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Global Process Effectiveness: When Overall Equipment Effectiveness Meets Adherence to Schedule

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Abstract

In recent decades, research has been done to better assess the effectiveness and efficiency of a production process. Therefore, some methods like Overall Equipment Effectiveness (OEE) or Overall Line Effectiveness (OLE) were proposed, however, none of the analysed methods has been able to illustrate accurate results in terms of adherence to a production plan. The purpose of this article is to present a metric, Global Process Effectiveness (GPE), based on OEE, that assesses effectiveness based on OEE factors and the schedule-adherence of a process to a pre-defined production plan, regarding product variety and quantity. If this new performance indicator replaces OEE, it will add one more goal to OEE without increasing the number of key performance indicators used in a company, giving a valuable assessment to operations planning experts.

Keywords: OEE; effectiveness measurement; Benchmarking; Production Plan fulfilment; Schedule-adherence.

1. Introduction

In the manufacturing sector, competition is becoming global and markets are price sensitive. These challenges force corporations to implement numerous productivity improvements to meet the requirements of the ever-changing market demand. Manufacturers effort to cooperate with clients to produce products of high quality at

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competitive prices [1]. Managers must establish convenient metrics for evaluation purposes [2] in order to take better decisions to manage production systems effectively and efficiently. Productivity and quality are two of the most important and most used metrics of efficiency in manufacturing operations [3]. Overall Equipment Effectiveness (OEE) is a quantitative metric used to recognize indirectly and 'hidden' productivity and quality costs, in the form of production losses. These losses are formulated as a function of the mutually exclusive factors: Availability (A), Performance (P) and Quality (Q) [4]. OEE is the result achieved by multiplying these three factors (eq. 1, 2, 3, and 4).

$$OEE = A * P * Q \tag{1}$$

$$A = \frac{Operating\ time}{Schedule\ time} x\ 100 \tag{2}$$

$$P = \frac{Parts\ Produced\ x\ Ideal\ Cycle\ time}{Operating\ time}\ x\ 100 \tag{3}$$

$$Q = \frac{Total\ units\ produced - defective\ units\ produced}{Total\ units\ produced}\ x\ 100 \tag{4}$$

The availability factor measures the total time that a system does not work due to setups, breakdowns, adjustments and other stoppages. The performance factor is the ratio between the actual operating speed of the system (e.g. the ideal speed minus loss of speed, small stop, and idling) and its ideal speed is calculated [5]. Finally, the quality factor expresses the proportion of defective production.

Currently, OEE is regarded as one of the most important metrics used by manufacturing companies not only to monitor productivity and quality, but also as an indicator and motivator of performance improvements [6]. This has led to the widespread circulation of academic research.

Extensive research aimed at expanding the scope of the OEE's application was done, as its original evaluation scope was limited. One of the limitations is that it ignores problems related to the production plan and timetable adherence. In a production environment in which several semi-products or finished products can be produced during the same period, it can be understood that the manufacturing process can produce more from one product and less from another and still meet the expected performance and quality requirements, while the expected quantities of each product are not delivered [7].

For processes that provide more than one output, for example, it is necessary to complement the OEE measurement with other performance measures that can provide a broader and more complete overview of the operations [8]. However, considering that measuring does not add value to products, companies must reduce the number of performance measures, using the necessary ones to follow up objectives and control processes.

The main goal of a company regarding its processes is to maintain a material flow in a highly coordinated process among all processes without disruption. Coordinated operations allow responding to the customer changing requirements, managing material flows by both volume and time, aiming at handling the quantity needed by one process or equipment from the one that precedes it [9], feeding from one step of the chain to the following one the quantity needed at the scheduled timing. As macro processes in the industry have numerous types of equipment and sub-processes, the challenge is to manage and control these in order to achieve the highest performance and ultimately profit for the plant. Thus, Key Performance Indicators (KPIs) such as OEE, are essential for the management, control, and measurement of performance in different areas such as manufacturing, maintenance, planning and scheduling, product quality, inventory [10], among others.

