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Procedia Manufacturing 38 (2019) 1582–1591

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland.

Continuous improvement in maintenance: a case study in the automotive industry involving Lean tools

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Abstract

Maintenance function assumes a key role in today's industry. The automotive industry is not an exception and there are strict rules to comply with. Indeed, the IATF 16949:2016 imposes the implementation of key performance indicator as a mean to control the overall manufacturing performance. This work presents a case study carried out in a multinational company related with the production of parts for the automotive industry where it was necessary to implement key performance indicators to comply with the IATF 16949: 2016 standard and a model was also created for the management of spare parts linked to the maintenance of existing equipment. The introduction of these changes forced the application of some Lean tools, with a view to improving procedures and information flows. The work was completed successfully, and key performance indicators were implemented, whose support data, which is now collected and calculated automatically on a routine basis, and the spare-parts management was validated with a view to optimization of warehouse space and at a conveniently low inventory level in this type of parts, without endangering critical equipment in production. The SMED methodology was applied, which allowed the setup time to be reduced by 11%, and the Lean 5S tool was used to organize the mould exchange activities. An OEE of more than 90% has been achieved.

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Peer-review under responsibility of the scientific committee of the Flexible Automation and Intelligent Manufacturing 2019 (FAIM 2019)

Keywords: Automotiveindustry; Maintenance;; MTBF; MTTR; OEE; Lean; Continuous improvement; Performance Indicators; SMED.

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10.1016/j.promfg.2020.01.127

1. Introduction

Competitiveness in the automotive industry is very strong. Companies have to be competitive and have very effective management systems. Costs in the companies' productive process should be reduced to achieve higher effectiveness. There are several factors influencing the production process, such as machine failures causing unwanted stoppages, unskilled human resources making longer production times and accidents at work, inefficient layouts causing a long time in the exchange of semi-products between machines, among others. All these problems must be controlled to make production efficient, meeting the customer's expectation about product quality, at a reduced production cost [1,2]. To avoid or minimize production outages, Maintenance and Quality departments must have well-developed process control. The maintenance department needs to keep up with the complexity of the current industrial process is important. Industrial competition and the development of new industrial products and processes will require the maintenance department to continue its work in order to reduce costs, increase efficiency and improve safety without compromising the quality of the final product or process [3]. The performance of industrial maintenance continues to play a key role. However, its strategy should be based on a good logistics system and in solid production planning, by establishing the best practices in all processes [4]. In the automotive industry, there are strict rules to comply with, and the standard International Automotive Task Force (IATF) 16949: 2016 [5] imposes the implementation of the key performance indicator as a mean to control the quality of manufactured products, ensuring a high level of performance for the equipment used in the manufacture of the products.

The main objective of this work was to implement routines that would automatically obtain indicators that are indispensable for compliance with the IATF standard 16949: 2016 [5], such as Mean Time Before Failure (MTBF), Mean Time to Repair (MTTR) and Overall Equipment Effectiveness (OEE). For this, it was necessary to improve some procedures using Lean and tools such as PDCA cycle, 5S, SMED and Pareto diagram. The management tool PDCA Cycle is a tool that means Plan, Do, Check, and Act. Its aims at continuous improvement in processes making them faster and more accurate. In a general way, 5S (sort, set in order, shine, standardize, and sustain) helps to eliminate waste that results from a poorly organized work area. The SMED tool allows to reduce of an efficient and faster way the waste for the machine setup, in the process of manufacture. The Pareto diagram is a quality tool that allows to detect the most frequent defect type or the most common sources of defects in lean manufacturing. After automating the calculations of the previous indicators, a new goal was established to reduce downtime and improve overall product quality. This work is divided into four chapters. In the first one, an introduction is made to the work where the main goals and steps to achieve them are described. In the second, a literature review is done regarding the methodologies and tools used. In the third chapter, the practical work is presented. Finally, the conclusions and proposals for future work in this area are presented.

