Overall Equipment Effectiveness (OEE) Complexity for Semi-Automatic Automotive Assembly Lines

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Abstract: In industrial practice, measuring and monitoring production performance is an essential task. The production plan performance is monitored by middle and top management of companies daily, weekly and monthly and make short and long-term operational and strategic decisions when necessary. One of the most common ways of measuring the performance of production and, within this, of assembly lines, is to use the Overall Equipment Effectiveness (OEE) indicator. Although companies sometimes interpret and use this Key Performance Indicator (KPI) in their own way, it is the indicator that best reflects the development of the production efficiency for a given company. A high OEE percentage means high performance, which directly increases the company's profitability. This article explores the complexity of the OEE indicator, supported by the use of a cause and effect diagram. Firstly, a literature review demonstrates scientific relevance. Secondly, the factors affecting OEE are grouped and analyzed according to the following six aspects: man, environment, method, material, machine, and measurement. Each factor is further subdivided into five groups, and then these subgroups also cover five key factors of importance for the approachability of 100% OEE. The 150 aspects listed herein, provide a complete guideline for a semi-automatic assembly line, to consistently increase efficiency in industrial practice.

Keywords: KPI; OEE; assembly line; cause and effect diagram

1 Introduction

Today's automotive manufacturing environment is becoming increasingly complex thanks to Industry 4.0, Smart manufacturing, Big Data, Artificial Intelligence, Lean, IoT, among others. Production logistics systems are becoming increasingly complex in a turbulent industrial environment [1]. Efficiency and flexibility on the part of manufacturing companies are particularly important especially due to periodic shortages of raw materials (e.g. semi-conductor, chip, metal, plastic) and other constraints (e.g. COVID situation).

The complex environment also adds complexity to performance indicators. The efficiency of production systems, including assembly lines, is increasingly effected by a number of components, both positively and negatively. Modularity, flexibility, digitalization, automation, autonomous processes, autonomous systems, autonomy of an equipment [2], cloud computing help to achieve higher efficiency and productivity, while higher product variety, growing product complexity, shortening product life cycle [3] and complex material flow hinder [4]. Increasingly, the question of efficiency arises: which scopes should be assembled in the final assembly and which ones in the pre-assembly line [5]?

In industrial practice, measuring and monitoring production performance is an essential task. The production plan performance is monitored by middle and top management of companies daily, weekly and monthly and make short and long-term operational and strategic decisions when necessary. One of the most common ways of measuring the performance of production and, within this, of assembly lines is to use the Overall Equipment Effectiveness (OEE) indicator. Although companies sometimes interpret and use this KPI in their own way, it is the indicator that best reflects the development of the production efficiency of a given company. Key Performance Indicators (KPIs) or also known as Key Success Indicators (KSIs) are quantitative measurement tools for the improvement of the machine or line performance [6]. A high OEE percentage means high performance, which directly increases the profitability of the company.

The aim of this paper is to reveal the complexity of OEE using cause and effect diagram. The paper is organized as follows. Section 2 focuses on the relevant scientific work regarding to OEE and cause and effect diagram. Following, Section 3 introduces and details the OEE complexity at a semi-automatic assembly line in automotive industry by fishbone diagram. Last section, Section 4, concludes the paper.

2 Literature Review

Higher expectations of the customers' and new industrial and IT developments have resulted is an increased complexity of Production System (PS) especially assembly systems [7] [8]. This also implies the complexity of the performance evaluation system. Okwir et al. define the following six forms of Performance Measurement Complexity (PMC): role, task, procedural, methodological, analytical and technical complexity [9].

Nowadays, the traditional Key Performance Indicator (KPI) system is still well managed due to the Manufacturing Execution System (MES) [10], but further increasing the efficiency indicators such as Overall Equipment Effectiveness (OEE) is not a simple task in practice. It is becoming increasingly difficult to take real measures that will lead to significant improvements in the short term. Problems almost always have multiple root causes and this complexity is also increased especially at the hybrid assembly lines where automatic devices are combined with manual work in one system [11].

2.1 OEE at the Semi-Automatic Line

A plethora of publications shows the applicability of OEE in the domain of manufacturing [12], Corrales et al. collected almost 900 articles between 1996 and 2020 [13]. This standard indicator is widely used for internal efficiency at the semi-automatic assembly lines [14]. Within the concept of Total Productive Maintenance (TPM), OEE metric was introduced in 1988 by Nakajima [15]. The original formula for calculating OEE is written as:

$$OEE = A\ P\ Q \quad [\%] \qquad (1)$$

Where:

A = Availability

P = Performance

Q = Quality

100% OEE means, that we exclusively produce high-quality products without stop at maximal capacity, although there are no machines with 100% reliability [16]. During the last few decades several performance indicators and techniques are developed from the basic OEE structure [17] among others: Overall Equipment Effectiveness of a Manufacturing Line (OEEML) [18] and Global Production Effectiveness (GPE) [19].

