PRODUÇÃO ONLINE
REVISTA CIENTÍFICA ELETRÔNICA DE ENGENHARIA DE PRODUÇÃO
ISSN 1676-1901

HOW THE IMPLEMENTATION OF A MANUFACTURING EXECUTION SYSTEM CAN IMPROVE SHOP FLOOR MANAGEMENT AND INCREASE PRODUCTIVITY

COMO A IMPLEMENTAÇÃO DE UM SISTEMA DE EXECUÇÃO DO PRODUÇÃO PODE MELHORAR A GESTÃO DO CHÃO DE FÁBRICA E AUMENTAR A PRODUTIVIDADE

Micael Michelon* E-mail: MMichelon6@ucs.br
Universidade de Caxias do Sul (UCS), Caxias do Sul, Rio Grande do Sul, Brasil.

Abstract: This article seek to analyze and to describe the results obtained through the implementation of a Manufacturing Execution System (MES) and how this appliance can contribute to the improvement of the methodology Shop Floor Management (SFM) and increasing the productivity. The present case study was accomplished in a foundry company, the methodology used was the qualitative research with exploratory feature. Through the MES system and elements of methodology SFM, the organization of this case study can gather data and obtain information in real time of your productive resources, in this way the company can identify the main reasons of inefficiencies and take actions about them. The monitored sector obtains positive results in production management and significant increases in productivity.

Keywords: Manufacturing Execution System (MES). Shop Floor Management (SFM). Overall Equipment Effectiveness (OEE).

Resumo: Este artigo procura analisar e descrever os resultados obtidos através da implementação de um Sistema de Execução de Produção (MES) e como este aparelho pode contribuir para a melhoria da metodologia Gestão de Piso de Loja (SFM) e para o aumento da produtividade. O presente estudo de caso foi realizado numa empresa de fundição, a metodologia utilizada foi a investigação qualitativa com carácter exploratório. Através do sistema MES e de elementos da metodologia SFM, a organização deste estudo de caso pode reunir dados e obter informações em tempo real dos seus recursos produtivos, desta forma a empresa pode identificar as principais razões das ineficiências e tomar medidas sobre as mesmas. O setor monitorizado obtém resultados positivos na gestão da produção e aumentos significativos na produtividade.

Palavras-chave: Sistema de Execução de Produção (MES). Gestão de Piso de Loja (SFM). Eficácia Global do Equipamento (OEE).

1 INTRODUCTION

Currently, with the high competitiveness in the industrial sector, organizations are looking for improvements in production processes, in order to obtain faster, more flexible processes at lower costs. With the objective of reducing waste, increasing productivity and seeking continuous improvement of the production process, the Shop Floor Management (SFM) methodology appears to show that results can be achieved and supported by one of the pillars of Industry 4.0, which consists of the connectivity and transparency of information, that is, the collection of data and analysis of indicators of manufacturing equipment in real time.

Through Workplace Management, organizations have the opportunity to efficiently use their productive resources, increasing the results expected by the company and solving existing problems, together with all those involved with the work place (ANTUNES *et al*., 2013). SFM improves the operational efficiency of equipment, implementing improvement actions to increase production capacity and flexibility (ANTUNES *et al*., 2013). On the other hand, the current generation is witnessing the digital revolution driven by Industry 4.0, where the goals are: to improve manufacturing processes, increase profits and minimize waste (KUMAR; NAYYAR, 2020). These objectives consist of identifying and eliminating activities that do not add value to your processes.

Equipment connectivity can be performed through the Manufacturing Execution System (MES), a system that groups the company's planning and production, providing access to information displayed in graphics, which allows monitoring and analyzing production, as well as the status of products and equipment, making it possible to track its use, leading to a reduction in idleness (BESUTTI; CAMPOS; CECCONELLO, 2019).

MES systems emerged from the growing demand to deal with process, resources, maintenance, quality and provenance monitoring, as well as traceability requirements in manufacturing (MESA, 1997). Nowadays, there are several unknown losses and inefficiencies within some of the manufacturing processes and, if there is no efficient system to collect this data and point out where the losses are, the organization will have difficulties in taking assertive actions to eliminate the said losses. To achieve these expectations, top management performs the analysis and makes its decisions guided by production performance indicators (GARZA-REYES *et al*., 2010). An MES is, above all, a support system for decision-making by managers (NAEDELE, *et al.,* 2015).

With an MES system, the organization will be able to measure the global index OEE (Overall Equipment Effectiveness), which is an indicator that measures the efficiency of equipment, identifying losses due to productivity, performance and quality.

The measurement of the OEE index is effective to analyze both the efficiency of a single machine and an integrated manufacturing system (NAKAJIMA, 1988). The most important objective of OEE, therefore, is not to obtain an optimal measure, but to obtain a simple but comprehensive measure of internal efficiency that can function as an important indicator in the process of continuous improvement (JONSSON; LESSHAMMAR, 1999).

From this understanding, the present work aims to show how the implementation of a MES system can improve the Management of the Workplace. For that, a case study is presented, carried out in the sector of sand molds for castings, of a foundry company in Serra Gaúcha.

2 THEORETICAL FRAMEWORK

2.1 Shop Floor Management (SFM)

The SFM methodology is intended to optimize a company's resources, increasing production capacity and flexibility, without the need for investments (ANTUNES *et al.,* 2013). Also according to Antunes et al. (2013), SFM uses tools and techniques that can offer a quick, low-cost and quality response, acting on the efficiency of the equipment and, consequently, increasing the results (KLIPPEL; OLIVEIRA, 2004).

SFM follows these instructions:

- Identifies the company's critical equipment such as (bottlenecks, CCRs and RPQs) using TOC concepts - Theory of Constraints;
- Determines the global efficiency index of critical equipment;
- Identifies the main causes of equipment inefficiency;
- It applies the techniques and tools of the Toyota Production System to increase flexibility and reduce or eliminate waste.

The operation of a workstation requires the involvement and participation of several professionals from sectors of the company such as: production, quality, processes, maintenance, safety and improvements, being essential the alignment of the actions of these professionals, with the objective of improving the processes of work.

The first point is to efficiently manage the work place, which is nothing more than a management of people and machines, aiming at three aspects, namely the systemic vision of the company, integrated/Unified vision and results-oriented vision. TOC (Theory of Constraints) allows the objective of an organization to generate profits in the present and in the future, in addition to proposing that production be conducted from the constraints.

The second approach, in turn, is supported by the Toyota Production System and is listed with the improvement of processes in the organization, through the flow of raw materials and products that are synchronized with production and improvements in operations considered bottlenecks. This approach is carried out using Toyota Production System techniques and tools such as: Kanban, Kaisen and Just in Time, and may also use other means of managing material flows, such as electronic systems or MRP/MRPII manuals. (KLIPPEL *et al*., 2003). According to Antunes *et al*. (2013), for the organization to manage the job more efficiently, it is necessary for the company to understand the production systems more comprehensively and identify their limitations.

