Proposal for productivity indicators through the Manufacturing Execution Systems

Carlos Jefferson de Melo Santos[1][0000-0002-0612-1220], Ângelo Márcio Oliveira Sant'Anna[2] [0000-0001-8332-8877] and Joilson Nascimento Paim[3][0000-0003-1214-4485]

[1] Polytechnic School, Federal University of Bahia, UFBA, Aristides Novis street, 2, 40210-630, Salvador, Bahia, BRA cj.ufba@gmail.com

[2] Polytechnic School Federal University of Bahia, UFBA, Aristides Novis street, 2, 40210-630, Salvador, Bahia, BRA angelo.santanna@ufba.br

[3] Polytechnic School Federal Universityof Bahia, UFBA, Aristides Novis street, 2, 40210-630, Salvador, Bahia, BRA jnppaim@gmail.com

Abstract. Manufacturing industries tend to constantly use integrated systems based on Industry 4.0 to manage processes virtually with the constant increase in productivity. One of these systems is Manufacturing Execution Systems (M.E.S), which makes products available in real time and provides data for better decision-making with probabilistic maximization. This study proposes productivity indicators that best reflect production based on the M.E.S. and how these indicators are calculated. Analyses were carried out in the literature of the main productivity indicators and conceived, through the reality of the M.E.S. deductions and calculation formulas construction of indicators through a process analyzed in a sanitizing industry. Indicators were created about the use of equipment, maintenance (availability and reliability), quality efficiency, and partial and global productivity of the process. The indicators demonstrated compatibility with the information generated in the M.E.S, and they can perform the decision-making cycle with less interference from the operator and the company's strategy. New applications will be needed to expand the indicator database over time and conduct predictive statistical evaluations.

Keywords: Productivity, Manufacturing Execution Systems, Performance Indicators

1 Introduction

The concept of productivity in industries has added value to manufacturing systems in terms of process reliability. It directs results that measure the efficiency of the productive process and if its functionality addresses practical concepts with all sectors involved. New ERP systems are capable of stochastically demonstrating the variables that define productive efficiency. However, the data necessary for the release formation of the productivity indicator are often entered manually in spreadsheets or the ERP itself, without practical functionality for making full-time decisions. Knowing the limitations of productive efficiency at the time of consultation is still not the limitations of productive efficiency at the time of consultation are still not tangible in most of the discrete manufacturing companies.

The Manufacturing Execution Systems (M.E.S) exerts an extra functionality in decision-making in production processes. It allows you to define the productive bottlenecks at the time of consultation at any hierarchical level (operational, tactical, or strategic). However, these identifications are often abstract, without clear performance indicators for assertive decision-making. Process performance measurements are carried out and imputed automatically in the M.E.S., enabling the creation of indicators upon request by the employee or senior management. This enables greater credibility in decision-making that requires real and historical grounds, such as making robust purchases of machinery to increase production online X or deactivating a production unit that does not prove to be more economically and productively viable. This article theoretically demonstrates how to create productivity indicators through the M.E.S. and, in practical cases, how these indicators are calculated. For the latter, a database of a sanitizing company was used.

