Productivity Improvement in Manufacturing Systems Through TPM, OEE and Collaboration Between Maintenance and Production: A Case Study

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Abstract. The following paper describes a project where Total Productive Maintenance (TPM) methodology was used in order to improve an automotive industry production line availability and quality. After performing a diagnosis, major flaws were revealed about maintenance and production communication, as well as missing information about the production of defects and maintenance interventions. It was necessary to solve these problems before being able to analyse production inefficiencies, define and implement improvement actions. This project showed the significant impact on costs and quality that can be achieved using TPM, OEE and collaboration between production and maintenance. But beyond that, it showed that despite the industry 4.0 being on the agenda, there is a low use of communication technologies and, therefore, significant gains can still be achieved through basic analysis of recorded data if they are properly organized and standardized. It appears that special attention must be paid to the collection of data, to ensure its proper use for decision making.

Keywords: Collaboration, Data Management, OEE, Quality management, TPM.

1 Introduction

Nowadays, to become competitive and market leaders, manufacturing companies seek to adopt behaviour patterns and rules that guarantee a good performance of their production systems, as well as to embrace innovation [1]. High quality, low cost and small lead time are the three main client demands, that can be met through methods and tools provided by Lean Manufacturing. Nonetheless for achieving these goals, it is imperative to have control over every expense generated by the company [2]. Maintenance department is usually seen as non-value adding in a company, however, there is a clear need for reducing costs related to equipment status, keeping it in optimal conditions for preventing catastrophic ruptures to production flow. Total Productive Maintenance

(TPM) is a maintenance methodology that allows a company to maintain equipment in perfect conditions. The methodology objective is to maximize general equipment effectiveness, improving the Overall Equipment Effectiveness (OEE) indicator, through direct collaboration of every department [3]. The OEE indicator considers produced quantities, number of defects, planned and unplanned stop times, allowing manager to know the factors that need improvement and to make internal and external benchmarking [4]. The desired output for production is only tangible through high equipment availability influenced by equipment reliability and maintainability [5].

Managers are focused in highlighting existing or potential maintenance related problems, in order to improve performance and minimize maintenance operational cost. Systems used for data collection that allow the use of prediction techniques may help to discover useful rules that allow locating critical issues that will have substantial impact on improving all maintenance processes [6]. Although these techniques are appropriate to deal with a large amount of data, the quality of data is crucial for a fast and adequate feeding of the prediction system. During normal plant activity, large quantities of data are produced and are not always considered “clean”, or proper to be used. Usually the records include noisy, missing and inconsistent data, making this the first barrier to be solved before going for more advanced data prediction systems that industry 4.0 has to offer [7].

This paper describes a project that aimed to improve the performance of a production line that manufactures Exhaust Gas Recirculation (EGR) valves that composes an EGR module in modern combustion vehicles. The EGR valve is responsible for controlling the mixed amount of combustion expelled gases with fresh air, reducing the amount of greenhouse gas emissions. Given the huge amount of EGR valves needed to feed vehicle manufacturers around the world, errors should be avoided to be able to fulfil placed order quantities.

The project was undergone by a team composed by quality engineers, process and maintenance technicians. It started by the identification of the causes of inefficiency and flaws using OEE and the TPM pillars as diagnosis tools. Then, taking advantage of the collaboration between team members, improvement actions were defined and implemented.

The present paper is organized as follows. In Section 2, the diagnosis of the studied production line is depicted, revealing the prime failures of its low performance. Section 3 describes the improving actions implemented to the production line in order to correct the flaws identified. In section 5, the results of those improvements are presented and conclusions from the study are drawn.