2. Literature Review

Maintenance is a critical issue to achieve excellent industrial performance. According to Smith *et al.*, [6] maintenance is focused on "preserving the functional capacities of equipment and systems in operation" and aims, according to Moubray, [7] "to ensure that physical items continue to do what the users want them to do". Kobbacy *et al.* [8], state that maintenance can generally be considered as a "set of activities necessary to maintain physical assets in the desired operational condition, or to restore them to this condition". Production is becoming increasingly demanding, and the introduction of Lean Manufacturing has reflected the impact on product quality and process productivity, which leads to production costs reduction and customer satisfaction [9]. In this context, maintenance is extremely relevant. In the last decades, industrial maintenance has evolved a lot, becoming a strategic sector for companies. Global competitiveness has increased exponentially and maintenance has to be seen not as a loss, but as an asset to business management. The main objectives are to increase production, using the minimum resources, focusing on the assets of each company. The facilities need to transform themselves technologically so that the process is more robust and better controlled [8]. Maintenance is very important in several factors, for example, the availability of assets and facilities, optimization of reliability, costs and safety, among others. Regarding Kardec *et al.* [10], the main idea is to move from corrective to preventive maintenance.

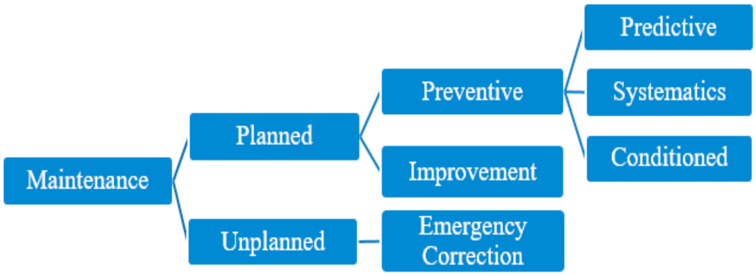

Fig. 1. Types of Maintenance.

Some problems in maintenance routines were already clearly identified, such as lack of proactive maintenance, recurring problems, poorly planned maintenance activities, lack of tracking and vision in the maintenance program, predictive maintenance practices, lack of people's commitment in the medium and long term, non-application of 80/20 rule and inefficiency in the application of new processes and equipment [11]. Fig.1 describes the types of maintenance used in the companies.

Warehouses of spare parts are very important in maintenance tasks. Gulati *et al.* [11] believe that the best practice for replenishing all the necessary material is good inventory planning. Stocks should be managed regarding cost, delivery time and failure frequency. Usually, after the acquisition of an asset, the supplier provides an FMEA analysis of the equipment, fundamentally translating into the main parts subject to degradation and their preventive maintenance. The computerized maintenance systems include a database with all the assets' inventory, in which each asset has a set of specific details, guaranteeing the good maintenance of them [11].

Improvements in process performance have grown more and more, and so, there is a need to measure and develop the key performance indicators (KPIs). Performance indicators can be structured into three groups: economic, technical and organizational. In the area of maintenance, the technical indicators are usually the most requested, namely: failure rate (λ), MTBF and MTTR [1]. MTBF represents the reliability of the company's assets and represents the mean time between failures. Its calculation formula is deducted by the total operating time and number of system failures. Its function (Eq. 1) is essential to inform the behaviour of the asset, ensuring the good functionality of the asset [1,11]. The MTBF can be calculated by the ratio of "Total Operating Time" to "Total Faults", or by the inverse of the failure rate (λ), Eq. 2. The time between failures can be considered the time between the first fault occurred and the second fault. The higher the MTBF, the greater the equipment reliability is. MTTR is exactly the time it takes to restore a device, bringing it back to good functionality. MTTR is calculated by the ratio of "Total Repair Time" to "Total Failures" (Eq. 3). The total repair time includes the time of diagnosis, time to gather the necessary resources and tools, repair, test the equipment and deliver it in the best operating conditions.

$$MTBF = Total\ Operating\ Time / Total\ failures\ \text{[min]} \quad (1)$$
$$MTBF = 1/\lambda\ \text{[min]} \quad (2)$$
$$MTTR = Total\ Repair\ Time\ /\ Total\ failures\ \text{[min]} \quad (3)$$