- System input: information directly related to jobs, that is, information from the Manufacturing Planning and Control (MPC) sector, quality and shop floor;
- Processing: it is essential that the equipment data are provided, which are usually extracted through a data collector or some type of logbook, where they are pointed out by the operators themselves or by computerized equipment installed in the equipment (ANTUNES *et al.,* 2013).). Data collection, in turn, provides information such as: quantity of good parts produced, amount of scrap generated, production time of each item, setups, reasons and times of machine downtime (ANTUNES *et al.,* 2013). These data are used to calculate the efficiency of the equipment (KLIPPEL *et al.,* 2003).
- System outputs: enables the organization, managing restrictions for routine tasks and for implementing improvements;
- Training: all subjects involved in the process must undergo training to understand the proposed methodology and correctly fill in a “Logbook” or type it correctly in the data collectors. These trainings must be done regularly or whenever necessary;

- System management: it is carried out through meetings with those involved in the process, from managers, supervisors and work teams to discuss the results obtained and direct improvements.

In view of what was exposed through the statements of the authors mentioned above, it is clear that in order to obtain the expected results it is essential for the organization to understand the five fundamental elements of SFM.

The Theory of Constraints (TOC), in turn, was developed by the physicist Goldratt during the 1980s and published in the book A Meta de 1984 (NAOR; BERNARDES; COMAN, 2013). It is an integrated management concept, which helps to change managers' thinking and becomes an excellent tool for problem solving (WU; LEE; TSAI, 2014). According to Goldratt and Cox (2003), the best way to illustrate a system is by the relationship of a chain, because the global resistance of the chain is measured by the strength of its weakest link, that is, the restriction. In this way, the restriction or bottleneck limit the performance of the system, making it difficult to reach the goals (MABIN; BALDERSTONE, 2003).

In some occasions, companies may not have real bottlenecks, as all productive sectors are oversized in relation to demand, however, there is always some equipment that limits production (PRATES; BANDEIRA, 2011). According to Goldratt and Cox (2003), the flow of production must occur according to demand and not according to production capacity. In this way, the achievement of the goal will happen through the five stages, where it will be possible to reach only one point that determines the functioning of the entire system (GOLDRATT; COX, 2003). Below are the five steps of the methodology according to the same author:

- Identify the system constraint;
- Exploit system constraint;
- Subordinate the other processes to restriction;
- Raise the restriction capacity;
- Return to step 01 (one) and identify a new constraint, not letting inertia take over the system.

Based on the above, it can be concluded that the theory of constraints is a management concept that helps to achieve results and solve problems, through the identification of constraints.

For organizations to manage more efficiently, it is necessary that they have a systemic view of production processes and recognize their restrictions (ANTUNES; KLIPPEL, 2001). Resources whose available capacities are less than the capacities needed to meet market demands are considered bottlenecks. The resources considered as bottlenecks give the company production speed (KLIPPEL *et al.,* 2003).

The Capacity Constraints Resources are resources that generally have a capacity above the necessary, however, they can become bottlenecks when poorly managed (KLIPPEL *et al*., 2003). The Capacity Constraints Resources also arise from changes in demands and system fluctuations, which are usually related to equipment maintenance, setups above schedule, product quality, sequencing of production orders and seasonality of demand (ANTUNES *et al.,* 2008).

2.2 Productivity Indicators

In this topic, considerations will be made on productivity indicators, whose main ones are the Global Operating Income Index (IROG), Total Effective Equipment Productivity (TEEP) and Overall Equipment Effectiveness (OEE), which will be analyzed in more depth, demonstrating the monitoring and data collection, as well as the form of calculations to obtain results.

The IROG indicator monitors the reasons that most influence the availability and performance of the organization's resources, which must be constantly monitored, consequently generating better use of equipment, resulting in increased productivity (ANTUNES *et al.,* 2008). The IROG global operational performance index is a performance measurement tool that helps to identify the types of production losses and indicates areas for improvement in the monitored processes (MUCHIRI; PINTELON, 2008).

According to Klippel *et al.* (2003), the IROG indicator is performed taking into account two ways: 1) if the equipment is considered a bottleneck, the global efficiency indicator of the equipment is called TEEP; 2) and if the equipment is a non-bottleneck critical resource, in this situation, the overall efficiency indicator of the equipment is called OEE.

According to Antunes *et al*. (2013), Total Effective Equipment Productivity, is applied where resources are considered bottlenecks. In this indicator, the available time of equipment without any scheduled stop should be considered, since resources considered bottlenecks cannot stop, as they delimit production. The TEEP indicator looks for the total improvement of the productive time in the resource considered as a constraint, avoiding unplanned and planned stops (MUCHIRI; PINTELON, 2008). TEEP shows possibilities that are not taken advantage of, associated with total capacity (PIRAN *et al.,* 2015).

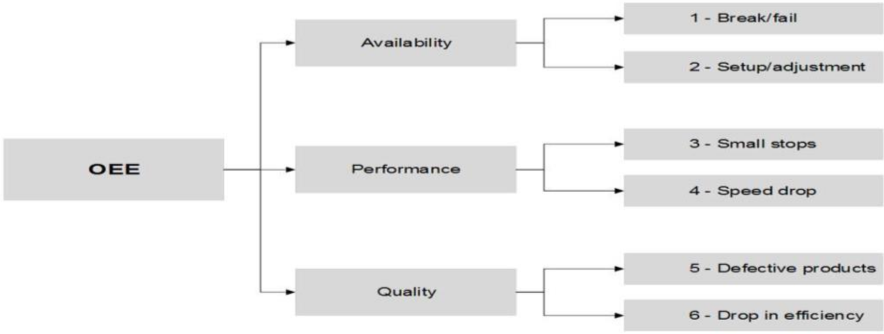
2.2.1 Overall Equipment Effectiveness

Overall Equipment Efficiency (OEE) is an ordering of elaborated criteria, which were first incorporated by Nakajima, in 1960, to leverage production efficiency and also for a method-based analysis (SARI; DARESTANI, 2019). The OEE is seen as a determining indicator to identify productivity in the manufacturing process, which is a way of measuring the availability of resources at the moment when these equipments are planned to work (NASCIF; DORIGO, 2013).

To record key numbers and investigate how production contributes to overall performance, it is critical to measure and understand how to measure problems in the manufacturing process. Problems can be divided into two classes, which are chronic problems and sporadic problems, depending on the regularity with which they occur (JONSSON; LESSHAMMAR, 1999). Chronic problems are usually minor, hidden, and complicated, as they are consequences of several concurrent causes. On the other hand, sporadic problems are more evident, because they occur quickly, irregularly and their impacts are responsible for serious problems and, therefore, there are chronic problems that are due to low use of resources and high costs, as they occur frequently (NORD *et al*. ., 1997).