2 Diagnosis

2.1 Data registration process

During the diagnosis phase, some limitations to the analysis due to the method used in the production line to register information related to production activities were immediately identified:

1. No distinction between different types of stops: During normal production time, different reasons may lead to the equipment stoppage, resulting in an overall temporary stop of the line production activities. Equipment stops can either due to equipment breakdown (ex: failure of mechanical or electrical components), or due to a production part quality issue that forced the equipment to stop in order to correct the issue. The non-differentiation of these stops, since all stops are registered as "breakdown", and the lack of details about actual equipment breakdowns do not allow future analyses regarding where to invest the company's time and resources in order to make improvements in that equipment.
2. Wrong quantification of quality defects: During a normal production shift, information that is documented regarding quality defects does not refer any detail about the stage of the process where they were produced or what caused them. The lack of detailed and normalized information does not allow the team to use quality tools like Pareto diagrams with the scope of identifying and solving those quality problems.
3. Maintenance interventions information: The fact that maintenance technicians do not register all interventions performed on the production line equipment, and the fact that the ones that were registered are not normalized, not allowing for future detailed analyses, becomes one more step-back to the production line managers to decide in what improvement actions to invest.

2.2 Analysis based on OEE

By analysing the OEE indicator of the production line, it was possible to find out the factors that most contribute to the low value of OEE. Figure 1 shows the behaviour of both OEE and its constituting factors. From April 2019 to December 2019, the average value of the OEE was 54,90%. In that same period of analysis, the availability factor had the worst result, with an average of 60,75%, followed by quality factor with 90% and performance factor with 94%.

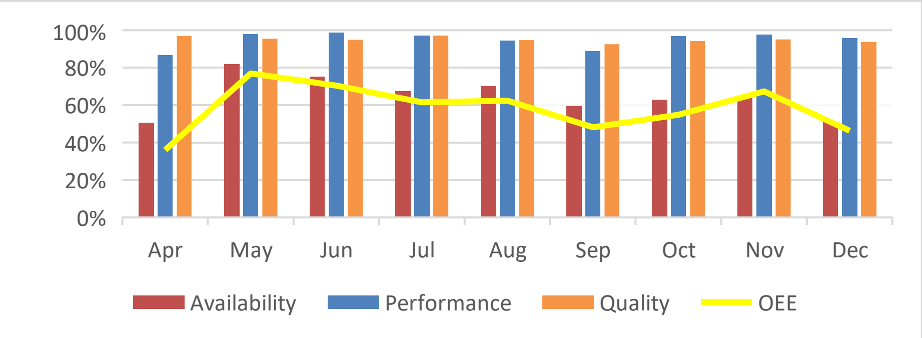

Fig. 1. OEE behaviour from April 2019 to Dec 2019

After deducing that the availability factor was the main responsible for the low value of OEE, the analysis was focused on the inefficiencies related to this factor. Figure 2 identifies through an accumulated bar chart, the sum of inefficiencies registered in the production line. All reported inefficiencies are quantified as wasted time and the chart exhibits the percentage compared to the production time.

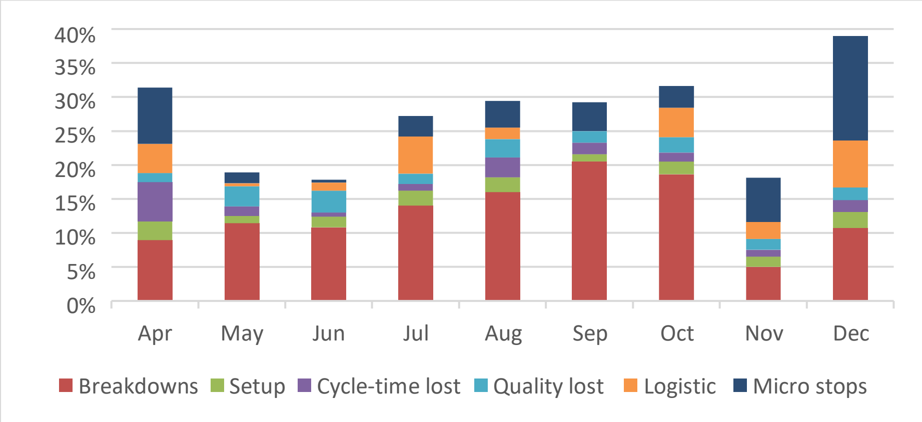

Fig. 2. Inefficiencies quantified from production line from April 2019 to Dec 2019

The chart of Figure 2 shows that the biggest inefficiency is "breakdowns". As it was explained in section 2.1, the "breakdowns" inefficiency must be interpreted as "equipment stops" motivated by failures or by product quality issues.