In a manufacturing process, adherence to plan refers to the ability of the production system to manufacture units according to the schedule. By accurately planning all steps and requirements, and adhering to that plan, the goal is to produce and deliver goods just in time to be sold, produced at the right time and pace, and purchase materials on time to be transformed into parts [11], aiming to reduce the investment on stocks while significantly increasing responsiveness towards the customer [12]. Therefore, a company must not only be flexible in terms of customer requests but also be able to coordinate and synchronize effectively (do the right things) and efficiently (do it well) [8, 10].

This paper proposes a new method to calculate the process efficiency based on the OEE formula. Global Process Effectiveness (GPE) intends to evaluate a process effective performance based on equipment availability, production speed, quality level and its ability to comply with a pre-defined production plan. Therefore, a comprehensive perspective can be achieved in terms of performance and identification of development opportunities.

Following this introduction, the next section presents a concise literature review on different KPIs based on OEE. The third section exhibits the development of GPE KPI to assess process effectiveness, complemented by an example of calculation and interpretation of the proposed KPI, ending with results analysis and discussion. The fourth section presents some conclusions and future work remarks.

2. Previous studies based on the OEE formula

As OEE can be used as an index of performance evaluation of equipment or a production system, some authors have proposed performance indicators based on OEE (Table 1) in order to complement that evaluation.

Table 1. KPIs based on OEE

Measure name	Definition	Advantages	Disadvantages
TEEP	Total Effective Equipment Productivity (TEEP) is generated to calculate hidden operation times [7, 13].	Maintenance activates and adjustments are considered on the planned downtimes to gain accurate understanding of maintenance contributions to productivity [7].	Focused on operational losses, TEEP will present low values if valuable operating time is not well defined [7, 13].
OLE	Overall Line Effectiveness (OLE) is a metric focused on measuring effectiveness of continuous line manufacturing systems [14].	As all machines are directly related together, the output of a machine is assessed by its contribution on the following one, which in turn links to the output of the upstream machines, leading to precise results in continues line manufacturing systems [14].	Requires more training and experience to implement than OEE. Also, if the planned downtime is not properly considered, it will lead to sub optimization of resources in the production line [14].
OPE	The Overall Plant Effectiveness (OPE) measures alignment of the supply chain with effective utilization of the manufacturing assets [7].	Considers planned down time and unscheduled time [7].	Due to wide range of production losses that can be included, some important ones could be missed [7].
OAE	Overall Asset Effectiveness (OAE) is generated for the measurement of divided-type processes and continuous process effectiveness [7].	Suited for the measurement of individual equipment where capacity utilization has high priority [7].	It considers a wide range of production losses, from commercial demand fluctuation to other losses due to external reasons or internal business, which are difficult to measure and detect [7].
OEEML	Overall Equipment Effectiveness of a Manufacturing Line (OEEML) provides an integrated approach to assess and mitigate criticalities that affect the effectiveness of a manufacturing line [15].	It can measure the degradation of the ideal cycle time, identify and quantify the reasons of inefficiencies and where they take place, and it can be applied in lines that have buffers between processes [15].	OEEML alone fails to evaluate and find to which extent effectiveness is affected by high-inventory levels that can hide throughput problems [15].
PEE	Production Equipment Effectiveness (PEE) is similar to OEE where the main difference it is that allows to consider difference weights to the three factors [7, 16].	Similarly to the TEEP planning rate, the availability rate considers planned downtime and it also makes distinction continuous process operation and discrete production operations [7, 16].	The main disadvantage is related to continuous process operation, where it does not consider setup time [7, 16].
ORE	Overall Resource Effectiveness (ORE) is a manufacturing performance measure that was developed with the objective to be applied either to a machine or entire process [17].	ORE measure considers an economic investment (input) in materials and resources [17].	Requires the determination of some economic and cost parameters, making the KPI sensible to cost variations regarding materials and processes [17].

