Concepts of Calculation Technological Equipment Efficiency Criteria

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Abstract. Various criterions can characterize the work of mechanic processing equipment. We know the “Compression of working time factor” and the «Overall Equipment Effectiveness» (OEE). The last criterion became known in the 80s-90s of the last century. Was performed the analysis of the efficiency index of OEE equipment. The first criterion was known in the 40s of the last century. They use different concepts. They are reflected in the article, the article also presents the calculation of indicators. An important indicator of OEE contains three components. The meaning of each of them reflects historically applicable indicators. The calculation of the coefficient "OEE" is disclosed through the indicators used in Russian practice. The element base of the Russian indicators is the opposite of the elemental base of the "OEE" indicator and together they form a single whole. The measurability of the indicators makes it possible to make a prediction about the efficiency of the equipment.

1. Introduction
Improving labor productivity by reducing the loss of time is an urgent problem in enterprises in the manufacture of products all the time. In the period of a planned economy in our country, methods of accounting and analysis of working time were widely used and covered in scientific and educational literature.

The ability to account for cost and time wasted in automatic mode appeared with the use of CNC machines and advanced information technologies in the production. At the end of the last century, the level of equipment of foreign industries was higher than the level of equipment of the machine park in our country. The methodology for assessing the effectiveness of equipment based on the use of digital data transmission was not born in our country. Foreign authors have proposed the indicator "OEE" to assess the effectiveness of equipment based on their goals, concepts, terminology.

However, it should be noted that long before the birth of the OEE indicator, Russian researchers presented similar indicators to readers. They reflected the savings in equipment operation time. It would not be fair to forget the history of the development of equipment efficiency indicators, born in our country. This article analyzes the methods and discloses methods for calculating the OEE indicator in order to establish links between the indicators for evaluating the performance of equipment used abroad and in our country. Author was trace and compare the calculation of indicators by methods that appeared at different times.

2. The concept and definition of the indicator "OEE" and its elements
Currently, the OEE (Overall Equipment Effectiveness) indicator has gained fame and is one of the “generally accepted key indicators of the overall efficiency of technological equipment" worldwide [1, 2]. The term itself was proposed in the late sixties of the last century by Seiyichi Nakajima ) [3], but began to be used outside of Japan only in the late eighties, gained fame at the turn of the century, especially in connection with the publication of the book by the American researcher Hansen, Robert C [4].

General parameter of effectiveness (OEE) determined by 3 following items:

- A-Availability: (percentage of scheduled time that the operation is available to operate.
- **P-Performance**: (speed at which the Work Center runs as a percentage of its designed speed).
- **Q-Quality**: (Good Units produced as a percentage of the Total Units Started).

\[ OEE = A \cdot P \cdot Q \]  

(1)

Each parameter can be represented by coefficients: For instance if \( A = 0.87; \ P = 0.50; \ Q = 0.95 \), than 
\[ OEE = 0.87 \cdot 0.50 \cdot 0.95 = 0.42 \]

«Availability» (A) is calculated [1, 2, 3, 4, 5, 6]:

\[ A = \frac{OT}{PPT} = \frac{PPT-DTL}{PPT} \]  

(2)

Where the designation is using:

- **OT** - Operating Time (reducing stand by time),
- **DTL** - Down Time Loss - all stand by or non-operational time by all reasons, loss at stops, including any unscheduled stops, such as: equipment breakdowns and failures, stops due to a shortage of raw materials or lack of storage space (transition time is also included in the OEE analysis, as it is one of the forms idle time, although the transition time cannot be eliminated, in most cases it can be reduced).
- **PPT** - Planned Production Time.

