Optimization model to increase the efficiency of the flexible packaging production process applying the Johnson Method, SMED and TPM in a SME in the Plastics Sector

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Abstract*– In the current context, the plastic industry has had a recession phase caused by the COVID-19 pandemic, however, according to the Manufacturing Production Report of the year 2020 reveals a recovery of 4.7% in the manufacture of plastics compared to the previous year. Faced with this, new challenges have emerged such as the increase in demand and the demand for high quality products; these are added to the old challenges of the sector such as unproductive times and non-compliance with delivery deadlines. This research is carried out in a small Peruvian company in which the low efficiency of its production process was identified as a central problem. In this sense, we propose the implementation of an optimization model based on the Johnson method, SMED and 2 pillars of the TPM methodology, resulting in an increase of 24.39% in the productive efficiency of the company, product of reduced setup times and increased mean time between failures.

***Keywords*-- Lean Manufacturing; Plastic Company; Production Efficiency; Setup Times; Machine Stops.**

I. INTRODUCTION

Global plastic production reached 369 billion tons produced in 2018, constituting a 4% share in Latin America [1]. In Peru, the Gross Domestic Product (GDP) has been affected since mid-March 2020, since according to statistics in February of that same year the GDP grew 3.8%, however, in January 2021 the GDP decreased to 1%, product of the impact of the COVID-19 pandemic. Under this context, the percentage variation of plastic production between June 2019 and June 2020 is -12.5%. Also, the percentage change from January to December 2019 and from January to December 2020 is -7.8%, so a recovery of 4.7% is presented [2]. According to The Flexible Packaging Association Inc., the trend to offer more sustainable options in the face of the emergence of ecommerce, provides future opportunities for the flexible packaging industry, it is for this reason that the SMEs of the sector are in the need to increase their productive efficiency to remain active in the market, meeting the customer's requirements regarding the quality and the agreed delivery times [3].

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The magazine Plastic Technology mentions that, in companies of this category, it is common to address in an inefficient, improvised and undocumented manner the drawbacks in the production process, leading to increased unplanned downtime and production imbalance in processes [4]. According to the literature, the application of Lean Manufacturing tools in the plastic sector has caused major improvements, as is the case of 2 studies that highlight the application of conventional SMED to reduce the preparation time of equipment in a range of 29.55% to 40.51%. Both studies highlighted the implementation and redesign of a transport system for tools used in matrix change and installation activities [5][6]. In recent decades, companies have noticed the critical influence of set-up time on job scheduling, particularly when these are times that depend on the sequence of the production process. However, they adopt the SMED technique to standardize the process of product change, leaving aside the adoption of programming techniques to optimize both the production sequence and the frequency of machine configurations [7]. On the other hand, another study reveals that the high rate of defects of a plastic company, made them assume a high cost due to the loss of product and poor quality. However, in applying TPM, some factors that cause such defects were identified, such as low quality of raw materials, low performance equipment and work procedures [8].

This article proposes an optimization model based on the Johnson Method to optimize the productive sequence of work orders, then implement the SMED technique and the pillars of Autonomous Maintenance and Planned Maintenance, in order to achieve a productive efficiency greater or equal to that of the average indicator of the sector (73%)[9].

Finally, the deployment of this article describes: in the second part the revised information of the articles based on the scenario, problem and techniques, in the third section the contribution of the company under study is presented, in the fourth part the validation of the proposed model, in the fifth section the discussion of the results; and finally, the conclusions.

II. STATE OF THE ART

Being efficient in productive terms is one of the main objectives of the organizations. The literature reveals that for SMEs in the plastic sector to be competent and profitable in the current environment must adopt techniques to optimize the scheduling of work orders and to reduce downtime in the production process [10][11].

A. *Johnson method for scheduling work orders*

Currently, manufacturing companies choose to increase their production efficiency through the selection and application of programming techniques that serve as a support to achieve the optimization of manufacturing times [11][12]. One of the most used techniques in the industrial sector is Johnson's Rule, because it provides consistent improvements in the production flow, machine utilization, downtime, and average lead time [13][14]. Several studies show the application of Johnson's Rule to solve the difficulties in sequencing operations with independent configuration times. [15][16].