2 Materials and methods

2.1 Literature Review

Manufacturing Execution Systems

The term Manufacturing Execution Systems (M.E.S) is considered new on the market, and little applied in manufacturing industries compared to ERP applications. M.E.S. (Manufacturing Execution Systems) collects and accumulates information on what was done on the shop floor and feeds it back to the planning system [1]. McClellan (2001), in his article related to marketing the use of M.E.S. in large companies, reports that the MES system bridges the gap between the planning system and the control system by using online information to manage production resources: people, equipment, and inventory [2]. With direct electronic connections to the planning system and equipment control systems, the MES is the hub that collects and provides information and guidance within the scope of production activities and supports online the management decisions of the M.E.S. usually include direct connection to functions such as Time and Attendance, Product Data Management, Maintenance Management, and any other similar tool [2]. In this way, the M.E.S. can accurately guarantee the reality of electronic equipment, usually, putting the meaning of the acronym PLC (PLC's), playing the role of interface with the company's strategies (ERP) and the operational industry (S.C.A.D.A.) [3]. This only occurs if there is integration between manufacturing systems. It is more than a planning tool like ERP or MRPII. It is an online extension of the planning system emphasizing the execution or execution of the plan [2]. The historical basis that the M.E.S. provides e the system in computer-assisted manufacturing through series graphics, mass balances in real-time, inputs, and outputs of raw materials, and control of notes related to productivity [4]. For this, the accuracy of sensors and data collectors must be at their correct set point, calibrated, and measured according to their suppliers, as wrong collections generate distorted and undesirable results. This can be verified if there is a follow-up of these instruments on the production line or at other performance levels. For example, if there is any distortion in the instrument readings, the graphs generated will have their information contested with the E.R.P, which also cannot fail to be a functional system for planning and resolving process demands. For these cases, such as reading raw material tank levels, the inventories carried out will serve as a basis for measuring whether the information may tend to diverge between what the instrument actually “reads” and what exists in the tank. The direct dependence on the accuracy of the instruments makes it the only large-scale continuous investment that companies should be aware of when performing systems integration [5]. Suppose any instrument shows damage and it does not need to be corrected in time. In that case, the M.E.S. will provide erroneous data to the E.R.P., which may compromise, for example, the sales strategy of the manufacturing unit. If the system indicates that there is more products being manufactured (supplied by an in-line sensor), the E.R.P. will program a greater demand for production, which may lead to high inventories and high levels of work overload, both for machines and inputs and for employees [6]. Often due to a lack of knowledge about the M.E.S. system, there are implications for acceptance in small industries [7]. This can lead to a lack of competitiveness compared to large companies that already use the system and its integrations with other software. Proper decision-making for supervisory and management positions with consistent data differs from mistakes made by companies where guesswork methods or outdated systems dominate [5]. The MES system is the eyes and ears for management and gathers information so that the system can remain current where, through various types of sensor devices and control interfaces, data from the shop floor can be collected, corrected, and dispersed on any basis [2].

The functionality of the M.E.S. is also argued mainly for new customers who need to learn the software, due to a lack of information in the market and the very existence of the system [8]. The M.E.S. is responsible for the complete programming of industrial activities in the production system. It launches work orders, tracks production activities, and quickly responds to random events [9]. Manufacturing industries can gain higher output and better quality at lower cost and real-time product tracking through the enforcement of a correctly deployed MES [10].

Productivity Concepts

Productivity is a measure of aggregating yields and related external factors in a database, which will be useful in measuring the effectiveness and efficiency of the production process. There are several ways to see and define productivity. Depending on people's perception, knowledge, and experience, the understanding of the term will be better, as well as its measurement, on how to improve it to achieve competitiveness from its measurement [11].

The concept of productivity for a physical production system is defined as the relationship between what is obtained at the output and what is consumed at the input of this system [12]. That productivity is linked to a productive system's effectiveness, with efficiency relative to the better or worse use of resources [13].

A more classic view of productivity is analyzed by [14] taking three definitions as reference: a) Single Factor Productivity: when it relates some production measure to only one of the inputs used in the production process, such as capital, machine, energy, man, the latter being the most referenced in partial productivity measures; b) Added Value Productivity: based on the concept of added value, whose productive performance is measured by the relationship between the added value and the different production resources used. As it uses only monetary value in its calculations, it eliminates the possibility of determining the factors' technical productivity. Hence its indicators are used in the scope of economic productivity; c) Total Factor Productivity: when more than one input (generally labor and capital) combined are considered simultaneously [14]. The scope of this measure creates the concept of multiple-factor productivity to designate the relationship between some production measure and all possible production factors: capital, labor, raw materials, energy, etc. [12].

