applied sciences

MDPI

Review

Overall Equipment Effectiveness: Systematic Literature Review and Overview of Different Approaches

Lisbeth del Carmen Ng Corrales [1,2,*], María Pilar Lambán [1], Mario Enrique Hernandez Korner [1,2] and Jesús Royo [1]

1 Design and Manufacturing Engineering Department, Universidad de Zaragoza, 50018 Zaragoza, Spain; plamban@unizar.es (M.P.L.); mario.hernandez2@utp.ac.pa (M.E.H.K.); jaroyo@unizar.es (J.R.)
2 Department of Industrial Engineering, Universidad Tecnológica de Panamá, Ciudad de Panama 0819-07289, Panama
* Correspondence: lisbeth.ng@utp.ac.pa; Tel.: +34-610-330-536

Received: 28 August 2020; Accepted: 13 September 2020; Published: 17 September 2020

check for updates

Abstract: Overall equipment effectiveness (OEE) is a key performance indicator used to measure equipment productivity. The purpose of this study is to review and analyze the evolution of OEE, present modifications made over the original model and identify future development areas. This paper presents a systematic literature review; a structured and transparent study is performed by establishing procedures and criteria that must be followed for selecting relevant evidences and addressing research questions effectively. In a general search, 862 articles were obtained; after eliminating duplicates and applying certain inclusion and exclusion criteria, 186 articles were used for this review. This research presents three principal results: (1) The academic interest in this topic has increased over the last five years and the keywords have evolved from being related to maintenance and production, to being related to lean manufacturing and optimization; (2) A list of authors who have developed models based on OEE has been created; and (3) OEE is an emerging topic in areas such as logistics and services. To the best of our knowledge, no comparable review has been published recently. This research serves as a basis for future relevant studies.

Keywords: overall equipment effectiveness; OEE; systematic literature review; model-based

1. Introduction

Currently, various key performance indicators (KPIs) are used to make decisions at different organizational levels. Chan and Chan (2004) [1] considered KPIs as general indicators for identifying performance losses. Bititci et al. (2012) [2] reported that performance measurement has been developed in response to global and business trends. KPIs are used to measure process deviations to ensure that corrective action can be performed [3]; they are typically presented in dashboards and scorecards. Digital transformation has enabled information to be obtained quickly to accommodate the market changes. Martinez (2019) [4] suggested including digitalization as part of the business aspect of the evolution. In the Industry 4.0 framework, the digitalization of the production process in factories and data collection is important for improving business efficiency.

Overall equipment effectiveness (OEE) is a KPI introduced by Nakajima (1988) [5]; this metric was developed as part of the total productive maintenance (TPM) to measure the equipment productivity in a manufacturing system. OEE is a productivity ratio between real manufacturing and what could be ideally manufactured [6]. This indicator is widely accepted as a tool by some companies, e.g., when implementing lean manufacturing [7] or maintenance programs [5] to monitor the actual performance of an equipment. OEE identifies six big losses comprising aspects of availability, performance and quality that reduce the equipment effectiveness. Dunn (2015) [8] defined those three aspects as follows: (i) availability—'Is the machine running or not?'; (ii) performance—'How fast is the machine running?'; and (iii) quality—'How many products satisfied the requirements?'.

Availability measures downtime losses due to breakdowns or setup/adjustments; performance measures speed losses due to minor stoppages and reduced speed; and quality measures defect losses due to process defects or reduced yield [9]. Over time, OEE applications have been modified depending on industry needs; some authors have slightly modified the original formula, whereas others have proposed new formulas.

The insufficiency of OEE as an indicator has resulted in its modification [10]. Many industries have customized it to fit to their particular requirements [11]. Based on the OEE structure, models have been developed for domains such as sustainability [12], line manufacturing [13,14], assets [10], resources [15], transport [16,17] and ports [18].

The objective of this research is to review and analyze the evolution of OEE. Hence, we conducted a systematic review. In this study, the chronology of the main contributions and modifications pertaining to OEE was analyzed to establish future trends.

For a systematic review, we defined the research questions (RQs), selected and searched the database, applied inclusion and exclusion criteria, analyzed the results and answered the following (RQs).

RQ (1) What is the focus of the current research effort in the OEE domain?

RQ (2) What models based on OEE have been developed?

RQ (3) What are the principal contributions in OEE and what are the future trends?

This paper is structured as follows: Section 2 describes the methodology; Section 3 explains the systematic review process developed to obtain the information; Section 4 provides the results; and the final section presents the discussion and conclusions.

2. Materials and Methods

Reports and research results that contribute to science are constantly evolving; hence, an overview of the changes is necessitate. In this study, a systematic review was performed through a rigorous and transparent methodology to organize existing information. The systematic literature review was identified, evaluated and interpreted using existing empirical evidence to answer specific RQs [19]. Some reasons for performing the systematic literature review were as follows: to identify gaps by summarizing existing information to propose new investigation areas and to provide a background for suggesting new research activities [20].

The methodology used in this study was based on that used in a previous study [20,21], where a series of procedures was defined to execute a systematic process. The procedures adopted in this study were as follows:

1. Definition of RQs
2. Selection of scientific databases
3. General search in selected databases using the search string
4. Define inclusion and exclusion criteria and apply them to articles from general search
5. Data extraction and analysis of selected articles
6. Answer RQs

This methodology is used to develop a structured and transparent study by establishing procedures and criteria that must be followed to select information for review.

2.1. Definition of RQs

First, RQs for guiding the development of this study were formulated. These questions must be answered using the data collected and analyzed in this study. Table 1 presents the RQs and the motivation of each based on the research objectives.

Table 1. Research questions and motivation.

Research Questions	Motivation
RQ1. What is the focus of the current research effort in the OEE domain?	Present a descriptive finding that exhibits interest in the topic and identify trends signified by keywords.
RQ2. What models based on OEE have been developed?	Generate a list of different models that have been developed based on the original OEE, to determine fields of study that have applied the indicator as an effectiveness measure.
RQ3. What are the principal contributions in OEE and what are the future trends?	Summarize main contributions from different authors and establish future trends to propose new research activities.

Based on these three questions, we aim to fulfil the objective of this study: analyze the OEE chronology, main contributions of OEE and model developed based on OEE.

2.2. Search Process

Web of Science (WoS) and Scopus were the two electronic databases used in this study because they contain relevant, updated and high-quality bibliographic information. WoS is a digital platform of Clarivate Analytics, in which Scopus is affiliated with Elsevier; both databases were formed based on thousands of peer-reviewed journals in the fields of science, technology, medicine, social sciences, arts and humanities.

A generalized search for the term 'overall equipment effectiveness' was performed to obtain broad results. The keywords used for this search were 'overall equipment effectiveness' AND 'OEE'. The search string applied in the WoS electronic databases was topic (TS) = ('overall equipment effectiveness' AND 'OEE'). In Scopus, a combined field that searches abstracts, keywords and document titles was used, i.e., TITLE–ABS–KEY ('overall equipment effectiveness' AND 'OEE').

The total number of documents obtained in the general search was 847, i.e., 281 from WoS and 566 from Scopus. Only articles were selected for this study. Compared with proceedings papers, articles are more influential and complete as they contain more information and citations [22]. The results were based on articles obtained after eliminating duplicates and applying the inclusion and exclusion criteria detailed in the following section.

2.3. Selection of Relevant Papers

The selection of relevant articles was standardized as per [20] to avoid information bias. Hence, inclusion (I) and exclusion (E) criteria were defined to ensure that the selected papers were the least subjective.

The I and E criteria were defined as follows:

- I1: The paper is a literature review and/or is related specifically to OEE and its application;
- I2: The study mentions an OEE-based model;
- I3: The study only uses OEE to verify an improvement or change in any process;
- E1: The paper cannot be obtained and/or is not written in English;
- E2: The term "OEE" is only mentioned; no OEE-based model is calculated or applied;
- E3: The paper is not an article, e.g., proceedings papers, magazines, books, editorial material and letters.

This review was adapted from the preferred reporting items for systematic review and meta-analysis (PRISMA) statement [23]. Figure 1 shows a PRISMA flow chart that illustrates the different phases of the systematic literature review.

- E3: The paper is not an article, e.g., proceedings papers, magazines, books, editorial material and letters.

This review was adapted from the preferred reporting items for systematic review and meta-analysis (PRISMA) statement [23]. Figure 1 shows a PRISMA flow chart that illustrates the different phases of the systematic literature review.

