Overall Equipment Effectiveness (OEE) Life Cycle at the Automotive Semi-Automatic Assembly Lines

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Abstract: In the automotive industry, manufacturing companies are constantly improving and monitoring their processes with different Key Performance Indicators (KPIs) in order to achieve higher profits. One of the KPIs is the Overall Equipment Effectiveness (OEE), which represents the efficiency of the different machines and assembly lines. High OEE percentage means good performance and quality. Using Manufacturing Execution System (MES) data the OEE contributors such as availability, performance and quality are calculated and followed at the manufacturing area day by day. This paper concentrates on the entire OEE life cycle at the automotive semi-automatic assembly lines. Firstly, a literature review demonstrates scientific relevance. Secondly, the phases of OEE life cycle are revealed and presented regarding a passenger car seat structure production life cycle. Third section points at the connection between OEE percentage and maintenance, labour and quality costs at the assembly lines. In addition to the theoretical approach, real, practical data are also demonstrated based on experiences from the last fifteen years.

Keywords: KPI; OEE; MES; assembly line; life cycle; production cost

1 Introduction

Assembly is a very important process in the domain of production. Subassembly, assembly and final assembly lines are widespread and indispensable in manufacturing industries such as automotive, electronics, furniture or textile [1]. Assembly of manufactured products accounts for over 50% of the entire production time and 20% of total production cost [2].

For automotive companies, machine manufacturers and part suppliers it is inevitable to measure their assembly processes and define the level of performance at corporate level.

In the area of production, enterprises use different Indicators (I's), Performance Indicators (PI's) and Key Performance Indicators (KPI's) to monitor their efficiency. In general, I's such as number of not proper products are used at shop floor level, PI's such as scrap rate are used middle operation level and KPI's such as Overall Equipment Efficiency (OEE) are used at management level. Continuous monitoring of these metrics supports the improvement of efficiency and contributes to the achievement of higher profits.

Nowadays, a Manufacturing Execution System (MES) can provide a real-time database for production control [3], manufacturing enterprises collect shop floor data in digital format [4]. Using MES data the OEE contributors such as availability, performance and quality are calculated and followed at the manufacturing area day by day.

The aim of this paper is to reveal the phases of the OEE life cycle, to describe their charasteristics, and to examine in industrial practice the impact of OEE on production cost for semi-automatic assembly lines.

2 Product Life Cycle and OEE

There is no revealed and described long-term connection in the scientific literature between the life cycle of the product and the efficiency of the assembly of the manufactured product. This is especially true for a longer period of time.

2.1 Scientific and Practical Relevance of OEE

OEE has an extensive literature, based on the research work from Corrales et al. [5], more than 850 articles dealt with OEE between 1996 and 2020. OEE was most commonly used at individual machines or assembly lines in automotive and electronics industry [6, 7]. In addition, this indicator was used in Fast-moving consumer goods (FMCG) sector [8, 9, 10], plastic industry [11], paper and pharmaceutical industry [12], at manufacturing companies, chemical processes and continuous process production [13].

Within the framework of Total Productive Maintenance (TPM), Overall Equipment Effectiveness (OEE) indicator was introduced in 1988 by Nakajima [14]. The basic formula for calculating OEE is written as:

$$OEE = a\,p\,q \quad [\%] \tag{1}$$

Where:

a: availability,

p: performance,

q: quality.

OEE indicator shows the reliability of the production network [15] and unleash the hidden capacity [16]. This metric is a productivity ratio between the real manufacturing output and what could be ideally manufactured [17]. For the same planned production period at the assembly line:

$$OEE = \frac{Product_a}{Product_{ta}} \; [\%] \tag{2}$$

Where:

$Product_a$: assembled products [unit],

$Product_{ta}$: theoretically assemblable products [unit].

Beside the optimal circumstances the availability rate should be greater than 90%, the performance rate greater than 95% and the quality rate greater than 99%. According to this conditions, OEE percentage should be greater than 84.6% [14]. The excellent OEE values in the following areas were determined by Hansen [18]:

- batch type production: OEE > 85%
- discrete process: OEE > 90%
- continuous process: OEE > 95%.