The OEE indicator comes from the comparison between the time for which the equipment adds value to the product, and the total sum of waste (BUSSO; MIYAKE, 2013). According to Piran *et al.* (2015), the OEE calculation is formed by three parameters: availability, performance and quality, as can be seen in Figure 1 below.

Figure 1 - OEE and the six types of waste



Source: Serra *et al*. (2010).

Figure 1 shows the link between the time available for production and the 06 (six) losses, so that each index is related to its main molds, that is, the availability index is demonstrated by the waste due to breaks, setup and adjustments. The performance indicator correlates with waste due to idleness or equipment slowing down. The quality indicator is determined by losses linked to non-conforming parts (PIRAN *et al*., 2015).

In relation to process monitoring, it consists of collecting, monitoring and analyzing the information provided by the production sector (WICHER *et al.,* 2012).

The collection of data on losses, in turn, is a step of continuous improvement and performance measurement (JONSSON; LESSHAMMAR, 1999). Improvements in manufacturing processes and productivity gains only arise with monitoring, being able to identify waste and understand the gains of actions taken against losses (JEONG; PHILLIPS, 2001).

According to Hansen (2006), erroneous notes about the yield of resources can omit the lack of performance. Therefore, critical and daily monitoring of the information collected in a protected and guaranteed database is required. For monitoring the OEE indicator, the essential notes are downtime, quantity produced, scrap and rework (DORNELES; SELLITO, 2015). According to Oliveira and Librantz (2012), for the release of data in the OEE, the stops are divided into scheduled and unscheduled. As per the chart below:

Table 1 - Types of Stop

Category	Type	subtype
Scheduled Stops	No load Preventive Maintenance try-out	
unscheduled stops	Own stops	Set-upFaultsMicro StopsLow Speed

	Organizational Shutdowns	Meals, Meetings, Training Lack of materials, lack of energy and lack of operator
	No Quality	

Source: Adapted (Oliveira and Librantz, 2012).

Thus, through mathematical equations 1, 2 and 3 (NASCIF; DORIGO, 2013) it is possible to obtain the OEE result:

$$Availability = \frac{Available\ time\ -\ Machine\ stops}{Available\ time}\ X\ 100 \qquad (1)$$

$$Performance = \frac{Theoretical\ cycle\ time\ x\ Quantity\ produced}{Operating\ time}\ X\ 100 \qquad (2)$$

$$Quality\ = \frac{Quantity\ produced\ -\ Defective\ quantity}{Quantity\ produced}\ X\ 100 \qquad (3)$$

The OEE index is calculated by equation 4, which is the multiplication of the result of the three indices: availability, performance and quality (NAKAJIMA, 1988), as follows:

OEE= Availability Index x Performance Index x Quality Index (4)

According to Nakajima (1988), under ideal circumstances, organizations should have availability indices of 0.90, performance of 0.95 and quality of 0.99, such that these numbers would result in an OEE of 84% for class organizations. world. The JIPM (Japan Institute of Plant Maintence) formulated the “World Class OEE” concept to identify the most productive plants in the world. Organizations with an index greater than or equal to 85% achieve this classification.

2.3. Manufacturing Execution System

Industry 4.0 is based on the combination of information and communication technologies, offering organizations opportunities to reach new levels of productivity, flexibility, quality and management, generating new strategies and forms of business. Due to these factors, Industry 4.0 is called the fourth industrial revolution (SACOMANO *et al.,* 2018). In industries 4.0, people and machines will use technologies that make it possible to work collaboratively, where intelligent machines will be competent to help and will use speech recognition, computer vision and machine learning (BESUTTI; CECCONELLO; CAMPOS, 2019).

Industry 4.0 is made up of 09 (nine) fundamentals referred to as: simulation, intelligent robots, vertical and horizontal integration of systems, internet of things, cyber security, big data, cloud computing, manufacturing of additives and augmented reality (RÜßMANN *et al.,* 2015).

The problems faced by organizations during the implementation of methods to increase productivity can now be solved through Industry 4.0 technologies, one of them is MES, which fits into a vertical integration of information, supporting the management of manufacturing processes and helping to reduce waste (BESUTTI; CECCONELLO; CAMPOS, 2019).

MES manufacturing execution systems are systems that perform the integration between the planning and production of an organization, providing the shop floor procedures and connecting with other systems within an organization (BESUTTI; CECCONELLO; CAMPOS, 2019). The MES system according to Kall (1999) and Choi and Kim (2002), are like an operational sphere that integrates ERP (Enterprise Resource Planning) systems and monitors the manufacturing sectors in a feasible way, the MES system, therefore, fulfills the gap between the ERP system and the automation of processes.

The MES comes from the demand for a system that supports the decision-making of administrators, for better production design and also helps the processing of improvements, reduction of production costs and reduction of manual entries of information (NAEDELE *et al.,* 2015). According to Hwang (2006), MES is a manufacturing information system that collects information, analyzes data on finished and semi-finished products and analyzes equipment performance, time and cost in real time. Thus, the MES system was created to assist in the control of work in progress information (Work in Progress), analyzing real-time data of planned performance and what is actually happening in production (WITSCH; VOGEL-HEUSER, 2012).

There is a great diversity of MES systems, some of them more generalist, however, currently, the vast majority has been specializing. The MESA (Manufacturing Enterprise Solutions Association) has classified eleven (11) processes that a MES system supports: programming, process management, document control, data collection, work management, quality management, production order entry, maintenance, traceability, performance analysis, resource allocation and status (NAEDELE *et al.,* 2015).

The technology of MES systems can confirm the availability of data, however, it cannot be sure that the available data are accurate. This accuracy, in turn, depends on the data collection method implemented and the analyzes of the information that are carried out (SAENZ DE UGARTE; ARTIBA; PELLERIN, 2009). The MES puts into practice the planning of the corporate system, such as the MRP (Manufacturing Resource Planning) system, on the factory floor, contemporary organizations face the challenge of increasing competitiveness, with factories increasingly meeting the needs of customers and maintain the trust of the information collected (RÜßMANN *et al.,* 2015).

3 METHODOLOGY

At this stage, the methodological path sought to achieve the objective of the present work is based on the case study applied in a manufacturing sector of a foundry company. The case study is a research method used in various fields of science, which consists of a very detailed research on 01 (one) or more objects of study. The idea of the case study is to reflect on a set of data to describe in depth the object of study, be it a family, a company or a community (MASCARENHAS, 2012).

This work can be classified as an applied research with a qualitative approach. For Cooper and Schindler (2016), qualitative research obtains data from different sources, such as people, whether individuals or groups; of organizations and institutions; of published texts or through virtual means; by scenarios and environments; objects, artifacts and media products, as well as events and happenings.