Several authors agree that the adaptation of a work sequencing model generates a significant impact on the management of the total elapsed time. In addition, they reveal that optimized work order sequencing will reduce production time, late deliveries, and time lost due to frequent process configurations [13][16]. On the other hand, they assert that the Johnson Rule provides a valuable approach to increasing value-added activities, prior to the application of lean techniques in the production system [11][15].

B. *SMED for standardization of the configuration process*

The SMED tool provides instructions and guidelines for standardizing configuration activities, considering the real limitations in the production environment [17]. Several studies of the industrial sector adopt production models that integrate the conventional SMED tool with other techniques such as the Method of Evaluation of Muscle Fatigue with the Taguchi Method, and the Statistical Analysis with Visual Management, to achieve a 62.5% and 30% reduction in machine setup time, respectively[18][19]. On the other hand, three studies carried out in SMEs in the plastic sector, affirm that the application of conventional SMED reduces the time of product change by 29.55%, 40.51%, and 56.84% through 4 phases, where activities are first identified in detail, then they are classified into internal and external activities, then tasks are outsourced; and finally activities are rationalized to obtain better replacement solutions and time reduction [5][6][20].

Different studies agree that in the phase of conversion of internal to external activities it is important to analyze the implementation or redesign of the tool transport system to reduce the time of change of matrices [6][21], while in the rationalization phase the application of the analysis of the 5 whys is highlighted to minimize the high time of operation of the internal activities that could not become external [22].

C. *TPM to minimize unplanned downtime*

SMEs in the plastic sector adopt the TPM methodology to maximize the effectiveness of equipment throughout its useful life and to avoid incidents of failures or functional failures. The literature suggests that both short and long term results are obtained depending on the pillars to develop [23][24][25]. The pillars most used in the sector are Autonomous Maintenance, as it reduces losses significantly by involving workers in small maintenance activities related to cleaning, lubrication, inspection and adjustment of equipment; and Planned Maintenance, because it focuses on increasing the availability and reliability of equipment, in order to achieve zero breakdowns [23][26].

Several studies integrate the Autonomous Maintenance pillar with other techniques such as 5S with Kaizen; and 6S with Statistical Process Control, to reduce mechanical downtime by 32.28% and 13%, and increase overall equipment efficiency from 50% to 53% and from 35.27% to 57.42%, respectively [27][8].

On the other hand, two studies carried out in manufacturing SMEs integrate the Planned Maintenance pillar with the "Education and Training" pillar and Kaizen events, achieving the increase in operational efficiency from 55.6% to 85.6% and from 55.45% to 68.04%, respectively [28][25].

Different articles claim that due to TPM implementation, availability, performance and efficiency increased by a considerable amount, while rejected parts and downtime decreased [8][27]. They also affirm that the implementation of TPM requires the participation of the whole company, so seminars and training are needed to provide knowledge about the maintenance pillars and to improve the technical skills of all production personnel [25][27][28].

III. CONTRIBUTION

This section will present the contribution of the research, which is based on an optimization model that integrates the Johnson method with lean techniques frequently used in the plastic sector. The particularity of the proposed model is that it adopts the implementation of the Johnson rule in a scenario that did not present previous studies, which allows the article to generate new scientific knowledge.

A. *Basic View*

The proposed optimization model is based on the efforts made in [5] y [23], where activities are presented both to reduce setup times and to reduce unplanned stops. Both studies show the lack of a short-term programming technique to support the alignment of both preparation and maintenance activities, through optimal sequencing of work orders, in such a way as to identify the appropriate times to plan and execute such activities.