OEE can be characterized by the following items:

- Metric which shows the reliability of the production network [20]
- OEE is a mechanism to continuously monitor and improve the efficiency of a production processes, focus on zero loss, zero break downs, zero defects and zero accidents [21-23]
- Clearly shows current status of production [24] [25]
- Standard and best practice, can be used to compare with the other assembly line performance during the operation [26]
- Reduce or eliminate six major losses (equipment breakdown losses, setup and adjustment losses, minor stoppage losses, speed reduction losses, defective losses and startup losses) [15, 27] and increase efficiency in the production processes [28].

From other perspective, availability is influenced by the technical failures of workstations and changeover, performance is influenced by small stops and reduced speed, quality is influenced by scrap and rework [29]. Real example of OEE analysis using the waterfall chart at an assembly line shows Fig. 1. (Source: data collected by the authors on the semi-automatic assembly line of a Hungarian automotive supplier.)

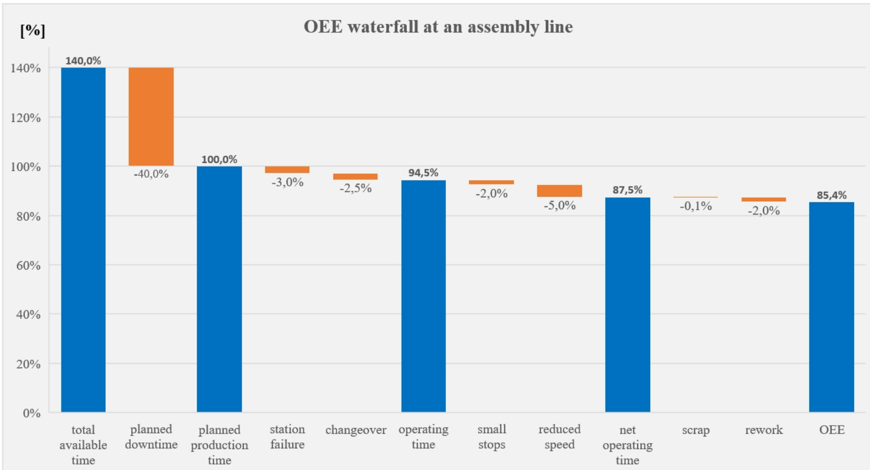

Figure 1
Real example of OEE waterfall chart at an assembly line

The main benefits of implementing and applying OEE are the reduced manufacturing cost, increased uptime, higher speed, minimalized material waste, better asset utilization, lower overhead cost, additional sales capacity, reduced inventory and reliable assembly processes [30]. At an assembly line at least one of the workstations is the bottleneck. This article focus on this bottleneck station regarding OEE.

2.2 Cause and Effect Diagram

In manufacturing industry huge losses and/or waste occur in the production shop floor. These losses due to operators, maintenance personnel, process, tooling problems and lack of components in time, etc. [31]. In case of capacity problems, increasing overtime and shift numbers, purchasing new machines, equipment and tools can be a solution to fully meet customer demands, but a much better alternative is to make better use of existing resources, increase machine efficiency, keep bottlenecks under control, and reduce downtime and set-up times.

To decrease losses, several quality management concepts and tools such as Lean Manufacturing, Toyota Production System (TPS), Total Productive Maintenance

(TPM), and Failure Mode and Effect Analysis (FMEA) had been developed in order to achieve higher operational level. There are numerous quality improvement techniques available for improving equipment OEE among others as PDCA cycle, Failure Tree Analysis (FTA), why-why analysis, Value Steam Mapping (VSM), RADAR, DMAIC, EFQM, DFSS, Pareto chart and cause and effect diagram [32] [33].

Cause and effect diagram, Ishikawa or fishbone diagram is one of the seven tools in the quality control system. Firstly, it was presented as a casual diagram by Ishikawa in 1968 [34]. Fishbone diagrams have been constructed mostly based on the categories of man, machine, method, material measurement and environment. Ishikawa diagram is a useful tool to determine the possible causes for a problem, represents the relationship, but it directly does not identify the root causes of the problems [35] [36]. According to Czifra et al. Ishikawa diagram is the most used method on a regular basis in automotive industry in addition to FMEA, 8D, and 5 Why analysis [37].

In the manufacturing industry, several cause and effect research works were published related to OEE. Table 1 shows the articles over the last six years.

Table 1
List of used cause and effect diagrams for improving OEE

Author	Year	Ishikawa elements	Effect on OEE
[38]	2015	manpower, material, methods, milieu, machine	process deviation
[39]	2016	man, machine, material, method, environment	technical failure (part clamping)
[39]	2016	man, machine, material, method, environment	technical failure (hydraulic oil is mixed up with cutting oil)
[40]	2016	environment and social, lead time, machine, management, quality issues, man	poor OEE
[41]	2017	waiting, extra-processing, defects, workforce, environment	low performance
[35]	2017	man, machine, material, measure, management, environment	idling and minor stoppage losses
[35]	2017	man, machine, material, measure	breakdown losses
[36]	2017	man, machine, material, measure, management, environment	idling and minor stoppage losses
[36]	2017	man, machine, material, measure	breakdown losses
[42]	2017	people, work method, environment	technical failure (limit switches failure)