Since the registration method used by the company did not provide enough information for the team to study the existing problems, a new one that allows for more detail about defects production and equipment stops was implemented. This method relies on an input form that categorizes and differentiates the type of stops and defects so that the operators can register the information without mistakes and with the necessary details during normal production activity. The detail provided allows the engineers to understand what the main motives of defects are, and the respective causes. After two months of records with this new method, it was possible to build Table 1.

Table 1. Quantity: stops vs production defects

Average time stopped	Time stopped	Nº Stops	Equipment	Nº defects	% Defects
143,46	5164	36	OB128	658	57,87%
47,38	1042,5	22	OB100	175	15,39%
43	430	10	OB131	63	5,54%
37,33	560	15	OB130	35	3,08%
21,5	129	6	OB127	88	7,74%
158,96	3179	20	OB129	86	7,56%

Through Table 1, it is possible to conclude that the equipment which produces the highest number of defects is also the one which stops the most, suggesting that those stops aimed solving those problematic quality defects.

Given the fact that the data retrieved during these two months had enough detail to determine the main reasons of defects in production by applying quality tools, it was possible to find their root-cause and consequently proceed to improvements. Two main categories of defects were uncovered. The first one was a leakage detected in the leakage test and the second is detected at the final stage of the process, at the hysteresis test. The first category occurs when the valve is not able to restrain the air stream to a certain desired volume. The team used an Ishikawa diagram in order to find the source of error and, after carefully testing all parameters, it was unveiled that a small misalignment of the valve regulating membrane, the flap, caused an undesired leak. This leak occurred due to a gap in the flap caused by the degradation of the tool that adapts and secures the valve in the machine during the welding stage. The second category was unveiled during the hysteresis test that consists in simulating the valves normal field behaviour, exposing it to routine stress while in normal operation. The team found that this defect is the result of two problems, both due to wrong inner component angles. The gas mixture is controlled by a small electric motor that is attached to the valve. The two components that are responsible to connect the motor to the valve, in order to transfer the energy, are usually welded in a wrong and non-functional angular position, causing the valve to fail in the test. After carefully testing the welding equipment, the team unveiled that the equipment components responsible to stabilize those two components during the welding process were heavily damaged and worn out, causing unwanted gaps.

2.3 Analysis based on TPM pillars

Pillar	Observation
Autonomous Maintenance	The presence of dust, debris, and obsolete components in the production line are indicators that this pillar is not present. Therefore, autonomous maintenance plans are needed.
Planned Maintenance	Maintenance plans for the equipment of the production lines are defined, but they are not fulfilled.
Focused Improvement	Equipment improvements meant to solve momentary problems to resume production activity as soon as possible and are not part of a continuous improvement approach.
Quality Maintenance	During the performed quality analysis, a problem with a measuring system was identified. A gage R&R study led to the conclusion that this system was not able to evaluate production parts. This fact suggests that this pillar is not well embed in the company.
Office TPM	Communication between logistics and maintenance is not the finest. The fact that maintenance technicians do not have any information about spare parts stock, suggests that improvements within this pillar are needed.
Training	Both pillars are well present, they represent the base beliefs of the company, and their presence is remarkable due to the heavy attention given to the workers.
Safety, Health and Environment	

Maintenance team efficiency is also noticeably low. Maintenance interventions take a long time to complete due to low availability of technicians and tools, and lack of knowledge. Given the fact that this type of industry is highly automated, the need for maintenance technicians specialized in automation is clear. One other problem detected was the lack of support to the production line, with only one specialized technician working in central shift, not even providing support to the night shift. Due to the high number of maintenance calls, almost no time is left for technicians to register the actions or changes made during that maintenance intervention.
The company uses a software to manage and monitor its plant maintenance activities and controlling its expenses, however, due to some inefficiencies with the software, it becomes poorly used by the maintenance technicians. The software is slow to run, requiring a lot of data entries to register a maintenance intervention and around 8 minutes necessary to fulfil the registration of a single intervention.