Based on the original OEE approach several efficiency metrics are used in the production and assembly areas such as Overall Plant Effectiveness (OPE) [19], Overall Factory Effectiveness (OFE), Overall Throughput Effectiveness (OTE) [20], Overall Resource Effectiveness (ORE), Overall Line Effectiveness (OLE) [21], Overall Equipment Efficiency of a Manufacturing Line (OEEML) [17], Overall Asset Effectiveness (OAE), Production Equipment Effectiveness (PEE), Total Equipment Effectiveness Performance (TEEP) [22], Global Process Effectiveness (GPE) [23], Machine Utilization (MU), Capacity Utilization (CU) and Sustainable Overall Throughput Effectiveness (SOTE) [24].

Hossain and Sarker published an evaluation of the usability of OEE and made a comparison (advantages and drawbacks) between the existing methods for calculating OEE [25]. Ales et al. described different OEE calculation methods in serial, parallel and combined machine systems in the production lines [26]. According to Parihar, Jain and Bajpai OEE has a beneficial effect on equipment, personnel, process and quality [6]. Although the basic OEE, generally cannot be used at an unbalanced production line [12], the application of the OEE indicator has many advantages. For example, it helps increase productivity, reduce scrap rate, extend equipment lifetime, decrease labour cost, improve process efficiency and improve the process stability.

2.2 Product Life Cycles

In the science literature the term of product life cycle (PLC) is well known that refers to the length of time from the market analysis until the product runs out from the market. The chart of product life cycle (Figure 1) was published at first in 1965 by Levitt [27]. The four stages of product life cycle as market development, growth, maturity and decline are still determining and relevant elements in the fields of marketing and economy. Initially, the term of PLC was used in business environment. The production of goods is always linked to manufacturing or assembly processes thus the efficiency of these processes is important. Product and service life cycles are widely used models.

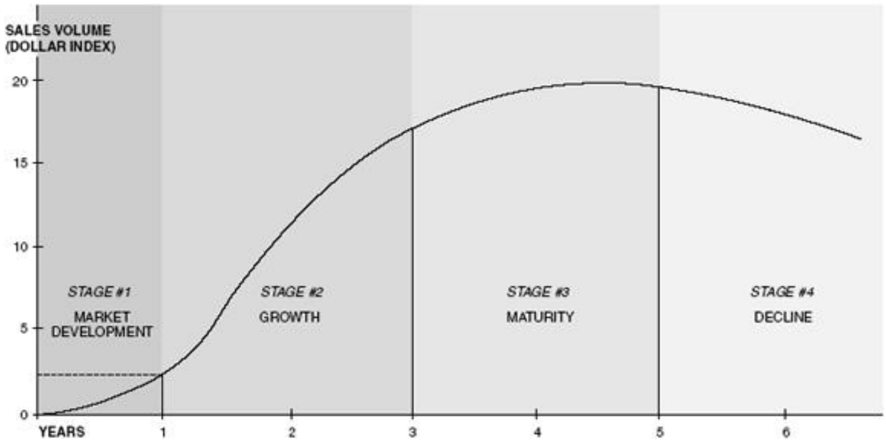

Figure 1
Product life cycle [27]

In terms of today's trends manufacturers are facing several challenges such as shortening of product life cycles and growing product complexity [28]. Product Lifecycle Management (PLM) was introduced after 2000 and has a focus on market analysis, product design, product distribution, aftermarket, service and product recycling [29]. PLM is a holistic strategic business solution which includes among others the product's manufacturing phase, such as the process planning, production planning, components production and assembly [30]. Figure 2 shows the position of production in the entire product life cycle.