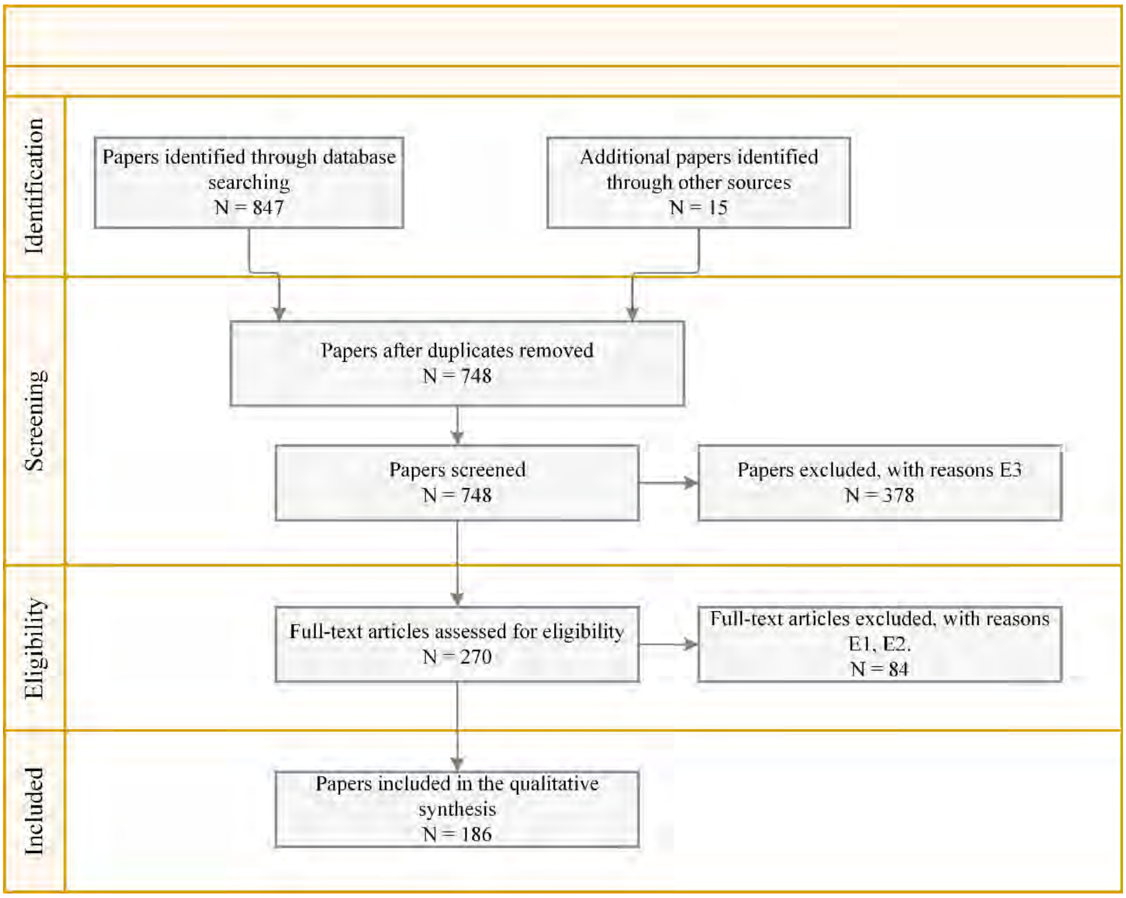


Figure 1. Preferred reporting items for systematic review and meta-analysis (PRISMA) flow chart.

First, a general search was performed using the search string (Section 2.2) in the selected scientific databases. Subsequently, using an Excel spreadsheet, articles were filtered to eliminate duplicates. Finally, the articles were examined, and the I and E criteria were applied to retain the selected articles for answering the RQs.

3. Results

RQ (1). What is the focus of the current research effort in the OEE domain?

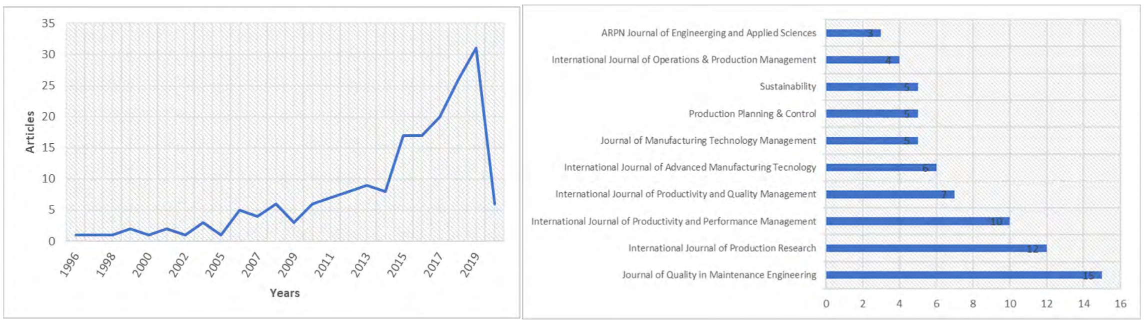
The bibliometrix R-package was used to analyze the 186 articles from the electronic databases. This package, which is written in the R language, provides a set of tools for quantitative studies in bibliometrics and scientometrics [24]. Using this program, the data extracted from WoS and Scopus were consolidated to perform a comprehensive bibliometric analysis of the current research effort pertaining to OEE. Table 2 shows a general data summary from the 186 articles.

Despite a 24 years timespan, scientific productivity increased only in the later years. The results show that more than 50% of the publications regarding OEE were published in the last five years, indicating that interest in the OEE indicator has increased, i.e., by 9.1% in 2015, 9.1% in 2016, 10.8% in 2017, 14.0% in 2018 and 16.7% in 2019. Thus, far, an increase of 3.2% has been reported for 2020. Figure 2 presents (a) the number of articles per year since 1996 until 9 April 2020, revealing an increasing interest in the subject and (b) the top 10 journals with increasing publications over time.

Table 2. General data summary.

Timespan	1996–2020
Sources (journals)	102
Documents	186
Average citations per document	16.57
Author keywords	554
Keywords plus	434
Authors	450
Authors of single-author documents	25
Authors of multi-author documents	425

Despite a 24 years timespan, scientific productivity increased only in the later years. The results show that more than 50% of the publications regarding OEE were published in the last five years, indicating that interest in the OEE indicator has increased, i.e., by 9.1% in 2015, 9.1% in 2016, 10.8% in 2017, 14.0% in 2018 and 16.7% in 2019. Thus, far, an increase of 3.2% has been reported for 2020. Figure 2 presents (a) the number of articles per year since 1996 until 9 April 2020, revealing an increasing interest in the subject and (b) the top 10 journals with increasing publications over time.

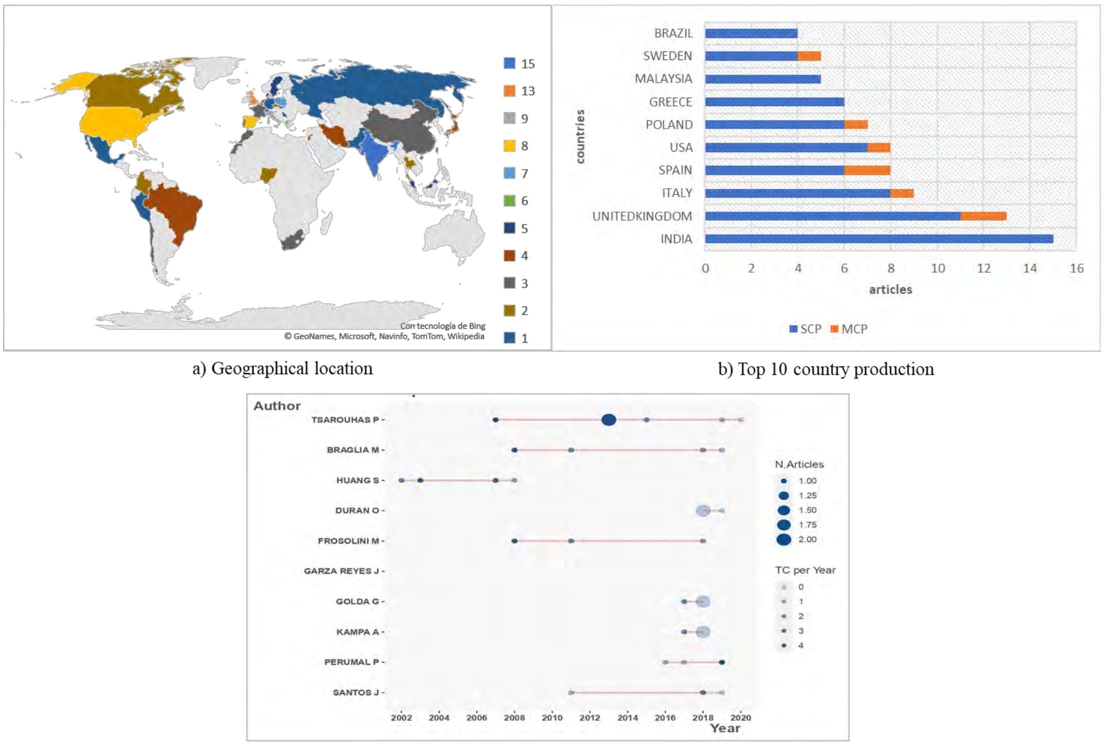


a) Number of articles per year b) Top 10 Journals

Figure 2. Basic data analysis of (a) number of articles per year and (b) Top 10 journals.

The total number of journals published regarding OEE was 102. Journals pertaining primarily to manufacturing or maintenance issues were not the only ones that focused on the OEE indicator. Evidence shows that an increasing number of journals are focusing on sustainability, business, logistics, mining, etc.

The current effort to spread the topic based on contributor and geographical location is shown in Figure 3. Europe is the continent with the most publications (45%) followed by Asia (26%), America (7%) and Africa (5%), as shown in Figure 3a. Figure 3b presents the top 10 countries in terms of single country publication (SCP) and multiple country publication (MCP). More than 80% of the publications were written by authors belonging to the same country; all the scientific productions in India were based entirely on SCPs, unlike the UK and Spain, who collaborative with other countries. Figure 3c indicate the top 10 most productive authors, including the number of articles (N articles) and total citations per year (TC per year). Greek author Panagiotis Tsarouhas was the first in the top 10, with 83.33% of his publications reporting cases in which OEE was applied to different production industries, e.g., croissant production lines [25], ice cream production lines [26] and production plants of Italian cheese [27] to identify potential opportunities for improving production systems. Braglia and Huang published four articles, whereas the other authors from the top 10 published three articles each. Some of them have developed new models based on OEE, whereas others have applied the indicator in different industries to measure equipment, process or resource effectiveness.



a) Geographical location

b) Top 10 country production

c) Top 10 author's production over the time

Figure 3. The effort in terms of (**a**) geographical location (**b**) top 10 country production and (**c**) authors contribution over the time.

Three inclusion criteria were used for the analysis in this study. (a) Criteria I1—include papers that are literature reviews and/or are related specifically to OEE and its application; (b) Criteria I2—studies that mention OEE-based models; (c) Criteria I3—papers that only use the OEE to verify an improvement or change in any process (Table 3). Approximately 20% of the articles contributed scientifically to the modification or new development of models based on the original OEE (Figure 4). Instead of for use in production, the new models were built to measure the effectiveness in areas such as transportation, sustainability, mining, electricity and resources (human and monetary).

Table 3. Overall equipment effectiveness (OEE) application contribution by area.