These elements of the formula (2) and other elements of time we present in Figure 1:

\[ POT \ - \ Plant \ Operating \ Time. \]
\[ PSD - Planned \ Shut \ Down \ - \ this \ time \ to \ be \ excluded \ from \ efficiency \ analysis, \ since \ production \ at \ this \ moment \ is \ impossible. \]
\[ SL - Speed \ Loss; \]
\[ NOT - Net \ Operating \ Time, \]
\[ QL - Quality \ Loss \]
\[ FPT - Fully \ Productive \ Time. \]

The coefficient "Performance" is calculated according to the following dependencies:

\[ P = \frac{ICT}{(OT/TP)} \]  

(3)

or

\[ P = \frac{(TP/OT)}{IRR} \]  

(4)

Further accepted:

- **ICT** – Ideal Cycle Time – theoretical, minimum time required for unit production;
- **IRR** – Ideal Run Rate – theoretically, the maximum amount of production per unit of time is the inverse ICT;
- **OT** – Operating time.
- **TP** – Total Pieces – the actual number of units released during the operating time OT.
The third element in the criterion OEE is the element that defines the "quality level" (Q). The quality criterion takes into account the loss in quality, i.e. production, which does not meet the standards [1, 5]:

\[ Q = \frac{GP}{TP} \]  

(5)

The designation is accepted:

GP – “Good Pieces” – the actual number of units of standards products released during the operating time OT.

3. The concept of time accounting for the rationing of manufacturing parts process

The concept of labor intensity or item-calculated time \( t_{item} \) is used in domestic practice. Elements of time and the methods by which these elements can be calculated are marked in Figure 2.

- \( t_{item} \) or \( t_{table} \) - time of item manufacturing;
- \( t_{op} \) - operational time; \( t_{op} = t_{base} + t_{add} \)
- \( t_{base} \) - base time;
- \( t_{add} \) - additional time.
- \( t_{break} \) - break time; \( t_{break} = t_{maintenance} + t_{op.m} + t_{wp} \)
- \( t_{maintenance} \) - maintenance time;
- \( t_{op.m} \) - time for operational management;
- \( t_{wp} \) - operator’s private time.
- \( t_{p.e} \) - preparation and ending time

The method of “Motion study” (“MS”) [7] is based on the recording of activities in the workplace. The special form (“Workshop report for the month on motion study of the working day on the workplace”) noted the actual work of each machine, taking into account two categories of time: productive work of the machine and time of organizational and technical losses. The time of loss revealed after processing the results of the report, the classification of the elements of time. After this procedure, the calculation of the ratio of compression and an increase in labor productivity.

It is especially worth emphasizing that this method was used in the late 30s and early 40s of the last century. The list of references intentionally contains the work of Soviet scientists [7], dated before the beginning of the Great Patriotic War. Such publications testify to the fact of the steady development of the domestic industry in those early years.

The ratio of time compression [8, 9] is shown below:

\[ C_{compr} = \frac{T_{shift} - (t_{p.e} + t_{op} + t_{maintenance} + t_{op.m} + t_{wp})}{T_{shift}} \]  

(6)

where \( C_{compr} \) - the ratio of time compression;
\( T_{shift} \) - observation time or time of one shift;
Time of effective work of the equipment \( (t_{eff}) \):

\[
t_{eff} = t_{p.e} + t_{op} + t_{maintenance} + t_{op.m} + t_{pe}
\]  

(7)

This coefficient helps to determine proportional workforce productivity.

\[
C_{WP} = \frac{C_{compr}}{1 - C_{compr}}
\]  

(8)

or

\[
C_{WP} = \frac{t_{loss}}{T_{shift} - t_{loss}}
\]  

(9)

where \( t_{loss} \) - down time loss, \( t_{loss} = T_{shift} - t_{eff} \)

4. Record of the indicator of "OEE" in terms that are used in the domestic literature

We can write the elements of the indicator "OEE" using indicators adopted in the domestic literature with the following notation: \( OT = t_{eff}, DTL = t_{loss}, PPT = T_{shift} \).