Summarizing the information presented on table 1, TEEP considers as planned downtime maintenance and setup activities in order to obtain higher values of OEE [13, 18]. So to identify and recognize problems in deviation of planned production process both TEEP and OEE should be considered [19].

OLE can be used to calculate interdependent parameters between machines [7, 14, 17]. In order to improve the effectiveness of a continuous production line manufacturing system, the OLE provides an appropriate solution. However, defectives units and parts that need to be reworked or eliminated are considered all together, so if the line process is decoupled the method loses its logical.

One other usable variation of OEE is PEE [16]. The main focus of PEE is on the weight assignment to the various items. It assumes the same factors as in OEE but weights them in different types of production operation, mainly between discrete-type production and continues process operation [7]. Other variation, ORE considers that an economic investment (input) in materials and resources is required to run a manufacturing process. This KPI considers the monetary value spent on materials and process resources, as well return of investment based on the number of units produced and accepted, monitoring also the process resources and material waste value [17].

OAE and OPE have some differences in the calculation by applying various parameters concerning time or quantity. OPE in contrast to the OAE is not determined by output quantity but by length of time. However, in both cases losses are considered but an identification of the mentioned weaknesses is not possible as losses are organized in categories and treated altogether, disregarding specific actions to solved each loss individually [7].

Since there was a gap in analysing production systems with several equipment working as a manufacturing line, a new variation of OEE named OEEML was introduced by [15], evaluating effectiveness as a result from the entire line while being able to locate where the production losses occurred. However, "It is well known that overproduction and WIP accumulation is one of the main causes of waste, as it creates queue and congestion on the shop floor, resulting in an increase of both operating costs and production lead time. So, it is important to discriminate between a system that is truly efficient, from one that protects production by use of high in-process inventory levels" [15]:26.

By analysing these performance indicators, it is hard to find coherence and precise research about the production planning fulfilment and its effect on final result of OEE. When a production deviation has occurred, it is not supposed to be repeated in the near future, even if the deviation has been corrected and the production planning manager is able to design a suitable production planning process to eliminate the mistake in final result of production planning by hidden production planned errors. The effectiveness of any concept of production planning structure can be quantified and managed in order to generate more coherence in a production process, which leads to overcome barriers in business competitiveness.

3. Global process effectiveness

In the previous section, variations from the original OEE KPI have been presented in order to account for other possible measurement factors regarding processes and their complexity.

As mentioned by [9], optimal production planning and scheduling impacts on how well plant and equipment capacity is used, influencing production system effectiveness. This suggests the relevance of developing a KPI to measure the level of fulfilment of the production plan.

Supposing that a production plan is done to answer customer demands, the production plan should be done accordingly, avoiding to under or overproduce products that are not required from the final consumer [10], neither in quantity nor timing.

Thus, assuming that an organization is focussed on producing and supplying what the customers and markets are requiring and planning their operations to achieve customer satisfaction, it is important to keep track of the performance regarding those plans, as adherence to the production plan will ensure that the organization is working effectively to its customers. As adherence to schedule is usually checked after a production order occurred, it tends to be limited for operational production control, however as important as complying with the commitments of a production order, it can also be used for controlling variables such as sequence deviation, lead time and work in progress, which will influence the adherence to schedule [20].

3.1. GPE proposal

As previously mentioned, although there are several KPIs based on the OEE, to the best of the authors knowledge, none of them assesses the effectiveness of a process regarding the variety and quantity of products that were planned in order to be supplied to its customers. Therefore, based on the OEE formulation, Global Process Effectiveness (GPE) intends to evaluate process effective performance based on its availability, performance, produced quality and its ability to comply with the pre-defined production plan. The GPE should be calculated using eq. 5.

