Available online ***www.jsaer.com***

***Journal of Scientific and Engineering Research*, 2018, 5(7):397-406**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Analysis of Overall Equipment Effectiveness (OEE) with Total Productive Maintenance Method on Jig Cutting: A Case Study in Manufacturing Industry

Humiras Hardi Purba, Erwin Wijayanto, Niko Aristiara

Master of Industrial Engineering Program, Mercu Buana University, Jakarta, Indonesia

Abstract A manufacturing company that produces filter air conditioner for four wheels also not apart from problems related to the effectiveness of the machine/equipment caused by the six big losses. This can be seen with the frequency of damage that occurs in the machine/equipment because of the damage so that the production target is not achieved. TPM is one of the methods developed in Japan that can be used to improve the productivity and efficiency of company production by using machine/equipment effectively. Not exactly the handling and maintenance of machines/equipment not only cause damage problems but also other losses called six big losses. The object studied in this research is cutting jig in Blow Molding Department. The data used are data between July and September 2017. During the period from July to September 2017, the total equipment effectiveness (OEE) value is 81.48% - 86.05%. The availability ratio is 95.82% - 92.9%. The performance result is 93.83% - 93.88%. The result of the rate of quality is 95.76% - 96.11%. The highest value of OEE in July was 86.4%.

Keywords Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE).

Introduction

Overall Equipment Effectiveness (OEE) is a widely used performance indicator in manufacturing industries around the world. It is initiated when Nakajima [1] introduced the Total Productive Maintenance (TPM) concept where the main goal is to improve and sustain equipment efficiency. Most of the research involving the OEE measure is, thus, related to maintenance [2], but also to areas such as performance measurement [3] and productivity improvement [4]. In the manufacturing sector, the improvement of the manufacturing system is one of the intensive improvement efforts undertaken. To support the manufacturing system, the performance of the equipment used should be improved, so that it can be used properly. Improvement efforts in the manufacturing industry in terms of equipment is to improve the utility of existing equipment. According to Hansen (2001), one of the techniques used to perform the analysis of machine utility efficiency is Overall Equipment Effectiveness (OEE).

OEE aims to improve the effectiveness of the production line equipment so as to achieve greater volumes with good results so that the production costs incurred are lower. It takes the most common and important sources of manufacturing productivity loss, places them into primary categories and distills them into metrics that provide an excellent gauge for measuring where you are and how you can improve [5]. This method is chosen because the calculation is based not only on availability factor but also Performance Efficiency factor and product quality (rate quality product). By knowing the level of machine effectiveness, the company is expected to increase its productivity through various improvement efforts. The process of maintenance and maintenance related to engine effectiveness factors can be categorized under the category of six big losses. The company chosen by the author as a place to carry out the research is Manufacture company which is a company that produces filter air conditioner which is inseparable from the problems related to the effectiveness of machine/equipment caused by six big losses. This can be seen with the frequency of damage that occurs in the machine/equipment because of the damage so that the production target is not achieved.