[43]	2018	man, environment, machine	technical failure (overheating of electric motors]
[44]	2018	equipment failure, reduced speed, defect and rework, setup and adjustment, idling and minor stoppage, startup issue	reduced OEE
[45]	2018	method, human, material, machine	low OEE value
[46]	2018	atmosphere, method, man, material, machine	reduce OEE
[47]	2019	machine, man, method, material, measurement	six big losses
[48]	2019	machine, man, method, material, environment	reduced speed losses
[48]	2019	machine, man, method, material, environment	rework losses
[48]	2019	machine, man, method, material, environment	breakdown losses
[49]	2019	method, material	process cycle efficiency
[50]	2020	machine, man, environment, material, method	idling and minor stoppage losses

3 Complexity of Overall Equipment Effectiveness

The complexity of the OEE indicator on assembly lines is best represented by a cause and effect diagram. The areas of man, environment, method, material, machine and measurement, fully cover the conditions that have to be fulfilled for the OEE indicator to be 100% (Fig. 2).

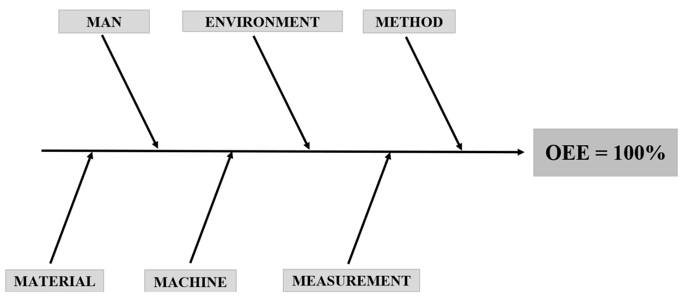

Figure 2
Elements of cause and effect diagram

Each of the six elements is described in detail below in case of the semi-automatic assembly lines.

3.1 Man as a Key Element

In case of hybrid lines, the human is a key factor, as a certain percentage of assembly operations are physically carried out by humans. In addition to work operations, machine set-up, quality control operations, some material handling and operational management are also performed by human beings. The human factor manifests itself in five major areas:

- **Qualification:** Typically determined by the operator's, setter's education, special knowledge for the assembly task, practical experience, internal and external training
- **Skills and abilities:** Workers and machine adjusters must have proper perceptions (eyesight, hearing) to fulfill the assembly and machine setting processes, another important factor is fine motor skills, stamina and communication skills (e. g. be able to indicate the problems properly)
- **Personality and character:** For right assembly operations punctuality, adequate speed, compliance, monotony tolerance and systematic, conscientious work is needed
- **Motivation:** Maximum efficiency can be achieved based on pre-defined goals, need the expectations of employee, crucial factor the rewards and condemnations, management must ensure the team spirit, company welfare and excellent work conditions
- **Organization:** The most critical factor is the available staff (right person in the right workplace), within the factory the continuous improvement activities are indispensable, manufacturing and assembly processes should be supported by the leaders, engineers and managers, scheduling and production planning are also significant elements.

Fig. 3 depicts the role of the Man factor in the cause and effect diagram.

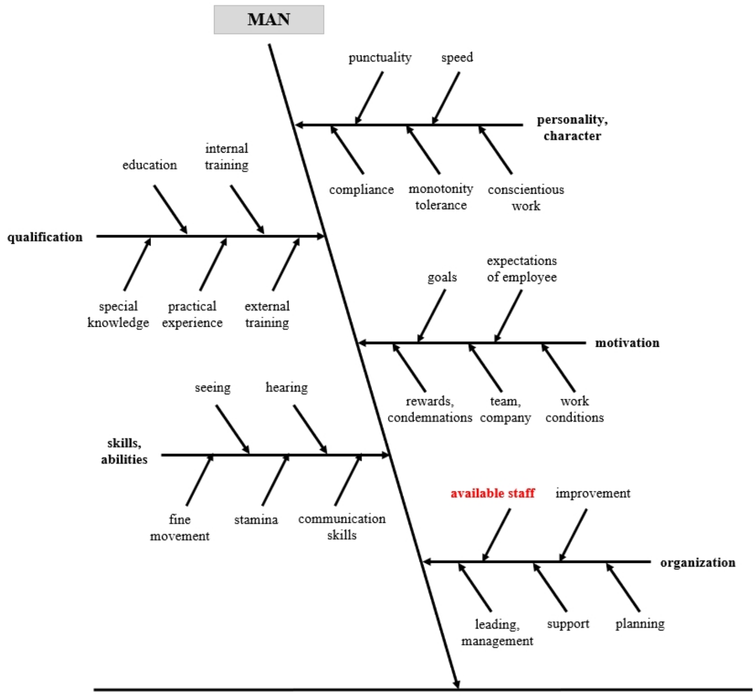

Figure 3
Role of the Man factor in cause and effect diagram

3.2 Environment of Assembly Operations

The manufacturing environment for semi-automatic assembly lines or hybrid lines is extremely complex. Several assembly operations take place simultaneously, the steps of the process are built on each other, and in the case of a one-piece material flow, it is essential to serve the production with raw materials and semi-finished products in time. Companies have to adapt to changing market needs (batch size, product variety) in a number of ways. This requires a thorough understanding of the following 5 key environmental factors:

- **Work environment:** The direct working environment of the assembler, which includes safety and health protection, ergonomic design of workstations, correct perception of the environment and automation of machinery
- **Production environment:** The correct execution of assembly workflows is ensured by technological complexity and concerns, the 5S design of the manufacturing environment, lossless assembly processes and visual support

- **Market environment:** The turbulent market environment includes, on the customer side, the intensity of orders, the state of competition in the market, the pull system, and on the supplier side, the production plan feasibility and, as main factors, the cycle time and cycle time feasibility of assembly operations
- **Company environment:** Within manufacturing companies the production team organization is important, as well as to define the appropriate shift schedule with necessary overtime, employees need to be motivated, committed and engaged
- **Worker environment:** Operator and setter social situation and social acceptance (be able and want to work in that position), easy plant and workplace availability, preferred benefit package.

