to [61], Lean Manufacturing also maximizes the value of the product by eliminating these wastes, which can be hidden in policies, procedures, processes, product design and operations, consuming resources without adding value to the product [56].

Hence, a company to become Lean they must implement an integrated approach from the supplier to the client; and this is where logistics plays a vital role in optimizing the flow of material to increase profitability [36].

The main pillars of Lean Manufacturing are TPM, Worksite Organization, Setup time reduction, Cellular Manufacturing and Continuos Improvement [34].

2.2. Lean Operations

Lean Manufacturing techniques initially focused on improving productivity rather than quality. However, improved productivity leads to leaner operations that expose more waste and quality problems. In this way, not only waste is attacked, but also factors that reduce quality and generate management problems [56]. According to [19], Lean Operations means reducing and eliminating activities that do not add value. Consequently, as a result, performance improvements are obtained in aspects of quality, costs, speed, and reliability of delivery [59].

According to [14], Lean Operations also refers to maintaining order and cleanliness of the physical environment or workplace, a fundamental component of the 5S philosophy. The 5S philosophy is the basis for the lean manufacturing philosophy and its principles have the potential to effectively organize the workplace, to keep it clean and orderly [10]. The application of 5S allows to obtain a place of work more efficient, clean, orderly, and safe; Unproductive times, movements and costs are also reduced [32].

2.3. Supply Chain and Lean Supply Chain (LSC)

Supply chain Management (SCM) is the systemic and planned coordination of the different critical processes of the company, such as to purchase, procurement, conversion, and logistics [14]. These key processes include different areas of the company, such as finance, purchasing, sales, logistics, information system, production, and others [17].

Consequently, SCM must have the appropriate analytical tools that provide the necessary flexibility to adapt to supply chain variability in a changing market environment [54].
The use of Lean in the supply chain allows the system to be more optimized and efficient, fulfilling the supply-demand and with minimum waste [7]. The application of Lean is an effective way to improve operations and eliminate waste throughout the SC; It is aimed at reducing production lead time and costs related to SC in order to obtain greater manufacturing efficiency, reduced costs, greater flexibility and competitiveness [45].

Considering the principles of SCM, Lean Supply Chain (LSC) should use the concept of Lean Manufacturing in the supply chain when applicable. Table 1 provides information on the topics covered by Lean, LSC and SCM, where it is important to highlight the role of Value Stream Mapping (VSM) in the three approaches [43].

Table 1: Comparison of topics treated by Lean, LSC and SCM.

Topic	Lean	LSC	SCM
Continuous improvement and cultural aspect	*	●	●
VSM	*	*	*
Logistics			*
Marketing			*
Production methods and quality	*	*	
Relationship management	●	*	*
Work practices	*		
*	Essential		
●	May be considered		

Source: Developed from [43].

2.4. Maintenance and Lean Maintenance

Maintenance is a set of activities that are executed in order to maintain the capacity of the machinery to develop products in the mandatory quantity and quality levels [31]. In today's competitive environment, companies should view Maintenance as a potential source of cost savings and competitive advantage [5].

The improvement in maintenance activities helps to achieve the production objectives, and in this way, achieve the objectives of the Company [32], see figure 1.

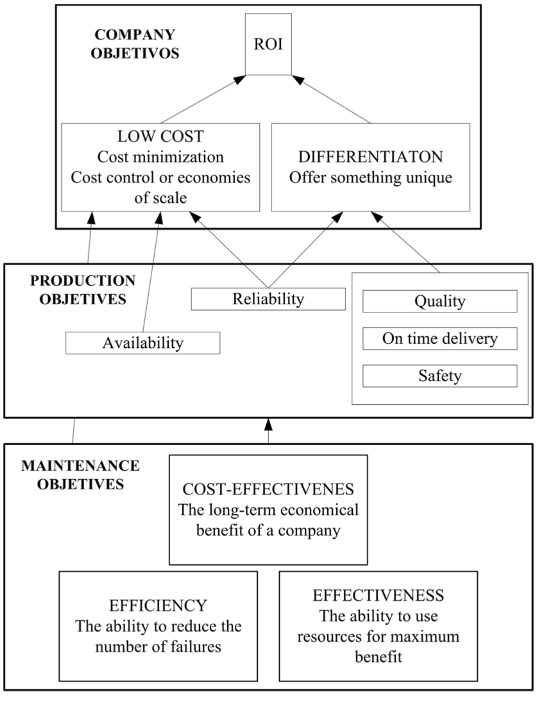

Figure 1: Maintenance and its objectives aligned to the organizational objective. Source: Developed from [32]

According to [33], poor maintenance also affects consumer confidence. Frequent failures cause unplanned downtime that hampers on-time delivery to customers, and constant delays lead to a bad reputation for the company resulting in an economic impact.

For this reason, it is necessary that maintenance be seen as a profit centerrather than cost, where the implementation of lean methodologies should not focus not only on manufacturing efficiency but in the application of lean maintenance to ensure its success [32]. Lean Maintenance represents the application of Lean principles in maintenance processes in order to reduce downtime by using tools such as VSM, 5S, Total Productivity Maintenance, (TPM), Kaizen, among others [41].