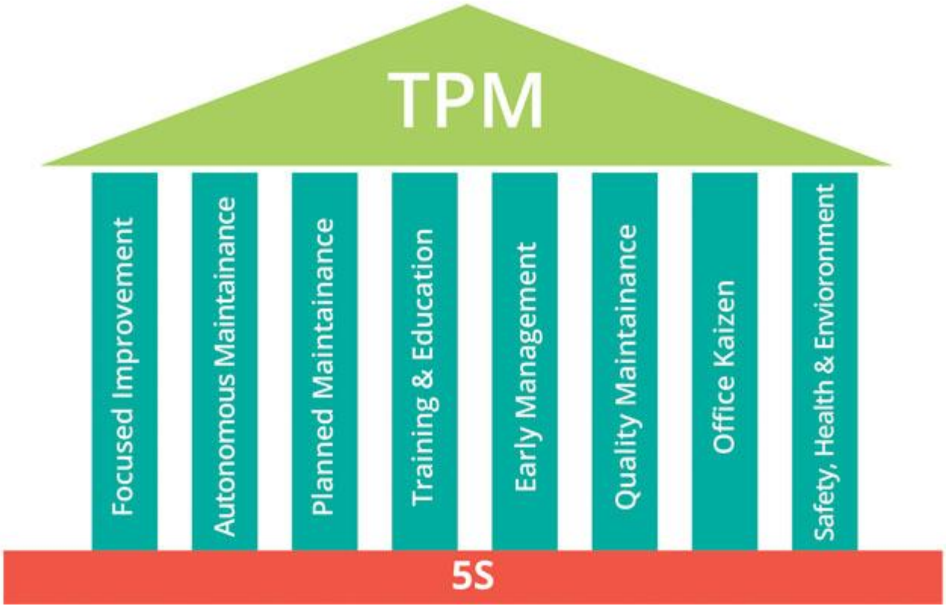

Figure 1.The pillars of TPM
Source "Seiichi Nakajima - The Principles and Practice of TPM",
Retrieved from: www.cetpm.de.

Research Methods

1. Problem Formulation

The problem faced is the low effectiveness of the effectiveness of the usage of main / equipment due to the inability in proper management of the treatment, so it is necessary to identify the dominant factors and the losses caused by damage of machine/equipment and analyze the cause of the contribution of these factors so that can be an input in the application of effective TPM within the company. The implementation of total productive maintenance (TPM) has shown considerable results in Japanese enterprises [6].

2. Research Objectives

In order to deal with global competition, industries have undertaken many efforts directed to improve manufacturing efficiency [7]. The general purpose of this research is to know the level of effective use of machine/production equipment by using the method of OEE (Overall Equipment Effectiveness) as a consideration in the application of TPM in the company. The purpose of this study is to analyze the factors that become the main priority as the basis for improvements using cause and effect diagrams and to know the existence of each of the factors that in the six big losses that give the largest contribution of the six factors of big losses using Pareto diagram. Text reduction is also demanded by a globalized industrial world and economy: in this context, minimizing text is a way to overcome language and cultural barriers, as it happens in other fields [8]. This research was conducted in the hope that can be used by some parties because it can give solution if TPM executed correctly and right in company, target finally will extend machine life (lifetime machine), become input material for company in developing plan of productivity and efficiency of machine / by maximizing the effectiveness of the use of machinery / equipment, providing input to the company to be able to improve the maintenance method that has been applied by the company, gained experience to be able to solve the problems regarding maintenance in the company.

3. Limitation Problems

Blow molding process is an important technology to produce parts with complex geometry and high precision and is suitable for automatized mass production. Melt pressure and temperature during molding affect the melt properties and crystallization of the polymers as well as the quality of the final parts such as dimensional accuracy, mechanical properties, optical properties, and appearance of esthetic defects. Therefore, extracting and analyzing the features of the molding process variable is a significant endeavor [9]. Limitation of the problem is to limit the problem so as not to be too broad and the focus on the object of research, while the problem limitation in this study is the method used is OEE method used to measure the level of effectiveness of machinery / equipment according to the principles of TPM to know the magnitude of losses on the machine / equipment better known as six big losses, production data of July, August, and September of 2017, the measurement of machine/equipment effectiveness focuses only on cutting jig E in Blow Molding Department, because this machine/equipment has the level of damage often occurs compared to other machines, the research is not done to the calculation of costs, maintenance of the machine/equipment under investigation whether it is the way of disassembly, replacement, and installation of equipment is not discussed, research only done to the proposal or evaluation evaluation. This paper has considered the main journal impact indicators that are currently available through citation databases as these are the primary ones that are used in practice for decisions about journal ranking lists, destinations for research papers, jobs, promotions, and submissions to research evaluation programmes [10].

4. Data Collection

In preparing this report, the data collection and collecting data using the method is primary data (interview and observation) and secondary data (factory data and bibliography). Infectious disease models are both concise statements of hypotheses and powerful technique for creating tools from hypotheses and theories. As such, they have tremendous potential for guiding data collection in experimental and observational studies, leading to more efficient testing of hypotheses and more robust study designs. Because analysis of infant cries may help in identifying the needs. Since data collectors are required to collect useful information, useless and meaningless information should be dropped. Redundant information should be fused [11]. About how to conduct research, and what challenges may be encountered during research [12].