Otherwise, OEE is an indicator that allows the assessment of the overall performance. This indicator can act on a set of equipment, but also on an individual basis. The main function is to indicate the behaviour that the equipment or set of equipment is presenting on a permanent basis. Performance, availability and quality are three parameters used to calculate OEE [12]. Sousa *et al.* [13] stratified the calculation of OEE by the product between "Performance", "Availability" and "Quality", as shown in Eq. 4. Nakajima [14] defined the ideal value for the OEE metric at 85% or higher. The three parameters should present minimum values of 90% regarding availability, 95% to performance and 99% to quality. The way each of these parameters is usually calculated can be seen in [13]. Moreira *et al.* [1] through an adequate selection of solvents and other specific products used in the printing industry, achieved a 2 to 4% increase in the OEE of a printing company. Sousa *et al.* [13], using the OEE indicator, was able to identify that the biggest cause of the low efficiency of a sector of a cork stopper company was the successive micro-stops to which the equipment was subject. Antoniolli *et al.* [18] achieved a gain of 16% in the OEE of a company producing automotive air conditioning systems through the application of Standard Work and other techniques of optimization of manufacturing processes. Guariente *et al.* [2], through the application of concepts of autonomous maintenance, increased by 8% the OEE of this same company of air conditioning systems for motor vehicles.

$$OEE = Performance \times Availability \times Quality\ [\%] \quad (4)$$

Lean can be understood as a set of tools that assist in the identification and constant elimination of waste, improving as well the quality and productivity, and reducing the costs and production time [15-17]. Lean can be interpreted as continuous improvement of the process through a continuous cycle of improvements: less material, less investment, reduced inventory, increased space and minimized human resources [18]. Ohno [19] and Womack [20] typified the eight types of waste that can normally be thrown into the company when starting continuous improvement processes. According to Shingo *et al.* [21], Lean philosophy has as focus the five following fundamental Lean principles: value specification, value flow mapping, productive flow system, pulled production and lean manufacturing. The quest for perfection must be in the mind of the whole organizational structure. Rosa *et al.* [22] improved the productivity of a production line of control cables for motor vehicles by improving line balancing, upgrading of equipment, elimination of supply problems to the line, study and improvement of operator movement and increase the reliability of production line. Neves *et al.* [16], through the application of some Lean tools such as the PDCA, 5S and 5W2H cycle, managed to save 10% of the time usually spent by operators in a textile trimmings industry.

3. Problem statement and Methodology

This work was developed based on a company dedicated to the production of rubber seals for the automotive industry. This company had not established practices for collecting, processing and controlling data on maintenance activities, as stipulated in IATF 16949: 2016 [5]. According to the standard, it is necessary to monitor OEE, MTTR, MTBF and preventive maintenance compliance metrics. The MTBF was calculated by the company but was not linked to the calculation of the OEE indicator and was kept as a register but not giving rise to any continuous improvement process nor was it properly communicated to all stakeholders in order to generate improvement processes. All operators had free access to the spare-parts warehouse but were not adequately trained to understand the importance of proper management of this type of components. This situation led to ruptures in the stock of critical parts, which generated equally critical stops in the productive sector. It was thus established that there would have to be a very close control of the spare parts warehouse, with restricted access to the employee who was responsible for the management and supply of those spare parts to the maintenance teams. Although the company had a good organization, some sectors presented some functioning deficiencies, which were based on shortcomings in the employees' skills, lack of planning in the acquisition of components for the molds used in the seals manufacturing process, lack of planning in the exchange of molds to be used in production and poor labeling and organization in the location of molds into the warehouse. Detection of these organizational shortcomings led to the drawing up of a list of needs in terms of vocational training, with a view to eliminating shortcomings that were essentially based on the lack of skills to perform the functions to which the employees were assigned. After a first approximation to the actual situation in the shop floor, it was possible to elaborate Table 1 where some of the problems are described and their consequences.

Table 1 – Identified problems in the studied sector.

Problem	Consequence	Type of associated waste
Lack of data control	Low traceability of equipment performance	Waste of time; Information
Lack of access control to spare-parts	Stock racking due to bad registration and parts control	Waiting time; Inventory
SMED technique Application	High setup time	Waiting time; Transport
The absence of organization in the studied sector	Lack of autonomy and organization in the exchange of reference and materials	Waiting time; Inadequate movement
People commitment	Unmotivated collaborators	Waste of time

Based on the detected problems, improvement actions were enumerated and a corresponding order of priority was established grounded on their easiness of implementation, global importance and impact on results (Table 2).