PLM normally applies Computer Aided Design (CAD) and Product Development Management (PDM) softwares their purpose is to manage products across their lifecycle [31]. Data-driven strategies support the enterprises to optimize their performance by collecting and analysing data through the whole product life cycle [32]. The entire product life cycle can be divided into three parts, beginning of life, middle of life and end of life, each part has special characteristics from the view of design, maintenance, production and customer [33]. The next chapter describes the combination of OEE and life cycle at the semi-automatic assembly lines.

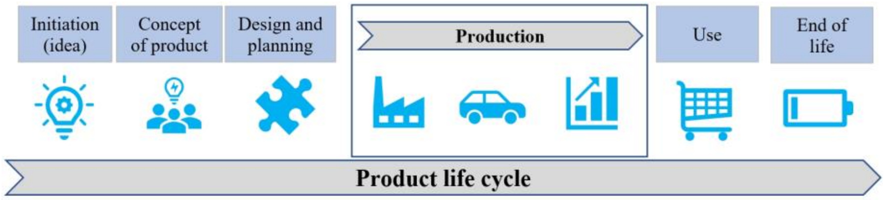

Figure 2
Production in the product life cycle

3 OEE Life Cycle in the Mass Production at the Semi-Automatic Assembly Lines

The value of OEE changes continuously within a given period, in a favourable case it shows an increasing trend or a trend with high-level stability. Even in the case of stable assembly processes, there may be more or less OEE fluctuations due to the turbulent environment such as not planned machine downtimes, missing raw material, volume changes, short-term customer orders, work shift pattern changes, etc. In the practice, OEE values of two consecutive identical periods (e.g., week, month) are in most cases different.

3.1 OEE Life Cycle as a Concept

In the science literature several articles can be found, which present different methods, analysis to improve OEE, although these research works refer to just a short time or a maximum of one year. During this period generally an improvement can be seen, but the whole impact on the entire product life cycle of the taken actions is not visible. Therefore, it is essential to define the term of OEE life cycle. In the assembly domain, OEE life cycle is a series of percentage values during an examined period from the first assembled product until the last assembled unit. The first assembled product means the first unit produced whether it is good or scrap. The last product means the last assembled unit at the assembly line. After this unit there is no serial assembly, only small batch sized aftersales production occurs when needed. OEE life cycle contains every OEE value, which is calculated during the entire assembly period.

The figures used in the following sections are data collected by the authors involving a Middle-European manufacturer and published data are not scaled with a factor.

3.2 Practical OEE Life Cycle at an Assembly Line

Nowadays, more and more modern assembly lines are manufactured based on the concept of modular system for higher flexibility. The traditional lines were designed for a fixed time. In this chapter, a traditional semi-automatic automotive assembly lines are examined. Passenger car metal seat structures are assembled en masse production volume. Figure 3 shows the position of final assembly processes in the production system.

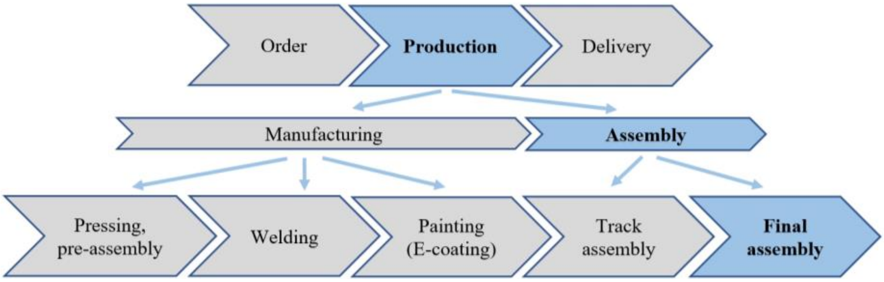

Figure 3
Position of final assembly process in the production system

Semi-automatic final assembly lines consist of:

- manual assembly stations (assembly process by human)
- automatic assembly stations (assembly process by machine)
- test stations (automatic function checking)
- conveyor (transport system station to station)
- repair station (for rework or tear down)
- quality checking stations (visual and function checking)
- packaging station (prepare to delivery)

All stations are connected in one network and Manufacturing Execution System (MES) gathers all relevant data which are necessary to calculate OEE percentage values. Data processing is a part of daily business and the method to collect availability, performance and quality data has not changed for years except the increasing processing speed. On the assembly lines the main products have not changed only the different variants. This does not influence the cycle times and OEE values significantly. Due to the continuity, reliability and digital form of the data, the entire OEE life cycle is representable (Figure 4).