5. Data Processing

After obtaining the required data then the data is processed. The processing steps are as follows:

1. Calculates the OEE value

OEE is a common approach for the measurement of production equipment efficiency and originated in the frame of lean management with the introduction of Total Productive Maintenance [13]. OEE value is a value as a measuring tool to determine the value of the effectiveness of the machine as a whole. The value of OEE is the multiplication of the value of availability, performance efficiency, and rate of quality. So before we have to search for these three values. OEE involves the process of monitoring the availability, performance, and quality of manufacturing equipment and/or facilities. Performance of the operation to each of the three components to planned levels gives managers information about where and how management decisions should be focused to improve productivity and profitability. The data provide the foundation for quantitative validation of choices as dissimilar as setting optimal maintenance schedules and calculating the value of investing in new process control systems. As a tool for process improvement, OEE connects the converter’s operation to a global body of best practices and benchmarking information.

a. Availability

Continuous availability of reliable sophisticated equipment with precision with precision is need of the competitive market. Overall equipment effectiveness (OEE) is an important performance measure metric for equipment effectiveness. An attempt has been done to measure and analyze existing overall equipment effectiveness of critical machinery producing important automobile components like serration cap, hose air cleaner. Which are using by leading automobile company [14].The value of availability is so that we can know what percent availability of effectiveness on the machine. To find availability value using available time data, planned downtime, breakdown time, and set up time. After the data is available the processed meal uses the following equation.

$$\text{Availability (ketersediaan)} = \frac{\text{Operation Time}}{\text{Loading Time}} \text{x } 100\%$$

$$= \frac{\text{Loading Time} - \text{Downtime}}{\text{Loading time}}$$

b. Performance efficiency

The global speed of change within the manufacturing industry forces companies to constantly improve production performance. In that effort, performance measures are critical for driving and managing production improvements. Two of the most commonly used measures in operations are productivity and overall equipment efficiency (OEE). However, the potential of using these measures as improvement drivers is not fully utilized in industry today due, for example, to ambiguities in definitions and their interpretation [15]. At this stage done data processing to determine the value of the performance of the effectiveness of the machine. To calculate the value of performance efficiency requires data cycle time, operation time, and total production data. For performance, efficiency calculation can use the following equation.

$$\text{Performance efficiency} = \frac{\text{Theoretical Cycle Time x Processed Amount}}{\text{Operating Time}} \text{x } 100\%$$

c. Rate Of Quality Product

The global speed of change within the manufacturing industry forces companies to constantly improve production performance. In that effort, performance measures are critical for driving and managing production improvements[16].Isconstantly under tough pressure to increase its competitiveness. To be able to maintain and develop their ability to compete on the global market, manufacturing companies need to be successful in developing innovative and high-quality products with short lead times, as well as in designing robust and flexible production systems providing the best preconditions for operational excellence [17]. Calculating the value of a rate of the quality product is used as a measure of inner equipment capability produce products that conform to standards. The calculation of a rate of quality product requires production data such as good product and total reject. To calculate the rate of a quality product can use the following equation.

$$\text{Rate of Quality} = \frac{\text{Procesed Amount} - \text{Defect Amount}}{\text{Processed Amount}} \text{x } 100\%$$

2. Calculate the value of Six Big Losses

The activities of TPM (Total Productive Maintenance) are identical in observing the value of OEE or Overall Equipment Effectiveness which in OEE has some diseases that cause a decrease in value At this stage to find the main cause factor waste/loss due to low effectiveness on the machine. Which includes six big losses are:

a. Breakdown Losses

This loss is caused by a sudden engine failure so that the machine can not operate. To calculate breakdown losses value can menggukan the following equation.

$$\text{Breakdown Losses} = \frac{\text{Breakdown Time}}{\text{Loading Time}} \text{x } 100\%$$

b. Set Up and Adjustment Losses

Disadvantages due to installation and adjustment are all installation times and time of adjustment required for activities to substitute a product for the next product for subsequent production. In other words, the total requirement of the machine does not produce to replace the equipment. To calculate the value of set up and adjustment losses can use the following equation.