Application Area	Inclusion Criteria	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020
Productivity in manufacturing processes	I1		[28–30]	[31,32]	[33–39]	[26,40–60]
	I3			[61]	[62–75]	[76–93]
Productivity in maintenance	I1	[94,95]			[27,96–98]	[25,99–110]
	I3	[111,112]	[113]	[114–121]	[122–129]	[130–141]
Oriented to resources productivity	I1			[142]	[143]	[144–149]
	I3					[150–152]
Supply chain productivity	I1				[153]	
	I3				[154,155]	[156]
Other	I1	[9]	[157]	[158,159]	[160–163]	[164–166]
	I3		[167]	[168]	[169]	[170–173]

Application Area	Inclusion Criteria	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020
	I3		[167]	[168]	[169]	[170–172]

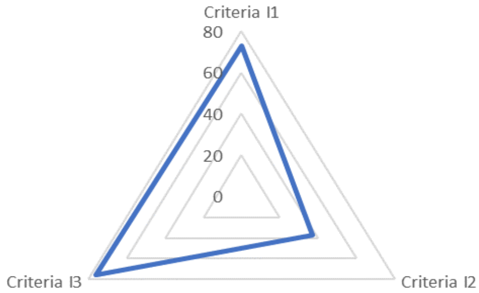


Figure 4. Distribution of inclusion criteria of analysis.

Two types of keywords are shown in Table 2: the author's keywords and keywords plus. The former is provided by the original authors, whereas the latter is extracted from titles of cited references by Clarivate Analytics (WoS). Figure 5 shows the co-occurrence network of the author's keywords; the number of nodes in the network was 40 and was related through association; the clustering algorithm used was Louvain. The network comprised four clusters. The first one comprised nine keywords related to the OEE formulation, availability, performance, quality, downtime, speed loss, etc. The second cluster comprised 12 keywords related to total productive maintenance, optimization, production, maintenance and autonomous maintenance. The third cluster comprised terms such as effectiveness, throughput and performance measurement. The last cluster comprised 13 keywords pertaining to current issues, such as industry 4.0, simulation, lean manufacturing, six sigma, SMED and DMAIC.

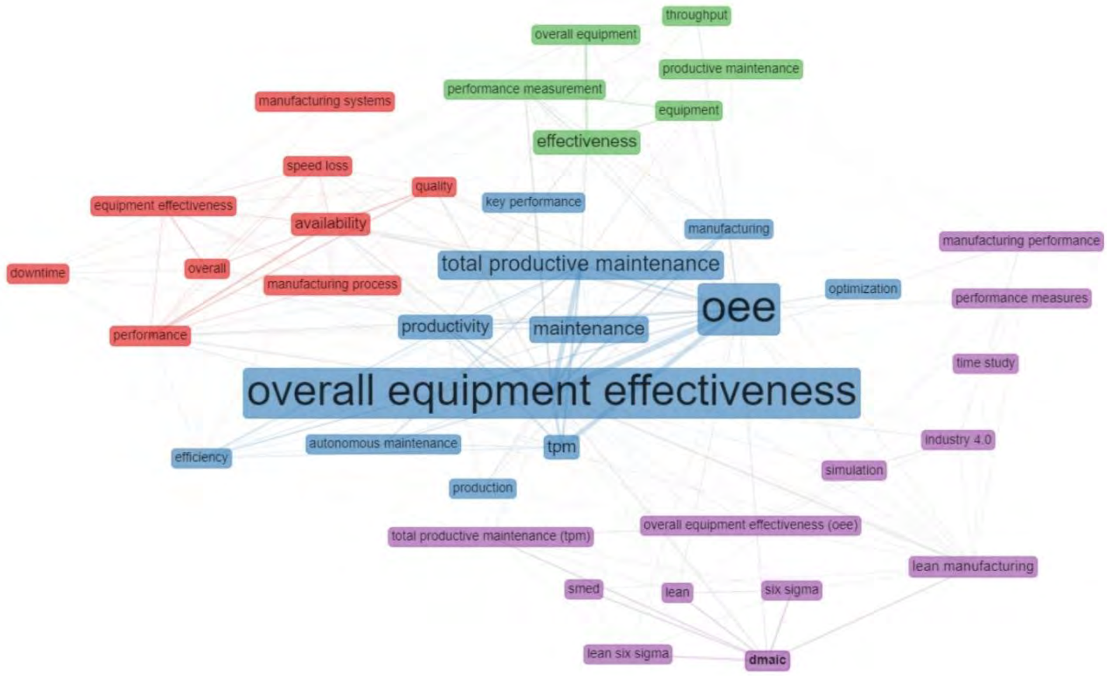


Figure 5. Co-occurrence network.

Initially, studies regarding OEE are associated with total productive maintenance; subsequently, they are associated with the industry, availability and manufacturing process. Currently, they are related with terms such as lean manufacturing, improvement, implementation, reliability, design and optimization. The most cited document obtained from the systematic review considers quality assessments, such as lean tools and six sigma, to improve productivity and financial savings, e.g., in the die-casting unit of a company [115].

RQ (2). What models based on OEE have been developed?

Over time, industries have adapted OEE to their needs. Hence, several authors have developed slight modifications to Nakajima's model whereas others have developed new indicators based on the originally formulated OEE.

A list of models based on OEE, listed by the author and model name, is shown in Table 4. A brief description of each model is provided as well.

Table 4. List of models based on OEE.

Author	Year	Model Name	Brief Description
[173] [174]	2002 2007	Overall throughput effectiveness	Calculates the productivity of a manufacturing system; measures the factory level performance; identifies the bottleneck and hidden capacity.
[175]	2005	Equipment effectiveness	Measures the equipment-dependent states, such as productive state, scheduled downstate and unscheduled downstate.
[13]	2006	Overall line effectiveness	Measures the productivity of a line manufacturing system.
[176]	2006	Total equipment efficiency	To achieve total equipment efficiency, it must include the resource usage efficiency of a machine. This input factor (resource requirements) is known as the overall input efficiency.
[10]	2008	Overall asset effectiveness Overall production effectiveness	Measures losses due to external and internal factors contributing to overall production/asset effectiveness.
[177]	2008	Modified OEE	Includes new factor usability; it classifies unplanned downtime events into equipment-related downtime.
[6]	2008	Overall equipment effectiveness of a manufacturing line	Measures the performances of an automated line in the system.
[16]	2010	OEE for shovel/oee for trucks	OEE is calculated for mining equipment.
[14]	2010	Overall line effectiveness	The performance of the production line in the manufacturing system is measured.
[178]	2010	Overall equipment effectiveness market-based	Monitors production in the steel market; measures equipment effectiveness for a full process cycle.
[179]	2011	Integrated equipment effectiveness	This integration is based on three elements: loading-based, capital-based and market-based elements.
[180]	2012	Overall equipment and quality cost loss	Calculates the losses of equipment, specifically production and quality cost losses, in monetary units.
[181]	2013	Overall resource effectiveness	Includes losses related to resources, e.g., people, machines, materials and methods.
[182]	2015	Machining equipment effectiveness	Calculates the OEE of a high-mix-low-volume manufacturing environment.
[15]	2015	Overall resource effectiveness	Provides information regarding the process performance based on factor material efficiencies, process cost and material cost.
[12]	2015	Overall environmental equipment effectiveness	Identifies losses due to sustainability, based on the calculated environmental impact of the workstation.
[183]	2015	Fuzzy overall equipment effectiveness	Identifies performance fluctuations through LR Fuzzy numbers.

Table 4. *Cont.*

Author	Year	Model Name	Brief Description
[184]	2016	Stochastic shovel effectiveness	Quantifies performance effectiveness of electric and hydraulic shovels.
[185]	2017	OEE of BELT equipment	Bucket-based excavating, loading and transport (BELT) including all equipment comprising a bucket, e.g., draglines, shovels, load-haul-dumps and trucks.
[186]	2017	Strategic equipment effectiveness Operational equipment effectiveness	A global measure of the effectiveness of an integrated electrical system.
[187]	2017	Overall machinery effectiveness	Identifies and ranks decision-making-units in terms of efficiency.
[18]	2017	OEE of port terminal	Identifies the most efficient terminal, addressing either manageable or unmanageable factors.
[188]	2017	Modified OEE	Includes losses associated with human factors and usability (the frequency of setup and changeover process)
[189]	2018	Extended overall equipment effectiveness	Evaluates the entire process considering human resources and equipment Performance. It is applied in medicals activities of operating rooms.
[17]	2018	OEE to transport management	Improves efficiency in road transport by adapting OEE to transport management.
[11]	2018	Modified OEE	Optimizes the effectiveness of urban freight transportation.
[190]	2018	Overall material usage effectiveness	Measures material usage effectiveness and identifies material loss in the manufacturing process.
[191]	2018	Sustainable overall throughputability effectiveness	Includes sustainability criteria and can be used in the system lifecycle.
[7]	2019	Overall task effectiveness	Analyses and evaluates losses related to manual assembly tasks.
[192]	2019	Modified OEE	Improves the effectiveness of scheduling jobs with earliness/tardiness.
[193]	2019	OEE–TCQ	Improves the process approach in maintenance in terms of time, cost and quality.
[194]	2019	Overall effectiveness indicator	Adapted for mining production to examine the effectiveness of the mining machine.
[195]	2019	Standalone OEE	Identifies system bottleneck and excludes effects from upstream and downstream.
[196]	2019	Modified OEE	Calculates the OEE in serial, parallel and combined machine systems in the production line.
[197]	2019	Modified OEE	Includes a term that considers material utilization.
[198]	2019	Overall substation effectiveness	Measures substation performances and indicates the overall maintenance performances.

As presented above, the OEE was modified to solve gaps in various issues, such as sustainability, human factor, transport, manufacturing system, mining, cost, port and resources.

RQ (3). Which are the principal contributions in OEE and what are the future trends?

Initially, OEE was used in production, in particular for TPM, which assists in identifying the overall equipment performance in a manufacturing process [199]. To accommodate industry needs, some researchers began to analyze the productivity of manufacturing line systems [6,13] or factories [174]. Currently, OEE is used with continuous improvement methodologies, such as lean manufacturing to increase productivity by eliminating waste [200]. It is also used as a KPI and data collection tool to measure the effectivity and process capability of new six sigma implementations [61]. Following the methodology of continuous improvement, Braglia et al. (2019) [7] developed a new metric based on OEE, known as overall task effectiveness. This new indicator supports lean and six sigma methodologies to identify, analyze and evaluate losses that occur during manual assembly activities.