Table 2 – Proposals for improvement and selection of the priority level for implementation.

Suggestion	Implementation easiness	Importance	Result	Implementation order
Creation of documentation for data control	4	5	20	1º
Involvement of people	3	5	15	2º
SMED technique Application	3	4	12	3º
5S tool Application	3	4	12	4º
Monitoring access to spare parts	3	3	9	5º

(1-Easy, 5-Difficult) and its importance (1-Not Important, 5-Very Important).

From Table 2, it was concluded that the first improvement action to be implemented is the "creation of documentation for data control", in order to enable traceability in the process. Thus, new forms used for the collection of the information were standardized, allowing the information to be passed in a simpler and more perceptible way. Moreover, a form-filling procedure was also created to guide current employees, as well as new ones to be hired. After the first completed action, the SMED technique is applied in parallel to the first task, which will aim at reducing the setup time in the studied sector and a better organization, using the 5S tool. A new procedure was created to collect data on failure events as well as the effective operating time regarding each workstation/equipment. According to Equation 1 and Equation 2 above, in order to calculate the MTBF to the equipment, there is a need to record the data. The creation of standardized and automated spreadsheets has the purpose of reducing the time of introduction, as well as the calculation of them and also allows a better perception of the results for the various sectors. The Magnetization Inspection Machine (MI) sector was selected as an example to be described in this study. Data are now collected weekly and per shift. A meeting is held at the beginning of each week to analyze data from the previous week to gather suggestions for improvement and action plans to correct problems and implement concrete improvement actions. Based on the MTBF, information about the time of micro-stops due to equipment and moulds failures was extracted, which is shown by equipment and per week. The data are then shown in the form of a graph, which now contains the time spent in micro-stops (in minutes), combining in a Pareto’s diagram the information on the top 10 equipment responsible for the greatest stopping times.

A closer look at the numbers evidenced by the calculation of the MTBF and the study of the reasons behind these values allowed to realize that much of the non-productive time of the equipment was due to adjustments to be made whenever it was necessary to change from product to be manufactured. This evidenced the need to apply SMED methodology in order to minimize these setup times and increase the equipment production time.

Although the production department already had a procedure for recording the time of scheduled and unscheduled stops, the MTTR is not calculated or monitored as required by the automotive standard, IATF 16949: 2016. In order to perform the MTTR calculation, there is a need to control the number of stops and the stop times for maintenance execution. Once these two factors are gathered, and according to Equation 4, the mean time to repair of the equipment is calculated. Thus, the procedure was revised and, as in the case of the MTBF, the collection of data was standardized and calculations have been adjusted to meet the requirements of the above-referred standard.

On the basis of the above data, it was possible to calculate the availability of the equipment, that is, one of the essential factors for the calculation of the OEE. Given that data on productivity and quality already existed, this was the only factor missing in the calculation of this indicator.

4. Results and Discussion

As can be seen in the chart of Fig. 2, the equipment that contributed most intensively to the overall equipment downtime was the Up/Down Washer Claws, with a 604-minute stop in a week, followed closely by another seven equipment, which contribute to 95% of the stopping time, based on the top 10 of equipment with longer stopping time in the week considered. An investigation into the causes behind the micro-stoppages registered and which require the intervention of the maintenance team, are operations of fine-tuning, repair of small faults and help in solving small problems. This chart shows clearly that there is room for a strong improvement since the numbers indicated represent about 8% of the working time, considering that they work 5 days a week and each day has 3 shifts of 8 hours.