$$\text{Set Up and Adjusment} = \frac{\text{Set Up Time}}{\text{Loading Time}} \text{x } 100\%$$

c. Idling and Minor Stoppages

Idling and Minor Stoppage Losses are caused by events like machine stop moment, machine jam, and idle time from the machine. To calculate the idling and minor stoppage losses value can use the following equation.

$$\text{Idling Minor Stoppages} = \frac{\text{Non Productive Time}}{\text{Loading Time}} \text{x } 100\%$$

d. Reduce Speed Losses

Speed Losses is a loss because the engine does not work optimally (decreased speed of operation) occurs if the actual speed of machine/equipment operation is less than the optimum speed or engine speed designed. To calculate the value of reduced speed losses can use the following equation..

$$\text{Reduce Speed Losses} = \frac{\text{Operation Time} - (\text{Ideal Cycle Time x Total Product})}{\text{Loading Time}} \text{x } 100\%$$

e. Rework Losses

Rework Losses is a loss caused by a defective product but still can the product be reworked. To calculate the value of rework losses can use the following equation.

$$\text{Rework Losses} = \frac{\text{Ideal Cycle Time X Rewark}}{\text{Loading Time}} \text{x } 100\%$$

f. Reject Losses

Reject Losses due to unused materials or raw materials waste. To calculate the value of reject losses can use the following equation.

$$\text{Reject Losses} = \frac{\text{Ideal Cycle Time X Reject}}{\text{Loading Time}} \text{x } 100\%$$

Result and Discussion

1. Calculation of Availibilty value

Based on the data obtained and performed processing using equation 1 availibilty value for cutting jig machine.

Table 1: Production data, Gross Product, Over Cutting, Hole Not Center July - September 2017

Month	Production of Hose Air Cleaner (Pcs)	Gross Product (Pcs)	Over Cutting	Hole Not Center	Total
July	11520	11663	302	158	460
August	15360	14736	409	215	624
September	16128	15525	398	205	603

There are about 4% of the Not Good products produced by machines in July - September 2017.

Table 2: Data work hours and delay cutting jig July - September 2017

Month	Availability workhours (h)	Warm-up Time	Machine Cleaning (h)	Set-up Sparepart	Schedule Shutdown	Planned Downtime	Machine Break	Total Delay
July	240	1	2.5	5.8	3.75	3.75	1.1	17.9
August	320	1.33	3.33	8.3	5	5	1.5	24.46
September	336	1.4	3.5	7	5.25	5.25	1.3	23.7

While total delay time in July-September is about 8%. Which indicates still TPM on the machine is not running properly.

Table 3: Calculation Loading Time

Month	Available Time (h)	Planned Downtime (h)	Loading Time (h)
July	240	3.75	236.25
August	320	5	315
September	336	5.25	330.75

Table 4: Calculation of Downtime for July - September 2017

Month	Set-up Sparepart	Schedule Shutdown	Machine Break	Total Downtime
July	5	3.75	10.1	18.85
August	6.66	5	31.26	31.26
September	7	5	28.75	28.75

With total downtime that still exceeds the standard set from the TPM, then the waste means that the machine's productivity is declining and is very detrimental to the company.

Table 5: Calculation Availibility Ratio July - September 2017

Month	Loading Time	Total Downtime	Operation Time	Availibility (%)
July	236.25	18.85	226.4	92.02
August	315	31.26	301.84	90.07
September	330.75	28.75	317.2	91.51

In Availability Ratio from July - September 2017 still reach the target.

2. Calculation Performance Efficiency Value

Table 6: Calculation Performance Efficiency July - September 2017

Month	Gross Product (Pcs)	Ideal Cycle Time (h)	Operation Time (h)	Performance Efficiency (%)
July	11663	0.0189	226.4	97.36
August	14736	0.0189	301.84	92.27
September	15525	0.0190	317.2	92.99

While the achievement of Performance Efficiency from July to September only reaches the target in July, which means August and September need improvement to reach the target.

3. Calcuation Rate of Quality Value

Table 7: Calculation Rate of Quality Product July - September 2017

Month	Gross Product (Pcs)	Total Broke (Pcs)	Rate of Quality (%)
July	11663	460	96.05
August	14736	624	95.76
September	15525	603	96.11

In Calculation

Rate of Quality July – September 2017 still reach the target.