As for the objectives, the research is classified as exploratory and descriptive, as it has the idea of facilitating the readers' understanding of the topics covered. For Mascarenhas (2012) exploratory research is recommended to those who want to create more familiarity with a problem, and then create hypotheses about it. Often, in this type of study, a bibliographic survey is carried out on the subject.

In view of the above-mentioned authors' statements, it is understood that the methodologies chosen and mentioned above are the most appropriate for the type of study proposed.

4 DEVELOPMENT OF THE CASE STUDY

4.1 Characterization of the Company

The organization where the present case study was carried out is located in the mountain region of Rio Grande do Sul, which produces and sells cast components for several models of turbochargers, in the aftermarket of the light and heavy transport sector. It serves the national market (70%) and the foreign market (30%). The plant of the referred company has a production capacity of 12 (twelve) tons of nodular and gray cast iron parts per day and is composed of an interconnected molding line, following the processes of making, molding, melting and finishing, and all these sectors are supported by the Engineering, R&D, MPC and HR departments.

Manufacturers of trucks and agricultural machinery have been developing engines with turbines for a long time, however, currently in this market, there is notoriety in relation to turbocharged engines, since to meet the new environmental legislation, in several countries, the assemblers are working to develop vehicles that consume less fuel and emit less CO_2. The tendency for the vast majority of vehicles to be turbocharged straight from the factory is a positive indicator and the foundry industry, in turn, must be prepared to meet this growing demand.

The company in question has the scope to produce quality parts, meeting international technical standards for cast iron, focusing on customer satisfaction and continuous improvement of production processes, aiming at increasing productivity and opening new markets in the face of opportunities for Business.

4.2 Improvement Proposals

In the foundry industry, traditionally, waste occurs in different processes and for changing reasons, making organizations find it difficult to detect the root cause of waste, so that, many times, the resolution of problems depends on practical knowledge developed by the company's experience in the sector of foundry.

Over the last few years, the cast iron sector of the company object of the present study has had a significant increase in the demand for cast parts and the variety of products, these with varied geometric areas, dimensions and thicknesses, making the manufacturing process more complex and dynamic. Operations notes are made directly in the company's management system to monitor operations, but the control of machines is performed manually by operators, since the company does not have data collection to analyze production information, maintenance, setups and stops in real time. The lack of information about the events that occurred in the production process has caused a series of difficulties related to the planning and control of production,

Faced with this scenario, managers, coordinators and production leaders met to discuss the matter, and after several meetings and different understandings about the productive capacity of the resources, the company came to the conclusion that the way of management used in the processes of manufacturing needed some improvements and investments regarding the collection, control, analysis and management of data related to its productive resources.

The company, with this new guideline, in order to improve the control of its resources, that is, to have the reliability of indicators on factory efficiency and with that to reach goals elaborated according to the real capacity, chose to implement a MES system in the equipment sectors considered critical or bottlenecks. For the development of techniques and tools to improve the management of the sectors, in turn, the company used concepts from the SFM methodology as a line of thinking for production management in sectors considered critical. Based on these precepts defined by the company, namely, organizing the operational station and generating consistent indicators and controls, the aim was to develop maturity in relation to a systemic vision focused on productive efficiency and achievement of results.

4.3 Stages of Implementation of Improvements

The implementation of the improvements took place in stages, being used as a working method, techniques and tools of the SFM approach, until the acquisition and implementation of a MES system in equipment of sectors considered critical by the company. The elaboration, negotiations and execution of the improvements defined by the organization took place in a period of approximately 18 (eighteen) months.

The first stage resulted from the creation of a working group that was responsible for planning, implementing and monitoring the improvement stages established by the organization. In the present case study, the team was created by the following professionals: industrial manager, production supervisor, quality analyst, MPC coordinator and maintenance supervisor.

In order to identify the company's critical equipment, the work group responsible for implementing the improvements, after meetings and analyses, chose at first to select the machining sector to have the workstation monitored, which was classified as a critical resource with restricted capacity (CCRs). This sector is where the production process begins, manufacturing sand molds for the parts to be cast, feeding the company's molding line. The coremaking sector is, therefore, composed of four sand blowing machines called S1, S2, S3 and S4 and an automatic sand mixing system and two ovens, currently operating in two work shifts, with each shift working during 8:40 am per day, with a 1-hour lunch break, from Monday to Friday. At the time of production, the sector receives production orders from the MPC with the product codes, quantities and priorities to be produced. Each production order refers to a product/component code, so that these components have different sizes and geometries, different weights and cycle times. It should be noted that the scrap rate is around 8%. After evaluations by the technicians responsible for the sector, the necessary tools are transported for the manufacture of sand cores, which are distributed to the blowing stations, and each blowing machine has 03 (three) work stations, where the sand cores are injected, assembled, inspected and stored by operators. Each production order refers to a product/component code, so that these components have different sizes and geometries, different weights and cycle times. It should be noted that the scrap rate is around 8%. After evaluations by the technicians responsible for the sector, the necessary tools are transported for the manufacture of sand cores, which are distributed to the blowing stations, and each blowing machine has 03 (three) work stations, where the sand cores are injected, assembled, inspected and stored by operators. Each production order refers to a product/component code, so that these components have different sizes and geometries, different weights and cycle times. It should be noted that the scrap rate is around 8%. After evaluations by the technicians responsible for the sector, the necessary tools are transported for the manufacture of sand cores, which are distributed to the blowing stations, and each blowing machine has 03 (three) work stations, where the sand cores are injected, assembled, inspected and stored by operators.

The feasibility study for the acquisition of a MES system in the machining industry took place in stages, starting with the search for suppliers of MES systems, information on information systems, alignment of the company's objectives with potential suppliers, scope of proposals with budgets and services and supplier definition.

The first condition when looking for suppliers of MES systems was to find companies with knowledge and proven market experience and that also had good technical support during the implementation process and after sales. To this end, research was carried out in the region through websites, articles, magazines and some technical visits to companies that already used an MES system. After collecting information and obtaining more knowledge on the subject, the company selected some suppliers, which could meet the needs of the sector.

Subsequently, knowing the potential suppliers, 03 (three) proposals were selected more compatible with the needs and requirements of the company. The proposals from the suppliers named A, B and C, which were chosen, had the following criteria for evaluation: fixed initial investment, monthly fees, installation costs, integration costs with the ERP (Enterprise Resource Planning) system, specifications and functionalities of the modules, technical information about software and hardware, and technical information about deployments.

In the stage of analysis and definition of which company would be responsible for providing an MES system, the organization gathered the working group, adding two members to contribute to the decision making, namely, the Coordinator and the IT Analyst of the company, to analysis of the characteristics of the proposals and offering all technical and theoretical knowledge on the implementation of information systems, creating a basis for decision making. In this way, the most important criteria for choosing the MES system supplier, according to the responsible working group, were the technical quality of the system, the supplier's experience with foundry companies, technical support, installation incomplexity and integration with the company's ERP software and system acquisition costs. After 02 (two) meetings with those involved, the last one, together with the company's management, the organization decided, taking into account all the aforementioned requirements, that company B presented greater convergence with the needs and criteria established by the organization of the case study. The company, however, did not authorize the disclosure of the values referring to the proposals of suppliers A, B and C.