Reliability and Maintenance Management

Maintenance is the term used to address how organizations try to avoid failures by taking care of their physical facilities. Maintenance is carried out to prevent failures or restore the system to its operating state in the event of a failure. The main objective of maintenance is to maintain and improve the reliability and regularity of the operation of the production system [15]. It is necessary, especially in the industrial area, to implement methods for analyzing the causes of failures, which always occur, being an integral part of registering them, defining their criticality, and developing action plans covering all involved [16]. In this sense, there is a need to know the term reliability in Maintenance management. Reliability-Centered Maintenance is a method used for planning industrial maintenance, aiming to rationalize and systematize the definition of maintenance tasks and guarantee reliability and operational safety at the lowest cost [17]. Reliability is the probability that a piece of equipment or item correctly performs its specified purpose under predetermined conditions and is related to a given period of observation [18].

2.2 Instrumentalization of Indicators

The proposed indicators to measure the productivity of the production process are based on the terms used in the industry under study. The form of calculation is demonstrated according to construction methods for each subarea of production management.

Usage Index (UI)

This index will be represented as everything that was used related to everything that was transformed into a final product, obeying the following relationship: UI, with Usage Index; IP, with Inputs directed to production and IAG, with inputs added to the final product.

$$\text{U} = \frac{IP}{IAG} \tag{1}$$

To compose a productivity indicator, it will be necessary to split this equation into two, related to the monetary value of the raw material and its quantity in kilograms, preparing an index in both, being: MPP, with Processed Raw Material (Kg) and MPE, with Raw Material involved in the Basic Structure of the material (Kg).

$$\text{IUmssica} = \frac{MPP}{MPE} \quad (2)$$

And being: GMPR, with Actual Expenditure of Raw Material in the Process, and GMPP, with Standard Expenditure of Raw Material in the process.

$$\text{IU monetary} = \frac{GMPR}{GGMPP} \quad (3)$$

Combining the equations, we have the UI:

$$\text{availableIU} = \frac{\left(\frac{MPP}{MPE}\right) + \left(\frac{GMPR}{GMPP}\right)}{2} \quad (4)$$

This indicator that will compose the productivity of the production system is linked to the Production Planning and Control (PCP) area. Such data that will compose this indicator are also available in the M.E.S. This way, the data can be reliable according to the installation of good automation for correct data collection.

Availability

This indicator provides an overview of the availability of items in general that will be needed by the production system, prioritizing product output according to established standards (quality standards, production time, delivery time, etc.). These items can be characterized according to the process area, with the most relevant areas for the indicators being Maintenance and PCP. The external availability (DE) is directed to the PCP, related to the materials and inputs necessary for the product to be manufactured. Internal availability (DI) is related to the equipment available for the production process to start and finish manufacturing the product associated with the Maintenance sector. The external availability is represented by the equation below: MPD, with Raw material available for the process (Kg), and MPE, with Raw Material involved in the Basic Structure of the material (Kg).

$$\text{DE} = \frac{MPD}{MPE} \quad (5)$$

Applied in percentage (indicative index), two other indicators represent internal availability internal. Are they: MTBF, with Mean Time Between Failures, and MTTR, with Mean Time to Repair?

$$\text{MTBF} = \frac{hours\ (working)}{hours\ (interval)} \quad (6)$$

$$\text{MTTR} = \frac{hours\ (repairs)}{hours\ (interval)} \quad (7)$$

Where the intervals are related to operation (number of intervals observed with the equipment operating) and repairs (number of intervals observed with the equipment undergoing maintenance), MTBF and MTTF units are usually measured in hours. The process study for the case study will also be in hours. Thus, we have the Availability equation, constituted by the ratio (in percentage):

$$\text{Availability} = (MTBF)/(MTBF + MTTR) \quad (8)$$

Reliability

According to a bibliographical study (item 2.1), the reliability of the equipment can be defined as:

$$R(t) = exp\left[-\int_{0}^{t} h(t)\, dt\right] \quad (9)$$

Where h(t) would be the observed equipment failure rate, to transcribe in terms of reliability index, a standard reliability value for a given machine must be linked to the values found with this standard. Thus, the Process Reliability Index (RI) is determined by: R(t), with Reliability Found, and r(t), with Default Reliability established.