Figure 4 depicts the theoretically ideal OEE condition where the values are always 100%, although this percentage can be a goal but economically not feasible. Reasonable target could be the 85% OEE value after the start of the production (SOP). Besides these target values real OEE percentages of an automotive semi-automatic assembly line are depicted from 2014 until end of 2020. In order to interpret the entire OEE life cycle in more detail, we need to separate the data into different phases.

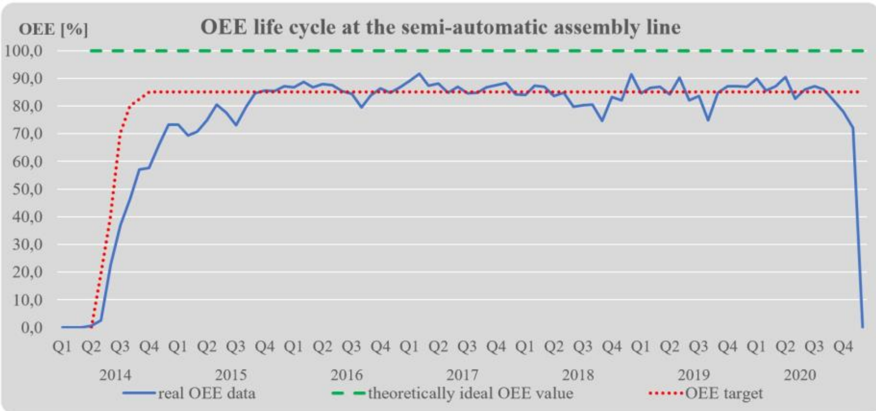

Figure 4

OEE life cycle at the semi-automatic line

Based on Figure 5 the OEE life cycle has the next three main phases:

- ramp-up phase
- effective productive phase
- run-out phase

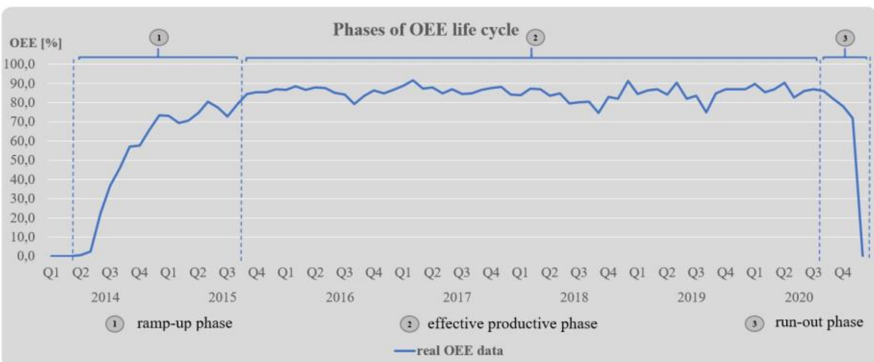

Figure 5

Phases of OEE life cycle cycle

The efficiency of product assembly varies over time. The individual sections are separable from each other and have a specificity from the view of OEE. The ramp-up phase begins with the first assembled unit and ends when the OEE percentage at first reaches the planned OEE target (e.g. 85%). Effective productive phase starts with the end of ramp-up section and ends when the monthly average OEE value:

- is reduced by 30% in two months, or
- from the beginning of productive phase, the standard deviation is above 10% for three months

These values are derived from the real data of several assembly lines and manufactured products. Run out phase starts with the end of effective production phase and ends when the last unit was assembled.