The objective of Lean Maintenance is to minimize waste, or reduce activities that do not add value and that customers would not be willing to pay for: waiting times, displacements, excessive maintenance, redundant application of resources, and rework [36]. Likewise, the reduction of waste in maintenance means a better organization in the stock of spare parts, and lower the mean time to repair (MTTR) and standardization of maintenance procedures [19].
Within the maintenance processes it is also possible to find the seven main types of waste; some authors consider the following:

- Improper maintenance. Excessive preventive maintenance and at non-optimal frequencies [41]. According to [29] this is very bad because it contributes to other forms of waste.
- Waiting for maintenance resources. Maintenance services are delayed due to permits, waiting for tools, documentation, spare parts, specialized service, etc. [41], [29].
- Centralized maintenance. The maintenance stores are located far from the work station, spare parts are not easily accessible, work orders are not available, all cause excess transportation [41].
- Poor maintenance. Source of rework, which affects the cost of maintenance and quality of service [41]. Also, this may be caused by unnecessary inspections or poor maintenance practices [29].
- Sequencing and programming of inefficient tasks. It occurs when maintenance interventions are not planned correctly, and equipment stops are not optimally utilized [29].
- Excessive inventory. Have more inventory of spare parts than needed [29].
- Movements due to futile efforts searching for parts, tools, documents, etc. Inadequate and non-ergonomic design of equipment, which makes maintenance activities unproductive [29].

2.5. Overall Equipment Effectiveness (OEE)

OEE is a measure of equipment performance based on the availability, performance, and quality of its result expressed in percentage. It is the main KPI used by TPM. OEE is calculated based on the main losses of a productive process such as breakdowns, minor stoppages, changes, reduced speed, defects, and adjustment waste, [41].
These losses are composed of three main dimensions: availability, the rate of performance and output quality rate [6]. OEE is obtained through the production of these three performance measurements [44].

$$OEE = Availability \times Performance \times Quality \quad (1)$$

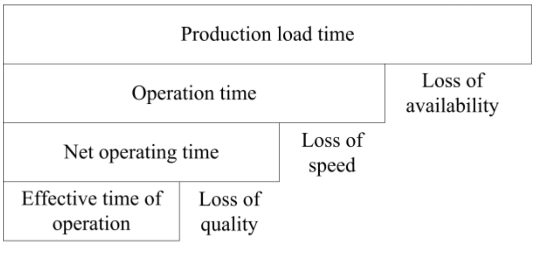

Figure 1: Decomposition of losses according to the OEE. Source: Developed from [6]

The availability can be defined as the ratio between the amount of time the machine is producing and the amount of time it was scheduled to produce [6]. See equation 2.

$$Availability = \frac{Required\ availability - Downtime}{Requiered\ availability} x100\% \quad (2)$$

Availability is mainly reduced by unforeseen events, such as machine breakdowns and production interruptions related to setup and reconfiguration of the machine [60]. The ideal world-class level for availability must be 90% according to [60] and [35].

The rate of performance considers the loss of speed caused by different factors that do not allow the equipment to reach its maximum speed. When the theoretical cycle time of the machine is multiplied with the units produced, the theoretical net time is obtained, this divided by the operation time that was needed to produce said units gives us the Performance as a result [21]. Equation 3 shows the rate of return and is related to the losses by reduced speed.

$$Perform = \frac{Theoreticalcycletime \times unitsproduced}{Operationtime} x100\% \ (3)$$

The quality rate can be expressed according to equation 4 and is related to losses due to quality defects. It excludes manufactured parts that do not meet established standards or needs rework [21].

$$Quality = \frac{Productionoutput - Defectivebyquality}{Productionoutput} x100\% \ (4)$$

According to [22], for a typical Lean production environment, an ideal OEE for a profitable TPM should be at least 85%. Likewise, the objectives for each OEE factor can change with respect to one industry or another, experts propose accepted OEE objectives of 85% with 90% availability, 95% performance and 99.9% quality [35].

2.6. Inherent availability

The inherent availability is calculated based on the Mean Time Between Failures (MTBF) and the MTTR, of the machines based on their reliability and maintainability [64]. The availability is calculatedthrough the below equation (5).

$$Inherentavailability(Ai) = \frac{MTBF}{MTBF + MTTR} * 100\%; \ (5)$$

The delay times are not included due to logistical issues. Some authors argue that when the ratio between the MTTR and the MTBF begins to rise, it is necessary to optimize the strategies with the appropriate maintenance policies [64].

2.7. Main tools and practices used by Lean Maintenance

A total of 40 articles have been reviewed in order to define the lean tools most used in the improvement of production processes. Table 2 shows the findings. It can be seen that 5S is the most referenced tool in the articles followed by TPM, Kaizen, and VSM.