$$\text{IR} = \frac{R(t)}{r(t)} \quad (10)$$

$$\text{Productivity} = \frac{(DE + DI + IR + EfficQual + EfficProd)}{5} \quad (11)$$

Quality

For a process with low failure rates related to the final product and not to the process or equipment (these terms are associated with maintenance management and not product quality), the process must be performed as it is pre-defined. in writing and that Quality management carries out efficient control regarding the input of inputs and the output of the finished product for the final consumer. In this study, an indicator of the rate of conforming products is carried out, where at the end of the process it is possible to calculate how much of the final product will be sent to the consumer customer and how much of the finished product will be transformed into scrap or reprocessed. Even if the scraps are sold or the product is being reprocessed, these values reduce the Quality Efficiency since efforts were made (machine, labor, inputs) that will not be directed in monetary return since they will not be with the final consumer in the expected time. Often, additional effort is expended to produce what was not manufactured according to the customer's requirements. Therefore, the efficiency of Quality is exposed with the variables and equation: BQ, with Blocks performed in period X (Kg), and Prod, with production carried out in period X (in kilograms).

$$EfficQual = 1 - \frac{BQ(x)}{Prod(x)} \tag{12}$$

Simple Overall Efficiency

Simple Global Efficiency is related to the quantity produced, whether within the specified or not (specifications in terms of product quality). This is the ratio between what was made and what was expected to be paid for a given time X (standard machine time).

$$Efficprod = \frac{Produced(x)}{lead\ production(x)} \tag{13}$$

Productivity

The productivity indicator will be formed by the average of the indicators that were outlined in order to oppose mass production with the restrictions that made the entire production system more expensive, more unproductive and less efficient. For that, you have:

$$\text{Productivity} = \frac{(UI + DE + DI + IR + EfficQual + \ EfficProd)}{6} \tag{14}$$

Certain companies assign studied values of weights to some of these indicators. However, for the case study process, the variables will be assigned equal weights, 1. These weights depend on the criticality of each variable and indicator. Some processes require more maintenance (in the case of machines with frequent breakdowns) and others more in the PCP (in cases of long delays in the arrival of raw materials due to the distance between the supplier and the production unit).

2.3 Manufacturing methods

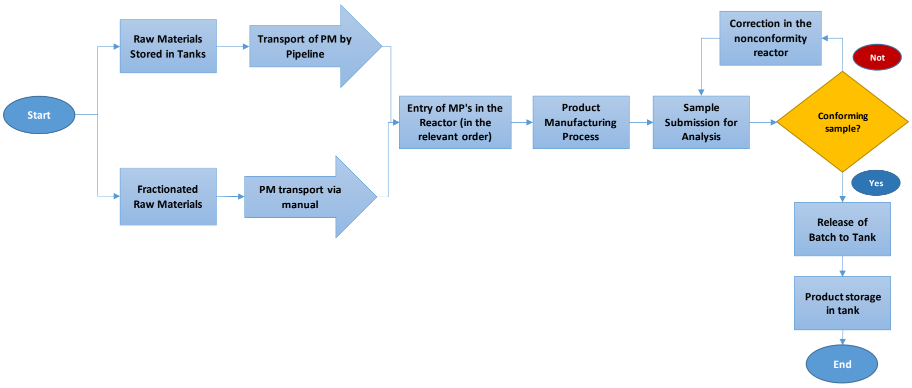
Global Sanitizing Manufacturing Process

The company's model follows 3 large production areas, which differ only in terms of the by-product each one produces. However, the process itself is interconnected, which makes these 3 productive cells linked. Without one producing, the other cannot produce. Are they: manufacturing sector, with Production of sanitizing liquid. It will be the object of study for the formation of the Productivity indicator through the M.E.S; plastic Blowing Sector, with the production of plastic bottles to be filled in the Filling sector (it will not be the object of the case study) and; filling Sector, with filling the liquid prepared in the Manufacturing sector into bottles produced in the Blowing sector (it will not be the object of the case study).