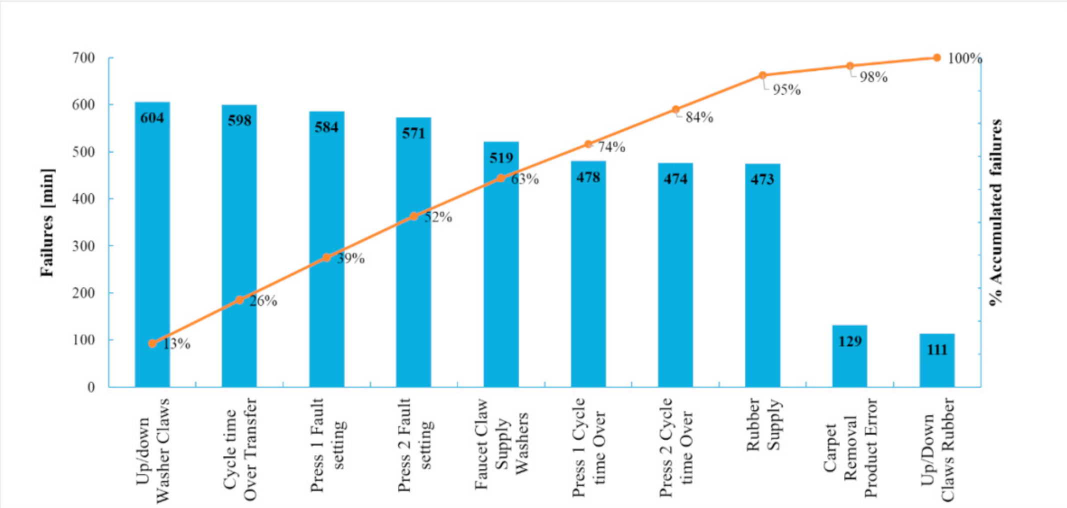

Fig. 2 – Pareto's diagram for the top 10 stops of the week considered in this work.

Once the equipment's downtimes had been properly parameterized, it became possible to advance to the OEE calculation, since all other parameters (productivity and quality) were duly recorded and calculated. Table 3 shows the source of the data and the Department responsible for its delivery.

Table 3 – Parameters for OEE calculation.

	Data	Department
Performance	**Production planning control** ✓ Recording hours planned for production vs. actual hours of production	Production Planning
Availability	**Maintenance time control** ✓ Business days of work ✓ Maintenance times ✓ Equipment setup ✓ Extra hours ✓ MTBF and MTTR	Maintenance
Quality	**Control of the quality rate** ✓ Recording of the production of pieces by equipment; ✓ Registration of non-compliant parts by equipment.	Quality

The MTTR of the equipment is five minutes for all sectors. There are several reasons for the large fluctuation of values, such as lack of manpower, lack of personnel management in relation to corrective maintenance and lack of commitment on the part of the operators/lack of autonomous maintenance. The shortage of labour, causes a lack of time and attention of the operators to execute autonomous adjustments. The need to carry out more detailed training actions related to daily problems in equipment was identified, and this problem is transversal to all sectors of the company. After calculating the values for the MTBF and MTTR, the values referring to the OEE were then calculated. The OEE calculations were performed by each OEE parameter and by company individual sectors. These values were also compared to the reference values indicated by Nakajima [14], as can be seen in Table 4. This comparison allowed to analyze in which of the three slopes there was a greater margin for improvement, helping to concentrate the focus on the parameter that is more away from that reference. As can be observed, Availability is the parameter of the OEE that is further away from the objective outlined by Nakajima [14].

Table 4 – World reference values *vs*. Company internal values.

Parameters	World Reference	Company Reference
Performance	95%	98%
Availability	90%	85%
Quality	99.9%	99.3%

Fig. 3 shows in detail the evolution of the three parameters for the above-mentioned sector regarding the first three months of 2018. This makes it simpler to compare and evaluate individual evolution. Thus, it is possible to notice a positive evolution of Performance in these three months, but, on the other hand, there was a decrease in the Availability, while the Quality maintained the values unchanged in that period. These figures reflect that concerns should be centred essentially on Availability, a parameter that has deteriorated over time. The causes of this degradation of values must still be understood.