Table 2: Survey of articles for the most used Lean tools

Tools / Paper	Banduka, Veža y Bilić (2016)	Epler et al. (2017)	Abrha et al. (2015)	Fourie y Umeh (2017)	Mia y Uddin (2017)	Bernardo y Prías (2014)	Kolanjiappan (2015)	Duran, Capaldo y Acevedo (2017)	Mostafa, Dumrak y Soltan (2015)	Djekic et al. (2014)	Arslankaya y Atay (2015)	Sundar, Balaji y Satheesh (2014)	Belekoukias, Garza-Reyes & Kumar (2018)	Singh, Gohil, Shah y Desai (2013)	Gupta, Gupta y Parida (2017)	Mostafa et al. (2015)	Ebeid, El-Khouly y El-Sayed, 2016	Abreu, Calado y Requeijo (2016)
5S		*		*			*	*	*	*	*			*	*	*		*
Kaisen	*			*	*	*			*				*	*	*	*		
TPM							*		*	*	*		*	*		*		
VSM // VSA				*	*	*		*	*			*	*		*	*		*
Kanban		*					*		*			*			*	*		
JIT					*	*	*						*		*			
SMED								*		*		*						
Standardized work	*		*															*
Visual control tables // Visual System		*								*								*
Poka Yoke									*						*	*		
FMEA // Reverse FMEA				*													*	
Jidoka (Autonomation)	*												*					
CMMS																*		
Pull System												*						
TQM						*	*											

Tools / Paper	Irajpour et al. (2014)	En-Nhaili, Meddaoui and Bouami (2016)	Oware et al.(2015)	Jasiulewicz-Kaczmarek y Saniuk (2018)	Van Ness, Mothersell y Motwani (2015)	Hamrol (2018)	Olivella y Gregorio (2014)	Qiang, Zhu y Li, (2011)	Ahmad et al. (2017)	Ayeni et al. (2011)	Tabares, Robles-Cárdenas y Romainville (2017)	Pascu et al. (2018)	Proulx (2014)	Magdaleno, Castañeda y Casco (2015)	Cox y Ulmer (2015)	Poycheva (2018)	Ayeni, Ball y Baines (2015)	Frequency
5S	*	*		*	*	*	*	*	*			*	*		*	*	*	24
Kaisen		*		*	*		*			*	*		*		*	*	*	19
TPM	*			*			*	*	*			*	*	*	*	*		17
VSM // VSA		*	*	*					*			*			*			16
Kanban		*			*	*	*		*		*				*		*	14
JIT					*				*	*	*			*	*		*	12
SMED		*				*	*		*			*	*			*		10
Standardized work		*	*	*	*	*						*						9
Visual control tables // Visual System		*			*		*					*			*			8
Poka Yoke		*				*						*						6
FMEA // Reverse FMEA					*			*					*					5
Jidoka (Autonomation)						*					*	*						5
CMMS				*				*					*			*		5
Pull System			*		*						*	*						5
TQM					*					*								4

Source: Own study developed from [4][42][11][23][2][25][39][13][36][19][41][18][8][61][12][57][29][42][20][1][31][22][48][33][65][30][46][53][4][9][62][49][52][16][51][9]

Table 3, details 5 case studies where OEE was successfully improved in industries such as the textile industry and automotive. These cases use a combination of various tools and methodologies such as TPM, 5S, Kaizen, VSM, and 5Why.

5S. Its objective is to maximize efficiency and speed up the execution of tasks by eliminating unnecessary movements through the proper location of tools and equipment, cleaning and ordering [23]. It focuses on the effective organization of the workplace and standardized work procedures [36].

Table 3: Study cases with application of Lean Maintenance and improvement of OEE.

Cases	Tools	Achievement	Company and / or Industrial Sector
Case 1, [6]	TPM, Pareto, WWBLA work sheet, Cause-Effect Diagram and Kaizen	OEE increase from 75.09% to 86.02%	Akij Textile Mills Limited; Textile industry
Case 2, [44]	TPM, Cause-Effect Diagram, Pareto y reduction of adjustment time.	Increase the OEE from 60% to 75%	Machining parts sector with CNC for mills.
Case 3, [57]	TPM, 5S and Kaizen,	OEE increase from 63% to 79%	Company with CNC turning center; Automotive industry
Case 4, [49]	4Q Charts, TPM,	An OEE of 95% is achieved in one year	Company supplier of automotive components for Ford and Fiat; Automotive industry

Case 5, [22]	5S, VSM, Kaizen, Kanban, Standardized Work, Visual System, 5 why, Pareto, SMED, Poka Yoke, Skill Matrix	OEE improvement in 8.3%	American company supplier of interior parts for cars; Automotive industry

Source: Adopted from [6],[44],[57],[49],[22].

TPM. It seeks to maximize the effectiveness of equipment through planned maintenance and maintenance optimization techniques [18]. TPM requires the participation of all employees in productive activities and provides them with responsibility for the autonomous maintenance of the machine they operate [8]. It is a basic methodology for all Lean Manufacturing projects because processes and production can not be improved if it is not possible to sustain themselves in their equipment and machinery [49].