Sustainability is an aspect that has been investigated by several companies in recent years [201], which shows that concerns regarding the environment have been growing. Hence, it has become increasingly important to include this variable as a criterion in business decision-making. Ghafoorpoor Yazdi et al. (2018) [150] created a design in a study based on OEE and its relationship with sustainability in Industry 4.0. Meanwhile, other authors incorporated the concept of sustainability in OEE, e.g., Domingo et al. (2015) [12] developed the overall environmental equipment effectiveness to identify and measure losses due to sustainability. Likewise, Durán et al. (2018) [191] designed the Sustainable Overall throughput effectiveness indicator to measure the operating performance and factory level sustainability.

The OEE has been adapted for the transport sector. To the best of our knowledge, it first occurred in the mining industry [16] and was used to identify possible losses in the availability, performance and quality of equipment such as shovels and trucks. In recent years, the efficiency framework in the port terminal [18] that considers manageable and unmanageable variables has been studied to create indicators based on OEE. Additionally, the OEE has been adapted to road transportation [17] based on distance, load capacity, route time, stops and services. Furthermore, it has been used to evaluate the effectiveness of urban freight transportation [11] as well as optimize availability, performance and quality metrics.

Accordingly, some authors have established interesting frameworks that can be developed in future studies. Some of them proposed future studies based on the frameworks that they have developed thus far, whereas others developed innovations in new areas. Abdelbar et al. (2019) [193] used a new OEE formula to identify and implement process improvements. Braglia et al. (2018) [190] extended the proposed methodology, including the analysis of material losses based on the finished product. Ghafoorpoor Yazdi et al. (2018) [150] proposed re-performing experiments for long time periods and as a case study in the manufacturing industry. Dadashnejad and Valmohammadi, (2019) [76] applied the same value stream mapping technique that is used to identify improvements in other factories.

By contrast, other authors proposed different areas in which OEE is applicable. In the study by García-Arca et al. (2018) [17] where OEE was adapted to transport management, they assume that the same methodology is applicable to the service sector and other logistics processes, such as goods reception or performing selection in a warehouse. Sharma et al. (2018) [137] and Supriyanto and Mokh (2018) [59] reported that their studies can be replicated in the service sector as well as in other industries, such as pharmaceutical, electrical/electronic, textile and transportation (rail and air travel).

4. Discussion and Conclusions

Companies use measurement systems to identify areas on which to focus to enhance performance and productivity. It is assumed that all parameters that can be measured, can be improved. Through this systematic study—and with the formulation and development of the proposed RQs—the state of the art, evolution, and future trends of OEE indicators were better understood.

The OEE started as a component of TPM and was used to increase productivity and reduce time, speed and quality losses. Dal et al. (2000) [29] reported that the indicator involves aspects other than monitoring and controlling because it provides performance data to make decisions by combining techniques, systematic method and process improvement. The practical and academic interest indicated over time was demonstrated in this study review and in the answer to the RQs. According to the answer to the first question, academic interest increased in the last five years and that the indicator is used beyond production maintenance. This study illustrates the evolution of keywords related to OEE beginning from terms relevant to maintenance and production to concepts related to six sigma, lean manufacturing, sustainability, etc. The second question resulted in a compilation of models developed based on OEE; the results presented a framework of areas or sectors where the indicator was applied. The models have evolved for the analysis of complete production lines, material handling, transportation, ports and sustainability. The answers to the final question were the principal contributions of some authors and future trends that are expected to be followed.

In conclusion, the results indicated that OEE is an emerging topic that can be used as input information for decision-making in business. Industry 4.0, which is based on cyber-physical systems and information digitalization, facilitates the accumulation and transformation of real-time process information into decisions to reduce uncertainty in the results. After analyzing the approaches of the OEE indicator it can be noted that it is adaptable to different domains by measuring the effectiveness not only of production equipment but also the effectiveness of material, economic and human resources. This will require an in-depth study of the process to determine the losses, variables and factors to be included in other OEE approaches. Future studies regarding OEE can be transferred to the logistics sector and may be included in the formulation of environmental variables, such as carbon footprint generated during a specific process. In supply chains, OEE can be used to measure the productivity of cargo movement equipment in a warehouse. Meanwhile, in the service sector, OEE can be used to measure client satisfaction in terms of the availability, performance and quality of the services received. Additionally, an OEE-based model can be incorporated into a balanced scorecard to visualize the overall productivity of a business. All these measures provide a general perspective of the business and achieve the main objectives of production, i.e., increasing productivity and reducing waste.

Author Contributions: Conceptualization, M.P.L. and J.R.; methodology, M.E.H.K. and L.d.C.N.C.; software, M.E.H.K.; validation, L.d.C.N.C.; formal analysis, L.d.C.N.C.; investigation, L.d.C.N.C.; data curation, M.E.H.K. and L.d.C.N.C.; writing—original draft preparation, L.d.C.N.C.; writing—review and editing, M.P.L., J.R., M.E.H.K. and L.d.C.N.C.; supervision, M.P.L.; project administration, J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to acknowledge the scholarship granted by the government of Panama under the IFARHU—SENACYT program for a candidate from 2018 to 2021.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chan, A.P.C.; Chan, A.P.L. Key performance indicators for measuring construction success. *Benchmarking Int. J.* **2004**, *11*, 203–221. [CrossRef]
2. Bititci, U.; Garengo, P.; Dörfler, V.; Nudurupati, S. Performance Measurement: Challenges for Tomorrow. *Int. J. Manag. Rev.* **2012**, *14*, 305–327. [CrossRef]
3. Maté, A.; Trujillo, J.; Mylopoulos, J. Specification and derivation of key performance indicators for business analytics: A semantic approach. *Data Knowl. Eng.* **2017**, *108*, 30–49. [CrossRef]
4. Martinez, F. Process excellence the key for digitalisation. *Bus. Process Manag. J.* **2019**. [CrossRef]
5. Nakajima, S. *Introduction to TMP*; Productivity Press: Portaland, OR, USA, 1988.
6. Braglia, M.; Frosolini, M.; Zammori, F. Overall equipment effectiveness of a manufacturing line (OEEML). *J. Manuf. Technol. Manag.* **2008**, *20*, 8–29. [CrossRef]
7. Braglia, M.; Gabbrielli, R.; Marrazzini, L. Overall Task Effectiveness: A new Lean performance indicator in engineer-to-order environment. *Int. J. Product. Perform. Manag.* **2019**, *68*, 407–422. [CrossRef]
8. Dunn, T. OEE Effectiveness. In *Manufacturing Flexible Packaging*; Elsevier: Amsterdam, The Netherlands, 2015; pp. 77–85.

9. Jonsson, P.; Lesshammar, M. Evaluation and improvement of manufacturing performance measurement systems—The role of OEE. *Int. J. Oper. Prod. Manag.* **1999**, *19*, 55–78. [CrossRef]
10. Muchiri, P.; Pintelon, L. Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion. *Int. J. Prod. Res.* **2008**, *46*, 3517–3535. [CrossRef]
11. Muñoz-Villamizar, A.; Santos, J.; Montoya-Torres, J.; Jaca, C. Using OEE to evaluate the effectiveness of urban freight transportation systems: A case study. *Int. J. Prod. Econ.* **2018**, *197*, 232–242. [CrossRef]
12. Domingo, R.; Aguado, S. Overall Environmental Equipment Effectiveness as a Metric of a Lean and Green Manufacturing System. *Sustainability* **2015**, *7*, 9031–9047. [CrossRef]
13. Nachiappan, R.M.; Anantharaman, N. Evaluation of overall line effectiveness (OLE) in a continuous product line manufacturing system. *J. Manuf. Technol. Manag.* **2006**, *17*, 987–1008. [CrossRef]
14. Raja, P.N.; Kannan, S.M.; Jeyabalan, V. Overall line effectiveness—A performance evaluation index of a manufacturing system. *Int. J. Product. Qual. Manag.* **2010**, *5*, 38. [CrossRef]
15. Garza-Reyes, J.A. From measuring overall equipment effectiveness (OEE) to overall resource effectiveness (ORE). *J. Qual. Maint. Eng.* **2015**, *21*, 506–527. [CrossRef]
16. Elevli, S.; Elevli, B. Performance Measurement of Mining Equipments by Utilizing OEE. *Acta Montan. Slovaca Ročník* **2010**, *15*, 95–101.
17. García-Arca, J.; Prado-Prado, J.C.; Fernández-González, A.J. Integrating KPIs for improving efficiency in road transport. *Int. J. Phys. Distrib. Logist. Manag.* **2018**, *48*, 931–951. [CrossRef]
18. Pinto, M.M.O.; Goldberg, D.J.K.; Cardoso, J.S.L. Benchmarking operational efficiency of port terminals using the OEE indicator. *Marit. Econ. Logist.* **2017**, *19*, 504–517. [CrossRef]
19. Higgins, J.P.; Green, S. *Cochrane Handbook for Systematic Reviews of Interventions*; Version5.1.; The Cochrane Collaboration: Chichester, UK, 2011.
20. Kitchenham, B.; Charters, S. *Guidelines for Performing Systematic Literature Reviews in Software Engineering*; EBSE: Durham, UK, 2007.
21. Medina-López, C.; Marín-Gracía, J.A.; Alfalla-Luque, R. Una propuesta metodológica para la realización de búsquedas sistemáticas de bibliografía. *Work. Pap. Oper. Manag.* **2010**, *1*, 13–30. [CrossRef]
22. González-Albo, B.; Bordons, M. Articles vs. proceedings papers: Do they differ in research relevance and impact? A case study in the Library and Information Science field. *J. Informetr.* **2011**, *5*, 369–381. [CrossRef]
23. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Altman, D.; Antes, G.; Atkins, D.; Barbour, V.; Barrowman, N.; Berlin, J.A.; et al. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, e1000097. [CrossRef]
24. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
25. Tsarouhas, P. Improving operation of the croissant production line through overall equipment effectiveness (OEE): A case study. *Int. J. Product. Perform. Manag.* **2019**, *68*, 88–108. [CrossRef]
26. Tsarouhas, P.H. Overall equipment effectiveness (OEE) evaluation for an automated ice cream production line: A case study. *Int. J. Product. Perform. Manag.* **2019**. [CrossRef]
27. Tsarouhas, P.H. Equipment performance evaluation in a production plant of traditional Italian cheese. *Int. J. Prod. Res.* **2013**, *51*, 5897–5907. [CrossRef]
28. Huang, S.H.; Dismukes, J.P.; Shi, J.; Su, Q.; Razzak, M.A.; Bodhale, R.; Robinson, D.E. Manufacturing productivity improvement using effectiveness metrics and simulation analysis. *Int. J. Prod. Res.* **2003**, *41*, 513–527. [CrossRef]
29. Dal, B.; Tugwell, P.; Greatbanks, R. Overall Equipment Effectiveness as a Measure of Operational Improvement a Practical Analysis. *Int. J. Oper. Prod. Manag.* **2000**, *20*, 1488–1502. [CrossRef]
30. Bamber, C.J.; Castka, P.; Sharp, J.M.; Motara, Y. Cross-functional team working for overall equipment effectiveness (OEE). *J. Qual. Maint. Eng.* **2003**, *9*, 223–238. [CrossRef]
31. Ilar, T.; Powell, J.; Kaplan, A. Modelling, simulation and analyses of systems with breakdown imposed scrapping. *J. Simul.* **2009**, *3*, 107–113. [CrossRef]
32. Ferko, R.; Znidarsic, A. Using OEE approach for improving manufacturing performance. *Inf. Midem Ljubl.* **2007**, *37*, 105.