Fig. 4 shows the role of the Environment factor in the fishbone diagram.

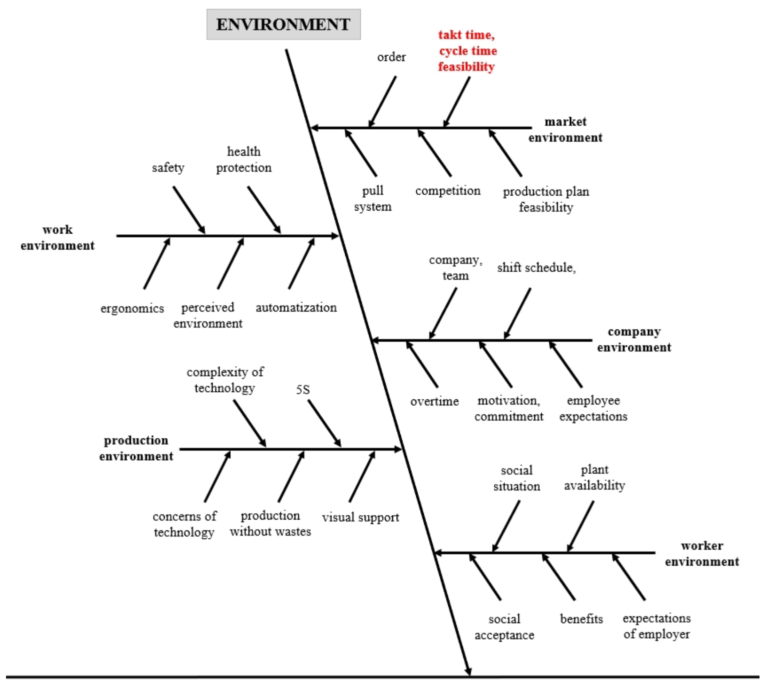

Figure 4

Environment factor in fishbone diagram

3.3 Methods to Achieve the Set Goals

The methods, especially the practical methods, show the way to achieve a high OEE percentage on a semi-automatic assembly line. There is no single method to achieve 100% efficiency, either in the short or long term. On the contrary, a combination of well-chosen procedures and processes can bring you closer to the desired result. In the case of OEE, the following five main groups of methods need to be examined:

- **Production technology:** The most important category is the properly designed assembly technology and processes, it pays attention to repair, rework checking, packaging processes with necessary automation
- **Measurement and control:** During the assembly operations, the quality of the product and the correctness of manufacturing processes must be constantly monitored, aided by the 100% inspection, SPC control, six sigma method, failure analysis, PDCA cycle, Pareto analysis, Poka-yoke and the check of prescriptive maintenance activities
- **Work process:** Relevant factor the predefined Standard Operational Procedures (SOP), assembly processes, material flow, applied best practices and the planned and realized cycle time
- **Lean methods:** Numerous Lean tools exist, but before using them we need to determine the goals of assembly process, the expectations by taking into account company characteristics, working conditions, team structure and reward- and motivation factors
- **Material and information flow:** Besides the workforce it is important to take into consideration the components and materials flow, besides planning, continuous development and support, the organization must also adapt to achieve loss-free assembly.