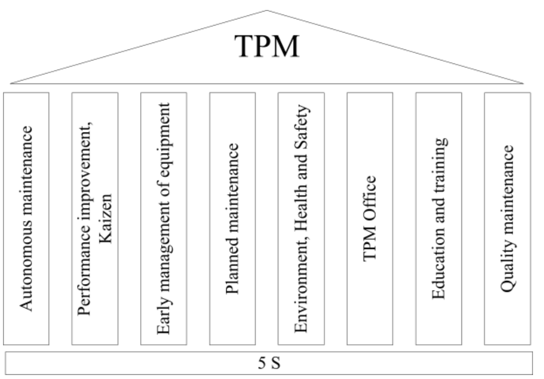

Figure 2: Pillars of the TPM.Source: Developed from [57], [42], [6].

TPM can identify six categories of losses, losses by (1) failures; (2) adjustment or configuration; (3) minor stops and empty runs; (4) reduced speed; (5) reworks, defects; (6) starts. The losses 1 and 2 affect the availability, the 3 and 4 to the performance, the 5 and 6 to the quality [41].

TPM involves all levels of the organization, adequately addressing the life cycle of the production system, and in this way, creating a robust plant-based system to prevent losses, [32].

KAIZEN. It refers to the search for continuous improvement, based on the fact that a small number of improvements is more effective than a great value improvement in an organization [6]. Kaizen can be applied in different types of jobs; however, its application in Lean Manufacturing is well known [39]. Figure 4 shows a scheme for the implementation of Kaizen.

Authors suggest that the tools most used by Kaizen are 5S, Brainstorming, Continuous Flow, Kanban, Verification Sheet, 5 Whys, Pareto, VSM, and Gantt Chart, which seeks small incremental improvements in order to provide the support needed to sustain other Lean improvement initiatives such as TPM or JIT [26]. Kaizen aims to achieve and maintain zero losses in relation to minor stops, adjustments, defects and unavoidable downtime [57]. Its success requires good leadership, planning, and good performance measurement, which is very important for the teams that design and implement the improvement [32].

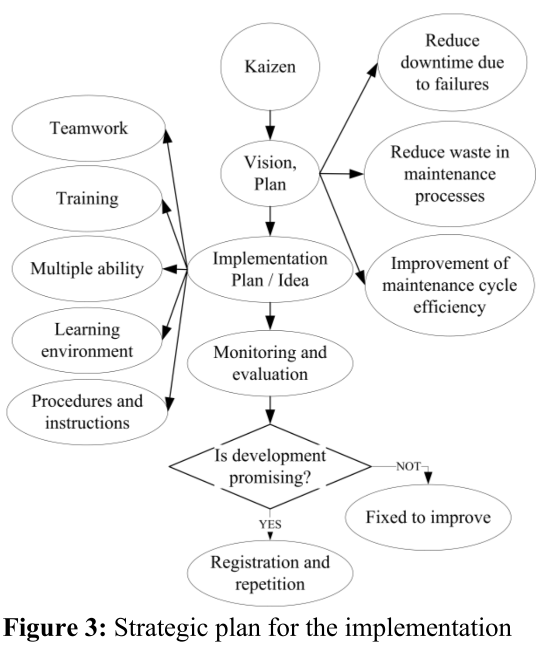

Figure 3: Strategic plan for the implementation of Kaizen in maintenance. Source: Developed from [39]

VSM. It is an easy-to-use Lean tool that identifies the flow of value and identifies potential sources of waste [13]. Are all actions, with added value (VA) or no added value (NVA), which are required to carry a product or a group of products that use the same resources through the main flow, from the raw material to the customer. It aims to identify all the waste in the value stream and takeaction to eliminate it. It allows to link and visualize the flow of information and materials along the supply chain [39]. VSM can represent all the maintenance activities from the machine stop, the execution of the maintenance until the commissioning. These can be: machine stopped, communication problems, identification and location of resources, generation of orders, repair, and testing of a machine [41]. It also gives us an idea of global maintenance efficiency through NVA time, VA time, maintenance efficiency and financial efficiency of maintenance [22].

The tools used by VSM are current state map, future state map and flow diagrams [26]. If the VSM has been correctly carried out, it would not be strange to be able to reduce the processing time by half or even more [16].

3. Research methodology

The analysis of the current status of the web offset printing process was made with quantitative data from the production control systems and maintenance information system reports. Likewise, the atypical data caused by isolated and specific causes were discarded for ease of research.

About 70 articles related to Lean thinking and supply chain management processes were surveyed for their methodology and to identify the tools most used in the improvement of the maintenance processes. An application proposal was then elaborated forthe different components of the OEE of the printing process. This research will estimate the expected value of the OEE and how it can impact the ROI of the printing process.

4. Case study

4.1. Background of the company

The company under study belongs to the print industry, which has different processes in its productive activities and where the web offset printing process is the one with the highest fixed production cost and the largest productive capacity of the company. Likewise, the current market of the print industry is very competitive, which is why it is necessary to improve operating efficiency in order to reduce costs and increase the fulfillment of deliveries.

According to [3], the supply chain of a printer company begins with the supply of raw materials such as paper and ink, and continues with manufacturing processes such as pre-press, printing, finishing and ending with the dispatch of the final product to customers as shown in figure 5. The application of Lean tools throughout it describe LSC [43].