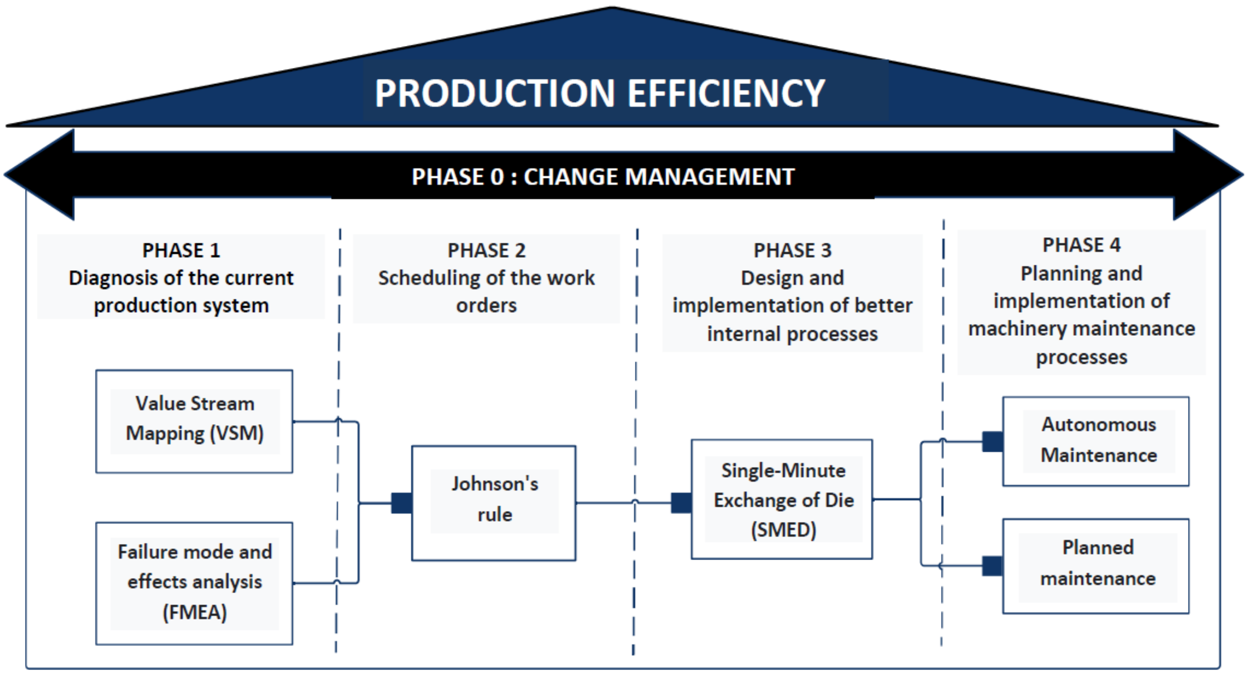


Fig. 1. Overview of the Optimization Model

B. General View

Figure 1 presents the optimization model with its respective phases and components that mainly seek to increase the production efficiency of SMEs in the plastic sector. The interaction of the components of each phase is shown, as well as the suggested sequence for the application of each technique.

C. Specific View

Next, each of the phases of the proposed optimization model will be detailed below.

1. Phase 0: Management of Change:

This component is fundamental to the progress of this model, as it will be applied transversely throughout the project, integrating the Lewin and ADKAR change models. Both models are linked for effective change management, since in the phase of thawing the change will be managed with an open attitude, evaluating the operator about the understanding of the problem and the reasons why it is important to reduce the deficiencies found.

Then, in the phase of change, the displacement of new patterns of behavior, behaviors and activities begins, through the filling of a format that determines the skills and knowledge that are required by the operator. Finally, in the Recongeling phase, continuous reinforcement is applied to ensure and maintain change, where strategies are established and group and individual success is celebrated.

2. Phase 1: Diagnosis of the current production system:

This component is composed of the VSM and the FMEA in order to diagnose the main deficiencies of the current production system. First, the VSM was performed to analyze the current situation of the flexible packaging production line.

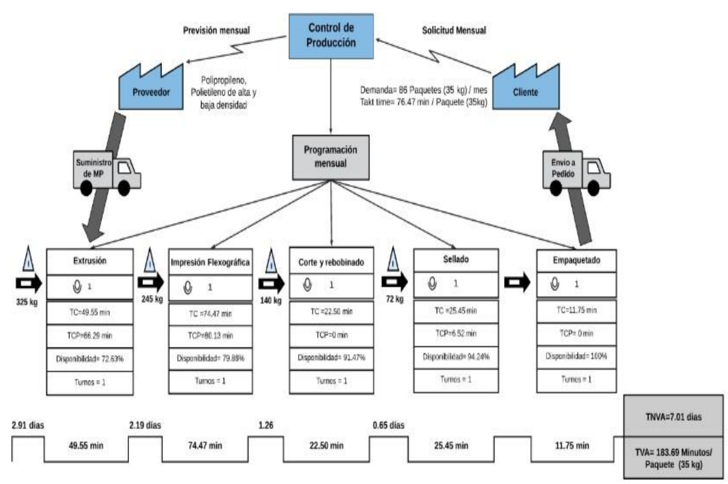


Fig. 2. Current VSM of flexible packaging manufacturing line.