Fig. 5 shows the relationship of Methods in the Ishikawa diagram

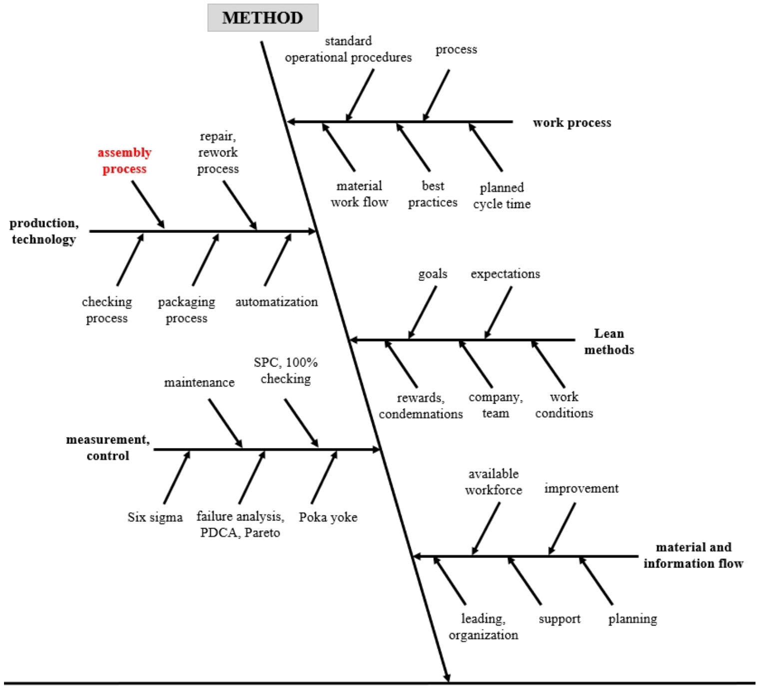

Figure 5
Relationship of Methods in the Ishikawa diagram

3.4 Material, Component, Part and Subassembly

Raw materials, auxiliary materials, semi-finished products, assemblies, sub-assemblies are essential for the operation of assembly processes. They must be available at the right time, in the right quantity, in the right order, in the right place and of the right quality. Any one of these missing will result in a significant OEE loss. A particular aspect is that the availability of components to be assembled can be taken into account in production planning and, if necessary, the production sequence can be modified to ensure continuous assembly. The following five main factors influence material complexity:

- **Material failure:** It is of paramount importance that the quality, surface and color of the materials to be incorporated, as well as the required quantity of materials, are available (problems can arise from incomplete or surplus materials during assembly)
- **Size error:** The materials used in the assembly must have the dimensions prescribed on the drawing, such as width, length, height, tolerances, defined shape and position

- **Quantitative error:** On the production lines, the right quantity of building materials must be available for assembly (not more, not less, not mixed, not interlocked)
- **Material handling:** During material handling processes, materials awaiting assembly must be protected from contamination and damage, stored at appropriate temperatures and they must be identifiable
- **Design failure:** During the design process focus should be placed on the possible function and comfort problems as well as, the ease of assembly, repair and general checking of the product.

Fig. 6 depicts the Material factor in the cause and effect diagram.

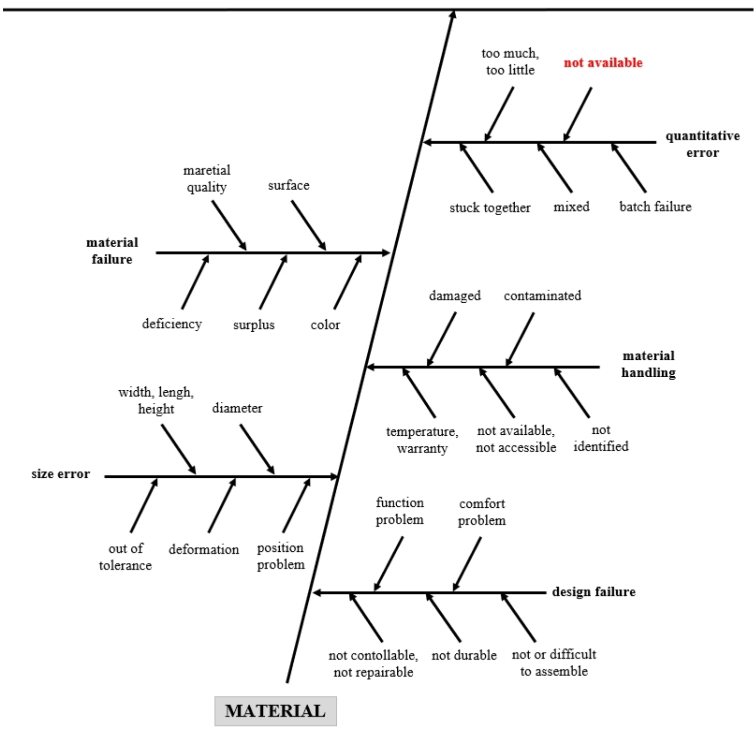

Figure 6

Role of the Material factor in cause and effect diagram

3.5 Machine, Tool and Workstation

Semi-automatic assembly lines consist of different workstations connected in series or in parallel, where mechanical and manual assembly operations are carried out. The continuous availability of modular assembly lines, machines, equipment and tools used today is complex in several respects. The five main aspects are the following:

- **Maintenance:** A maintenance plan must be drawn up and its content must be carried out in a timely and appropriate manner, the necessary documentation (drawings, manuals) must be available, machinery and tools must be easily repairable and replaceable
- **Machine and tool adjustment:** Workstations and tools must be easy to set up based on the setup instructions provided, a fault log is an essential requirement, and quick changeover during product changeovers must be ensured (using SMED and OTED)
- **Stability:** The assembly line must be stable and continuously operational with low energy consumption, supported by a reliable PC and PLC network, the degree of machine capability and process capability should be high
- **Standardization:** It is advisable to build the assembly line from standard parts for which the spare part must be continuously provided, the complete assembly line must be connected to the Manufacturing Execution System (MES) so that the installed parts and key process parameters and values are digitally recorded and stored
- **Safety:** Machinery and equipment must be safe, safe and easy to use from a safety point of view, and ergonomically designed.

Fig. 7 shows the role of the Machine factor in the fishbone diagram.