Throughout the SC of the company, it is necessary to evaluate for each process all the activities or operations that do not add value in order to eliminate or reduce them, this will allow achieving lean operations [19].
In the present study, the analysis will focus on the printing process capabilitiesby improving the maintenance processes with the application of Lean Maintenance, which will reduce unscheduled downtime and optimize the maintenance [41].

The improvement in the printing process will contribute to the objective of the SCM to efficiently integrate the entities that compose it, and in this way, produce and distribute correctly to improve productivity, inventory and cycle time of the SC, customer satisfaction and the benefit of the company [54].

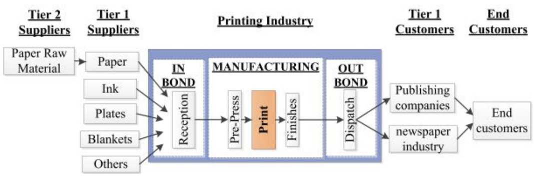

Figure 4: Print company Supply Chain mapping. Source: Developed from [3], [54].

4.2. Printing process Analysis

Figure 6 shows the OEE in the printing process in 2016 and 2017, where it can be seen that the indices achieved do not allow to describe a company with high levels of efficiency.

As described above, OEE is due to production losses in terms of availability, performance and/or quality, where maintenance policies may be one of the causes [22].

According to the experts, in companies with implemented Lean methodologies, an ideal OEE level should be in the order of 85%. However, this may vary depending on the type of industry [22] [35].

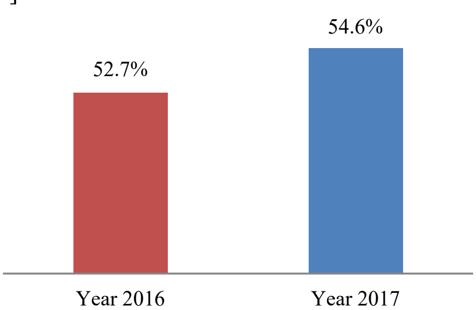

Figure 5: OEE of the printing process. Source: Own study

By performing the analysis of the components of the OEE in the company, we can see that the rate of performance is the lowest, followed by Availability and Quality rate, as is shown in figure 7.

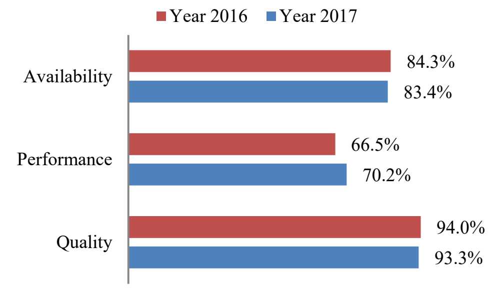

Figure 6: Indices of availability, performance and quality in 2016, 2017. Source: Ownstudy

4.3. Application of Lean Maintenance

In this chapter, the different components of the OEE are analyzed and how the application of lean tools to the maintenance processes can provide solutions to improve them are shown.

4.3.1. Availability Improvement

Using the Pareto diagram, it was determined that 80% of the occurrences that affect availability correspond to machine failures, cleaning operations and occurrences with paper, see figure 8.

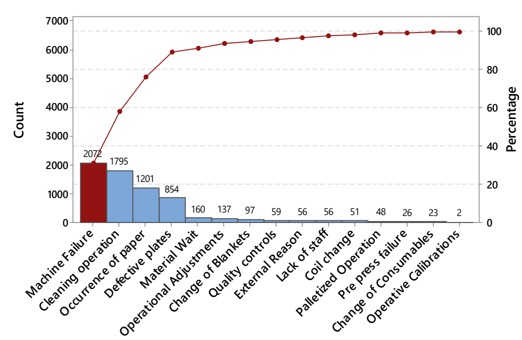

Figure 7: Pareto diagram of production stops on the printing process (2015-2017). Source: Own study

Likewise, a Box Plot allowed to define that machine failures have greater variability, average duration and number of occurrences, see figure 9. Further analysis indicates that the main cause that affects availability is due to maintenance problems. Therefore, the application of Lean Maintenance is necessary and basic, considering that is a prerequisite for the implementation of Lean Manufacturing [63].

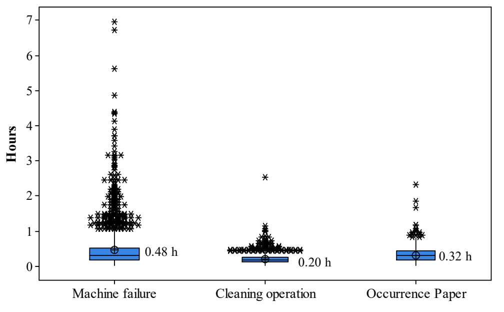

Figure 8: Box Plot of the stops with the greatest impact on availability. Source: Own study

5S Methodology

Implementation of 5Sresults in efficiency improvement. It accelerates the execution of maintenance tasks by appropriately locating tools and equipment in visible areas, maintain clean places, and leaving them ready to use [23].
The implementation of 5S will also ensure that the duration of the failures is not unnecessarily influenced by:

- Inability to locate tools and equipment
- Failing to find the necessary information for a correct diagnosis of faults
- Unavailability of spare parts
- Confusion between good and defective spare parts

5S allows the development of other Lean proposals to improve the maintenance processes. According to [57], TPM starts with 5S, and it is considered the corner stone of its implementation.