Depending on Figure 2, it was determined that the flexographic printing process is the bottleneck, since it has a cycle time greater than takt time.

It is also noted that setup times for extrusion and flexographic printing processes are high, as they exceed 60 minutes.

On the other hand, it is evident that the availability of such processes is low, since they do not exceed 80%. That is why, through the FMEA, it was determined that the main cause of the inoperativity of the equipment is due to the high unplanned downtime, which originated due to the frequent functional failures due to wear of the components; and for the poor method of lubrication, adjustment and cleaning of machinery.

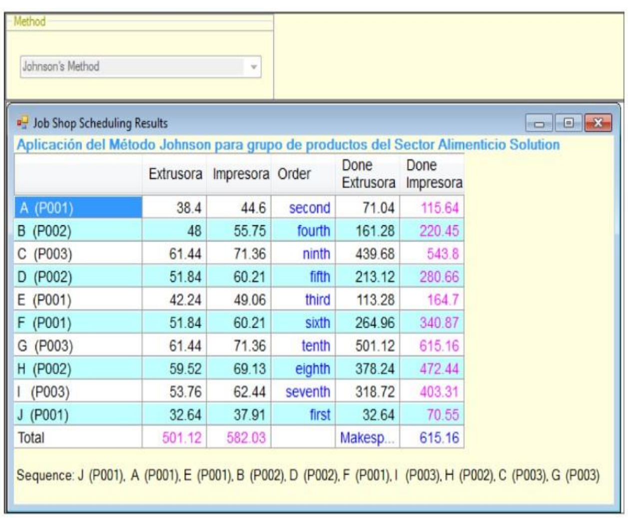
3. *Phase 2: Work order scheduling:*

This component is based on the application of the Johnson method, which is a heuristic algorithm that allows building a potential production sequence, compatible and optimized to take advantage of the productive capacity of the workstations. This method relies on the “Shortest Processing Time” rule, a basic operations scheduling rule for assigning the execution of production orders for scheduling horizons of one day, one week, or one month. For this case, a programming horizon of one week is considered.

The steps to follow in implementing the Johnson Rule are as follows:

- Step 1: Group work orders according to product code, for the purpose of executing a single machine configuration process for each product group with common specifications.
- Step 2: List the work orders with their respective processing time for each machine.
- Step 3: Enter the processing times of each product group in the software "QM for WINDOWS" and select as programming method "Johnson s Method".

Figure 3 shows how processing times are introduced into the programming software. Likewise, the optimal sequence of processing suggested by the program is evidenced, according to the Johnson method.



	Extrusora	Impresora	Order	Done Extrusora	Done Impresora
A (P001)	38.4	44.6	second	71.04	115.64
B (P002)	48	55.75	fourth	161.28	220.45
C (P003)	61.44	71.36	ninth	439.68	543.8
D (P002)	51.84	60.21	fifth	213.12	280.66
E (P001)	42.24	49.06	third	113.28	164.7
F (P001)	51.84	60.21	sixth	264.96	340.87
G (P003)	61.44	71.36	tenth	501.12	615.16
H (P002)	59.52	69.13	eighth	378.24	472.44
I (P003)	53.76	62.44	seventh	318.72	403.31
J (P001)	32.64	37.91	first	32.64	70.55
Total	501.12	582.03		Makesp...	615.16

Sequence: J (P001), A (P001), E (P001), B (P002), D (P002), F (P001), I (P003), H (P002), C (P003), G (P003)

Fig. 3. Input data for optimal sequence generation of the product group with codes P001, P002 and P003.

In this way, the current method of processing followed by the company (FIFO) is modified, by one that allows optimizing the total processing time of work orders, by reducing waiting times in critical processes, through the removal of unnecessary setup processes.

4. *Phase 3: Design and implementation of better internal processes:*

This component is based on the application of the Single Minute Exchange of Die (SMED) technique, with the purpose of analyzing and optimizing the current time of the process of changing dies and clichés of the extrusion and flexographic printing processes, as these exceed by 29.55% and 12.54% over the given standard time.