Manufacturing Sector

The manufacturing sector consists of 3 dishwasher reactors, all with approximately 11,500 kilograms of capacity. This value may vary according to the progressive insertion of the chemical components in the reactor. The dishwasher ingredients are inserted into the reactor, mostly via automated machines, controlled by the SCADA System (Supervisory Control and Data Acquisition), determined by the factory floor operators. These employees control the process by automating the valves and pumps, thus managing the correct manufacture of the sanitizer according to the company's standard technical list (predetermined by the R&D development sector). After the implementation of the M.E.S. system, with the SCADA system link, manufacturing data became more accessible and with better visualization. The SCADA system, in general, generates data as the sanitizing agent is manufactured (water filling time, Caustic Soda pouring time, homogenization time, analysis time, reactor downtime for a given reason, etc.) and the M.E.S. compiles this data into reports and spreadsheets, thus constituting a large database for studying the process and generating performance indicators. Finally, these can demonstrate the efficiency of each stage of the process as well as the manufacturing sectors involved (maintenance, human resources, production planning, and control, etc.).

Fig 1. Flowchart of the dishwasher manufacturing process in the studied company



3 Results and discussions

According to the database processed and collected via M.E.S., it is easy to measure all 6 individual indicators, thus establishing reliability between all data and the relationships they will have in the main productivity indicator. Therefore, according to the process studied in the article, we will only extract from the M.E.S. production data, establishing constancy in the Human Resources and Quality indicators, as if all the necessary labor were available and being used and all the product produced was complying, without blockages or production interventions due to the product being non-compliant. To apply the existing database of the process, it will be necessary to establish the time at which it will be withdrawn. For didactic purposes, data will be taken from a month of production in a given period of the year.

3.1 Usage Index Calculation (UI)

Being the UI:

$$IU = \frac{\left(\frac{MPP}{MPE}\right) + \left(\frac{GMPR}{GMPP}\right)}{2} \quad (4)$$

Averaging the database for the chosen month, we have:

IU= ((11459/11500) + (R$ 1.994/R$ 2.000))/2 = 0.9967 = 99.67%

3.2 Internal Availability Calculation

Being the DE (with MTBF and MTTR units in weeks):

$$\text{Availability} = (MTBF)/(MTBF + MTTR) \quad (8)$$

DE = 4.80/(4.80+0.65) = 0,8807 = 88,07%

3.3 Reliability calculation

Reliability being:

$$IR = \frac{R(t)}{r(t)} \quad (10)$$

We have the standard values of the batch production reactors of the studied sanitizing agent. Therefore, the reliability values of each reactor can see in Table 1:

Table 1. Standard values of reliability of Detergent reactors.

Reliability Values	Reactor 1	Reactor 2	Reactor 3
Reliability for 11 500 kg reactor	0.96	0.91	0.83

Source: The company Studied

Performing the average reliability of the period studied, we have:

For reactor 1

IR=R(t)/r(t) = IR_1=0,94/0,96 = 97,92%

For reactor 2

IR=R(t)/r(t) = IR_2= 0,83/0,91 = 91,21%

For reactor 3

IR=R(t)/r(t) = IR_3= 0,75/0,83 = 90,36%

For equal weights, we have the process mean:

IR= (IR_1 + IR_{2+} IR_3)/3 = (97,92+91,21+90,36)/3 = 93,16%

3.4 Quality Efficiency Calculation

Being the efficiency of Quality:

$$EfficQual = 1 - \frac{BQ(x)}{Prod(x)} \quad (12)$$

We have that would be identified in the M.E.S. if any batches had gone out of specification and were blocked or sent for reprocessing. During the studied period, there were no batches that required quality intervention. For the proposed study of the indicator, the efficiency will be referenced with a value of 100%.