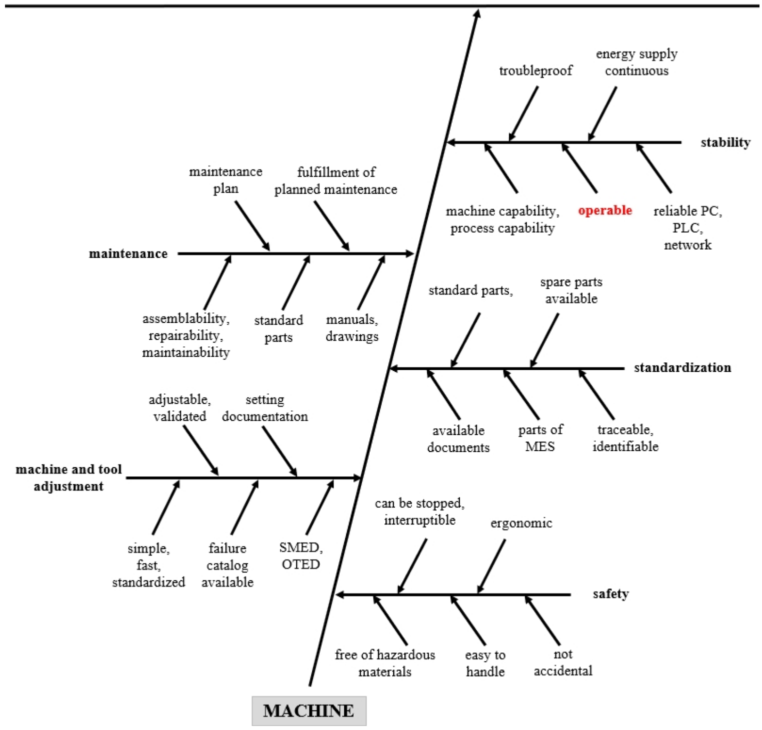

Figure 7
Machine factor in fishbone diagram

3.6 Measurement for Right Quality

The products ordered by the customer must be of the quality expected. Both the quality of the product and the quality of the processes must be measured and checked before and during production and assembly. Based on the results obtained, further interventions and corrections are possible. During measurement, the following 5 factors influence the OEE:

- **Material checking:** It is necessary to check the quantity, quality and function of the components and materials to be incorporated prior to assembly operations, preferably at the time of receipt of the goods, the traceability of materials (e.g. FIFO, batch) is also essential
- **Product control:** During assembly, the conformity of the product shall be checked and documented at the required frequency and in the required number of pieces in the defined condition and location with regard to its functional operation

- **Machine and tool checking:** Testing, checking, calibration and safety control by appropriate frequency essential at the machines and tools, in addition, the performance of maintenance should also be checked
- **Checking assembly process:** During assembly operations and type change the first and last assembled unit must be checked, in addition to these, simulation and poke yoke checks are also essential
- **Measuring instrument checking:** The measuring instruments and gauges used in production must be checked and documented at appropriate intervals for functionality, reliability and accuracy.

Fig. 8 shows the relationships of Measurement in the Ishikawa diagram

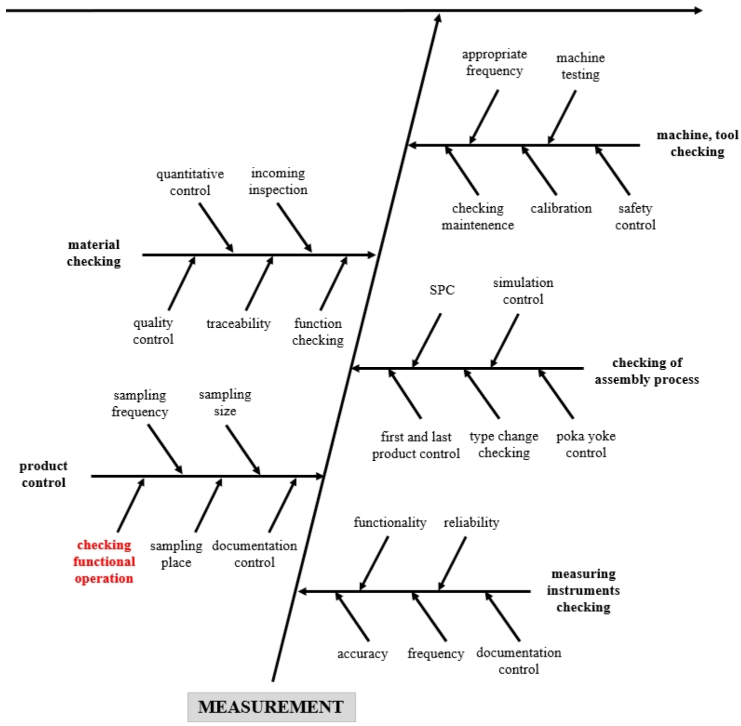

Figure 8

Relationships of Measurement in the Ishikawa diagram

In the cause and effect diagram, the most important factors for each branch have been highlighted in red, as follows:

- **Man:** Within organization, the available staff
- **Environment:** Within market environment, the Takt-time and Cycle-time feasibility

- **method:** Within production technology, the assembly process
- **material:** Within quantitative error, the not available material
- **machine:** Within stability, the operable machine
- **Measurement:** Within production control, the checking functional operation.