Formula (2) can be recorded in accordance with the parameters commonly used in Russian manufacturing practice:

\[
A = \frac{T_{shift} - t_{loss}}{T_{shift}}
\]  

(10)

We show the relationship indicators:

\[
A = \frac{T_{shift} - t_{loss}}{T_{shift}} = 1 - \frac{t_{loss}}{T_{shift}}
\]  

(11)
\[ C_{\text{compr}} = \frac{T_{\text{shift}} - (t_{\text{p.e.t}} + t_{\text{op}} + t_{\text{maintenance}} + t_{\text{wtp}})}{T_{\text{shift}}} = \frac{T_{\text{shift}} - t_{\text{eff}}}{T_{\text{shift}}} = \frac{t_{\text{loss}}}{T_{\text{shift}}} \]  

(12)

\[ A = 1 - C_{\text{compr}} \]  

(13)

\[ A + C_{\text{compr}} = 1 \]  

(14)

From formula (14) it follows that the indicator of “Availability” and “Ratio of time compression” are the exact opposite in meaning and at the same time constitute a single whole (see Fig. 3).

When considering the second element of the indicator "OEE" - "performance" (P), we can note the following. The concept of the ideal cycle time, the ideal rate of production for the domestic reader is not quite familiar. Since the words “work efficiency”, “productivity”, “ideal cycle time” can be correlated with the direct process of equipment operation during part processing, then the time elements “OEE” should be correlated with the norm elements of piece (calculation) time. Using the notation adopted in domestic practice in the manufacture of one part of the i-th name on one workplace of a simple type, you can write:

\[ ICT = \frac{t_{\text{base}}}{t_{\text{item}}} \]

\[ OT = \frac{t_{\text{item}}}{t_{\text{item}}-calc(i)} \]

Then the coefficient of "performance" will take the following form:

\[ P = \frac{ICT}{OT/TP} = \frac{t_{\text{base}}}{t_{\text{item}}} = \frac{t_{\text{base}}}{t_{\text{item}}} < 1 \]  

(15)

In total, while for production (N\text{real}(i)) of items (i) of work benches:

\[ P_N = ICT / (OT/TP) = \frac{\sum t_{\text{item}}-calc(i)}{\sum t_{\text{base}}(i)} = \frac{\sum N_{\text{real}}(i) t_{\text{item}}-calc(i)}{\sum t_{\text{base}}(i)} \]  

(16)

\[ PN = (TP/OT) / IRR = \frac{\sum N_{\text{real}}(i)}{\sum t_{\text{item}}-calc(i)} = \frac{\sum N_{\text{real}}(i) t_{\text{item}}-calc(i)}{\sum t_{\text{base}}(i)} \]  

(17)

or

\[ P = ICT/(OT/TP)=(TP/OT)/IRR= \frac{\sum N_{\text{real}}(i) t_{\text{item}}-calc(i)}{\sum t_{\text{base}}(i)} \]  

(18)

The third parameter of OEE defined a “quality level” (Q), by the following formula [1, 2]:

\[ Q = \frac{N_{\text{produced}}(i) - N_{\text{non-conforming}}(i)}{N_{\text{produced}}(i)} \]  

(19)

where \( N_{\text{produced}}(i) \) is a total production by defined time cycle (i),

\( N_{\text{non-conforming}}(i) \) – is a number of defective or non-conforming units by the same period.

In Russia a similar parameter “output level” is applied together with “level of non-conformities” (q):

\[ q = \frac{N_{\text{non-conforming}}(i)}{N_{\text{produced}}(i)} \]  

(20)

\[ Q = \frac{N_{\text{produced}}(i) - N_{\text{non-conforming}}(i)}{N_{\text{produced}}(i)} = 1 - q \]  

(21)

Or

\[ Q + q = 1 \]  

(22)
On Figure 4 correlations of those parameters drawn on pie chart:

We insert into the formula (1) the expression (13), (18), (21). The parameter $OEE$ will be the form (23):

$$OEE = (1 - C_{compr}) \cdot \left( \frac{\sum N_{real}(i) \cdot item\_calc(i)}{\sum base(i)} \right) \cdot (1 - q)$$  \hspace{1cm} (23)

5. Conceptual approaches to the prediction of equipment effectiveness criteria

The parametrical analysis shows that applied in the past "Motion study" method is based on data collected by the direct verification of production activities. For instance, there is no additional explanation or training required for operators to count non-conforming products or standby time. Application of $OEE$ parameter is based on the determination of the loss and cost deduction methods.