Ramp-up phase:

- after SOP the OEE is rising steeply, the degree of slope depends on the experience of the production team and the process complexity (in the case of similar second assembly line the improvement is faster)
- increasing produced volume with increasing OEE value
- the training should be effective and as long as necessary, but not too long
- it is typical to set up the second and third shifts, at the start of them the OEE falls slightly back

Effective productive phase:

- longest period during the entire OEE life cycle
- stable OEE section, small fluctuation with known and identified reasons
- during the assembly activities, focus on the continuous improvement process (Lean management, Six Sigma, TPM, etc.) which results OEE improvement
- high volume supports high OEE value (less change over, faster set up times)
- quality awareness and sensitivity supports the quality component of OEE
- full capacity utilization (focus on the continuous production, full speed, less planned downtime)

Run-out phase:

- it is a short planned period with low produced quantity
- decreasing OEE values, focus moves toward other area
- reduced resources (e.g. reduced staff)
- the focus is not on the efficiency but on aftermarket activities

In the industrial practice higher product variety leads to shorter life cycles and smaller production volume. Shorter product life cycle means shorter OEE life cycle. Figure 6 shows an existing assembly line OEE life cycle with the distribution of monthly ordered quantities.

$$pMOQ = \frac{MOQ}{TOV} \quad [\%] \tag{2}$$

Where:

pMOQ: percentage of monthly ordered quantities [unit],

MOQ: monthly ordered quantities [unit],

TOV: total ordered volumen during the entire life cycle [unit].

Figure 6

Product life cycle and distribution of monthly ordered quantities

According to Figure 6 the value of OEE is independent of the monthly ordered volumen, however at the ramp-up and the beginning of the effective production phase there are positive correlation between the data of ordered quantities and OEE. Analysing a number of assembly-lines it is recognizable that the OEE value can be high and stable regardless of the delivered or sold quantities. In the industrial practice increasing demands encourages and motivates the entire organization to reach higher efficiency and productivity.

3.3 Typical OEE Life Cycles at the Automotive Semi-Automatic Lines

After detailed examination of several similar automotive semi-automatic assembly lines, OEE life cycles are different but the same above introduced phases – such as ramp-up, effective productive and run-out sections – can be identified. Figure 7 shows OEE life cycle diagrams of six different assembly lines.

Since 2004 until end of 2020 from six assembly lines in three cases (Figure 7 b, c, d) stopped the production, in two cases (Figure 7 a, e) the lines are going to stop within three months, in the remaining case (Figure 7 f) the assembly will stop within six months.

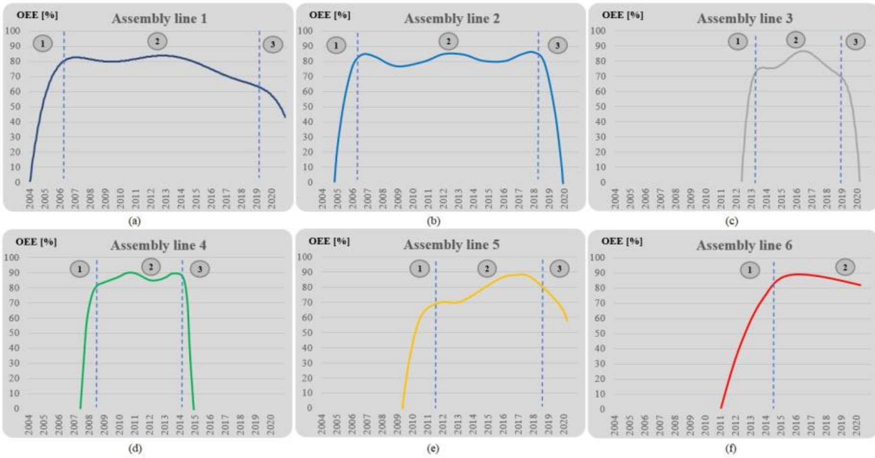

Figure 7
OEE life cycles of different assembly lines with three phases
(1 – rump-up, 2 – effective productive, 3 – run-out)

Knowing the underlying manufacturing and assembly processes of each life cycle, it is easier to determine the expected OEE value. For example, for high quality products, the ramp-up phase can be longer, while a faster ramp-up can be expected when starting a second or third similar assembly line. In case of relocation of an entire assembly line the ramp-up section will be short, furthermore the effective production phase will be balanced and accurately predictable. At complex assembly lines the standard deviation range of OEE is wider, while lines with a simple structure have a narrower one.