For the development of the SMED technique, the research carried out by Reyes et al. (2017) and Johnson et al. (2017) was taken as a reference [5][6]. These authors demonstrated the reduction of the preparation time of their critical equipment through the application of conventional SMED, composed of four stages: Preliminary stage, Stage 1, Stage 2 and Stage 3.

The preliminary stage consists in identifying each of the activities of the process of preparation and installation of dies or clichés of the extruder machine and flexographic printer; recording the times, materials and tools used in these tasks.

The first stage is the classification of internal and external activities. Considering as internal activities those tasks that are executed when the equipment is stopped, and external activities such as those that are performed when the machine is in operation.

The second stage is based on the conversion of internal to external activities. The main activities that would be outsourced are the selection, transfer and preparation of matrices or clichés for the extruder machine and flexographic printer, respectively. In the case of uninstallation activities and installation of matrices or clichés, the support of the maintenance technician is assigned, since this has a low workload. This reduces the time spent on these activities by half.

Finally, the third stage consists of maintaining and improving configuration operations, through the standardization of the new process, assigning and monitoring the personnel in charge of each task and additionally implementing the use of preheating cabinets and mobile containers to have more available the tools and manuals used in the configuration of both equipment.

5. *Phase 4: Planning and implementation of machinery maintenance:*

This component consists of the Autonomous Maintenance and Planned Maintenance pillars of the TPM methodology.

Regarding the Autonomous Maintenance pillar, cleaning and lubrication manuals have been designed and implemented to guide and indicate to the operators the frequency and times to correctly execute the autonomous activities. In addition, the monthly cleaning and lubrication programs were presented, as well as the checklists that will serve for the production and maintenance manager to monitor the activities to be performed according to the monthly schedule.

Regarding Planned Maintenance, it was evident that the current plan of preventive maintenance carried out by the company does not match the need for intervention required by the equipment, because in just one year 122 and 105 interruptions were recorded due to functional failures of the components in the extruder and printer machine. A new preventive maintenance plan is therefore proposed, with a maintenance frequency of 3 weeks. Finally, to follow up the implementation of this pillar, a format has been developed and presented for the supervision and execution of maintenance work orders on the company's critical machines.

D. Process View

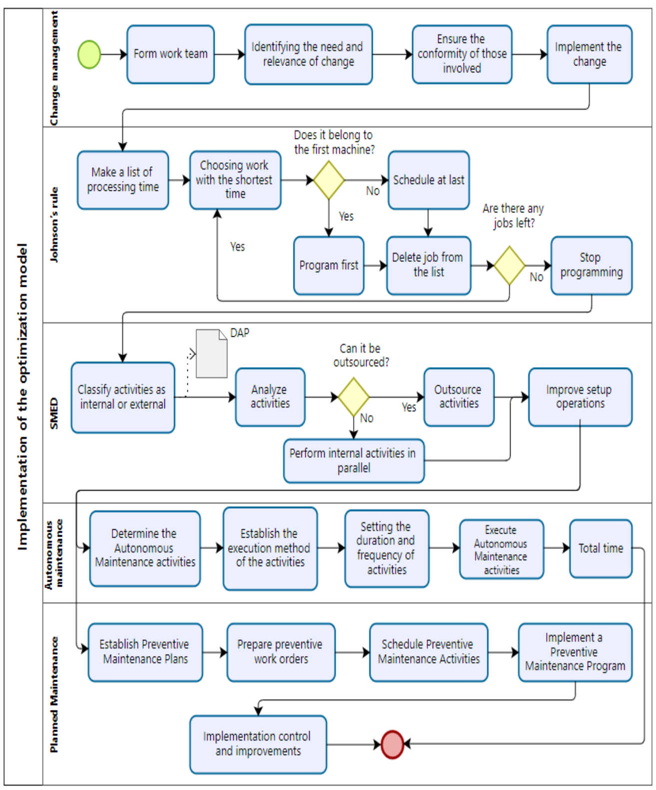


Fig. 4. Optimization Model Implementation Flowchart.

Figure 4 shows in detail the activities defined in the proposed model in order to improve the efficiency of the productive process. We also observe the interaction of each phase and how each tool is carried out.

E. Indicators of the Proposed Model

Table I shows the project's monitoring indicators. In addition, both the values of the current situation scenario (As Is) as well as the values of the expected scenario (To Be) are shown based on the success cases analyzed in the literature review.

