Revista Cintex | Vol26(2) | pp. 14-21 | enero-junio | 2020 | ISSN: 2422-2208 | Medellín–Colombia

Implementation of autonomous maintenance to pneumatic tools in an assembly line

Implementación de mantenimiento autónomo a herramientas neumáticas en una línea de montaje

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Recibido: junio 18, 2021. Aceptado: noviembre 06, 2021.

Abstract
The automotive sector's assembly and manufacturing companies have pneumatic network systems composed of piping systems, hoses, and pneumatic impact and impulse tools used for product adjustment and assembly processes. Most of these companies do not include this equipment within their preventive maintenance plans because it is not considered a fundamental part of the production process. For this reason, corrective maintenance of the equipment mentioned above only is applied when an unforeseen stop happens. When a failure occurs, production is stopped in an unscheduled manner, causing high repair costs and loss of production time and quality of the assembled product. There are also high energy consumption costs due to air leakage in the pneumatic network, which also affects the delivery compliance of the finished product. This paper presents a methodological proposal for implementing a focused improvement project for the pneumatic tools of assembling lines based on autonomous maintenance, one of the pillars of Total Production Maintenance. Line operators are solely responsible for equipment inspection to anticipate potential failures and thus make scheduled stops for equipment intervention, improving the quality of the finished product and avoiding accidents or losses due to breakdowns. The proposed solution manages to increase the pneumatic line's availability from 88% to 98%.
Keywords: Autonomous Maintenance, Focused Improvement, Pneumatic networks, Total Production Maintenance.

Resumen
Las empresas ensambladoras y manufactureras del sector automotriz cuentan con sistemas de redes neumáticas compuestas por sistemas de tuberías, mangueras y herramientas neumáticas de impacto e impulso utilizadas para los procesos de ajuste y ensamble de productos. La gran mayoría de estas empresas no incluyen este equipo dentro de sus planes de mantenimiento preventivo porque no se considera parte fundamental del proceso productivo. Por esta razón, el mantenimiento correctivo de los equipos antes mencionados sólo se aplica cuando ocurre una parada imprevista. Cuando ocurre una falla, la producción se detiene de manera no programada, lo que provoca altos costos de reparación y pérdida de tiempo de producción y calidad del producto ensamblado. También existen altos costos de consumo de energía por fugas de aire en la red neumática, lo que también afecta el cumplimiento de la entrega del producto terminado. Este trabajo presenta una propuesta metodológica para la implementación de un proyecto de mejora enfocada a las herramientas neumáticas de las líneas de ensamblaje basado en el mantenimiento autónomo, uno de los pilares del Mantenimiento Total de la Producción. Los operadores de línea son los responsables directos de la inspección de los equipos para anticiparse a posibles averías y así realizar paradas programadas para la intervención de los equipos, mejorando la calidad del producto terminado y evitando accidentes o pérdidas por averías. La solución propuesta logra aumentar la disponibilidad de la línea neumática del 88% al 98%.
Palabras clave: Mantenimiento Autónomo, Mejora Focalizada, Redes Neumáticas, Mantenimiento Total de la Producción.

1 INTRODUCTION

For decades, the industry has been experiencing methods and changes that seek to make companies more profitable, competitive, and sustainable [1], [2]. These experiments and changes may be exclusively administrative or executive tasks. On the contrary, they are efforts that share a corporate mission, where all employees participate with a multidisciplinary approach that promotes continuous improvement through implementing the Kaizen philosophy [3]. It focuses on maximizing productive effectiveness and creating a

Citar como:
D. Sanín, S. Gallego & Y. Arboleda. "Implementation of autonomous maintenance to pneumatic tools in an assembly line". Revista CINTEX, Vol. 26(2), pp. 14-21. 2021. DOI: https://doi.org/10.33131/24222208.365

methodology that prevents all types of losses, ensuring zero defects and zero failures throughout the lifetime of the production systems [4].

Previous efforts to make the industry more profitable, competitive, and sustainable can be summarized in a methodology called TPM (Total Productive Maintenance) [5]. TPM was born in Japan in the seventies, looking to eliminate the losses in a company through continuous improvement of all processes, a task that only the participation of all personnel could achieve. However, applying this methodology can be challenging, costly, and lengthy, as its main obstacle (and the main profit) is the goal of changing how people think and act by directly impacting the business culture in terms of production and organization [6]. Therefore, many companies choose to collect or apply good practices and some pillars of good practices to their production processes; for example, in this case, the autonomous maintenance for the compressed air network in an assembly line of the automotive sector with TPM is promoted.