33. Tsarouhas, P.H. Evaluation of overall equipment effectiveness in the beverage industry: A case study. *Int. J. Prod. Res.* **2013**, *51*, 515–523. [CrossRef]
34. Norden, C.; Ismail, J. Defining a representative overall equipment effectiveness (OEE) measurement for underground bord and pillar coal mining. *J. S. Afr. Inst. Min. Metall.* **2012**, *112*, 845–851.
35. Shahin, A.; Isfahani, N.G. Estimating overall equipment effectiveness for continuous production lines: With a case study in Esfahan Steel Company. *Int. J. Serv. Oper. Manag.* **2015**, *21*, 466–478. [CrossRef]
36. De Carlo, F.; Arleo, M.A.; Tucci, M. OEE Evaluation of a Paced Assembly Line through Different Calculation and Simulation Methods: A Case Study in the Pharmaceutical Environment. *Int. J. Eng. Bus. Manag.* **2014**, *6*, 27. [CrossRef]
37. Anand, R. Cloud computing OEE (Overall Equipment Effectiveness) for reducing production downtime. *SAE Int. J. Mater. Manuf.* **2013**, *6*. [CrossRef]
38. Mansour, H.; Ahmad, M.M.; Dhafr, N.; Ahmed, H. Evaluation of operational performance of workover rigs activities in oilfields. *Int. J. Product. Perform. Manag.* **2013**, *62*, 204–218. [CrossRef]
39. Palanisamy, V. Implementing Overall Equipment Effectiveness in a Process Industry. *Indian J. Sci. Technol.* **2013**, *6*, 1–5. [CrossRef]
40. Trattner, A.; Hvam, L.; Haug, A. Why slow down? Factors affecting speed loss in process manufacturing. *Int. J. Adv. Manuf. Technol.* **2020**, *106*, 2021–2034. [CrossRef]
41. Foulloy, L.; Clivillé, V.; Berrah, L. A fuzzy temporal approach to the Overall Equipment Effectiveness measurement. *Comput. Ind. Eng.* **2019**, *127*, 103–115. [CrossRef]
42. Fekri Sari, M.; Avakh Darestani, S. Fuzzy overall equipment effectiveness and line performance measurement using artificial neural network. *J. Qual. Maint. Eng.* **2019**, *25*, 340–354. [CrossRef]
43. Yılmaz Eroğlu, D. Systematization, implementation and analyze of overall throughput effectiveness calculation in finishing process of weaving industry. *Tekstil Konfeksiyon* **2019**. [CrossRef]
44. Roda, I.; Macchi, M. Factory-level performance evaluation of buffered multi-state production systems. *J. Manuf. Syst.* **2019**, *50*, 226–235. [CrossRef]
45. Sonmez, V.; Testik, M.C.; Testik, O.M. Overall equipment effectiveness when production speeds and stoppage durations are uncertain. *Int. J. Adv. Manuf. Technol.* **2018**, *95*, 121–130. [CrossRef]
46. Zennaro, I.; Battini, D.; Sgarbossa, F.; Persona, A.; De Marchi, R. Micro downtime: Data collection, analysis and impact on OEE in bottling lines the San Benedetto case study. *Int. J. Qual. Reliab. Manag.* **2018**, *35*, 965–995. [CrossRef]
47. He, F.; Shen, K.; Lu, L.; Tong, Y. Model for improvement of overall equipment effectiveness of beerfilling lines. *Adv. Mech. Eng.* **2018**, *10*, 168781401878924. [CrossRef]
48. Hwang, G.; Lee, J.; Park, J.; Chang, T.W. Developing performance measurement system for Internet of Things and smart factory environment. *Int. J. Prod. Res.* **2017**, *55*, 2590–2602. [CrossRef]
49. Kardas, E.; Brožova, S.; Pustějovská, P.; Jursová, S. The Evaluation of Efficiency of the Use of Machine Working Time in the Industrial Company—Case Study. *Manag. Syst. Prod. Eng.* **2017**, *25*, 241–245. [CrossRef]
50. Mousavi, A.; Siervo, H.R.A. Automatic translation of plant data into management performance metrics: A case for real-time and predictive production control. *Int. J. Prod. Res.* **2017**, *55*, 4862–4877. [CrossRef]
51. Fourie, H. Improvement in the overall efficiency of mining equipment: A case study. *J. S. Afr. Inst. Min. Metall.* **2016**, *116*, 275–281. [CrossRef]
52. Green, C.; Taylor, D. Consolidating a Distributed Compound Management Capability into a Single Installation: The Application of Overall Equipment Effectiveness to Determine Capacity Utilization. *J. Lab. Autom.* **2016**, *21*, 811–816. [CrossRef] [PubMed]
53. Samatemba, B.; Zhang, L.; Besa, B. Evaluating and optimizing the effectiveness of mining equipment; the case of Chibuluma South underground mine. *J. Clean. Prod.* **2020**, *252*, 119697. [CrossRef]
54. Cheah, C.K.; Prakash, J.; Ong, K.S. An integrated OEE framework for structured productivity improvement in a semiconductor manufacturing facility. *Int. J. Product. Perform. Manag.* **2020**. [CrossRef]
55. Putz, M.; Koriath, H.J.; Kuznetsov, A.P. Resource consumption classes of machine tools. *MM Sci. J.* **2019**, *2019*, 3301–3309. [CrossRef]
56. Bhattacharjee, A.; Roy, S.; Kundu, S.; Tiwary, M.; Chakraborty, R. An analytical approach to measure OEE for blast furnaces. *Ironmak. Steelmak.* **2019**. [CrossRef]

57. Pemural, P.A.; Yoong, S.S.; Tay, C.C. Classification of Losses in Overall Equipment Effectiveness Calculation. *Int. J. Recent Technol. Eng.* **2019**, 7–11.
58. Sharma, R. Overall equipment effectiveness measurement of TPM manager model machines in flexible manufacturing environment: A case study of automobile sector. *Int. J. Product. Qual. Manag.* **2019**, *26*, 206–222. [CrossRef]
59. Supriyanto, H.; Mokh, S. Performance evaluation using lean six sigma and overall equipment effectiveness: An analyzing tool. *Int. J. Mech. Eng. Technol.* **2018**, *9*, 487–495.
60. Stryczek, R.; Szczepka, W. Process Factors of Impact on OEE for Lathes for Machining of Wheelset. *J. Mach. Eng.* **2016**, *16*, 126–140.
61. Gibbons, P.M. Improving overall equipment efficiency using a Lean Six Sigma approach. *Int. J. Six Sigma Compet. Advant.* **2006**, *2*, 207. [CrossRef]
62. Benjamin, S.J.; Marathamuthu, M.S.; Murugaiah, U. The use of 5-WHYs technique to eliminate OEE's speed loss in a manufacturing firm. *J. Qual. Maint. Eng.* **2015**, *21*, 419–435. [CrossRef]
63. Arima, S.; Kobayashi, A.; Wang, Y.F.; Sakurai, K.; Monma, Y. Optimization of Re-Entrant Hybrid Flows with Multiple Queue Time Constraints in Batch Processes of Semiconductor Manufacturing. *IEEE Trans. Semicond. Manuf.* **2015**, *28*, 528–544. [CrossRef]
64. Olivella, J.; Gregorio, R. A case study of an integrated manufacturing performance measurement and meeting system. *J. Manuf. Technol. Manag.* **2015**, *26*, 515–535. [CrossRef]
65. Wang, T.Y.; Pan, H.C. Improving the OEE and UPH data quality by Automated Data Collection for the semiconductor assembly industry. *Expert Syst. Appl.* **2011**, *38*, 5764–5773. [CrossRef]
66. Bevilacqua, M.; Ciarapica, F.E.; De Sanctis, I.; Mazzuto, G.; Paciarotti, C. A Changeover Time Reduction through an integration of lean practices: A case study from pharmaceutical sector. *Assem. Autom.* **2015**, *35*, 22–34. [CrossRef]
67. Kuiper, A.; Van Raalte, M.; Does, R.J.M.M. Quality quandaries: Improving the overall equipment effectiveness at a pharmaceutical company. *Qual. Eng.* **2014**, *26*, 478–483. [CrossRef]
68. Uddin, M.K.; Puttonen, J.; Martinez Lastra, J.L. Context-sensitive optimisation of the key performance indicators for FMS. *Int. J. Comput. Integr. Manuf.* **2015**, *28*, 958–971. [CrossRef]
69. Chiarini, A. Improvement of OEE performance using a Lean Six Sigma approach: An Italian manufacturing case study. *Int. J. Product. Qual. Manag.* **2015**, *16*, 416–433. [CrossRef]
70. Singh, K.; Ahuja, I.P.S. Assessing the business performance measurements for transfusion of TQM and TPM initiatives in the Indian manufacturing industry. *Int. J. Technol. Policy Manag.* **2014**, *14*, 44. [CrossRef]
71. Benedetti, M.; Cesarotti, V.; Giuiusa, A.; Introna, V. Buffer Size Design in Pharmaceutical Packaging Lines: An Analytical Methodology Proposal and Case Study. *Int. J. Eng. Bus. Manag.* **2014**, *6*, 26. [CrossRef]
72. Singh, J.; Singh, H. Performance enhancement of a manufacturing industry by using continuous improvement strategies—A case study. *Int. J. Product. Qual. Manag.* **2014**, *14*, 36. [CrossRef]
73. Svrzic, U.; Danon, G. Solving problems in wood parquet production by using "7 steps" of world class manufacturing (WCM) methodology. *J. Appl. Eng. Sci.* **2014**, *12*, 113–120. [CrossRef]
74. Jebaraj Benjamin, S.; Murugaiah, U.; Srikamaladevi Marathamuthu, M. The use of SMED to eliminate small stops in a manufacturing firm. *J. Manuf. Technol. Manag.* **2013**, *24*, 792–807. [CrossRef]
75. Mandahawi, N.; Fouad, R.H.; Obeidat, S. An Application of Customized Lean Six Sigma to Enhance Productivity at a Paper Manufacturing Company. *Jordan J. Mech. Ind. Eng.* **2012**, *6*, 103–109.
76. Dadashnejad, A.-A.; Valmohammadi, C. Investigating the effect of value stream mapping on overall equipment effectiveness: A case study. *Total Qual. Manag. Bus. Excell.* **2019**, *30*, 466–482. [CrossRef]
77. Baghbani, M.; Iranzadeh, S.; Bagherzadeh khajeh, M. Investigating the relationship between RPN parameters in fuzzy PFMEA and OEE in a sugar factory. *J. Loss Prev. Process Ind.* **2019**, *60*, 221–232. [CrossRef]
78. Ghafoorpoor Yazdi, P.; Azizi, A.; Hashemipour, M. A Hybrid Methodology for Validation of Optimization Solutions Effects on Manufacturing Sustainability with Time Study and Simulation Approach for SMEs. *Sustainability* **2019**, *11*, 1454. [CrossRef]
79. Dresch, A.; Veit, D.R.; de Lima, P.N.; Lacerda, D.P.; Collatto, D.C. Inducing Brazilian manufacturing SMEs productivity with Lean tools. *Int. J. Product. Perform. Manag.* **2019**, *68*, 69–87. [CrossRef]