GPE = Availability x Performance x Quality x Schedule_Adherence (5)

Availability, Performance, and Quality factors are defined as on the original version of the OEE KPI [21]. The last factor of the GPE should be calculated as follows:

$$\text{Schedule\_Adherence} = \left(1 - \left(\frac{\sum_{i=1}^{n}\left(\frac{|ProductionPlan_i - ProductionDone_i|}{ProductionPlan_i}\right)}{Numberofproductionpartsplan(n)}\right)\right)x100 \quad (6)$$

Where $\sum_{i=1}^{n}\left(\frac{|ProductionPlan_i - ProductionDone_i|}{ProductionPlan_i}\right)$ represents the module difference between the schedule and the production done for each planned product reference.

An average deviation per product reference will be obtained by adding all the calculated deviations and dividing them by the number of products that were considered on the plan. Assuming that complying with the production schedule would be the ideal scenario, subtracting the above-calculated average will provide information on how much of the production plan was effectively done.

The novelty of GPE is the use of a factor that measures how much of the production schedule is effectively accomplished. The main achievement is not only to measure the efficiency of a process but also to assess the fulfillment of the production plan which is a relevant element to comply with customer expectations. Also, a second benefit from this calculation is to quantify in percentage the impact that a process output(s) has on the proceeding stock of products.

3.2. GPE application example

To better describe and provide understanding regarding the presented proposal and its desired effect, two examples of a production plan that require the production of 3 different products (to be done on the same process during one single shift) will be applied.

Assuming that there was a variation on product production volume (5% on scenario 1 and 10% on scenario 2) when compared with the initial schedule, Table 2 provides information on the schedule production and the production quantity. For the ideal process Run Rate time, it will be assumed the average Run Rate time of all products.

Table 2. Products and production information

Products	Production Plan (Quantity)	Ideal Run Rate (pieces per minute)	Scenario 1		Scenario 2	
			Prod. Variation +/-5%	Production done (Quantity)	Prod. Variation +/-10%	Production done (Quantity)
A	500	2.4	-5.0%	475	10%	550
B	350	2.5	5.0%	368	-10%	315
C	150	2.7	5.0%	158	-10%	135
Total	1000			1000		1000
Average	333	2.53		333		333

In the examples it was considered the shift length of 480 minutes, two short breaks of 10 minutes each, a meal break of 40 minutes, a downtime of 15 minutes, an average ideal run rate of 2.53 pieces per minute, and the number of rejected pieces (of the entire shift production) of 15. Table 3 details the intermediate calculations based on the mentioned considerations. These will be equal to both scenarios. Considering this information, Table 4 shows for each scenario, the calculations, data and results of each factor and, to allow a better understanding and impact of the GPE final results, the OEE final results are also presented for each scenario.

Table 3. Intermediate calculations

	Formulas	Data	Results	Units
Planned Production Time	Shift Length-Breaks	480-60	420	Minutes
Operating Time	Planned Production Time - Down Time	420-15	405	Minutes
Good Pieces	Total Pieces - Rejects Pieces	1000-15	985	Pieces

Table 4 OEE and GPE calculations

Scenarios	KPI	Factors	Formulas	Data	Results (%)
Scenario 1	OEE	Availability	Operating Time / Planned Production Time	405/420	96.43
		Performance	(Total Pieces / Operating Time) / Ideal Run Rate	(1000/405)/2.53	97.47
		Quality	Good Pieces / Total Pieces	985/1000	98.50
		OEE	Availability*Performance*Quality	0.9643*0.9747*0.9850	92.58
	GPE	Schedule-adherence	1-(∑(|Production Plan-Production done|/Production Plan))/Number of production parts plan	1- ((|500-475|+|350-368|+|150-158|)/1000)/3	98.33
		GPE	OEE*Schedule-adherence	0.9258*0.9833	91.03
Scenario 2	OEE	Availability	Operating Time / Planned Production Time	405/420	96.43
		Performance	(Total Pieces / Operating Time) / Ideal Run Rate	(1000/405)/2.53	97.47
		Quality	Good Pieces / Total Pieces	985/1000	98.50
		OEE	Availability*Performance*Quality	0.9643*0.9747*0.9850	92.58
	GPE	Schedule-adherence	1- (∑(|Production Plan-Production done|/Production Plan))/Number of production parts plan	1- ((|500-550|+|350-315|+|150-135|)/1000)/3	96.67
		GPE	OEE*Schedule-adherence	0.9258*0.9667	89.50