3.5 Global Productivity Calculation

For Simple global productivity, we have:

$$Efficprod = \frac{Produced(x)}{lead\ production(x)} \quad (13)$$

Thus, for the average of the values in the studied period, we have:

Production Efficiency = 99.6 minutes / 80 minutes = 75.5%

3.6 Final Productivity Calculation

Performing the Productivity calculation with the insertion of all the variables studied and considering that the productive sectors involved made available all the necessary inputs for the beginning and end of the batch, we have that:

$$\text{Productivity} = \frac{(UI + DE + DI + IR + EfficQual + EfficProd)}{6} \quad (14)$$

Productivity = (99.67 + 88.07 + 100 + 93.16 + 100 + 75.5)/6 = 92.73%

The chart below (fig. 3) shows a summary of the indicators and the proposed final indicator. The goals of each nominee must be achieved according to company guidelines or historical average, with advances in their gross value over the course of months or weeks.

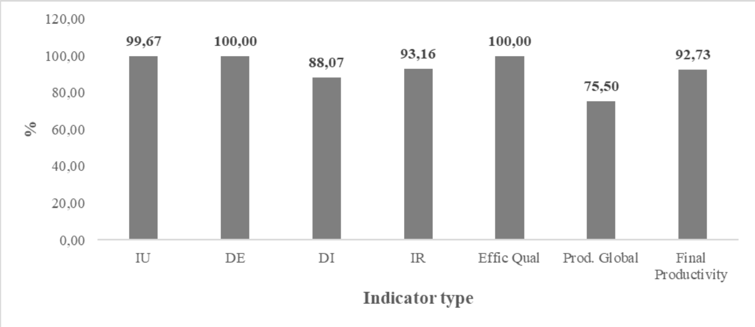


Fig 3. Final Productivity with the other indicators that compose it

4 Conclusions

Indicators in the industry represent the scenario that its processes that generate results in companies. Measuring critical processes and their effects is essential for compiling the generated data the products collecting for and building indicative scenarios. Productivity in a manufacturing industry is often understood ambiguously and the formulas and demonstrations of the case study revealed the objectivity of obtaining real and reliable values of the reality that each performance indicator can transmit.

Understanding the behavior of the areas that promote results also helps to understand that production does not arise only with factory floor labor and operational supervision. A systemic view with all correlated and supporting areas becomes essential for a better understanding of the market's scenarios and the company's correct decision-making. Despite the objective being achieved, there is still a range of opportunities and adaptations that the generalist formula obtained may need to improve.

The scope of productivity is extensive and often complex, depending on the monitoring and systematization of processes. The production line does not produce results by itself, and each bottleneck and step must be understood to understand how to model productivity for each different type of industry. The use of the M.E.S. differentiates from other companies that rely exclusively on Excel, ERPs, or shop floor operating systems (SCADA), as the demonstrations of integration with all areas and the generation of indicators focused on better decision-making is only possible thanks to the design that the MONTH. and how it can also be shaped as the industry is characterized, with a focus on improving productive results based on reliable and newly compiled data.

References

1. Corrêa, H. L.; gianesi, I. G. N.; Caon, M.: Planejamento, Programação e Controle da Produção: MRP II / ERP. Ed. Atlas, São Paulo, 1997.
2. McClellan, M. Introduction to Manufacturing Execution Systems. In: ______ Applying Manufacturing Execution Systems. Boca Raton: St. Lucie Press, 2000.