80. Daneshjo, N.; Malega, P.; Pajerská, E.D. Production Efficiency in Company with Small Series Production. *TEM J.* **2019**, *8*, 1118–1126. [CrossRef]
81. Al-Refaie, A.; Abbasi, G.; Al-shalaldeh, H. Lean and agile practices to improve the performance of filling process via simulation and data envelopment analysis. *SN Appl. Sci.* **2019**, *1*. [CrossRef]
82. Pereira, A.M.H.; Silva, M.R.; Domingues, M.A.G.; Sá, J.C. Lean six sigma approach to improve the production process in the mould industry: A case study. *Qual. Innov. Prosper.* **2019**, *23*, 103–121. [CrossRef]
83. Tortorella, G.; Fettermann, D. Help chain in companies undergoing a lean implementation: The impact of critical success factors on quality and efficiency performance. *Int. J. Lean Six Sigma* **2018**, *9*, 113–132. [CrossRef]
84. Fera, M.; Fruggiero, F.; Costabile, G.; Lambiase, A.; Pham, D.T. A new mixed production cost allocation model for additive manufacturing (MiProCAMAM). *Int. J. Adv. Manuf. Technol.* **2017**, *92*, 4275–4291. [CrossRef]
85. Lozano, J.; Saenz-Díez, J.C.; Martínez, E.; Jiménez, E.; Blanco, J. Methodology to improve machine changeover performance on food industry based on SMED. *Int. J. Adv. Manuf. Technol.* **2017**, *90*, 3607–3618. [CrossRef]
86. Morales Méndez, J.D.; Silva Rodríguez, R. Set-up reduction in an interconnection axle manufacturing cell using SMED. *Int. J. Adv. Manuf. Technol.* **2016**, *84*, 1907–1916. [CrossRef]
87. Gendre, Y.; Waridel, G.; Guyon, M.; Demuth, J.F.; Guelpa, H.; Humbert, T. Manufacturing execution systems: Examples of performance indicator and operational robustness tools. *Chimia* **2016**, *70*, 616–620. [CrossRef]
88. Chen, B.; Wan, J.; Shu, L.; Li, P.; Mukherjee, M.; Yin, B. Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges. *IEEE Access* **2017**, *6*, 6505–6519. [CrossRef]
89. Canizo, M.; Conde, A.; Charramendieta, S.; Minon, R.; Cid-Fuentes, R.G.; Onieva, E. Implementation of a large-scale platform for cyber-physical system real-time monitoring. *IEEE Access* **2019**, *7*, 52455–52466. [CrossRef]
90. Kasashima, Y. Easy-to-use detection method for micro-arc discharge in plasma etching equipment by measuring current flowing to ground. *Jpn. J. Appl. Phys.* **2018**, *57*. [CrossRef]
91. Chang, T.W.; Cho, E.; Jun, J.H.; Ahn, H. Implementation of smart factory for sme: Focusing on data acquisition and monitoring. *ICIC Express Lett. Part B Appl.* **2019**, *10*, 551–558. [CrossRef]
92. Alvarado, L.; Grimaldo Quispe, C.R. Method for optimizing the production process of domestic water tank manufacturing companies. *Int. J. Eng. Res. Technol.* **2018**, *11*, 1735–1757.
93. Perumal, P.A.; Teruaki, I.; Siang, T.Y.; Sieng, Y.S. Examination of Overall Equipment Effectiveness (OEE) in term of Maynard's Operation Sequence Technique (MOST). *Am. J. Appl. Sci.* **2016**, *13*, 1214–1220. [CrossRef]
94. Ljungberg, Õ. Measurement of overall equipment effectiveness as a basis for TPM activities. *Int. J. Oper. Prod. Manag.* **1998**, *18*, 495–507. [CrossRef]
95. Al-Najjar, B. Total quality maintenance: An approach for continuous reduction in costs of quality products. *J. Qual. Maint. Eng.* **1996**, *2*, 4–20. [CrossRef]
96. Abdul Samat, H.; Kamaruddin, S.; Abdul Azid, I. Integration of overall equipment effectiveness (OEE) and reliability method for measuring machine effectiveness. *S. Afr. J. Ind. Eng.* **2012**, *23*, 92–113. [CrossRef]
97. Tsarouhas, P.H. Evaluation of maintenance management through the overall equipment effectiveness of a yogurt production line in a medium-sized Italian company. *Int. J. Product. Qual. Manag.* **2015**, *16*, 298–311. [CrossRef]
98. Shahin, A.; Attarpour, M.R. Developing decision making grid for maintenance policy making based on estimated range of overall equipment effectiveness. *Mod. Appl. Sci.* **2011**, *5*, 86–97. [CrossRef]
99. Durán, O.; Durán, P.A. Prioritization of Physical Assets for Maintenance and Production Sustainability. *Sustainability* **2019**, *11*, 4296. [CrossRef]
100. Khisamova, E.D.; Kodolova, I.A.; Kucherbaeva, A.A. Impact of Lean Technology on Overall Equipment Effectiveness. *HELIX* **2019**, *9*, 5159–5164. [CrossRef]
101. Daniewski, K.; Kosicka, E.; Mazurkiewicz, D. Analysis of the correctness of determination of the effectiveness of maintenance service actions. *Manag. Prod. Eng. Rev.* **2018**, *9*, 20–25. [CrossRef]
102. Ylipää, T.; Skoogh, A.; Bokrantz, J.; Gopalakrishnan, M. Identification of maintenance improvement potential using OEE assessment. *Int. J. Product. Perform. Manag.* **2017**, *66*, 126–143. [CrossRef]
103. Saleem, F.; Nisar, S.; Khan, M.A.; Khan, S.Z.; Sheikh, M.A. Overall equipment effectiveness of tyre curing press: A case study. *J. Qual. Maint. Eng.* **2017**, *23*, 39–56. [CrossRef]