With the definition of the supplier of the MES system and after the formal treatment of acceptance of the proposal of supplier B, the IT and industrial automation sectors of the company, together with those responsible for the implementation of the supplier of the MES system, prepared a schedule of activities to the installation and implementation of the information system. The first phase of implementation took place with the physical installation of data collection hardware, bar code readers, interface modules, sensors and cabling.

Thus, after validating the hardware installation, the company released the access data to the Ethernet network central server for the installation of production management software, and licenses for data collection, data acquisition modules, production modules were also installed. and ERP integrator modules. In the stage of integration between the MES systems and the ERP system, several negotiations were carried out to align information and data collection, it is worth mentioning the fact that in this stage there were setbacks related to the validation of the integrations, with delays in relation to the schedule. Thus, after the resolution and validation of the system interactions, signal validations and screen flows, the MES system was tested and approved, meeting all the specifications established in the contract.

For the company to implement this new work methodology and understand the recent concepts and technologies in the implementation phase, a series of training sessions, divided by phases, were prepared for those involved in the project. The first stage dealt with management training, given by the team of the contracted MES system company, aimed at supervisors, coordinators and management, presenting the concepts used to calculate efficiency and use the MES system WEB environment. The other training carried out was aimed at employees in the machining sector, an opportunity in which the use and operation of data collectors with the blowing machines was presented, those responsible for the sector also participated in this training.

4.4 Data Collection Method and OEE Calculation

The MES system implemented by the company object of the present study uses the OEE indicator as a methodology to measure the efficiency of productive resources. To obtain this indicator, it is necessary to have the results of the availability, performance and quality of production resources. The information necessary to calculate the 03 (three) performance indexes mentioned above originate from data integrations between the MES system and the ERP system, so that both share information such as product codes, production orders generated in the management system , cycle times and quantity of injected parts per cycle. The current MES system also uses information collected from the blowing machines through data collection hardware, where information such as shift time, analysis time,

Machine downtime information is essential for the calculation of performance indexes and necessary for the organization to have knowledge of what are the main causes of inefficiencies in productive resources. In view of this, the company's working group was gathered, an opportunity in which they identified and elaborated the typologies of machine stops most suitable for the production process of the manufacturing sector, and the machine stops were classified as scheduled and unscheduled stops, and are described in Table 2 below:

Table 2 - Types of machine downtime

SCHEDULED STOPS	UNSCHEDULED STOPS
Meeting/training	No operator
Tool adjustment / cleaning	Bathroom going

Waiting for maintenance	Answer corrective maintenance (internal)
Answer preventive maintenance (internal)	Answer corrective maintenance (external)
Answer preventive maintenance (external)	Dependence on the previous process
Cleaning the workplace	Lack of raw material
Machine cleaning	Lack of electric power/water
Assistance in manual activity	End of production / idle
Lunch	Lack of production order
Change turn	
Setup	

Source: Author (2022).

To calculate the OEE index, the current MES system uses the information collected and pointed out in the system described above, where through parameterized calculations the information system computes and determines the factors of availability, performance and quality indices.

The availability index is obtained by dividing the time in production of the resource by the time programmed to produce, then the software multiplies by 100 to obtain the indicator in percentage. The performance index is achieved with the sum of the standard time of good parts plus standard time of bad parts divided by the time in production, then the software multiplies it by 100 to obtain the indicator in percentage. The quality indicator is calculated by the standard time of good parts divided by the sum of the standard time of good parts, plus the standard time of bad parts, after which the software multiplies by 100 to obtain the result in percentage. To measure the final OEE index, the MES system multiplies the result of the availability, performance and quality indicators.

5 RESULTS

The mold making sector previously operated without any type of performance indicator and/or machine downtime control, so the sector's productivity measurement was based on the number of molds/day of the next process. The molding sector has a production target of 350 molds/day, however it had an average of 250 molds/day.

As there was no certainty about the information on the efficiency of the productive resources of the mold making sector, it was not possible to measure the real production capacity, nor was it possible to clearly evidence when and where the performance losses of the injection machines occurred. However, currently through the MES system and obtaining real data from the productive events collected from the equipment, visibility and reliability in the result of the performance indicators was provided to the company. Table 1 shows the results obtained from the OEE indicator and its three constituent factors, the data refer to blowing machines S1, S2, S3 and S4, where they were analyzed in general, by work shift and individually. The results obtained refer to the period of six months after the implementation of the MES system.

Table 1 - OEE indicator results

Time course: 05/01/2020 to 10/31/2020

Machine: S1	Availability Index	Performance Index	Quality Index	OEE indicator
shift 1	60.44%	90.02%	96.07%	52.27%
shift 2	69.20%	86.60%	88.33%	52.93%
Total per resource	**64.82%**	**88.31%**	**92.20%**	**52.60%**
Machine: S2	**Availability Index**	**Performance Index**	**Quality Index**	**OEE indicator**
shift 1	68.91%	87.80%	94.52%	57.19%
shift 2	62.22%	84.33%	91.25%	47.88%
Total per resource	**65.57%**	**86.07%**	**92.89%**	**52.53%**
Machine: S3	**Availability Index**	**Performance Index**	**Quality Index**	**OEE indicator**
shift 1	71.60%	88.54%	92.22%	58.46%
shift 2	55.60%	86.37%	89.22%	42.84%
Total per resource	**63.60%**	**87.46%**	**90.72%**	**50.65%**
Machine: S4	**Availability Index**	**Performance Index**	**Quality Index**	**OEE indicator**
shift 1	67.25%	88.94%	90.73%	54.27%
shift 2	55.66%	83.24%	90.71%	42.03%
Total per resource	**61.46%**	**86.09%**	**90.72%**	**48.15%**
TOTALIZATION OF RESOURCES S1-S2-S3-S4	**63.86%**	**86.98%**	**91.63%**	**50.98%**

Source: Author (2022).