Although the presented examples do not represent any real case, they serve to illustrate how calculations are made and the impact that the schedule-adherence factor has on effectiveness assessment. More detailed analysis and discussion over the achieved results is presented on the following sub-section.

3.3. Results analysis and discussion

Table 4 shows that the factors availability, performance, and quality have the same value in both OEE and GPE KPI, but the consideration of a fourth factor that measures the compliance of the production done regarding a production schedule, shows a decrease of 1.55% on the final result for a 5% variation and 3.08% for a 10% variation on each product quantities. This means that, in terms of product quantity and variety, the more a production process deviates from the production plan that was built according to the customer requirements, the less effective that process will be regarding customer expectations, regardless its overall performance on the remaining factors.

Although OEE helps highlighting several wastes, it does not measure if the process output is correctly aligned with customer demand [10], meaning that a process could be running efficiently as represented by OEE but in fact, it is not producing according to the customer requirements. The bigger is the difference between the production plan and the production done, the lower will be the GPE value. Still, small and expected variations on production quantities can be compensated by buffers, suggesting that one could adjust the Schedule-Adherence formula to accommodate some variation flexibility.

Additionally, as it happens with OEE, GPE KPI does not measure what happens beyond the process outputs, meaning that the customer could not be receiving the required products and/or quantities on the correct timing and conditions, but on a just-in-time environment it will provide information on which products, and in what quantity, a process may be under or over performing. From the assumption that the production plan was correctly made to comply with customer expectations, the current proposal of GPE KPI through the Schedule-Adherence factor assesses the number of manufactured products vs planned quantities.

GPE measures not only process efficiency regarding its availability, performance, and quality (like OEE) but also measures the process effectiveness to deliver what is planned. Since it uses the same information that it is required to calculate OEE ((plus the schedule adherence factor), it should be not difficult to implement, and it does provide information regarding process and supply chain effectiveness, as well as valuable data for stock management.

4. Conclusions and future work

Based on the literature reviewed and on gaps identified, the proposed GPE KPI intends to more accurately translate the effectiveness of equipment or processes in a supplier-customer relationship. Using the same information that it would be required to measure OEE, GPE considers an additional factor that is usually measured as a separated KPI after completion of the production orders, which may provide late information regarding process effectiveness towards its customer expectations. When compared with OEE, this separated KPI usually has less visibility and collaborators may not consider it important. The main objective of GPE is to assess in one single KPI the efficiency and effectiveness of a supplier-customer relationship. This KPI can replace OEE and thus will not increase the number of KPI in use.

As production systems are often complex, parameters' definitions of the Schedule-Adherence formula (eq. 6) may need to be adapted to a real scenario, to represent the difference between production plan and production execution.

It is expected that with the proposed KPI the effectiveness of a production plan can be quantified and managed, overcoming some barriers to improve business competitiveness. By using the proposed method, one can detect, correct or even eliminate continuous mistakes or hidden errors on a manufacturing process and on the supply process.

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References

[1] I. Paprocka, W. Kempa, K. Kalinowski, and C. Grabowik, Estimation of overall equipment effectiveness using simulation programme, in IOP Conference Series: Materials Science and Engineering, vol. 95 (2015) 012155.