3.4 OEE Impact at the Production Costs

With stably high OEE values, unit costs are constantly decreasing during at all stages of OEE life cycle. Figures 8, 9 and 10 show an example of the three OEE contributors:

- maintenance cost regarding availability (Figure 8), percentage shows the values of quotient of maintenance costs and net sales,
- labour cost regarding performance (Figure 9), percentage shows the values of quotient of labour costs and net sales,
- quality cost (Figure 10) percentage shows the values of quotient of quality costs and net sales.

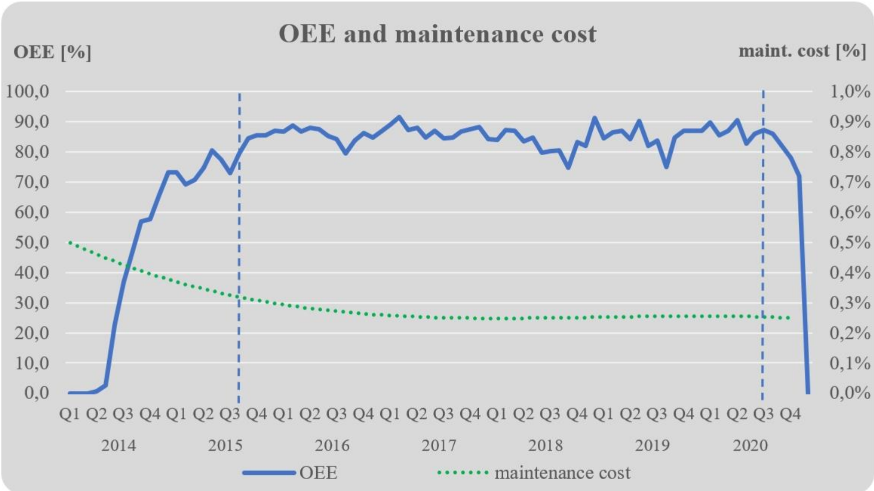

Figure 8
Maintenance cost regarding availability

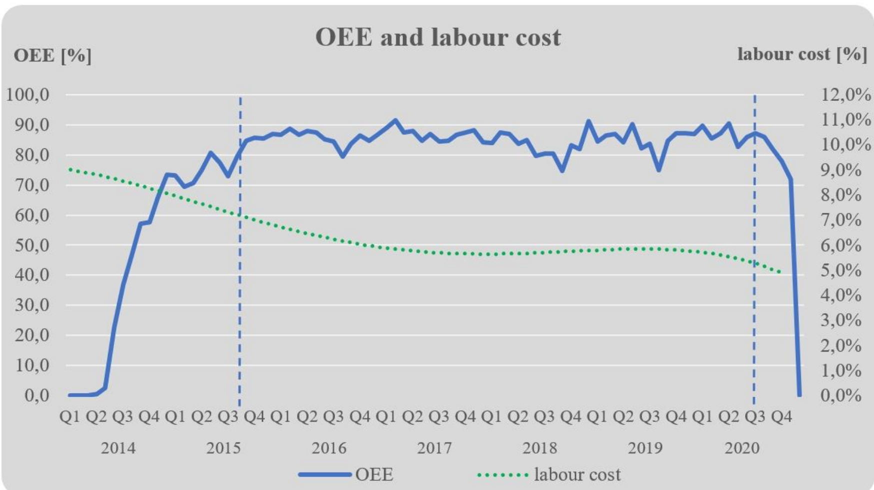

Figure 9
Labour cost regarding performance

Figure 10
Quality cost

At the ramp-up phase all cost types are higher in percentage rate. At the effective production section these costs are continuously decreasing due to systematic improvement processes. The lowest cost rates are in the run-out phase for the following reasons:

- further long-term expensive maintenance activities are not needed,
- assembly line operating with minimal but trained workers,
- rework and other sorting operations ended.