TABLE I. MONITORING INDICATORS

Indicator	***As Is***	***To Be***	***Source***
Efficiency of the production process	63.85%	73%	[9]
Maximum processing time	42.26 hr	36.08 hr	[11]
Setup Time - Extruder	66.29 min	39.44 min	[6]
Setup Time - Printer	80.13 min	57.24 min	[22]
Mean time to repair - Extruder	15.98 hr	19.03 hr	[26]
Mean time to repair - Printer	20.47 hr	24.38 hr	

IV. Validation

In this section, the aim is to show and study the environment where the problems identified are currently developed and then simulate the proposed model.

A. Foundation

The functional validation of the optimization model was performed through a simulation in the Arena software. To carry out the simulation of the current situation and the simulation of the proposed model, the time samples of the workstations were taken as input data, which were obtained through two-time studies, performed both before and after the implementation of the components presented in the previous section. Also, through the Input Analyzer, the analysis of the input data according to the probability model presented by each, considering that the distributions that best fit the context of the system under study are: Uniform, Normal, Exponential, Triangular and Erlang.

B. Case Study

The present case study is "Envolturas Libos S.A.C", a company dedicated mainly to the production of flexible polypropylene and high-density polyethylene packaging, whose purpose is to provide a high standard of quality and hygiene in the storage and presentation of products.

Currently the company has a productive efficiency of 63.85% in a sector where the average efficiency is 73%.

Year: 2019	
Quantity of orders (kg)	
Scheduled	53,330
Produced	34,049
Not Produced	19,281
Productive efficiency (Current)	**63.85%**
Productive efficiency (Objective)	**73%**

Fig. 5. Current efficiency of the flexible packaging production process.

Using the Pareto diagram presented in Figure 6, it was determined that the root causes of greater importance and that negatively affect the efficiency of the production process are: the incorrect method of preparation and installation of matrices or clichés (22.39%), poor lubrication, adjustment and cleaning of machinery (17.15%), functional failures due to component wear (23.68%) and inadequate sequencing of work orders (22.31%).

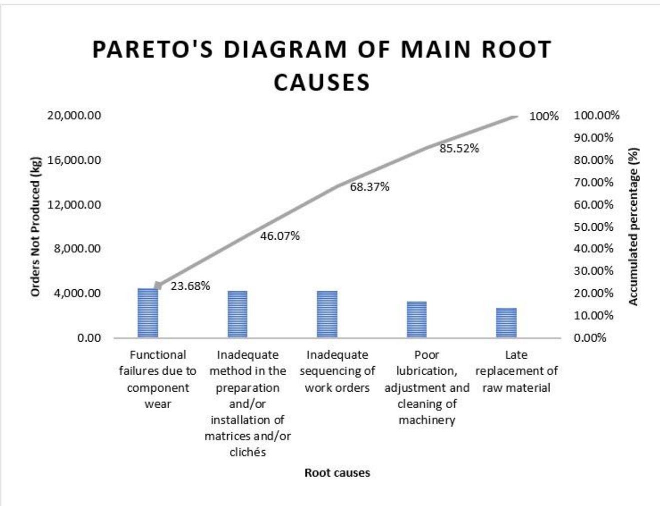


Fig. 6. Pareto's diagram of main root causes.

The economic impact of the central problem represented 26.75% of the annual gross profit. These costs are mainly caused by incurring overtime, late delivery penalties and production losses.

C. Simulation of the Current Situation

In order to simulate the current production system carried out by the company under study, it is necessary to know in detail each of the processes to be programmed, considering the time, the amount of resources and the incidents that are recorded, in order to model a productive system as real as possible.

For this reason, this section shows in Figure 7 the structure of the production system of the case study, which has been developed in the Arena software to validate both the simulation of the current situation and the simulation of the proposed model.

Using the Output Analyzer tool, it was concluded that the number of replications needed to comply with 95% security and an error of 10% regarding the average is 79. It should be noted that the run was initially carried out with 30 replications, in which a simulated period of one week was considered.

D. Simulation of the Proposed Model

To simulate the proposed model, it is necessary to consider that when it consists of tools such as: The Johnson method, SMED, Autonomous and Planned Maintenance, requires its application in situ, since it requires changes in the same plant. Therefore, the following data has been collected from the implementation of 3 months.