Determination of loss and cost deduction leads us to the next question, how to calculate a time loss. Calculation of "Availability" parameter does not give us methods of loss time accountability.

Stand by time determination is also missing. We should understand that $OEE$ methods are commonly applied with the support of IT and digitalization of the production process. By the integrated production statistical technics, those parameters are automatically calculated. However not all manufacturers could afford those IT/automatic calculation software, therefore additional loss parameters might be added in the future. According to “Motion study” methods structure is clearly defined. Same time $OEE$ does not give us an output for labor intensity/manpower calculation.

It was shown that $OEE$ and some commonly used parameters applied in Russian manufacturing practice are assimilated each other, are uniting same core parameters and can be applied together for determination of the full picture of manufacturing process management.

It was shown that by applying parameters together ($OEE, Q, q, C_{compr}$) production activities can be assessed from a different angle by focusing the same target of continues effectiveness improvement of the production process.

When the value of the performance index of equipment is projected and rationing, it is necessary to have a clear classification of the elements of productive time and time loss.

6. Conclusion

The recording of the “$OEE$” coefficient, taking into account the notation used in the Russian literature, reveals indicators characterizing the concentrated cause of the loss of time. A special place is given to the method of "Motion study".

The purpose of the method of "Motion study" – is the rationing of labor and fixing time loss.

The purpose of the $OEE$ indicator is not the rationing of loss time, but accounting equipment loss time.
The article shows the calculation of each parameter of the element base of the generally accepted in the world indicator of Overall Equipment Effectiveness ("OEE") in accordance with well-established concepts and definitions in domestic practice. This will allow for adequate adjustment and evaluation of equipment performance.

References
[1] OEE Primer, Calculating OEE, http://www.oee.com/calculating-oee.html
[2] Thomas R. Cutler. Improving overall equipment effectiveness with lean and value-stream mapping. 1/26/2010.http://www.qualitydigest.com/inside/twitter-ed/improving-overall-equipment-effectiveness-lean-and-value-stream-mapping.html#
[3] Shopin, A.G. OEE and downtime management: from theory to implementation in SIMATIC IT / A.G. Shopin, I.V. Zanin, “Automation in Industry”, 2006, 09, p. 24 - 29
[4] Hansen, Robert C. Overall Equipment Effectiveness (Print-On-Demand Edition) Powerful Production/Maintenance tool for Increased Profits. 290 Pages, Softcover Published: January, 2001. ISBN: 9780831102180. http://new.industrialpress.com/overall-equipment-effectiveness-1.html
[5] Antonenko I., Kryukov I., Shestopalov P. Efficiency of using production equipment. http://www.cfin.ru/management/manufact/oee.shtml
[6] Optimal planning of Planned Preventative Maintenance (PPM) - a way to increase the efficiency of equipment used / G. Medvedeva, A. Musuridze, Yu. Tikhonova, A. Kryukov, A. Zaydullin // CAD and graphics, 2013 №1, p. 84 - 89.
[7] Organization of engineering production, ed. by B.I. Katzenbogen. Approved All-Union Committee On Affairs Of High School under the Council of People's Commissars of the USSR approved as a textbook for engineering schools . Moscow, Leningrad, State United Scientific and Technical Publishing House of the People’s Commissariat of Heavy Industry of the USSR, 1941. 648 pp. (Before the title auth. Abramovich, Dumler, Katzenbogen, Kornitsky and Heifetz).
[8] Organization and production planning at a machine-building enterprise. [Textbook for universities in the specialty "Economics and organization of the engineering industry"]. Ed. Prof. V.A. Letenko. M., "High School", 1972.
[9] Abramova, I.G. Basis of the organization production of the engineering enterprise [Electronic resource]: (lecture course and workshop): study guide / I. G. Abramova; Samara State aerospace university named by S.P. Korolev (national research institute) (SSAU). - electronic text data. - Samara: 2011. - 1 CD-ROM.