TPM. Planned Maintenance

One of the pillars of TPM is the implementation of plan maintenance [6] and its management will reduce emergency and unplanned repairs using periodic inspection, scheduled services, lubrication plans and other preventive maintenance actions. [27] The company currently has a preventive maintenance plan and measures its effectiveness by means of the inherent availability [64], its relation with the general availability as a component of the OEE can be evidenced in figure 10.

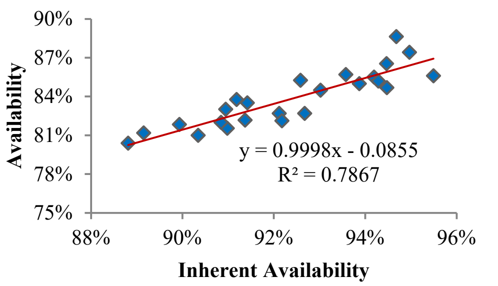

Figure 9: Regression analysis between inherent availability and availability, Source: Own study

A Box Plot of the monthly behavior of the Mean time between failures (MTBF) shows a decrease in its value, that is, machine failures have occurred more frequently, see figure 11. The decrease in MTBF implies that the current policies of maintenance should be optimized [64].

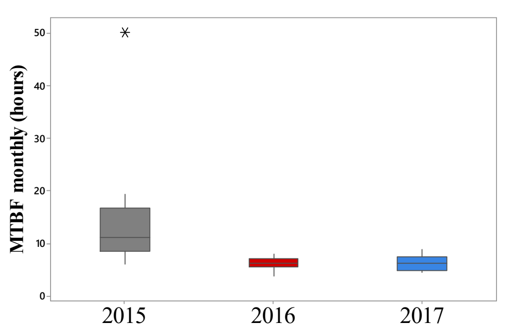

Figure 10: The deterioration of MTBF shows that failures are more frequent. Source: Own study

For the optimization of the maintenance plans, it is possible to apply the Planned Maintenance Optimization (PMO) technique, because it identifies and eliminates the inefficiencies of the current maintenance strategy [37] through an efficient approach to eliminate unnecessary maintenance activities [47].

Maintenance plans are improved by applying PMO and more effective maintenance activities obtained in optimal periods.

It is important to indicate the folder is the technical location where more faults occur in the printing press. In order to evaluate the effectiveness of the new maintenance plans, a simulation is carried out, which has an input variable with the current failure distribution, which must be prevented by the application of the new optimized maintenance plans. Those failures that can not be prevented will become repairs that will affect the inherent availability, see figure 12.

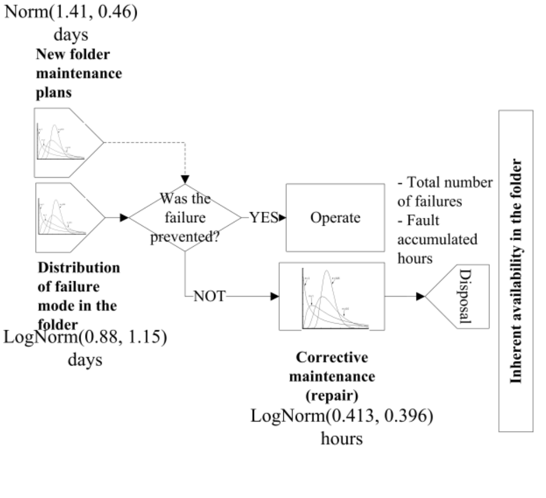

Figure 11: A simulation model for the expected maintenance effectiveness in the folder location, Source: Own study developed from [50] [55].

The simulation showed a decrease of approximately 50% of the folder failures; therefore, applying PMO in the entire press is expected to reduce the failures in half. The expected result can be seen in table 4.

In this way, it is expected to reach a value of 96.7% inherent availability, which corresponds to achieve 88.1% availability according to the regression formula of Figure 10.

Table 4: Results of the simulation in the folder and its projection to the entire printing process.

Ubic.	Situation	Faults	MTBF	MTTR	Ai
Folder	Base line	400	11.6	0.39	96.7%
	Expected	215	21.6	0.36	98.4%
Press	Base line	748	6.2	0.43	93.6%
	Expected	374	12.4	0.43	96.7%

Source: Own study

Autonomous maintenance

The new optimized maintenance plan will include cleaning and inspection activities that can be correctly executed by the operators, in this way, it will be possible to release maintenance personnel to perform more specialized tasks [57]. The objective of autonomous maintenance is to minimize breakdowns through the intervention of versatile and flexible operators to operate and maintain, eliminating defects at the source through their active participation [57].

Methodology KAIZEN

The involvement of all maintenance personnel in the Kaizen project is of the utmost importance, which will progressively eliminate the current waste and optimize maintenance resources [57]. It is possible to form a specific team that leads the initiative and develops short-term improvement projects [16]. The Kaizen team should aim to:

- Improve the search for technical support information. Correct ordering and maintenance of manuals are important. The digitalization of manuals with access from the computers located in the machines is a good strategy. Also, the location of the single-line diagrams in the corresponding electrical panel is a very supportive technique.