It is essential to mention that for the assemblers of the automotive industry, TPM and autonomous maintenance have become philosophies and working cultures gathering several "easy to perform" tasks that jointly result from disciplined work that synergistically leads to the success of these working philosophies. These methodologies have been widely studied by the JIPM (Japan Institute of Plant Maintenance), an institution dedicated to developing the methodology and concepts of TPM. According to JIPM:

> "The TPM aims to create a corporate system that maximizes the efficiency of the entire production system, establishing a system that prevents all losses in all the operations of companies. This includes zero accidents, zero defects, and zero failures throughout the lifecycle of the production system. It applies to all sectors, including production, development, and administration. It relies on the participation of all the company members, from the top management to the operational levels. Obtaining zero losses is achieved through the work of small teams" [7].

An example of the above is the 5S, a tool summarized in five Japanese words translated to classifying, ordering, cleaning, standardizing, and improving continuously. 5S is the best option to involve all company personnel in tasks that were believed to be solely for the maintenance staff. 5S will also bring significant benefits to companies, such as increased productivity, reduced operating costs, and even reduced occupational accidents [8]–[11].

In addition, the 5S method is the first step in implementing an autonomous maintenance plan, which includes a schedule of cleaning and lubrication activities for the machinery operators or the workstation, as proposed in previous applications of the 5S methodology [12]. Under this strategy, the maintenance personnel do not perform the essential maintenance, as the operator will oversee the daily cleaning and lubrication of the pneumatic tool of the line, based on preventive maintenance. Various maintenance strategies emerge to improve productivity and reliability; the present work focuses on implementing autonomous maintenance [13].

According to the literature, eight pillars are specified for implementing TPM in companies and are the fundamental basis of the applied methodology. Each pillar indicates a path to eliminate or reduce losses such as scheduled shutdowns, production adjustments, equipment failures, process failures, normal and abnormal production losses, quality defects, and reprocessing [14], [15]. This study employs autonomous maintenance following the steps described by Valdez [16], who defines the implementation of this pillar of TPM in seven stages. These stages aim to achieve the basic conditions of the equipment, establish a new discipline of inspection by operational staff and create a new form of management based on self-monitoring.

2 OPERATIONAL CONTEXT

To start implementing any specialized maintenance strategy, it is imperative to know the operating conditions. That is to say, the factors influencing the decisions and requirements needed in maintenance. These factors include the type of process, technical specifications of the equipment, operating times, and working capacity. As explained by Guariente *et al* [13], this information is crucial for making maintenance decisions, and it is known as the operational context. In consequence, this project started by defining the operating context of an average assembly line for a company in the Colombian automotive sector. In this case, the average assembly line has a pneumatic network consisting of piping and hoses, in addition to pneumatic impact and pulse tools (pistols) used for product adjustment and assembly processes. This pneumatic network works on average at a pressure of 90 to 100 psi in 10-hour shifts from Monday to Friday. In addition, there are two compressors of Kaitec and Ingersoll Rand brands. Table 1 describes the technical specifications of the Ingersoll Rand compressor.

The compressors simultaneously power the whole compressed air network, remaining on for 12 hours a day. However, the distribution of the CFM is not homogeneous since the compressors have different technical characteristics and service lifetimes, and the consumption per area is different.

TABLE 1.
TECHNICAL CHARACTERISTICS.

Trademark	Model	Capacity (ACFM)	Pressure (psi)	Power (HP)
Kaitec	KHE 378	210	125	51
Ingersoll Rand	SSRXF50SE	216	103	50

The air network of the assembly line has a maintenance unit for every four quick-coupling connection points, with 145 points in total, which simultaneously power the pneumatic pistols during a work shift (9.6 hours). This condition causes a lubrication deficit to occur. In addition, the compressor accumulator tank does not have an automatic drain, and a manual drain is not performed frequently, which causes an increase in humidity in distinct parts of the line. The compressor maintenance unit is shown in Figure 1.

Fig. 1. A photo of the compressor maintenance unit.

2.1 Current Situation

The research included an inventory of 363 pneumatic pistols, with 337 impact pistols and twenty-six impulse pistols. The preventive maintenance for both pistol types is the same but not highly effective, given that there is no schedule of maintenance activities for these tools. They are only attended when the operator perceives partial failures, when there is a loss of function or when the line is stopped by a broken tool. Once the failure is reported, a maintenance technician arrives to complete the pneumatic tool's overhaul and repair. For this, the maintenance area has a defined standard (see Table 2) which consists of the complete disarmament of the pneumatic tool. This standard procedure mandates an average intervention time of 115 minutes.