The authors are aware that the factors listed could be presented in much more detail, but for reasons of content, the article presents a kind of overview of how the OEE indicator can be influenced by a number of factors and how the interrelationships between factors lead to complexity on semi-automatic assembly lines.

Conclusions

In this work, the complexity of the Key Performance Indicator (KPI), used to measure the performance of a semi-automatic assembly line, has been presented. Based on a cause and effect diagram, the six main groups (man, environment, method, material, machine and measurement) were further broken down into five factors, within which, five factors were also identified. All the factors are necessary to a varying degrees, to achieve 100% OEE, but the indispensable factors are, available manpower, cycle time, cycle time feasibility, right assembly process, available material, operable machine and the checking functional operation. In the future, a further expansion of this article may apply weighting and ranking factors, presented in terms of their impact on the value of OEE.

References

[1] H. P. Wiendahl, J. Reichardt, P. Nyhuis, Handbook Factory Planning and Design, Springer-Verlag, Berlin, 2015

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

[3] 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

[4] M. Glatt, J. C. Aurich, Physical Modeling of Material Flows in Cyber-Physical Production Systems, Procedia Manufacturing 28 (2019) pp. 10-17

[5] C. Küber, E. Westkämper, B. Keller, H. F. Jacobi, Method for a Cross-Architecture Assembly Line Planning in the Automotive Industry with Focus on Modularized, Order Flexible, Economical and Adaptable Assembly Processes, Procedia CIRP 57 (2016) pp. 339-44

[6] L. M. Dawood, Z. H. Abdullah, Szudy impact of Overall Equipment and Resource Effectiveness onto Cement Industry, Journal of University of Babylon, Engineering Sciences 26 (2018) pp. 187-198

[7] 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

[8] A. Fast-Berglund, U. Harlin, M. Akerman, Digitalisation of Meetings – From White-Boards to Smart-Boards, Procedia CIRP 41 (2016) pp. 1125-1130

[9] S. Okwir, S. S. Nudurupati, M. Ginieis, J. Angelis, Performance Measurement and Management Systems: A Perspective from Complexity Theory, International Journal of Management Reviews 20, No. 3 (2018) pp. 731-754

[10] S. Mantravadi, C. Moller, An Overview of Next-generation Manufacturing Execution Systems: How important is MES for Industry 4.0?, Procedia Manufacturing 30 (2019) pp. 588-595

[11] H. P. Wiendahl, H. A. ElMaraghy, P. Nyhuis, M. F. Zäh, H. H. Wiendahl, N. Duffie, M. Brieke, Changeable manufacturing - Classification, design and operation, CIRP Annals 56/2 (2007) pp. 783-809

[12] G. Agyei, I. Asamoah, A Selection of Drill Rigs using Overall Equipment Efficiency Approach, Journal of Science and Technology Research 1, (2019) pp. 41-52

[13] 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) pp. 6469

[14] M. Kurdve, U. Harlin, M. Hallin, C. Söderlund, M. Berglund, U. Florin, A. Landström, Designing Visual Management in Manufacturing from a User Perspective, Procedia CIRP 84 (2019) pp. 886-891

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

[16] J. Dias, E. Nunes, S. Sousa, Productivity Improvement of Transmission Electron Microscopes - A Case Study, Procedia Manufacturing 51 (2020) pp. 1559-1566

[17] M. S. J. Hossain, B. R. Sarker, Overall Equipment Effectiveness measures of engineering production system, Annual Meeting of the Decision Sciences Institute, Conference Paper, 2016

[18] M. Braglia, M. Frosolini, F. Zammori, Overall equipment effectiveness of a manufacturing line (OEEML), Journal of Manufacturing Technology Management, 20 (2008) pp. 8-29

[19] 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

[20] 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

[21] G. R. Naik, V. A. Raikar, P. G. Naik, A Simulation Model for Overall Equipment Effectiveness of a Generic Production Line, Journal of Mechanical and Civil Engineering 12 (2015) pp. 52-63

[22] P. S. Sisodiya, M. Patel, V. Bansod, A literature review on Overall Equipment Effectiveness, International Journal of Research in Aeronautical and Mechanical Engineering 2 (2014) pp. 35-42

[23] K. Sowmya, N. Chetan, A review on Effective Utilization of Resources Using Overall Equipment Effectiveness by Reducing Six Big Losses, International Journal of Scientific Research in Science, Engineering and Technology 2 (2016) pp. 556-562

[24] A. J. Gujar, N. M. Kambale, S. D. Maner, S. S. Joshi, S. G. Chandne, A. A. Chavare, A case study for Overall Equipment Effectiveness improved in manufacturing industry 6 (2019) pp. 4841-4844

[25] J. Lee, E. Lapira, B. Bagheri, H. Kao, Recent advances and trends in predictive manufacturing system in big data environment, Manufacturing Letters 1 (2013) pp. 38-41

[26] S. F. Fam, S. L. Loh, M, Haslinda, H. Yanto, L. M. S. Khoo, D. H. Y. Yong, Overall Equipment Effectiveness (OEE) Enhancement in Manufacture of Elctronic Components and Boards, Industrx through Total Productive Maintenance Practices, MATEC Web of Conferences 150 (2018)