4. Calculation Overall Equipment Effectiveness (OEE)

Table 8: Calculation OEE July - September 2017

Month	Availibilty Ratio (%)	Performance Efficiency (%)	Rate of Quality (%)	OEE (%)
July	92.02	97.36	96.05	86.05
August	90.07	92.27	95.76	79.58
September	91.51	92.99	96.11	81.48

The value of OEE only reaches the target in July 2017 according to TPM standard while August and September 2017 did not reach taget.

5. Calculation Six Big Losses

Table 9: Equipment Failure Loss July - September 2017

Month	Total Breakdown (h)	Loading Time (h)	Breakdown Loss (%)
July	10.1	236.25	4.27
August	19.6	315	6.22
September	16.5	330.75	4.98
Total	46.2		

Table 10: Percentage Calculation Set-up and Adjusment July - September 2017

Month	Schedule Shutdown (h)	Set-up Sparepart (h)	Warm-up Time (h)	Total (h)	Loading Time (h)	Setup Loss (%)
July	3.75	5.8	1	10.55	236.25	4.46
August	5	8.3	1.33	14.63	315	4.64
September	5.25	7	1.4	13.65	330.75	4.12
Total				38.83		

Table 11: Percentage Percentage Reduced Speed Losses July – September 2017

Month	Operation Time (h)	Ideal Time (h/Pcs)	Total Prduct Process (Pcs)	Loading Time (h)	Reduced Speed Losses Time (h)	Reduced Speed Loss (%)
July	226.4	0.0189	11663	236.25	5.96	2.52%
August	301.84	0.0189	14736	315	23.32	7.40%
September	317.2	0.019	15525	330.75	22.22	6.71%
Total					51.5	

Table 12: Percentage Calculation Over Cutting Losses Month July – September 2017

Month	Operation Time (h)	Ideal Time (h/Pcs)	Total Prduct Process (Pcs)	Loading Time (h)	Reduced Speed Losses Time (h)	Reduced Speed Loss (%)
July	226.4	0.0189	11663	236.25	5.96	2.52%
August	301.84	0.0189	14736	315	23.32	7.40%
September	317.2	0.019	15525	330.75	22.22	6.71%
Total					51.5	

Table 13: Percentage Calculaion Over Cutting Losses July – September 2017

Month	Loading Time (h)	Ideal Cycle Time (h/Pcs)	Over Cutting (Pcs)	Over Cutting (h)	Over Cutting (%)
July	236.25	0.0189	302	5.7	2.41
August	315	0.0189	409	7.73	2.45
September	330.75	0.019	398	7.56	2.28
Total				20.99	

Table 14: Percentage Calculation Hole Not Center Loss July – September 2017

Month	Loading Time (h)	Ideal Cycle Time (h/Pcs)	Hole Not Center (Pcs)	Hole Not Center (h)	Hole Not Center (%)
July	236.25	0.0189	158	2.98	1.26
August	315	0.0189	215	4.06	1.29
September	330.75	0.019	205	3.89	1.17
Total				10.93	

Table 15: Percentage Sequence Six big Losses Factor Cutting Jig July2015 - September 2017

No	Six Big Losses	Total Time Loss (h)	Percentage (%)	Cumulative Percentage (%)
1	Reduced Speed Losses	51.5	28.98	28.98
2	Breakdown Loss	46.2	25.98	54.96
3	Set up and Adjusment Loss	38.83	21.84	76.8
4	Over Cutting Loss	20.99	11.8	88.6
5	Hole Not Center Loss	10.93	6.14	94.74
6	Idling Minor Stoppages	9.33	5.24	100
Total		177.78		

At point Percentage Sequence Six Big Loss Factor Cutting Jig is focused on Reduced Speed Losses, Breakdown Losses and Setup and Adjustment Loss.

Figure 2: Total Time Loss

Figure Pareto Diagram of Percentage Factor Six Big Losses Cutting Jig for July – September 2017. As a first step in this research program we want to establish under what conditions the Pareto boundaries of such an economy can be achieved and under which conditions (quasi-equilibrium) can be guaranteed [18]. In the pareto diagram, maintenance is more concerned with the highest loss values first. Proper scheduling is required by knowing which items must reside in the PM first.