Conclusions

In this article the OEE life cycle was defined based on a series of percentage values during an examined period from the first assembled product until the last assembled unit. This OEE life cycle was placed in the product’s manufacturing life cycle. The product’s entire manufacturing OEE life cycle was divided into three main sections and named as the ramp-up phase, effective productive phase and run-out phase.

Characteristic features for each phase were described. Analysing a number of assembly lines it is recognizable that the OEE value can be high and stable regardless of the ordered quantity. Different product’s OEE life cycles were presented based on real MES data with similar structure from 2004 until end of 2020. In the case of passenger car seat structure semi-automatic assembly line OEE values were compared to unit cost elements. During the OEE life cycle the maintenance costs, labour costs and quality cost shows continuously decreasing trends with stably high OEE values. It could be a topic of further research to analyse different technical PI’s for better OEE prediction and improvement.

References

[1] T. L. Nguyen, M. T. Le, T. T. T. Vu, N. H. Do, Lean line balancing for an electronics assembly line, Procedia CIRP 40 (2016) pp. 437-442

[2] H. ElMaraghy, W. ElMaraghy, Smart Adaptable Assembly Systems, Procedia CIRP 44 (2016), pp. 4-13

[3] B. Denkena, M. A. Dittrich, S. Wilmsmeier, Automated production data feedback for adaptive work planning and production control, Procedia Manufacturing 28 (2019), pp. 18-23

[4] M. Subramaniyan, A. Skoogh, H. Salomonsson, P. Bangalore, J. Bokrantz, A data-driven algorithm to predict throughput bottlenecks in a production system based on active periods of the machines, Computers & Industrial Engineering 125 (2018), pp. 533-544

[5] L. C. Corrales, M. P. Lambán, M. E. H. Korner, J. Royo, Overall Equipment Effectiveness: Systematic Literature Review and Overview of Different Approaches, Applied Sciences 10 (2020) p. 6469

[6] S. Parihar, S. Jain, L. Bajpai, Calculation of OEE for an Assembly Process, Internal Journal of Research in Mechanical Engineering and Technology 2 (2) (2012), pp. 25-29

[7] K. E. Chong, K. C. Ng, G. G. G. Goh, Improving Overall Equipment Effectiveness (OEE) through Integration of Maintenance Failure Mode and Effect Analysis (Maintenance-FMEA) in a Semiconductor Manufacturer: A Case Study, IEEE International Conference on Industrial Engineering and Engineering Management, Singapore (2015), pp. 1427-1431

[8] M. Mainea, L. Duta, P. C. Patic, I. Caciula, A method to optimize the Overall Equipment Effectiveness, IFAC Proceedings (2010), pp. 237-241

[9] M. Jasiulewicz-Kaczmarek, T. Bartkowiak, Improving the Performance of a Filling Line Based on Simulation, IOP Conference Series: Materials Science and Engineering 145 (2016)

[10] A. A. U. Nugeroho, G. R. Prabandanu, R. Nuryadin, E. Rimawan, Effectiveness Analysis of Soehnel L1 Machine Using Overall Equipment Effectiveness (OEE) Method in PT PQR, International Journal of Innovative Science and Research Technology 3 (9) (2018), pp. 296-300

[11] R. Hedman, M. Subramaniyan, P. Almström, Analysis of critical factors for automatic measurement of OEE, Procedia CIRP 57 (2016) pp. 128-133

[12] F. D. Carlo, M. A. Arleo, M. Tucci, OEE Evaluation of a Paced Assembly Line through Different Calculation and Simulation Methods: A Case Study in the Pharmaceutical Environment, International Journal of Engineering Business Management 6 (2014), pp. 1-11