As evidenced in Table 1, the general OEE index of the machine shop sector was at 50.98%, well below what the organization imagined. It can be seen that the availability factor is the most impacting on all machines in the process, totaling the mark of 63.86%, which can be concluded, is that the production resources of the sector had excess machine downtime. The performance index also caught the attention of managers with the mark of 86.98%, who realized that the machines were not operating at the programmed speed, causing inefficiencies in the production process. As for the quality index, the company considered that the results obtained are within the range of acceptance of the sand core production process. Faced with this scenario, the company decided to identify the main causes of machine downtime,

According to the data obtained through the MES system, Table 2 identifies the 05 (five) main reasons for machine downtime and their representativeness in view of the results obtained and shown in Table 1:

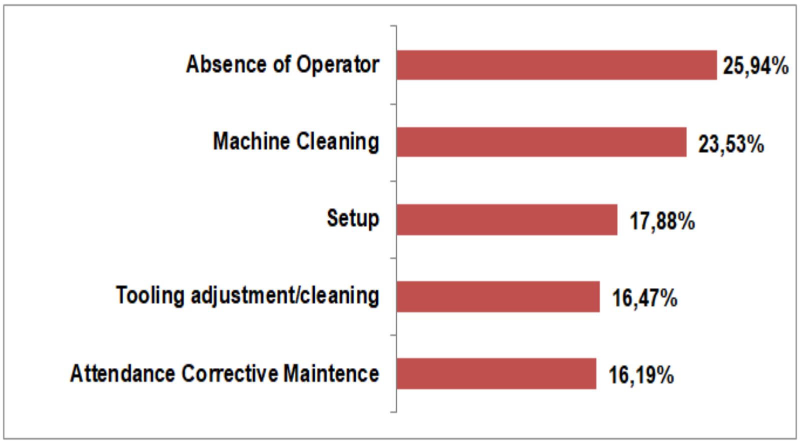
Table 2 - Representativeness of Machine Stops

Representativeness Machine Stops			
Period: 05/01/2020 to 10/31/2020 Shift work 1 and shift work 2			
Machine: S1		**Machine: S2**	
Stop Type	**%**	**Stop Type**	**%**
Machine cleaning	23.04%	absence of operator	28.33%
Tooling adjustment/cleaning	14.17%	Machine cleaning	16.05%
Attendance Corrective Maintenance (Internal)	13.78%	setup	12.03%
setup	12.51%	Tooling adjustment/cleaning	8.79%
Operator Absence	11.27%	Attendance Corrective Maintenance (Internal)	7.23%
Others	25.23%	Others	27.57%
Machine: S3		**Machine: S4**	
Stop Type	**%**	**Stop Type**	**%**
absence of operator	37.07%	Machine cleaning	20.10%
Machine cleaning	10.35%	setup	18.38%
Tooling adjustment/cleaning	10.25%	Tooling adjustment/cleaning	15.46%
setup	9.92%	Awaiting Maintenance	10.33%
Attendance Corrective Maintenance (Internal)	7.61%	Attendance Corrective Maintenance (Internal)	8.90%
Others	24.80%	Others	26.83%

Source: Author (2022).

In Graph 1 below, it is possible to visualize the 05 (five) most representative machine stops in the sand mold sector.

Graph 1 - Main Reasons for Machine Downtime



Source: Author (2022).

From the collection of data on the main machine downtimes shown in Graph 1, those responsible for the sector prepared an action plan in order to act on the main causes of machine downtimes, aiming to increase the efficiency index of the sector's resources of butchery. It is important to emphasize that some of the problems identified are complex and require more in-depth analysis and studies and take longer to resolve. According to the organization, the actions were designed as an emergency to obtain short-term results. The mentioned action plan is specified in Table 3, below:

Table 3 - Action Plan

ACTION PLAN					
what	***why***	***who***	***when***	***Where***	***How***
High employee absenteeism rate	Machines stopped due to the absence of operators, affecting the productivity of the sector	Management and HR	60 days	Sand mold Sector	1. Lectures and campaigns on absenteeism in the sector;2. Hiring a production facilitator employee, working on the sector's deficiencies;
Machine cleaning	Time above the planned for cleaning machines in the change of work shift and end of work shift	Sand mold sector Leader	60 days	Sand injection machines	1. Standardization of machine cleaning time;2. Operator training to reduce cleaning time;
High setup time	Setup time longer than planned	Sand mold sector Leader	60 days	Sand injection machines	1. Standardization of setup time;2. Operator training to reduce setup time;3. Study and analysis of setup activities in the sector;

Above-average tooling adjustments and cleanings	Machine downtime for cleaning and tooling adjustment above planned	Management, Leader of the sand mold sector and Leader of the Tooling Sector	60 days	Tools for making sand cores	1. Intensify maintenance and cleaning of all tooling 2. Check-list of critical points of the tools before releasing for production
Excessive corrective maintenance of equipment	Machine downtime for corrective maintenance	Management , Maintenance Coordinator	60 days	Sand injection machines	1. Schedule preventive maintenance of equipment;2. Perform preventive maintenance outside work shifts; 3. Train maintenance technicians to prioritize the repair of machine shop equipment

Source: Author (2022).

With the implementation of the emergency actions proposed and described in Table 3, together with the training prepared on the SFM methodology, presentations and clarifications on the concepts of performance indicators with everyone involved in the project, the organization was able to evidence increases in productive efficiency indicators. The period of collection and analysis of the sector's performance indicators was carried out in a period of 06 (six) months after the implementation of the activities of the action plan and can be evidenced in Table 3, below:

Table 3 - OEE indicator results

Time course: 05/01/2020 to 10/31/2020

Machine: S1	Availability Index	Performance Index	Quality Index	OEE indicator
shift 1	73.47%	91.23%	95.01%	63.68%
shift 2	69.27%	88.29%	93.33%	57.08%
Total per resource	**71.37%**	**89.76%**	**94.17%**	**60.38%**
Machine: S2	**Availability Index**	**Performance Index**	**Quality Index**	**OEE indicator**
shift 1	73.80%	87.25%	93.21%	60.02%
shift 2	70.21%	89.76%	92.09%	58.04%
Total per resource	**72.01%**	**88.51%**	**92.65%**	**59.03%**
Machine: S3	**Availability Index**	**Performance Index**	**Quality Index**	**OEE indicator**
shift 1	75.10%	88.39%	88.34%	58.64%
shift 2	69.26%	91.11%	90.23%	56.94%
Total per resource	**72.18%**	**89.75%**	**89.29%**	**57.79%**
Machine: S4	**Availability Index**	**Performance Index**	**Quality Index**	**OEE indicator**
shift 1	78.12%	87.19%	95.25%	64.88%
shift 2	73.20%	89.90%	90.44%	59.52%

Total per resource	**75.66%**	**88.55%**	**92.85%**	**62.20%**
TOTALIZATION OF RESOURCES S1-S2-S3-S4	**72.80%**	**89.14%**	**92.24%**	**59.85%**

Source: Author (2022).

As shown, the machine shop sector obtained increases in the availability indicator in all productive resources, raising the result from 63.86% to 72.80%, an increase of 8.94%, while the result of the performance factor reached an increase of 2.16% in relation to the previous period. The quality factor, which already had a considerable result, remained within the company's acceptance range with the mark of 92.85%. According to the results presented, the 03 (three) factors that make up the equipment efficiency index had significant increases, raising the final index of the OEE indicator from 50.98% to 59.85%, that is, an increase of 8.87%, which represents an increase in productivity from 250 molds/day to 293 molds/day.