TABLE 2.
MAINTENANCE STANDARD FOR PNEUMATIC PISTOLS.

Item	Activity	Item	Activity
1	Remove top accessories	8	Check bearings
2	Open tool	9	Lubricate parts
3	Remove engine	10	Assemble engine
4	Disassemble engine	11	Add oil to engine
5	Clean parts	12	Adjust cover
6	Check rotor	13	Assemble head

7	Check blades	14	Torque test and operation

To quantify the corrective interventions implemented in the last six months, Figure 2 shows a chart of the number of activities per month. From the information shown in Figure 4 emerges a goal initially proposed for self-sustainment: to reduce the number of remedial interventions. In addition, the reduction of maintenance labor by 50% brings benefits in time and cost. However, for comparison and implementation time purposes, the monthly data are averaged, and target numbers are set to reduce this type of intervention.

Figure 3 envisages a reduction of 60% in corrective interventions per month, from an average of 12.5 interventions per month to only five expected. This target also implies incrementing the availability and maintainability of tools since the decrease in interventions is directly related to the reduction of breakdowns [17].

Fig. 3. Goal corrective interventions.

Increasing maintainability means having tools with better lubrication and operation conditions, which leads to reduced functional failures, less wear and tear of internal components, and shorter time for repair or maintenance. Figure 4 illustrates the average repair time for a pneumatic tool.

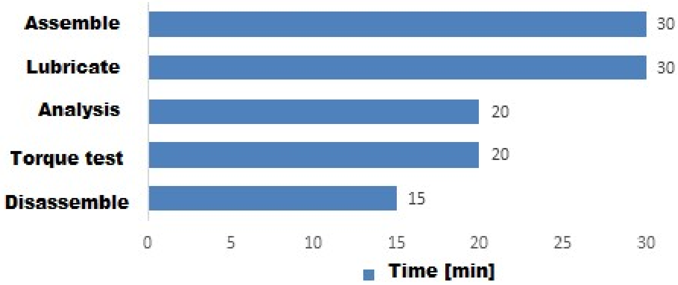

Fig. 4. Maintenance times for pneumatic pistols.

3 IMPLEMENTATION OF AUTONOMOUS MAINTENANCE PLANS

As mentioned above, what is sought with autonomous maintenance is to involve the equipment operator in the maintenance responsibilities. On his initiative, the operator oversees the equipment, identifying previous failures through routine activities and inspections that seek to maintain the equipment in optimal operating conditions [18]. The starting point for the implementation of autonomous maintenance is to implement the 5S policy in the pneumatic tool room. The following images explain the activities conducted through each of the "S"-initiated Japanese words of the proposed methodology:

3.1 Seiri (Classify)

In this first step, it is noted that in addition to storing pneumatic tools, this area was being used to store obsolete and non-operational devices. Therefore, an inventory of items to be destroyed or removed from this area was performed. Figure 5 presents the images of this process.

Fig. 5. Selection of Unnecessary Objects (left) and Selection of Necessary Objects (right)

3.2 Seiton (Order)

In this step, the tools were sorted and stored by type and geometry, as seen in Figure 6. This relocation improves staff productivity because every tool is demarcated and easy to identify and manipulate.

Fig. 6. Correct tool storage.

3.3 Seiso (Cleaning)

Having the tool room sorted and the tools classified, we performed a general cleaning of the place. That is, we swept and dusted.

3.4 Seiketsu (Standardize)

In this step, the demarcation of the storage place assigned for each tool was performed. This demarcation facilitates the visualization of the location, avoids storing the tool elsewhere, and standardizes the storage process.

3.5 Shitsuke (Discipline)

As the last step of the 5S methodology, it was necessary to design a monitoring plan to guarantee, through periodic audits, the fulfillment of the previous steps and to maintain continuous improvement. However, it is essential to mention that this activity is included in the audit reference designed to control and improve the entire operation.

4 RESULTS

Once the implementation of the 5S was completed, basic routines were defined for the execution of the preventive and autonomous activities conducted by the line operators. The assembly line leaders and operators were trained under a set of clearly defined instructions to ensure the execution of all the activities in the same way. This procedure generates a standardized and easy-to-control process.