[2] M. Jasiulewicz-Kaczmarek and M. Piechowski, Practical aspects of OEE in automotive company—case study, in Proceedings of the 2016 International Conference on Management Science and Management Innovation August, (2016) 13–14.

[3] J. A. Garza-Reyes, An Investigation Into Some Measures of Manufacturing Performance: Overall Equipment Effectiveness (OEE), Process Capability (PC), OEE+ and ORE. LAP Lambert Academic Publishing, (2010).

[4] S. H. Huang et al., Manufacturing productivity improvement using effectiveness metrics and simulation analysis, Int. J. Prod. Res., vol. 41, no. 3, (, 2003) 513–527.

[5] P. Jonsson and M. Lesshammar, Evaluation and improvement of manufacturing performance measurement systems-the role of OEE, Int. J. Oper. Prod. Manag., vol. 19, no. 1, (1999) 55–78.

[6] C. Andersson and M. Bellgran, Combining Overall equipment Efficiency (OEE) and productivity measures as drivers for production improvements, in Proceedings of the 4th Swedish Production Symposium (SPS11), (2011) pp. 3–5.

[7] P. Muchiri and L. Pintelon, Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion, Int. J. Prod. Res., vol. 46, no. 13, (2008) 3517–3535.

[8] C. Andersson and M. Bellgran, On the complexity of using performance measures: Enhancing sustained production improvement capability by combining OEE and productivity, J. Manuf. Syst., vol. 35, (2015) 144–154.

[9] C.-F. Lindberg, S. Tan, J. Yan, and F. Starfelt, Key performance indicators improve industrial performance, Energy Procedia, vol. 75, (2015) 1785–1790.
[10] Y. S. Teoh, T. Ito, and P. Perumal, Invisibility of impact from customer demand and relations between processes in Overall Equipment Effectiveness (OEE), J. Adv. Mech. Des. Syst. Manuf., vol. 11, no. 5, (2017).
[11] F. Klug, What we can learn from Toyota on how to tackle the bullwhip effect, in Proceedings of the Logistics Research Network Conference, (2011) 1–10.
[12] A. Gunasekaran, C. Patel, and R. E. McGaughey, A framework for supply chain performance measurement, Int. J. Prod. Econ., vol. 87, no. 3, (2004) 333–347.
[13] E. H. Hartmann, TPM: effiziente Instandhaltung und Maschinenmanagement. Vahlen, (2013).
[14] R. M. Nachiappan and N. Anantharaman, Evaluation of overall line effectiveness (OLE) in a continuous product line manufacturing system, J. Manuf. Technol. Manag., vol. 17, no. 7, (2006) 987–1008.
[15] M. Braglia, M. Frosolini, and F. Zammori, Overall equipment effectiveness of a manufacturing line (OEEML) An integrated approach to assess systems performance, J. Manuf. Technol. Manag., vol. 20, no. 1, (2008) 8–29.
[16] A. Raouf, Improving capital productivity through maintenance, Int. J. Oper. Prod. Manag., vol. 14, no. 7, (1994) 44–52.
[17] J. A. Garza-Reyes, From measuring overall equipment effectiveness (OEE) to overall resource effectiveness (ORE), J. Qual. Maint. Eng., vol. 21, no. 4, (2015) 506–527.
[18] G. Lanza, J. Stoll, N. Stricker, S. Peters, and C. Lorenz, Measuring global production effectiveness, Procedia CIRP, vol. 7, (2013) 31–36.
[19] J. Etteldorf, Analyse und Verbesserung der Gesamtanlageneffektivität an automatisierten Produktionsanlagen. VDI-Verlag, (2000).
[20] S. Kropp and G. Schuh, Event-Driven Production Control based on Sensor Events, in Smart Objects, Systems and Technologies (Smart SysTech), 2014 European Conference on, (2014) 1–9.
[21] S. Nakajima, Introduction to TPM: Total Productive Maintenance (preventative maintenance series), Hardcover ISBN 0-91529-923-2, (1988).