It was observed, therefore, that the results obtained in this case study, are in accordance with the organization's desire and that in addition to the main objective, that is, the increase in productivity, the MES system implemented together with techniques of the SFM methodology, made possible also other positive factors, such as the fact that the company now has industry 4.0 tools and concepts, which offer greater visibility and reliability of the information collected, that is, the organization can develop a deeper systemic vision in relation to the thinking of transforming. production data into actionable information to improve manufacturing processes, minimize waste and increase profits.

6 CONCLUSIONS

The objective of this case study was to describe and show how the implementation of a MES system can improve the management of jobs and increase productivity. In order to improve the productive efficiency of the coremaking sector of the company in the aforementioned study, techniques and concepts of the SFM methodology were used, so that, from these methods, the organization identified the need to obtain an information system that would provide reliability and visibility of the data and information from its production processes, in order to monitor, measure and control production.

The implantation of a MES system and the use of concepts of the SFM methodology, provided significant results for the referred organization. In this sense, the main objective was achieved, as it obtained an increase in daily productivity compared to the previous period of having the work station monitored. Thus, with the use of data collection from the equipment, integrated information in real time and monitoring of productive efficiency indicators, it was possible to measure and justify this increase by raising the OEE indicator.

Connectivity and data integration between the MES system and the productive resources of the coremaking sector were fundamental to achieve the expected results. By collecting data from production events and information organized by the MES system, the organization was able to identify and quantify the main causes of machine downtime, providing the company with greater agility and confidence in taking actions to correct these inefficiencies. An MES system is, above all, a decision-making support system for managers (NAEDELE, *et al.,* 2015). According to Jeong and Phillips (2001), improvements in manufacturing processes and productivity gains only arise with monitoring, thus being able to identify waste and understand the gains of actions taken against losses.

The results of the actions taken by the organization were monitored and evidenced according to the results obtained from the performance factors that make up the OEE index, in which it was possible to evidence increases in efficiency in all productive resources of the sector, raising the final index of the OEE indicator of the sand mold sector from 50.98% to 59.85%, that is, an increase of 8.87%. The measurement of the OEE index is effective to analyze both the efficiency of a single machine and an integrated manufacturing system (NAKAJIMA, 1988). The OEE, therefore, is seen as a determining indicator to identify productivity in the manufacturing process, which is a way of measuring the availability of resources at the moment when these equipments are planned to work (NASCIF; DORIGO, 2013).

As a managerial implication, it is worth noting that the SFM approach and the implementation of the MES system demanded planning, systemic vision and understanding from professionals from various areas, from management to the shop floor. As highlighted by Antunes *et al.* (2013), for the organization to be able to manage the workplace more efficiently, it is necessary for the company to understand the production systems more comprehensively. In this way, the role of those involved became essential for the success of the project, where everyone played the role of executor of change, promoting training, concepts and techniques in the face of the new methodologies and technologies implemented.

It is suggested as a future study, the viability of the organization to use the strategy of sequencing production orders (scheduling) in the manufacturing sector, in order to obtain better means of taking advantage of productive resources. It is also advisable to expand the use of the MES system to other sectors of the organization, in order to connect and obtain data and information from productive events in an integral way, thus allowing the organization to continue with the purpose of continuous improvement in processes productive to reach the proposed objectives.

7 REFERENCES

ANTUNES, J. A. V.; KLIPPEL, M. Uma Abordagem Metodológica Para O Gerenciamento Das Restrições Dos Sistemas Produtivos: A Gestão Sistêmica, Unificada/Integrada E Voltada Aos Resultados Do Posto De Trabalho. *In:* XXI ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO (ENEGEP), Anais..., Salvador – BA, 2001. DOI: https://doi.org/10.14488/enegep2018_tn_sto_265_520_35603

ANTUNES, J. A. V.; KLIPPEL, A. F.; SEIDEL, A.; KLIPPEL, M. **Uma revolução na produtividade**: A gestão lucrativa dos postos de trabalho. Porto Alegre: Bookman, 2013.

ANTUNES, Junico; ALVAREZ, Roberto; KLIPPEL, Marcelo; BORTOLOTTO, Pedro; DE PELLEGRIN, Ivan. **Sistemas de produção – sistemas e práticas para projeto e gestão da produção enxuta.** Porto Alegre: Bookman, ed. 1. 2008. DOI: https://doi.org/10.47749/t/unicamp.1999.182758

BESUTTI, Rangel; CAMPOS, Vanessa De; CECCONELLO, Ivandro. Development of an open source-based manufacturing execution system (MES): industry 4.0 enabling technology for small and medium- sized enterprises. **Scientia cum industria**, V. 7, N. 2, p. 1 – 11, 2019. DOI: https://doi.org/10.18226/23185279.v7iss2p1

BUSSO, C.; MIYAKE, D. Análise da Aplicação de Indicadores Alternativos ao Overall Equipment Effectiveness (OEE) na Gestão do Desempenho Global de uma Fábrica.

Produção, v. 23, n. 2, p. 205-225, 2013. DOI: https://doi.org/10.1590/s0103-65132012005000068

CHOI, B. K.; KIM, B. H. MES (Manufacturing Execution System) architecture for FMS compatible to ERP (enterprise planning system). **International Journal of Computer Integrated Manufacturing**, v. 15, n. 3, p. 274–284, 2002. DOI: https://doi.org/10.1080/09511920110059106

COOPER, D. R.; SCHINDLER, P. S. **Métodos de pesquisa em administração**. Tradução: Scientific Linguagem Ltda. Porto Alegre: AMGH, 2016.

CRUTE, V.; WARD, Y.; BROWN, S.; GRAVES, A. Implementing Lean in aerospace challenging the assumptions and understanding the challenges. **Technovation**, Reino Unido, v. 23, p. 917-928, 2003. DOI: https://doi.org/10.1016/s0166-4972(03)00081-6

DORNELES, J. V.; SELLITO, M. A. Eficácia global de equipamentos (OEE) para diagnóstico e melhoria de produtividade na indústria de fundição. **Revista GEINTEC**. São Cristóvão/SE, v. 5, n. 3, 2015. DOI: https://doi.org/10.7198/s2237-0722201500030013

GARZA-REYES, J. A. *et al.* Overall equipment effectiveness (OEE) and process capabi¬lity (PC) measures – a relationship analysis. **International Journal of Quality and Reliability Management**, v. 27, n. 1, p. 48-62, 2010.

GOLDRATT, E. M.; COX, J. **A meta:** um processo de melhoria contínua. 2. ed., rev. e ampl. São Paulo: Nobel, 2003.