The results of this methodology should be based on the availability of the assembly line and the reduction of the corrective maintenance interventions since this criterion allows us to evaluate the ability of the line to operate continuously [19]. For this case, the availability indicator is obtained according to equation 1, because of the production time quotient, between the time available, for a given production period.

$$Availability = \frac{Productive\ Time}{Available\ Time} \quad (1)$$

In equation (1), the productive time denotes the net duration of working time after discounting the times planned for meals, active breaks, and enlistment of the line. Figure 7 lists the standard times of specified downtimes for the line of work of pneumatic pistols.

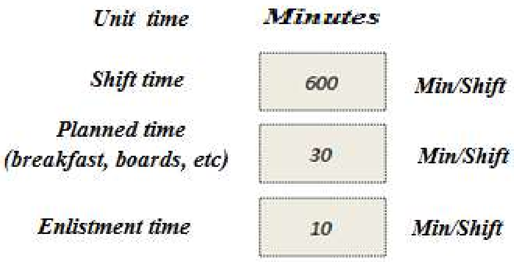

Fig. 7. Operating time.

TABLE 3.
SCOREBOARD OF INDICATORS.

Year 2019	Operation Time [min/shift]	# Corrective Stops	Average time of intervention [min]	Stop Time [min/Shift]	Available time [min]	Availability [%]
January	560	6	115	34.5	525.5	94
February	560	12	115	69	491	88
March	560	12	115	69	491	88
April	560	10	115	57.5	502.5	90
May	560	14	115	80.5	479.5	86
June	560	21	115	120.75	439.25	78
July	560	4	115	23	537	96
August	560	2	115	11.5	548.5	98
September	560	4	115	23	537	96
October	560	1	115	5.75	554.25	99

The table 3 shows the intervention times of the equipment, the production time, among other relevant data for the analysis of the implementation of autonomous maintenance. In this table, it can be identified that with the implementation of this pillar of TPM from the seventh month, the number of corrective interventions was reduced, exceeding the proposed target of reducing by 60% the number of unplanned stops in equipment and obtaining an average monthly value of the number of preventive interventions of 2.75. In addition, Figure 8 shows an increase in the availability of pneumatic equipment for the assembly line during the months when autonomous maintenance began to be implemented.

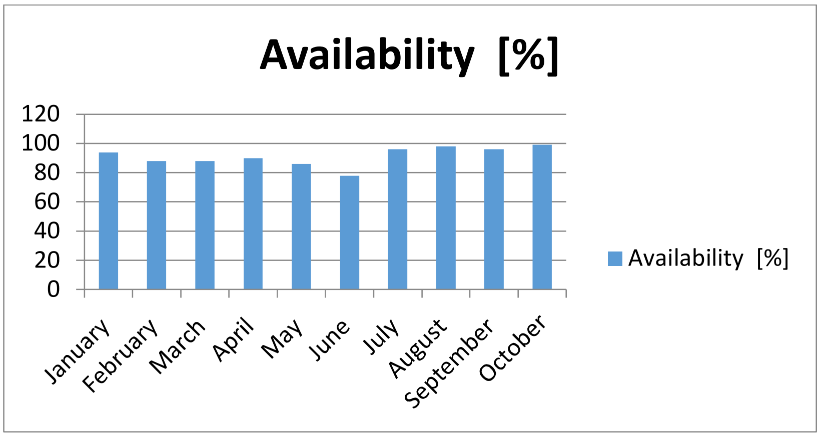

Fig. 8. Tool availability.

The increase in availability is linked to a reduction in operating costs. Since the equipment has increased continuity and working time, the cost of corrective maintenance is reduced by a proportional amount [20]. Considering the direct cost of each remedial maintenance at 32 USD and considering the reduction in the number of attentions for these events (see Table 3), an average monthly saving of 308 USD can be estimated. If, in addition, the profits and utilities resulting from the high availability of the tools within the entire process are considered, the results obtained with the autonomous maintenance proposal would be even more attractive.

5. CONCLUSIONS

This work successfully implemented a focused improvement strategy for the pneumatic tools of assembly lines based on autonomous maintenance. Operators are taught the Kaizen culture, especially autonomous maintenance routines for the pneumatic tool; this involves daily cleaning activities, essential lubrication, and generic applications of 5S rules to the workstation. By reducing interventions to tools, it is possible to demonstrate the importance of implementing autonomous maintenance and 5S methodology in the automotive industry. Finally, it is possible to demonstrate the need to continue implementing the plans and the ease with which the operators implement them. Finally, it is also concluded that autonomous maintenance helps to reduce production costs by an increase in the availability of equipment.

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