[13] S. Zandieh, S. A. N. Tabatabaei, M. Ghandehary, Evaluation of Overall Equipment Effectiveness in a Continuous Process Production System of Condensate Stabilization Plant in Assalooyeh, Interdisciplinary Journal of Contemporary Research in Business 3 (10) (2012), pp. 590-598

[14] S. Nakajima, Introduction to TPM: Total Productive Maintenance, Cambridge: Productivity Press, 1988

[15] J. Oliveira, J. C. Sa, A. Fernandes, Continuous Improvement through 'Lean Tools': An Application in a Mechanical Company, Procedia Manufacturing 13 (2017), pp. 1082-1089

[16] M. Subramaniyan, Production Data Analytics – To identify productivity potentials, Chalmers University of Technology, Gothenburg, Sweden, 2015

[17] M. Braglia, M. Frosolini, F. Zammori, Overall equipment effectiveness of a manufacturing line (OEEML): an integrated approach to assess systems performance, Journal of Manufacturing Technology Management 20 (1) (2008), pp. 8-29

[18] R. C. Hansen, Overall Equipment Effectivness: A powerful production / maintenance tool for increased profits, New York: Industrial Press, 2001

[19] J. R. Brandt, G. Taninecz, Capacity utilization, Glass in It Style, 1 (1) (2005), pp. 10-18

[20] K. M. N. Muthiah, S. H. Huang, Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection, International Journal of Production Research 45 (2007), pp. 4753-4769

[21] N. Anantharaman, R. M. Nachiappan, Evaluation of overall line effectiveness (OLE) in a continuous product line manufacturing system, Journal of Manufacturing Technology Management 17 (7) (2006), pp. 987-1008

[22] I. Ivancic, Development of maintenance in modern production, Euromaintenance '98 Proceedings, 14th European Maintenance Conference, Croatia, 1998

[23] R. Oliveira, S. A. Taki, S. Sousa, M. A. Salimi, Global Process Effectiveness: When Overall Equipment Effectiveness Meets Adherence to Schedule, Procedia Manufacturing 38 (2019), pp. 1615-1622

[24] O. Duran, A. Capaldo, P. A. D. Acevedo, Sustainable Overall Throughputability Effectiveness (S.O.T.E.) as a Metric for Production Systems, Sustainability 10 (2) (2018), pp. 1-15

[25] M. S. J. Hossain, B. R. Sarker, Overall Equipment Effectiveness measures of engineering production system, Paper presented at the Annual Meeting of the Decision Sciences Institute, Austin, Texas, 2016

[26] Z. Aleš, J. Pavlů, V. Legát, F. Mošna, V. Jurča, Methodology of Overall Equipment Effectiveness Calculation in the Context of Industry 4.0 Environment Ekspolatacja i Niezawodnosc - Maintenance and Reliability 21 (3) (2019), pp. 411-418

[27] T. Levitt, Exploit the Product Life Cycle, Harvard Business Review, 1965

[28] E. Permin, F. Bertelsmeier, M. Blum, J. Bützler, S. Haag, S. Kuz, D. Özdemir, Self-Optimizing Production Systems, Procedia CIRP 41 (2016), pp. 417-422

[29] J. Stark, Product lifecycle management, London, Springer, 2011

[30] P. Haydaya, P. Marchildon, Understanding Product Lifecycle Management and Supporting Systems, Industrial Management and Data Systems 112 (4) (2012), pp. 559-583

[31] H. ElMaraghy, G. Schuh, W. ElMaraghy, F. Piller, P. Schönsleben, M. Tseng, A. Bernard, Product Variety Management. CIRP Annals 62 (2) (2013), pp. 629-652

[32] D. Mourtzis, E. Vlachou, N. Milas, Industrial Big Data as a Result of IoT Adoption in Manufacturing, Procedia CIRP 55 (2016), pp. 290-295

[33] J. Li, F. Tao, Y. Cheng, L. Zhao, Big data in product lifecycle management, The International Journal of Advanced Manufacturing Technology 79 (2015)