3. Stouffer, Keit; Pillitteri, Victoria; Lightman, Suzanne; Abrams, Marshall; Hahn, Adam. Guide to Industrial Control Systems (ICS) Security. National Institute of Standards and Technology Special Publication 800-82, Revision 2 Natl. Inst. Stand. Technol. Spec. Publ. 800-82, Rev. 2, 247 pages (May 2015) This publication is available free of charge from: http://dx.doi.org/10.6028/NIST.SP.800-82r2
4. Naedele, M., Chen, H. M., Kazman, R., Cai, Y., Xiao, L., & Silva, C. V. (2015). Manufacturing execution systems: A vision for managing software development. *Journal of systems and Software*, 101, 59-68. https://doi.org/10.1016/j.jss.2014.11.015
5. Jin, Y., Vonderembse, M., Ragu-Nathan, T. S., & Smith, J. T. (2014). Exploring relationships among IT-enabled sharing capability, supply chain flexibility, and competitive performance. *International Journal of Production Economics*, 153, 24-34. https://doi.org/10.1016/j.ijpe.2014.03.01
6. Gumz, J., Fettermann, DC., Sant'Anna, AMO., Tortorella, GL. Social influence as a major factor in smart meters' acceptance: findings from Brazil. *Results in Engineering*, 15, 100510, (2022). https://doi.org/10.1016/j.rineng.2022.100510
7. Bordeleau, Fanny-Eve; Mosconi, Elaine; Santa-Eulalia, Luis Antonio. Business intelligence and analytics value creation in Industry 4.0: a multiple case study in manufacturing medium enterprises. Production Planning & *Control*, v. 31, n. 2-3, p. 173-185, 2020. https://doi.org/10.1080/09537287.2019.1631458
8. Zach, O., & Erik Munkvold, B. (2012). Identifying reasons for ERP system customization in SMEs: a multiple case study. *Journal of Enterprise Information Management*, 25(5), 462-478. https://doi.org/10.1108/17410391211265142
9. Younus, M., Hu, L., Yong, Y. & Yuqing, F. Realization of Manufacturing Execution System for a Batched Process Manufacturing Industry. In: International MultiConference of Engineers and Computer Scientists, Hong Kong, 2009.
10. d'Antonio, G., Segonds, F., Laverne, F., Bedolla, J. S., & Chiabert, P. (2017). A framework for manufacturing execution system deployment in an advanced additive manufacturing process. *International Journal of Product Lifecycle Management*, 10(1), 1-19.
11. Acosta, SM., Oliveira, RMA., Sant'Anna, AMO. Machine learning algorithms applied to intelligent tire manufacturing. *International Journal of Computer Integrated Manufacturing*, ahead-of-print, 2023. https://doi.org/10.1080/0951192X.2023.2177734
12. Sink, D. S. *Productivity Management: Planning, Measurement and Evaluation, Control and Improvement*, Somerset. New Jersey: John Wiley and Sons, Inc., 1985.
13. Moreira, D. A. Dimensões do desempenho em manufatura e serviços. São Paulo: Pioneira, 1996.
14. Severiano-Filho, C. Produtividade & manufatura avançada. João Pessoa. Editora Universitária. 1999.
15. Fogliato, F. S.; Ribeiro, J. L. D. Confiabilidade e Manutenção Industrial. Editora Elsevier. Rio de Janeiro, 2009.
16. Wohlgemuth, M., Fries, CE., Sant'Anna, AMO. Giglio, R. Fettermann DC. Assessment of the technical efficiency of Brazilian logistic operators using data envelopment analysis and one inflated beta regression, *Annals of Operations Research*, 286:703–717, 2020. https://doi.org/10.1007/s10479- 018- 3105- 7
17. Heng, A., Zhang, S., Tan, A. C., & Mathew, J. (2009). Rotating machinery prognostics: State of the art, challenges and opportunities. *Mechanical Systems and Signal Processing*, 23(3), 724-739.
18. Sharma, R., Singh, J., & Rastogi, V. (2018). The impact of total productive maintenance on key performance indicators (PQCDSM): a case study of automobile manufacturing sector. International Journal of Productivity and Quality Management, 24(2), 267-283.