104. Fattah, J.; Ezzine, L.; Lachhab, A. Evaluating the performance of a production line by the overall equipment effectiveness: An approach based on best maintenance practices. *Int. J. Eng. Res. Afr.* **2017**, *30*, 181–189. [CrossRef]
105. Binti Aminuddin, N.A.; Garza-Reyes, J.A.; Kumar, V.; Antony, J.; Rocha-Lona, L. An analysis of managerial factors affecting the implementation and use of overall equipment effectiveness. *Int. J. Prod. Res.* **2016**, *54*, 4430–4447. [CrossRef]
106. Gupta, P.; Vardhan, S. Optimizing OEE, productivity and production cost for improving sales volume in an automobile industry through TPM: A case study. *Int. J. Prod. Res.* **2016**, *54*, 2976–2988. [CrossRef]
107. Wudhikarn, R. Implementation of the overall equipment cost loss (OECL) methodology for comparison with overall equipment effectiveness (OEE). *J. Qual. Maint. Eng.* **2016**, *22*, 81–93. [CrossRef]
108. Duran, O.; Rojas, S.; Duran, P. Measuring the impact of maintenance postponement on overall performance in a chilean crushing plant. *IEEE Lat. Am. Trans.* **2018**, *16*, 1951–1958. [CrossRef]
109. Acharya, A.; Garg, D.; Singh, N.; Gahlaut, U. Plant effectiveness improvement of overall equipment effectiveness using autonomous maintenance training:—A case study. *Int. J. Mech. Prod. Eng. Res. Dev.* **2018**, *9*, 103–112. [CrossRef]
110. Saidi, R.; Soulhi, A.; El Alami, J. The role of the overall equipment effectiveness as a decision support tool for structuring the roadmap of a tfs transformation (Constraint theory, safety of operation, and six sigma). *J. Theor. Appl. Inf. Technol.* **2017**, 3441–3449.
111. Prickett, P.W. An integrated approach to autonomous maintenance management. *Integr. Manuf. Syst.* **1999**, *10*, 233–243. [CrossRef]
112. Blanchard, B.S. An enhanced approach for implementing total productive maintenance in the manufacturing environment. *J. Qual. Maint. Eng.* **1997**, *3*, 69–80. [CrossRef]
113. Wang, F.K.; Lee, W. Learning curve analysis in total productive maintenance. *Omega* **2001**, *29*, 491–499. [CrossRef]
114. Rashid, M.M.; Ismail, H. Generic approach for the customisation of the TPM programme: Using the process transformation model and reliability assessment tool. *Eur. J. Ind. Eng.* **2008**, *2*, 401–427. [CrossRef]
115. Kumar, M.; Antony, J.; Singh, R.K.; Tiwari, M.K.; Perry, D. Implementing the lean sigma framework in an Indian SME: A case study. *Prod. Plan. Control* **2006**, *17*, 407–423. [CrossRef]
116. Fore, S.; Zuze, L. Improvement of overall equipment effectiveness through total productive maintenance. *World Acad. Sci. Eng. Technol.* **2010**, *61*, 2010.
117. Shetty, D.; Ali, A.; Chapdelaine, J.J. A model for the total productive manufacturing assessment and implementation. *J. Adv. Manuf. Syst.* **2009**, *8*, 117–136. [CrossRef]
118. Azar, A.T. The influence of maintenance quality of hemodialysis machines on hemodialysis efficiency. *Saudi J. Kidney Dis. Transplant.* **2009**, *20*, 49.
119. Da Silva, C.M.I.; Cabrita, C.M.P.; De Oliveira Matias, J.C. Proactive reliability maintenance: A case study concerning maintenance service costs. *J. Qual. Maint. Eng.* **2008**, *14*, 343–355. [CrossRef]
120. Sarkar, B.N. Capability enhancement of a metal casting processes in a small steel foundry through Six Sigma: A case study. *Int. J. Six Sigma Compet. Advant.* **2007**, *3*, 56–71. [CrossRef]
121. Tsarouhas, P. Implementation of total productive maintenance in food industry: A case study. *J. Qual. Maint. Eng.* **2007**, *13*, 5–18. [CrossRef]
122. Jain, A.; Bhatti, R.S.; Singh, H. OEE enhancement in SMEs through mobile maintenance: A TPM concept. *Int. J. Qual. Reliab. Manag.* **2015**, *32*, 503–516. [CrossRef]
123. Rødseth, H.; Skarlo, T.; Schjølberg, P. Profit loss indicator: A novel maintenance indicator applied for integrated planning. *Adv. Manuf.* **2015**, *3*, 139–150. [CrossRef]
124. Arango Serna, M.D.; Alzate Lopez, J.F.; Zapata Cortes, J.A. Tpm implementation impact on companies' competitivity in the medellin metropolitan and Antioquia's eastern region, Colombia. *Dyna* **2012**, *79*, 164–170.
125. Santos, J.; Garcia, M.P.; Arcelus, M.; Viles, E.; Uranga, J. Development of a wireless PlugandLean system for improving manufacturing equipment diagnosis. *Int. J. Comput. Integr. Manuf.* **2011**, *24*, 338–351. [CrossRef]
126. Ananth, G.; Vinayagam, B.K. Effectiveness improvement through total productive maintenance using particle swarm optimisation model for small and micro manufacturing enterprises. *Int. J. Product. Qual. Manag.* **2015**, *16*, 473–503. [CrossRef]

127. Kumar, J.; Soni, V.K.; Agnihotri, G. Impact of TPM implementation on Indian manufacturing industry. *Int. J. Product. Perform. Manag.* **2014**, *63*, 44–56. [CrossRef]
128. Ohunakin, O.S.; Leramo, R.O. Total productive maintenance implementation in a beverage industry: A case study. *J. Eng. Appl. Sci.* **2012**, *7*, 128–133. [CrossRef]
129. Dogra, M.; Sharma, V.S.; Sachdeva, A.; Dureja, J.S. TPM—A key strategy for productivity improvement in process industry. *J. Eng. Sci. Technol.* **2011**, *6*, 1–16.
130. Wakiru, J.M.; Pintelon, L.; Muchiri, P.; Chemweno, P. Integrated maintenance policies for performance improvement of a multi-unit repairable, one product manufacturing system. *Prod. Plan. Control* **2020**, 1–21. [CrossRef]
131. Singh, J.; Singh, H.; Sharma, V. Success of TPM concept in a manufacturing unit—A case study. *Int. J. Product. Perform. Manag.* **2018**, *67*, 536–549. [CrossRef]
132. Nwanya, S.C.; Udofia, J.I.; Ajayi, O.O. Optimization of machine downtime in the plastic manufacturing. *Cogent Eng.* **2017**, *4*. [CrossRef]
133. Nallusamy, S. Enhancement of productivity and efficiency of CNC machines in a small scale industry using total productive maintenance. *Int. J. Eng. Res. Afr.* **2016**, *25*, 119–126. [CrossRef]
134. Bataineh, O.; Al-Hawari, T.; Alshraideh, H.; Dalalah, D. A sequential TPM-based scheme for improving production effectiveness presented with a case study. *J. Qual. Maint. Eng.* **2019**, *25*, 144–161. [CrossRef]
135. Nallusamy, S.; Kumar, V.; Yadav, V.; Prasad, U.K.; Suman, S.K. Implementation of total productive maintenance to enhance the overall equipment effectiveness in medium scale industries. *Int. J. Mech. Prod. Eng. Res. Dev.* **2018**, *8*, 1027–1038. [CrossRef]
136. Udomraksasakul, C.; Udomraksasakul, C. Increase improvement of overall equipment effectiveness of plastic molding machine. *Int. J. Mech. Eng. Technol.* **2018**, *9*, 1107–1113.
137. Sharma, R.; Singh, J.; Rastogi, V. The impact of total productive maintenance on key performance indicators (PQCDSM): A case study of automobile manufacturing sector. *Int. J. Product. Qual. Manag.* **2018**, *24*, 267. [CrossRef]
138. Fam, S.F.; Prastyo, D.D.; Loh, S.L.; Utami, S.; Yong, D.H.Y. Total productive maintenance practices in manufacture of electronic components & boards industry in Malaysia. *J. Telecommun. Electron. Comput. Eng.* **2018**, *10*, 97–101.
139. Pires, S.P.; Sénéchal, O.; Loures, E.F.R.; Jimenez, J.F. An approach to the prioritization of sustainable maintenance drivers in the TBL framework. *IFAC Pap. OnLine* **2016**, *49*, 150–155. [CrossRef]
140. En-Nhaili, A.; Meddaoui, A.; Bouami, D. Effectiveness improvement approach basing on oee and lean maintenance tools. *Int. J. Process Manag. Benchmarking* **2016**, *6*, 147–169. [CrossRef]
141. Kar, M.K. Implementation of planned maintenance using tpm methodology for a bi-cycle manufacturing industry. *Int. J. Mech. Eng. Technol.* **2016**, *7*, 253–270.
142. Gibbons, P.M.; Burgess, S.C. Introducing OEE as a measure of lean Six Sigma capability. *Int. J. Lean Six Sigma* **2010**, *1*, 134–156. [CrossRef]
143. Zammori, F.; Braglia, M.; Frosolini, M. Stochastic overall equipment effectiveness. *Int. J. Prod. Res.* **2011**, *49*, 6469–6490. [CrossRef]
144. Gołda, G.; Kampa, A.; Paprocka, I. Analysis of human operators and industrial robots performance and reliability. *Manag. Prod. Eng. Rev.* **2018**, *9*, 24–33. [CrossRef]
145. Tham, K.D.; Madni, A.M. Sox Compliance with OEE, Enterprise Modeling and Temporal-ABC. *Intell. Autom. Soft Comput.* **2017**, 1–9. [CrossRef]
146. Kampa, A.; Gołda, G. Modelling and simulation method for production process automation in steel casting foundry. *Arch. Foundry Eng.* **2018**, *18*, 47–52. [CrossRef]
147. Kampa, A.; Gołda, G.; Paprocka, I. Discrete Event Simulation Method as a Tool for Improvement of Manufacturing Systems. *Computers* **2017**, *6*, 10. [CrossRef]
148. Rylková, Ž.; Stelmach, K.; Vlcek, P. Overall equipment effectiveness within counterfactual impact evaluation concept. *Sci. Ann. Econ. Bus.* **2017**, *64*, 29–40. [CrossRef]
149. Esa, F.; Yusof, Y. Implementing overall equipment effectiveness (OEE) and sustainable competitive advantage: A case study of hicom diecastings SDN. BHD.(HDSB). *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 199–203.