After careful analysis, fault tree analysis, fishbone diagram analysis of the advantages and disadvantages of comprehensive evaluation methods and multiple risk matrices. Fishbone diagrams, and enhanced risk matrices are integrated to make up for their shortcomings and realize a comprehensive quantitative risk assessment. This method not only recognizes the quantification of in-depth causes and the consequent risk of bone fish diagrams, the probability accuracy of tree fault accidents, and the improvement of the risk matrix, but also reduces subjective influence and improves the accuracy of risk evaluation [19].

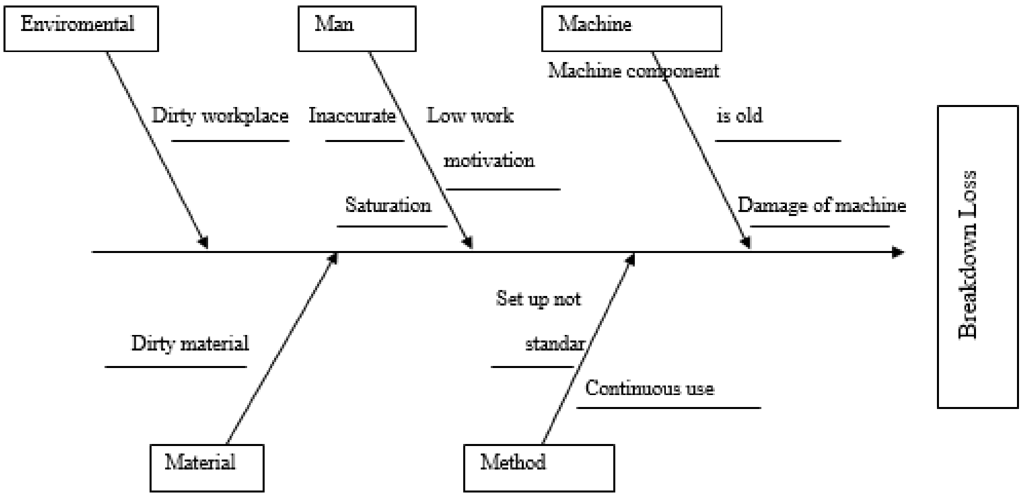

Figure 3: Fishbone Diagran Breakdown Loss

The figure above is the items - items that must be repaired in the Cutting Jig machine area, need control and scheduling and employee awareness and support from management for TPM implementation and can achieve the target that has been determined.

Conclusion

Based on the results of the analysis and description of OEE cutting measurements in Blow Molding in one manufacturing company in Indonesia, it can be concluded that the measurement of the effectiveness level of machinery/equipment using the method of Overall Equipment Effectiveness (OEE). OEE calculation results obtained from July to September 2015 with the largest percentage in July 2015 86.05% and the lowest in August at 79.58%. Factors that have the greatest percentage of big losses cutting the jig factor in the Blow Molding Department are reduced speed of 28.98%, loss of damage by 25.98%, adjustment and adjustment loss of 21.84%, loss of over-cut 11, 8%, loss of center 6.14, short termination of minor termination of 5.24%. Equipment failures that occurred during July to September 2105 have resulted in reduced machinery/equipment effectiveness, with the largest percentage loss of damage occurring in August at 6.22%. Arrangement and adjustment of machinery/equipment also affect the effectiveness of the use of machinery/equipment. During July to September 2015, the largest percentage occurred in August at 4.64%. The largest percentage of engine/equipment effectiveness factors lost due to idling and minor termination factors was 1.05% in July. The largest percentage of the effectiveness of the machine/equipment lost due to reducing speed losses is in August at 7.40%. The biggest percentage of the effectiveness of the machine/equipment lost due to more loss factor in August was 2.45%. The biggest percentage of the effectiveness of the machine/equipment lost due to the hole factor does not lose the center is in August amounting to 1.29%. From this research can be given some suggestions as follows: Guidelines care and routine inspection should be done well to avoid damage so that the damage time machine/equipment can be removed. The need for the provision of spare parts and supplies of equipment in the maintenance and maintenance of futures shall be made available to view the condition of machinery/equipment of great importance in order that maintenance activities are not disrupted which would be detrimental to the enterprise itself. The company should pay more attention to the condition of the machine/equipment by estimating the time of the damage through the calculation of the operation period to anticipate the damage of the machine/equipment or replacement of the component fund before the damage of the machine/equipment. The company needs to instill awareness to all employees to actively participate in improving efficiency and productivity for themselves and also for the company.