- Regarding the implementation of the Johnson method, there has been a reduction of 23.13% in the total processing time of work orders. As a result, the cost of overtime and the waiting time for orders to be processed mainly in extrusion and flexographic printing equipment were reduced.
- Regarding the implementation of the SMED technique, a reduction of 51.10% and 36.27% in the setup time of the extruder machine and flexographic printer has been evidenced, respectively.
- Regarding the implementation of the pillars of the TPM methodology, a reduction of 24.92% of the total number of hours stopped per year has been observed. This is reflected in the 20.63% and 17.55% increase in the mean time between extruder and printer failures, respectively.

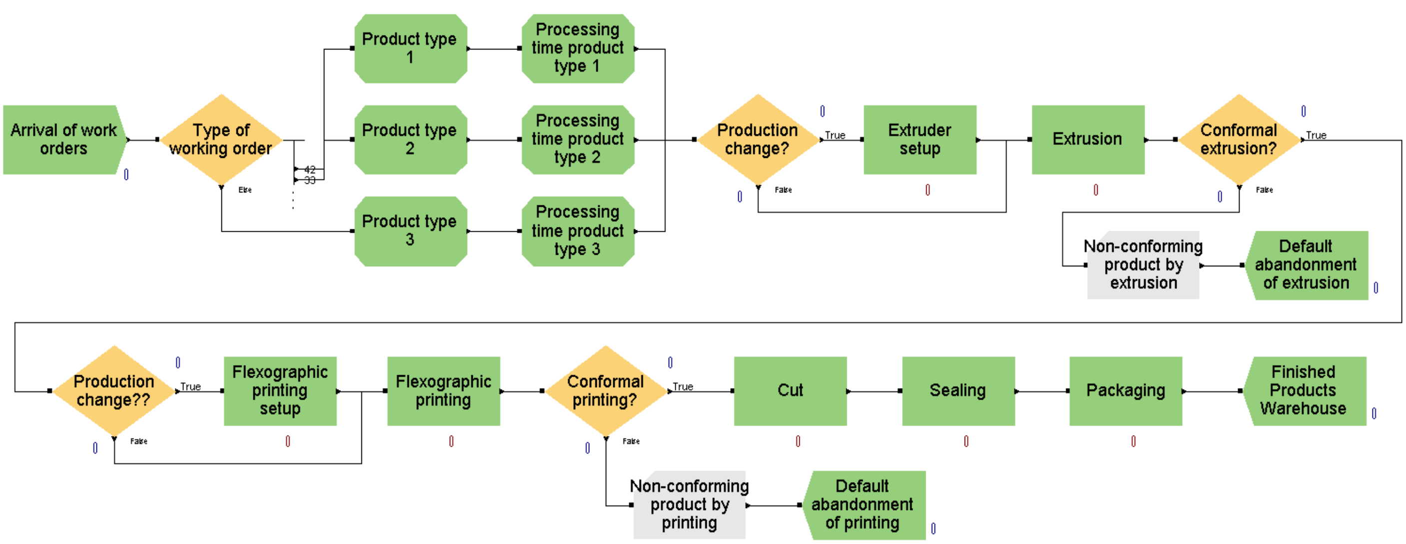


Fig. 7. Design of the structure of the production system in the Arena software.

Based on the data collected from the implementation of the optimization model, the improved times and the corresponding distribution for each analyzed equipment were determined in the Input Analyzer.

TABLE II. IMPROVED TIMES DUE TO THE IMPLEMENTATION OF THE PROPOSED MODEL

Analyzed Times	*Before*	*After*
Setup time (min) - Extruder	NORM(66, 5)	NORM(33, 2.5)
Setup time (min) - Printer	NORM(83.7, 5.15)	NORM(53.4, 3.28)
Mean Time to repair (hr) - Extruder	TRIA(10, 16.5, 23)	NORM(19.3, 3.27)
Mean time to repair (hr) - Printer	13 + ERLA(1.86, 4)	16 + ERLA(2.75, 3)

The improved times in Table II are programmed in the structure of the production system in Figure 7; and the optimization model is simulated, in order to compare it with the simulation of the current situation.