- Improve the availability of tools and equipment to reduce the time of maintenance operations. It is necessary that each technical staff has a tool kit of frequent use, likewise, each machine must have a correctly stored tool kit for the execution of the autonomous maintenance which can also be used by the maintenance personnel.

- Improve maintenance procedures and instructions. This will allow standardizing the activities, especially those frequent considering the necessary execution times, tools to use, information, spare parts and/or necessary resources. The objective is to eliminate any waste of time in the execution of these maintenance tasks.

The implementation of Kaizen in Maintenance must follow a strategy aligned with the company's vision and plan and must be monitored to verify that it meets the objective, otherwise, the necessary corrective measures must be taken [39].

4.3.2. To improve Performance

Figure 13 shows the behavior of the monthly average speeds reached by the three teams of operators in the printing press in the years 2015, 2016, and 2017. It can be noted that in 2016 the three teams had a similar rate drop in their speed with respect to 2015, which was improved in 2017 without yet achieving the results of 2015. Also, it is noticed the differences in speeds between teams.

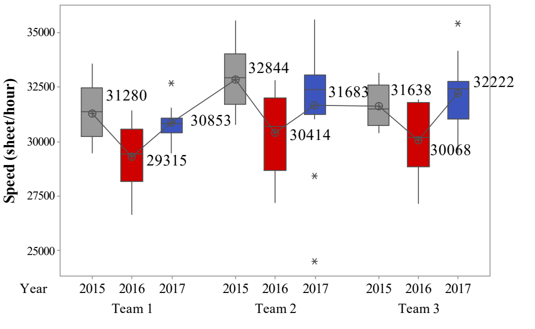

Figure 12: Annual speed behavior by work teams. Source: Own study

A root cause analysis with experienced operation and maintenance personnel resulted in the causes of loss of speed due to:

- Mechanical failures in the folder of the press.

- Wear of conveyor belts in the folder

- Expert in the operational adjustment of the folder

A large proportion of the improvement in speed in 2017 achieved by the three work teams was due to the calibration service performed by the machine manufacturer. This type of maintenance service should be considered as standard procedure, defining optimal periods of intervention and budget.

Likewise, it is evidenced how team 2 leads each year the average speed, which is based on their preference in the replacement of worn conveyor belts before sacrificing speed.

Mapping of the Value Stream Mapping (VSM) value chain

The preventive replacement of the conveyor belts will be included in the new maintenance plan. However, the breakage or wear of a single conveyor belt of a group of belts usually causes problems that require speed reduction, which is often decided due to the time it takes to replace it.

Figures 14 and 15 shows the current and improved VSM replacement of defective sheet transport belts. In this way, VSM gives the opportunity to measure the entire process, identify the activities that do not add value and apply Kaizen.

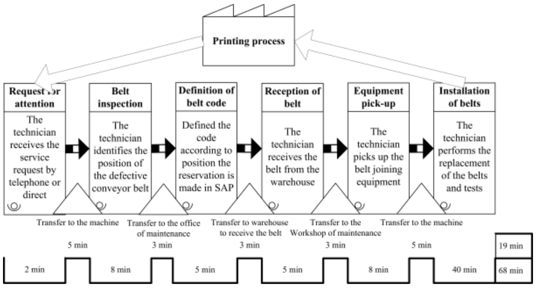

Figure 13: Current VSM for defective conveyor belt replacement in folder. Source: Own study developed from [1], [56].

As it can be seen, it is possible to achieve a reduction in the replacement time of the defective conveyor belts from 87 minutes to 37 minutes by applying Kaizen, in this case, the pre-installation in a spare belt machine for immediate replacement when necessary. With this improvement the decision to replace will be better than reducing the speed of the press and waiting for the next machine stop for replacement.

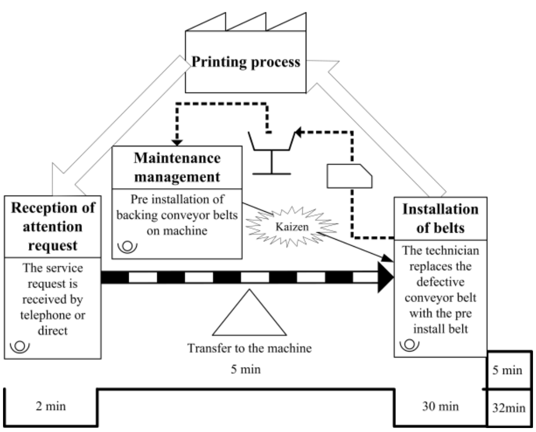

Figure 14: Future VSM for replacement of defective conveyor belt in folder. Source: Own study developed from [1],[56].

Once the issues of the machine and the time of replacement of defective conveyor belts are dealt with, it is expected to reach average speeds similar to that achieved by the team 2 in 2015: 32844 sheets/hour, which represents a performance increase from 70.2% to 73%, see figure 13.