References

[1]. Nakajima, S. (1988). Introduction to TPM: Total Productive Maintenance (preventative maintenance series). *Hardcover. ISBN 0-91529-923-2*.

[2]. Muchiri, P., Pintelon, L., Gelders, L., & Martin, H. (2011). Development of maintenance function performance measurement framework and indicators. *International Journal of Production Economics*, *131*(1), 295-302.

[3]. Chan, F. T. S., Lau, H. C. W., Ip, R. W. L., Chan, H. K., & Kong, S. (2005). Implementation of total productive maintenance: A case study. *International journal of production economics*, *95*(1), 71-94.

[4]. Muchiri, P., &Pintelon, L. (2008). Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. *International journal of production research*, *46*(13), 3517-3535.

[5]. Pomorski, T. (1997, October). Managing overall equipment effectiveness [OEE] to optimize factory performance. In *Semiconductor Manufacturing Conference Proceedings, 1997 IEEE International Symposium on* (pp. A33-A36). IEEE.

[6]. Ljungberg, Õ. (1998). Measurement of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations & Production Management*, *18*(5), 495-507.

[7]. D'Antonio, G., Bedolla, J. S., & Chiabert, P. (2017). A Novel Methodology to Integrate Manufacturing Execution Systems with the Lean Manufacturing Approach. *Procedia Manufacturing*, *11*, 2243-2251.

[8]. Scurati, G. W., Gattullo, M., Fiorentino, M., Ferrise, F., Bordegoni, M., & Uva, A. E. (2018). Converting maintenance actions into standard symbols for Augmented Reality applications in Industry 4.0. *Computers in Industry*, *98*, 68-79.

[9]. Zhou, X., Zhang, Y., Mao, T., Ruan, Y., Gao, H., & Zhou, H. (2018). Feature extraction and physical interpretation of melt pressure during injection molding process. *Journal of Materials Processing Technology*.

[10]. Mingers, J., & Yang, L. (2017). Evaluating journal quality: A review of journal citation indicators and ranking in business and management. *European Journal of Operational Research*, *257*(1), 323-337.

[11]. Zhou, D., Yan, Z., Fu, Y., & Yao, Z. (2018). A survey on network data collection. *Journal of Network and Computer Applications*, *116*, 9-23.

[12]. Stieglitz, S., Mirbabaie, M., Ross, B., & Neuberger, C. (2018). Social media analytics–Challenges in topic discovery, data collection, and data preparation. *International Journal of Information Management*, *39*, 156-168.

[13]. Adolph, S., Kübler, P., Metternich, J., & Abele, E. (2016). Overall commissioning effectiveness: systematic identification of value-added shares in material supply. *Procedia CIRP*, *41*, 562-567.

[14]. Baur, D. G., & Todorova, N. (2018). Automobile Manufacturers, Electric Vehicles and the Price of Oil. *Energy Economics*.

[15]. Andersson, C., & Bellgran, M. (2015). On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity. *Journal of Manufacturing Systems*, *35*, 144-154.

[16]. Bellgran, M., & Säfsten, E. K. (2009). *Production development: design and operation of production systems*. Springer Science & Business Media.

[17]. Wiktorsson, M. (2014). Consideration of legacy structures enabling a double helix development of production systems and products. In *Technology and Manufacturing Process Selection* (pp. 21-32). Springer, London.

[18]. Eveson, S. P., & Thijssen, J. J. (2016). Pareto optimality and existence of quasi-equilibrium in exchange economies with an indefinite future. *Journal of Mathematical Economics*, *67*, 138-152.

[19]. Luo, T., Wu, C., & Duan, L. (2018). Fishbone diagram and risk matrix analysis method and its application in safety assessment of natural gas spherical tank. *Journal of Cleaner Production*, *174*, 296-304.