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

[28] L. Hassani, G. Hashemzadeh, The impact of Overall Equipment Effectiveness on production losses in Moghan Cable and Wire manufacturing, International Journal for Quality Research 9 (2015) pp. 565-576

[29] M. P. Rössler, E. Abele, Uncertainty in the analysis of the Overall Equipment Effectiveness on the shop floor, IOP Conference Series: Materials Science and Engineering 46 (2013)

[30] A. S. Vairagkar, S. Sonawane, Improving Production Performance with Overall Equipment Effectiveness (OEE), International Journal of Engineering Research and Technology 4 (2015) pp. 700-704

[31] K. Pradeep, S. Raviraj, L. R. R. Lewlyn, Overall Equipment Efficiency and Productivity of a News Paper Printing Machine of a Daily News Paper Company – A Case Study, International Journal of Engineering Practical Research 3 (2014) pp. 20-27

[32] M. Sokovic, D. Pavletic, K. K. Pipan, Quality improvement methodologies – PDCA Cycle, RADAR Matrix, DMAIC and DFSS, Journal of Achievements in Materials and Manufacturing Engineering 43 (2010) pp. 476-483

[33] 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, In 2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, Singapore: IEEE (2015) pp. 1427-1431

[34] K. Ishikawa, Guide to Quality Control, Tokyo (1968)

[35] N. Ahmad, J. Hossen, S. M. Ali, Improvement of Overall Equipment Efficiency of ring frame through Total Productive Maintenance: a textil case study, International Journal of Advanced Manufacturing Technology 94 (2018) pp. 239-256

[36] J. Hossen, N. Ahmad, S. M. Ali, An application of Pareto analysis and cause and effect diagram (CED) to examine stoppage losses: a textil case from Bangladesh, The Journal of the Textile Institute 108 (2017)

[37] Gy. Czifra, P. Szabó, M. Mikva, J. Vanová, Lean principles application in the automotive industry, Acta Polytechnica Hungarica 16 (2019) pp. 43-62

[38] N. Galaske, D. Strang, R. Anderl, Process Deviation in Cyber-Physical Production System, Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA (2015) pp. 1035-1040

[39] A. Greeshma, A. V. Pooja, M. V. Machaiah, T. P. Govekar, A. Balakrishna, Improvement of Overall Equipment Effectiveness of Barrel Pre-Honing Machine Line, International Journal of Research Engineering and Technology 5 (2016) pp. 40-50

[40] K. S. Arun, B. K. Kanchan, G. Prabha, D. Rajenthirajumar, Increasing an Overall Equipment Effectiveness Visibility and Analysing in a Manufacturing Industry, International Journal of Manufacturing and Material Processing 1 (2016) pp. 89-103

[41] S. F. Fam, N. Ismail, H. Yanto, D. D. Prastyo, B. P. Lau, Lean Manufacturing and Overall Equipment Efficiency (OEE) in Paper Manufacturing and Paper Product Industry, Journal of Advanced Manufacturing Technology, Special Issue iDECON (2016) pp. 461-474

[42] S. Raut, N. Raut, Implementation of TPM to enhance OEE in a medium scale industry, International Research Journal of Engineering and Technology 4 (2017) pp. 1035-1040

[43] M. Kapuyanyika, K. Suthar, To Improve the Overall Equipment Effectiveness of Wheel Surface Machining Plant of Railway Using Total

Productive Maintenance, International Journal of Scientific Research in Science and Technology 4 (2018) pp. 1860-1874

[44] A. Gedefaye, M. Alehegn, H. Bereket, Balasundaram, TPM and RCM Implementation in Textile Company for Improvement of Overall Equipment Effectiveness, International Journal of Advances in Scientific Research and Engineering 4 (2018) pp. 129-136

[45] 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, No. 9 (2018) pp. 296-300

[46] S. Nallusamy, V. Kumar, V. Yadav, U. K. Praaad, S. K. Suman, Implementation of Total Productive Maintenance to Enhance the Overall Equipment Effectiveness in Medium Scale Industry, International Journal of Mechanical and Production Engineering Research and Development 8 (2018) pp. 1027-1038

[47] D. Nusraningrum, L. Setyaningrum, Overall Equipment Effectiveness (OEE) Mesurement Analysis for Optimizing Smelter Machinery, International Journal of Business Marketing and Management 4 (2019) pp. 70-78

[48] D. Nusraningrum, E. G. Senjaya, Overall Equipment Effectiveness (OEE) Measurement Analysis on Gas Power Plant with Analysis of Six Big Losses, International Journal of Business Marketing and Management 4 (2019) pp. 19-27

[49] A. Dalimunthe, Sukardi, I. Fahmi, Analysis of the Production Loss of the Automotive Company PT DNIA Using Value Stream Mapping and Overall Resource Effectiveness, International Journal of Research and Review 6 (2019) pp. 124-132

[50] E. B. Meike, K. Hayu, Sunardiyanta, Analysis of Effectiveness Measurement of Stretch Blow Machine Using Overall Equipment Effectiveness (OEE) Method, International Journal of Advances in Scientific Research and Engineering 6 (2020) pp. 131-137