4.3.3. To improve the Quality

The presence of failures generates an increase in losses, especially in the folder. In this particular location, there are problems of slight breakage, wrinkling, repainting and incorrect folding of the sheets. The improvement in this dimension of the OEE is based on the reduction of machine failures resulting from the improvement of the preventive maintenance plan. The number of machine stops is proportional to the paper waste, and consequently, to the quality index of the printing process in the press. This is depicted in figure 16.

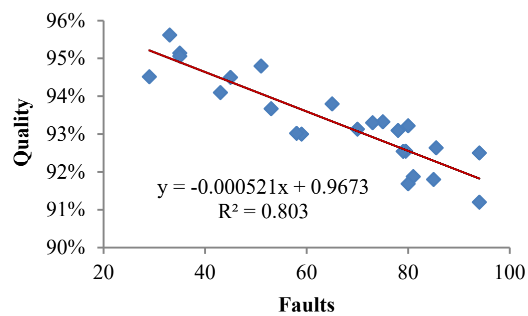

Figure 15: Regression analysis between the number of failures per month and the monthly Quality index. Source: Own study

In this way, the fulfillment of the objective of reducing the faults by half, that is, from 63 to 31 failures per month, would allow reaching a quality index of 95.1%.

5. Analysis and results

The expected results of the project can be summarized in Table 5, where an improvement in the OEE of 6.6% can be seen with respect to the result of 2017.

Table 5: Expected result of the OEE

Year	Availability	Performance	Quality	OEE
2017	83.4%	70.2%	93.3%	54.6%
Expected	88.1%	73.0%	95.1%	61.2%

Source: Own study

5.1. Impact on the Return on Investment (ROI)

The current scenario reaches an OEE of 54.6% with a profit margin of 35.16%; It also has an inventory value of$293.9K and $94.2K respectively. All this generates an ROI of 12.62%. In the expected situation, an OEE of 61.2% is estimated, which would allow a profit margin of 35.26%.

On the other hand, the value of the inventory and the accounts receivable will decrease due to the best operative operation. The present study shows that the ROI would increase from 12.62% to 14.23%; this would be achieved with the decrease in equipment stops, and at the same time, the standardization of maintenance activities, see figure 17.

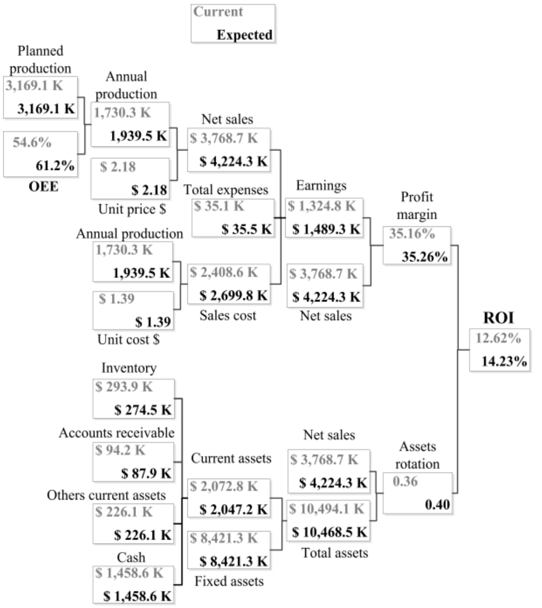

Figure 16: Current and expected ROI. Source: Own study

6. Conclusions

Maintenance continuously seeks to reduce costs and optimize its processes to meet its efficiency and effectiveness objectives.

In this investigation, it is possible to improve the manufacturing stage in the supply chain of a printing company by using the Lean tools applied for maintenance processes. These tools, prioritized by an analysis of use in different related articles, allow identifying key maintenance activities, eliminating tasks that do not generate value, optimizing preventive maintenance and reducing breakdowns.

The study makes the supply chain more efficient by optimizing the manufacturing process and reaching an OEE increase of 6.60%, allowing to increase profits by $ 164.4K per year; Therefore, the company is more profitable, achieving a ROI improvement of 1.60% in the supply chain.

6.1. Limitations

The demand for printing services has been impacted by the entry of digital media, especially in print advertising services. Also, is important to notice that part of the production is seasonal and this includes the services provided to publishing companies, however, these services are important in the year due to its significant volume and profitability. For this reason, the ROI analysis has been developed only based on this kind of production.

The present study does not cover the pre-press and post-press process. It is considered that this line has the sufficient capacity to assume the improvement in the printing process to continue with the flow of the supply chain in the dispatch area.

6.2. Future investigations

Since the research is applied in the manufacturing process of the supply chain and focused on maintenance it should continue with the investigation in the printing operating processes; this would lead to a greater reduction in waste caused by applying Lean Manufacturing [61] [56].

To continue developing the supply chain, within the manufacturing stage, the study should be extended to the pre-press and post-press processes, for which a similar analysis can be made to the present investigation.

Likewise, the study should be extended to suppliers and buyers to optimize the supply management of raw materials, supplies and the distribution of finished products to end customers. Therefore, the application of Lean tools at this level would allow talking about the development of Lean Supply Chain [3] [43], focused in emerging countries.

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