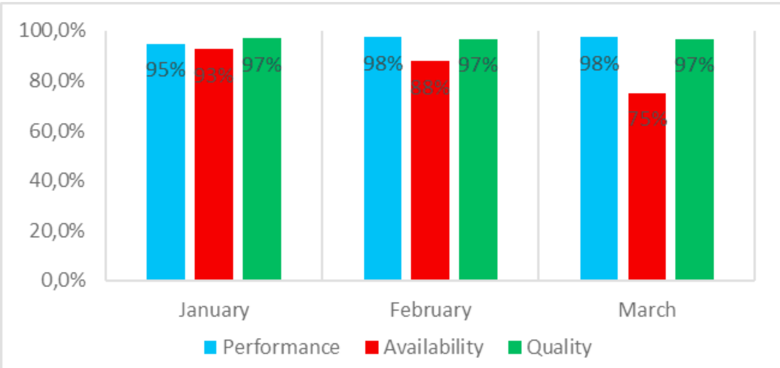

Fig. 3 – Individual evolution of the studied sector in the first three months of 2018: Performance, Availability and Quality

Fig. 4 shows the evolution of the company's OEE, representing an overview of the company during the first semester of 2018, making possible to have a global overview of the situation into the company. Overall data show that March of 2018 was a month with extremely low Availability, which depleted the overall OEE indicator, but thanks to the implementation of some measures, which will be explained later, a remarkable, but not consistent recovery in the following three months was achieved.

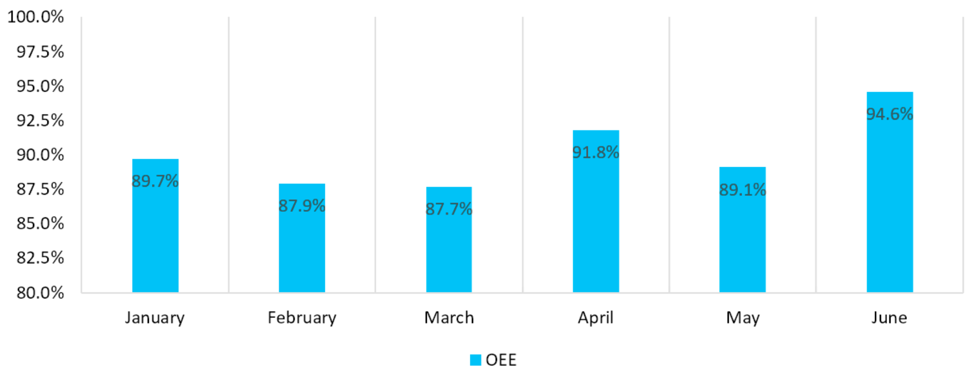

Fig. 4 – Company's OEE evolution in the first semester of 2018

In order to minimize downtime, increase availability and reduce the impact of setups on this Availability, a SMED study was conducted on some processes. The SMED technique in the company is well developed and controlled, however, it was possible to improve the time spent in placing the poles and components in the reference exchange cart. A closer look at the setup process led to the conclusion that it took the workers too long to find tools on the shelves, which were not conveniently organized and labelled. Thus, it was necessary to apply the 5S methodology to organize these shelves, facilitating the search of the necessary tool for each manufactured product. This 5S study allowed a reduction in the demand for the necessary tool from 13min10sec to 2min10sec, that is, about 85%. Given that the internal and external tasks were already well-defined and optimized, the time saved through the SMED study was summed up to the time gained through the 5S study. Thus, the total setup time decreased from 1h38min5sec to 1h27min5sec, thus saving 11 minutes, which corresponds to a saving of about 11%. This reduction can be considered relatively low considering the reductions of 50% in setup time achieved by Martins *et al.* [23] in a process of production of cross-linked cables for the automotive industry, or 43% presented by Sousa *et al.* [13] in the production of cork stoppers, or even a 58.3% reduction obtained by Rosa *et al.* [24] at setup time in a production line of metal cables for the automotive industry. However, these more significant reductions announced above had a greater margin of progression, due to the lack of previous work developed on these processes in terms of SMED. It should be pointed out once again that the process studied here was already well studied in terms of the balance between internal and external tasks, as regards the exchange of tools.

As previously mentioned, control of the stock of spare parts was also significantly improved by assigning responsibilities for access to the warehouse of a single employee at each shift. This evolution allowed minimizing the constraints on production and maintenance due to the inexistence of spare parts that allowed a quick resolution of unexpected problems in the operation of the equipment. A new preventive maintenance policy, taking into account the equipment history and correspondent fine-tuning of the operations to be performed in each intervention, as well as the adjustment of the time between preventive maintenance operations, also allowed to reduce by 42% the cases of unexpected failure of equipment operation, which contributed to a sustainable increase of the parameter Availability that affects the OEE of the company.