TABLE III. COMPARISON OF THE SIMULATION OF THE CURRENT SITUATION VS SIMULATION OF THE PROPOSED MODEL

Output	*Simulation of the Current Situation*	*Simulation of the Proposed Model*
Production efficiency	63.75%	79.30%
Work orders processed	21	27
Cost of overtime man	S/ 279.37	S/ 0
Penalty for late orders	S/ 261.84	S/ 0
Cost of non-conforming products	S/ 367.56	S/ 235.13
Average time in queue - Extrusion	58.90 min	48.30 min
Average time in queue - printing	120.61 min	70.34 min
Work orders in process	12.50	6.80

- First, the increase in productive efficiency from 63.75% to 79.30%. This is an indicator that the proposal offers favorable results for the company, since it exceeds both the productive efficiency of the current situation and that of the defined technical gap. This is reflected in the increase in productivity, since previously 21 work orders were processed per week, while with the application of the optimization model 27 would be processed.
- There was also a 100 per cent reduction in the cost of overtime and the penalty for late orders, as a result of the optimization of the production sequence and the reduction of the time exceeded in the process of product change in the extruder machine and flexographic printer.
- On the other hand, it is contemplated that the weekly cost of non-compliant products is reduced by 36.03%, product of the increase in the average time between failures in the critical equipment of the company under study.
- Finally, it is observed that the average time in glue of the extruder and flexographic printer are reduced by 18% and 41.68%, product of the implementation of the Johnson method in the productive process. This indicates that the number of products in process (WIP) was reduced from 12.50 to 6.80.

Table IV presents the annual economic benefit obtained in relation to the increase in income from increased productivity and the reduction of cost overruns. It should be noted that, in order to estimate the increase in revenue due to increased productivity, we rely on the weekly productivity increase evidenced in the simulation of the proposed model (6 orders), for which an additional production of 252 orders per year is estimated, generating new revenues amounting to approximately S/ 48,070. On the other hand, regarding the reduction of cost overruns, it was estimated the total cost savings incurred in penalties for delayed orders and overtime, as well as the reduction of 36.03% of the cost of non-conforming products.

TABLE IV. ECONOMIC BENEFIT FROM THE OPTIMISATION MODEL

Economic Benefit	
Increased Revenue from Increased Productivity	S/ 48,070
Penalty savings for delayed orders	S/ 5,788
Cost Savings for Overtime Man	S/ 14,588
Cost savings for non-compliant products	S/ 8,025
Total	**S/ 76,472**

From the above economic benefit, a projected 5-year cash flow was realized with an initial investment of S/ 19,253.19, obtaining a Net Present Value (NPV) of S/ 50,040, an Internal Rate of Return (IRR) of 75.78%, a Cost Benefit Ratio (RBC) 1.60 and a Discounted Recovery Period (PRD) of 15 months. Being the NPV>0, the TIR>COK=11.44% and the RBC>1, it is concluded that the proposal is profitable and economically viable, recovering the investment in 15 months.

V. CONCLUSIONS

The article focused on designing an optimization model that consists of the integration of the Johnson method, SMED and the Autonomous and Planned Maintenance pillars of the TPM methodology. It was demonstrated that the implementation of the tools managed to improve production efficiency from 63.75% to 79.30% as a result of the reduction of 23.13% of the total processing time of work orders, 51.10% and 36.27% in setup time of extruder machine and flexographic printer, as well as the increase of 20.63% and 17.55% in the average time between failures of both machines mentioned above.

To optimize the processing sequence of work orders (O/T), a comparison of the current programming with the proposed programming was made through the Johnson Rule, evidencing the reduction of the total processing time of O/T from 42.26 hr to 32.48 hr.

To reduce the preparation and installation time of dies and clichés, the SMED technique was implemented, reducing the setup time of the extruder and flexographic printer from 66.29 min to 32.42 min and 80.13 min to 51.07 min, respectively. Also, based on the analyzed literature, it was determined that in the companies of the plastic sector the use of auxiliary mobile containers and preheating cabinets is indispensable to expedite the transfer and installation of the matrices or clichés.

To reduce the downtime of unplanned machinery, Autonomous and Planned Maintenance of the TPM methodology was implemented, in which cleaning and lubrication manuals and follow-up checklist were proposed, as well as a new preventive maintenance plan (frequency every 3 weeks) with their respective formats for recording maintenance work orders, resulting in an increase in the average time between extruder machine failures and flexographic printer from 15.98 hr to 19.27 hr and 20.47 hr to 24.6 hr, respectively, for a 3-month implementation period.

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