3 Implementation of improvement actions

3.1 Autonomous maintenance

Since many equipment breakdowns or quality issues were related to detrimental production environments, there was an obvious need for improving that environment. Together, with the tacit knowledge of both maintenance technicians and equipment suppliers, an autonomous plan was created. The maintenance actions that comprise the plan are performed by the operators at the beginning of every shift. The aim of this maintenance plan is to reduce the chance of error or problems with production, via cleaning, lubricating and adjusting the necessary parts.

3.2 Quality improvements

In order to mitigate the quality problems in production, some improvements were made to the production line equipment. The problems were solved by developing and creating new tools to replace the older degraded ones, eliminating gaps that previously existed. The leak detected during the leakage test was eliminated by the replacement of the tool used to secure the valves position during the welding operation, assuring a good quality and continuous production.
New measurement systems were developed to adopt a new evaluation method to judge the productions output quality, reducing the variability compared to the older measurement systems, allowing for a more controlled production process.

3.3 Maintenance management and data gathering

The maintenance team was enhanced with the addition of an automation specialist, covering all three production shifts, becoming therefore more available. The lack of tools was also eliminated by investing in a maintenance tool car for every technician, eliminating waiting times for the tools to be available.

The implementation of a mobile maintenance management system was probably the biggest improvement of all, regarding maintenance organization and communication. The system also allowed for a better communication between technicians of different labouring shifts. This newly implemented mobile registration system allowed the maintenance technicians to both register and access information about equipment as well as consulting information about spare parts at the warehouse in a much faster and efficient way with the use of QR codes that connect the technician directly to the equipment profile. This improvement also reduced the time required to register a maintenance intervention, enhancing the maintenance technician's availability. Since the information can be accurately registered, KPI calculation can now be trusted by the engineers, allowing the identification of effective improvement actions.

4 Results

The improvement actions implemented in the project described in this paper brought significant upgrades to the production line. The new method of registration provided a structured data base to be used for studying problems and finding solutions. During the months of January and February 2020, information was registered using the new data record method, allowing for the definition of improvement actions, implemented throughout the months of March and April 2020. In the following six months (May to October 2020), the availability factor increased about 11%, compared to the previous nine months, from an average of 61%, to an average of 72%. Regarding quality, after the implementation period from March to April 2020, the following two months registered 4500€ saved in the production of defects. The company uses a KPI known as "scrap vs sales" which measures the value of scrap produced compared to the value of sales for that month. For the same period of analyses mentioned earlier, this KPI went from 3,4% to 2,4%.

5 Conclusions

In this project, the diagnosis phase allowed, through an analysis based on the factors and inefficiencies associated with the OEE and based on the TPM pillars, to prioritize improvement actions. The collaboration between production and maintenance and the redefinition of data records were key factors in achieving the portrayed improvements. A perfect synchronization between production and maintenance is desirable to obtain the maximum value from the assets. The need for standardized and organized records of information is also irrefutable, whether concerning defects on production or maintenance interventions. It is only possible to implement a predictive maintenance system, for instance, if this standardization is achieved, becoming the first step into industry 4.0. Therefore, the same way as Training is a pillar of TPM, it seems to be necessary to consider a new pillar designated by "Communication and data management" in order to enhance TPM implementation in today´s digital manufacturing environments.

A fast and effective communication between maintenance and production, maintenance and logistics and between shifts can bring significant gains. Good data management makes it easier to highlight inefficiencies and their causes, constituting a driver for continuous improvement. Since the time spent in manufacturing plant to collect and access data and information should be reduced, given the fact that it is a non-value adding activity, implementing available technologies such as mobile devices, is a key for a successful implementation of TPM in companies. However, this should be accompanied by a reorganization and standardization of data records for allowing appropriate analysis. Thus, the development and implementation of ontologies in the maintenance domain is required.

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