HANSEN, R. **Eficiência Global dos Equipamentos**: uma poderosa ferramenta de produção/manutenção para o aumento dos lucros. Porto Alegre: Bookman, 1 ed. 2006;

HWANG, Y. D. The practices of integrating manufacturing execution system and six sigma methodology **International Journal if Advanced Manufacturing Technology,** n. 30, p. 761-768, 2006. DOI: https://doi.org/10.1007/s00170-005-0090-1

JEONG, K.; PHILLIPS, D. Operational efficiency and effectiveness measurement. **International Journal of Operations & Production Management**, v. 21, n.11, 2001.

JONSSON, Patrik; LESSHAMMAR Magnus. Evaluation and improvement of manufacturing performance measurement systems-the role of OEE. **International Journal of Operations & Production Management, MCB University Press**, vol. 19, n. 1, p. 55-78, 1999.

KALL, J. Manufacturing Execution Systems: Leveraging Data for Competitive **Advantage, Quality Digest,** v. 19, n. 8, p. 31-34, ago., 1999.

KLIPPEL, A. F.; OLIVEIRA, J. C. A. Aumento da eficiência operacional através da abordagem de Gestão dos Postos de Trabalho (GPT): um estudo de caso na indústria de medicamentos, *In:* ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO (ENEGEP), XXIV., Anais..., Florianópolis – SC, 2004. DOI: https://doi.org/10.14488/enegep2019_tn_stp_000_1639_39016

KLIPPEL, Altair Flamarion; ANTUNES, Junico; KLIPPEL, Marcelo; JORGE, Rafael Rovaris. **Estratégia de gestão dos postos de trabalho – um estudo de caso na indústria de alimentos**. ENEGEP, out, 2003. DOI: https://doi.org/10.17771/pucrio.acad.9535

KUMAR, Akshi; NAYYAR, Anand. Si3-Industry: A Sustainable, Intelligent, Innovative, Internet-of-Things Industry. **A Roadmap to Industry 4.0**: Smart Production, Sharp Business and Sustainable Development, p. 1-21, 2020. DOI: https://doi.org/10.1007/978-3-030-14544-6_1

MABIN, V. J.; BALDERSTONE, S. J. The Performance of the theory of constraints methodology: analysis and discussion of successful TOC applications. **International Journal of Operations and Production Management**, v. 23, n. 6, p. 568-595, 2003. DOI: https://doi.org/10.1108/01443570310476636

MASCARENHAS, Sidnei Augusto. **Metodologia científica**. São Paulo: Pearson Education do Brasil, 2012.

MESA Organização. MES Explained: A High Level Vision. **Mesa Internacional,** White Paper 6, set. 1997.

MUCHIRI, Peter; PINTELON, Liliane. Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. **International Journal of Production Research**, v. 46, n. 13, p. 3517-3535, 2008.

NAEDELE, M. *et al*. Manufacturing execution systems: Avision for managing software development. **The Journal of Systems and Software**, v. 101, 2015. DOI: https://doi.org/10.1016/j.jss.2014.11.015

NAKAJIMA, S. Introduction to total productive maintenance. **Productivity Press,** Cambridge, MA, 1988.

NAOR, M.; BERNARDES, E. S.; COMAN, A. Theory of constraints: is it a theory and a good one?. **International Journal of Production Research**. v. 51, n. 2, p. 542–554, 2013. DOI: https://doi.org/10.1080/00207543.2011.654137

NASCIF, Júlio; DORIGO, Luiz Carlos. **Manutenção orientada para resultados.** Rio de Janeiro: Quality mark, 2 ed., 2013.

NORD, Christer *et al.* **TPM**: Total Productive Maintenance med. Erfarenhet från Volvo (in Swedish), Idrottens Grafiska i Göteborg AB, Mölnlycke, 1997.

OLIVEIRA, L.; LIBRANTZ, A. Aumento da Eficiência dos Equipamentos com a Utilização de Ferramentas de Resposta Rápida. *In*: ANAIS DO ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO (ENEGEP) BENTO GONÇALVES, RS, v. 32, 2012. DOI: https://doi.org/10.14488/enegep2020_tn_sto_348_1790_39793

PIRAN, Fabio Antonio Sartori. et al. A Utilização do Índice de Rendimento Operacional Global (IROG) na Gestão dos Postos de Trabalho: Estudo aplicado em uma empresa do segmento metal mecânico. **Revista Espacios**, v. 36, n. 24. p. 1-14, ago./set. 2015. DOI: https://doi.org/10.11606/d.18.2013.tde-12092013-103324

PRATES, C. C.; BANDEIRA, D. L. Aumento de eficiência por meio do mapeamento do fluxo de produção e aplicação do índice de rendimento operacional global no processo produtivo de uma empresa de componentes eletrônicos. **Gestão e Produção**, v.18, n. 4, p. 705-718, 2011. DOI: https://doi.org/10.1590/s0104-530x2011000400003

RÜßMANN, Michael *et al*., Industry 4.0: The future of productivity and growth in manufacturing industries. **Boston Consulting Group**, vol. 9, 2015.

SACOMANO, José Benedito.; GONÇALVES, Rodrigo Franco.; SILVA, Márcia Terra da; BONILLA, Sílvia Helena; SÁTYRO, Walter Cardoso. **Indústria 4.0**: conceitos e fundamentos. São Paulo: Blucher. 1. ed., nov., 2018.

SAENZ DE UGARTE, B.; ARTIBA, A.; PELLERIN, R. Manufacturing execution system – a literature review. **Production Planning & Control,** v. 20, n. 6, p. 525-539, 2009. DOI: https://doi.org/10.1080/09537280902938613

SARI, M. F.; DARESTANI, S. A. Fuzzy overall equipment effectiveness and line performance measurement using artificial neural network. **Journal of Quality in Maintenance Engineering***,* v. 25, n. 2, p. 340-354, 2019. DOI: https://doi.org/10.1108/jqme-12-2017-0085

WICHER, E. *et al.*. Medição do desempenho organizacional: o caso de um sistema integrado baseado no BSC implantado no setor sucroalcooleiro. *In:* Anais XXXII Encontro Nacional de Engenharia de Produção (ENEGEP) Bento Gonçalves, RS, v. 32, 2012. DOI: https://doi.org/10.14488/enegep2017_tn_sto_244_413_33744

WITSCH, M.; VOGEL-HEUSER, B. Towards a formal specification framework for manufacturing execution systems. **Computer Science IEEE Transactions on Industrial Informatics,** v. 8, n. 2, p. 311-320, 2012. DOI: https://doi.org/10.1109/tii.2012.2186585

WU, H. H.; LEE, A. H. I.; TSAI, T. P. A two-level replenishment frequency model for TOC supply chain replenishment systems under capacity constraint. **Computers &**

Industrial Engineering, v. 72, p. 152-159, 2014. DOI: https://doi.org/10.1016/j.cie.2014.03.006

Artigo recebido em: 27/04/2022 e aceito para publicação em: 27/12/2022
DOI: https://doi.org/10.14488/1676-1901.v22i2.4628