150. Ghafoorpoor Yazdi, P.; Azizi, A.; Hashemipour, M. An Empirical Investigation of the Relationship between Overall Equipment Efficiency (OEE) and Manufacturing Sustainability in Industry 4.0 with Time Study Approach. *Sustainability* **2018**, *10*, 3031. [CrossRef]
151. Teoh, Y.S.; Ito, T.; Perumal, P. Invisibility of impact from customer demand and relations between processes in Overall Equipment Effectiveness (OEE). *J. Adv. Mech. Des. Syst. Manuf.* **2017**, *11*, JAMDSM0065. [CrossRef]
152. Kukla, S. Modelling and Optimization of Organization of Workplaces in a Foundry. *Arch. Foundry Eng.* **2016**, *16*, 55–58. [CrossRef]
153. Buchmeister, B.; Friscic, D.; Palcic, I. Impact of demand changes and supply chain's level constraints on bullwhip effect. *Adv. Prod. Eng. Manag.* **2013**, 199–208. [CrossRef]
154. Jaegler, A.; Burlat, P. What is the impact of sustainable development on the re-localisation of manufacturing enterprises? *Prod. Plan. Control* **2014**, *25*, 902–911. [CrossRef]
155. Buchmeister, B.; Friscic, D.; Lalic, B.; Palcic, I. Analysis of a three-stage supply chain with level constraints. *Int. J. Simul. Model.* **2012**, *11*, 196–210. [CrossRef]
156. Perez Loaiza, R.E.; Olivares-Benitez, E.; Miranda Gonzalez, P.A.; Guerrero Campanur, A.; Martinez Flores, J.L. Supply chain network design with efficiency, location, and inventory policy using a multiobjective evolutionary algorithm. *Int. Trans. Oper. Res.* **2017**, *24*, 251–275. [CrossRef]
157. Jeong, K.Y.; Phillips, D.T. Operational efficiency and effectiveness measurement. *Int. J. Oper. Prod. Manag.* **2001**, *21*, 1404–1416. [CrossRef]
158. De Ron, A.J.; Rooda, J.E. OEE and equipment effectiveness: An evaluation. *Int. J. Prod. Res.* **2006**, *44*, 4987–5003. [CrossRef]
159. Garza-Reyes, J.A.; Eldridge, S.; Barber, K.D.; Soriano-Meier, H. Overall equipment effectiveness (OEE) and process capability (PC) measures: A relationship analysis. *Int. J. Qual. Reliab. Manag.* **2010**, *27*, 48–62. [CrossRef]
160. Yuniawan, D.; Ito, T.; Bin, M.E. Calculation of overall equipment effectiveness weight by Taguchi method with simulation. *Concurr. Eng.* **2013**, *21*, 296–306. [CrossRef]
161. Kumar, J.; Soni, V.K. An Exploratory Study of OEE Implementation in Indian Manufacturing Companies. *J. Inst. Eng. Ser. C* **2015**, *96*, 205–214. [CrossRef]
162. Maran, M.; Manikandan, G.; Thiagarajan, K. Fuzzy expert system for plant overall equipment effectiveness. *Eur. J. Sci. Res.* **2012**, *83*, 430–438.
163. Zuashkiani, A.; Rahmandad, H.; Jardine, A.K.S. Mapping the dynamics of overall equipment effectiveness to enhance asset management practices. *J. Qual. Maint. Eng.* **2011**, *17*, 74–92. [CrossRef]
164. Bengtsson, M. Using a game-based learning approach in teaching overall equipment effectiveness. *J. Qual. Maint. Eng.* **2019**. [CrossRef]
165. Ng, K.C.; Chong, K.E. A framework for improving manufacturing overall equipment effectiveness. *J. Adv. Manuf. Technol.* **2018**, *12*, 383–400. [CrossRef]
166. Hidayat, A.; Irdas, I. Evaluation of micro hydro power plant (MHPP) using overall equipment effectiveness (OEE) method. *ARPN J. Eng. Appl. Sci.* **2017**, *12*, 5271–5275.
167. Krokoszinski, H.J. Efficiency and effectiveness of wind farms-keys to cost optimized operation and maintenance. *Renew. Energy* **2003**, *28*, 2165–2178. [CrossRef]
168. Muthiah, K.M.N.; Huang, S.H.; Mahadevan, S. Automating factory performance diagnostics using overall throughput effectiveness (OTE) metric. *Int. J. Adv. Manuf. Technol.* **2008**, *36*, 811–824. [CrossRef]
169. Ng, R.; Low, J.S.C.; Song, B. Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric. *J. Clean. Prod.* **2015**, *95*, 242–255. [CrossRef]
170. Alzubi, E.; Atieh, A.M.; Abu Shgair, K.; Damiani, J.; Sunna, S.; Madi, A. Hybrid Integrations of Value Stream Mapping, Theory of Constraints and Simulation: Application to Wooden Furniture Industry. *Processes* **2019**, *7*, 816. [CrossRef]
171. Bokrantz, J.; Skoogh, A.; Ylipää, T.; Stahre, J. Handling of production disturbances in the manufacturing industry. *J. Manuf. Technol. Manag.* **2016**, *27*, 1054–1075. [CrossRef]
172. Abd Rahman, M.S.; Mohamad, E.; Abdul Rahman, A.A. Enhancement of overall equipment effectiveness (OEE) data by using simulation as decision making tools for line balancing. *Indones. J. Electr. Eng. Comput. Sci.* **2020**, *18*, 1040–1047. [CrossRef]

173. Huang, S.H.; Dismukes, J.P.; Shi, J.; Su, Q.; Wang, G.; Razzak, M.A.; Robinson, D.E. Manufacturing system modeling for productivity improvement. *J. Manuf. Syst.* **2002**, *21*, 249–259. [CrossRef]
174. Muthiah, K.M.N.; Huang, S.H. Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection. *Int. J. Prod. Res.* **2007**, *45*, 4753–4769. [CrossRef]
175. deRon, A.J.; Rooda, J.E. Equipment Effectiveness: OEE Revisited. *IEEE Trans. Semicond. Manuf.* **2005**, *18*, 190–196. [CrossRef]
176. Sheu, D.D. Overall Input Efficiency and Total Equipment Efficiency. *IEEE Trans. Semicond. Manuf.* **2006**, *19*, 496–501. [CrossRef]
177. Badiger, A.S.; Gandhinathan, R.; Gaitonde, V.N. A methodology to enhance equipment performance using the OEE measure. *Eur. J. Ind. Eng.* **2008**, *2*, 356. [CrossRef]
178. Anvari, F.; Edwards, R.; Starr, A. Evaluation of overall equipment effectiveness based on market. *J. Qual. Maint. Eng.* **2010**, *16*, 256–270. [CrossRef]
179. Anvari, F.; Edwards, R. Performance measurement based on a total quality approach. *Int. J. Product. Perform. Manag.* **2011**, *60*, 512–528. [CrossRef]
180. Wudhikarn, R. Improving overall equipment cost loss adding cost of quality. *Int. J. Prod. Res.* **2012**, *50*, 3434–3449. [CrossRef]
181. Eswaramurthi, K.G.; Mohanram, P.V. Improvement of manufacturing performance measurement system and evaluation of overall resource effectiveness. *Am. J. Appl. Sci.* **2013**, *10*, 131–138. [CrossRef]
182. Jauregui Becker, J.M.; Borst, J.; van der Veen, A. Improving the overall equipment effectiveness in high-mix-low-volume manufacturing environments. *CIRP Ann.* **2015**, *64*, 419–422. [CrossRef]
183. Zammori, F. Fuzzy Overall Equipment Effectiveness (FOEE): Capturing performance fluctuations through LR Fuzzy numbers. *Prod. Plan. Control* **2015**, *26*, 451–466. [CrossRef]
184. Dindarloo, S.R.; Siami-Irdemoosa, E.; Frimpong, S. Measuring the effectiveness of mining shovels. *Min. Eng.* **2016**, *68*, 45–50. [CrossRef]
185. Mohammadi, M.; Rai, P.; Gupta, S. Performance Evaluation of Bucket based Excavating, Loading and Transport (BELT) Equipment—An OEE Approach. *Arch. Min. Sci.* **2017**, *62*, 105–120. [CrossRef]
186. Larrañaga Lesaca, J.M.; Zulueta Guerrero, E.; Lopez-Guede, J.M.; Ramos-Hernanz, J.; Larrañaga Juaristi, A.; Akizu, O. Measuring global effectiveness of integrated electric energy systems. *Int. J. Hydrogen Energy* **2017**, *42*, 18121–18133. [CrossRef]
187. da Silva, A.F.; Marins, F.A.S.; Tamura, P.M.; Dias, E.X. Bi-Objective Multiple Criteria Data Envelopment Analysis combined with the Overall Equipment Effectiveness: An application in an automotive company. *J. Clean. Prod.* **2017**, *157*, 278–288. [CrossRef]
188. Puvanasvaran, A.P.; Yoong, S.S.; Tay, C.C. Effect of hidden wastes in overall equipment effectiveness calculation. *ARPN J. Eng. Appl. Sci.* **2017**, *12*, 6443–6448.
189. Nakhla, M. Designing extended overall equipment effectiveness: Application in healthcare operations. *Int. J. Manag. Sci. Eng. Manag.* **2018**, 1–10. [CrossRef]
190. Braglia, M.; Castellano, D.; Frosolini, M.; Gallo, M. Overall material usage effectiveness (OME): A structured indicator to measure the effective material usage within manufacturing processes. *Prod. Plan. Control* **2018**, *29*, 143–157. [CrossRef]
191. Durán, O.; Capaldo, A.; Duran Acevedo, P. Sustainable Overall Throughputability Effectiveness (S.O.T.E.) as a Metric for Production Systems. *Sustainability* **2018**, *10*, 362. [CrossRef]
192. Muñoz-Villamizar, A.; Santos, J.; Montoya-Torres, J.; Jesus Alvaréz, M. Improving effectiveness of parallel machine scheduling with earliness and tardiness costs: A case study. *Int. J. Ind. Eng. Comput.* **2019**, 375–392. [CrossRef]
193. Abdelbar, K.M.; Bouami, D.; Elfezazi, S. New approach towards formulation of the overall equipment effectiveness. *J. Qual. Maint. Eng.* **2019**. [CrossRef]
194. Brodny, J.; Tutak, M. Analysing the Utilisation Effectiveness of Mining Machines Using Independent Data Acquisition Systems: A Case Study. *Energies* **2019**, *12*, 2505. [CrossRef]
195. Tang, H. A new method of bottleneck analysis for manufacturing systems. *Manuf. Lett.* **2019**, *19*, 21–24. [CrossRef]
196. Aleš, Z.; Pavlů, J.; Legát, V.; Mošna, F.; Jurča, V. Methodology of overall equipment effectiveness calculation in the context of industry 4.0 environment. *Eksploat Niezawodn* **2019**, *21*, 411–418. [CrossRef]

197. Annamalai, S.; Suresh, D. Implementation of total productive maintenance for overall equipment effectiveness improvement in machine shop. *Int. J. Recent Technol. Eng.* **2019**, *8*, 7686–7691. [CrossRef]
198. Durga Prasad, N.V.P.R.; Radhakrishna, C. Key performance index for overall substation performance. *Int. J. Recent Technol. Eng.* **2019**, *8*, 6067–6071. [CrossRef]
199. De Groote, P. Maintenance performance analysis: A practical approach. *J. Qual. Maint. Eng.* **1995**, *1*, 4–24. [CrossRef]
200. Danese, P.; Manfè, V.; Romano, P. A Systematic Literature Review on Recent Lean Research: State-of-the-art and Future Directions. *Int. J. Manag. Rev.* **2017**, *20*, 579–605. [CrossRef]
201. Kamble, S.S.; Gunasekaran, A.; Gawankar, S.A. Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Process Saf. Environ. Prot.* **2018**, *117*, 408–425. [CrossRef]