Taking into account the organizational evolution above-mentioned, it was also detected that it was necessary to block free access to the mould warehouse since the formation of the operators did not allow to ensure a correct organization of the replacement of the moulds in the shelves. Thus, access to the mould warehouse was only carried out by the production manager at each shift, which ensured that the organization of the moulds on the shelves remained faithful to the previously stipulated. During the course of the work, and in the light of developments, it was possible to conclude that employee training was not able to keep pace with the organizational evolution. A training plan was then drawn up for the employees so that they acquired competencies in organizational terms and realized the importance of complying with the stipulated procedures. The training plan was divided into different stages, with a view to the partial involvement of the group of workers who needed this training. The standardization of knowledge is important in order to achieve a more stable production process.

The results of the training were also reflected in the overall performance of the company by improving the indicators that were now being measured and calculated, in accordance with the IATF standard 16949: 2016.

The performance indicator OEE was applied to all sectors. Nine sectors showed above-average values. Two sectors that presented values below the average, although one of them is old and little used and the other presented some breaks in spare parts supply. However, the values shown achieved are satisfactory. The remaining sectors are close to average.

Overall, the company demonstrated overall equipment efficiency above the company's goal. Regarding the period from January to June of 2018, during which the new solutions were implemented and tested, the OEE value was 90.22%, which is above the value understood as the global reference for this indicator: 85%. It should also be noted that in the same period, the OEE never reached values below that required by the company's top management, which is 83%. The OEE value of 90.22% obtained through this work is significantly higher than those obtained by Sousa *et al.* [13] for each of the shifts analyzed in the production of cork stoppers, who found values between 55 and 76%. The values obtained are also better than those obtained by Moreira *et al.* [1], which ranged from 72% to 75% in the printing industry. It can thus be observed that, in general, the existing competitiveness in the automotive components industry requires much more precise management of the production processes, leading to higher OEE. This can even be proven through the work developed by Guariente *et al.* [2], also in an automotive components industry, where the OEE obtained increased from 70% to 82% through improvements introduced in the maintenance procedures and management system, these values being more in line with those obtained through this study (90.22%). The values obtained in the present study also demonstrate that there was already a prior concern about the company's overall performance, reflecting Performance and Quality levels in line with what is typical in the manufacture of components for the automotive industry.

5. Conclusions

The performance indicators - MTBF, MTTR and OEE - were implemented, being these ones a requirement of the IATF 16949: 2016 standard, allowing the monitoring of results and respective evolutions.

Through the creation and standardization of documents related to indicators, tracking and data processing, it was possible to analyze the behaviour of each sector and identify the largest individual problems. Based on a weekly periodic analysis, the causes of the problems, corrective actions and verification of the effectiveness of the actions taken were discussed. Based on an implementation of continuous improvement actions, Lean improvement projects were carried out together with results monitoring. In this case, the SMED and 5S methodologies were applied to reduce the external setup time, since it was the one that was the biggest problem in the exchange of moulds in this company. The moulds and components organization led to a reduction of external setup time by about 11%. It should also be pointed out that the reduction of the time lost in the setups, as well as a better management in the attendance of malfunctions and small problems in the production, allowed to improve the OEE to values such as 90.22%, which cannot be compared with previous values in the same because this indicator was not previously calculated. The improvement achieved was mainly due to the increase in Availability, which resulted from the factors described above: shorter set-up times and more careful maintenance actions. There is still room for progression in order for all these values to be improved since there was a lack of training and motivation in the workers, which led to the need to develop training measures. After that, surely the values to be reached by the indicators that have now been routinely calculated will certainly be even more encouraging.

Regarding the improvement of the spare parts management, a new procedure was proposed and new rules of access to the warehouse of these components have been established. It should be noted that obtaining more adequate management of spare parts was one of the main objectives of this work.

Acknowledgements

The authors want to thank Uchiyama Portugal due to its willingness to receive Master's Students from ISEP.

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