

Overall Equipment Effectiveness Implementation Criteria

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Abstract. This article documents the methods applied in production control technics specifically focused on commonly used parameter OEE (Overall Equipment Effectiveness). The indicators of extensive and intensive use of equipment are considered. Their appointment this is comparison in the same type of production within the industry and comparison of single-type and / or different types of equipment in terms of capacity. However, it is shown that there is no possibility of revealing the reasons for the machine's operation: productive / unproductive, with disturbances. Therefore, in the article reveals the approaches to calculating the indicator characterizing the direct operation of the equipment. The Machine Load coefficient is approaching closely to the indicator of the efficiency of the use of equipment. Methods analysis is proceeded through the historically applied techniques such as "Stopwatch" and "Motion" studies. Was performed the analysis of the efficiency index of OEE equipment using the comparable indexes performance of equipment in the Russian practice. An important indicator of OEE contains three components. The meaning of each of them reflects historically applicable indicators. The value of the availability of equipment indicator is close to the value of the equipment extensibility index. The value of the indicator of the efficiency of work can be compared with the characteristic of the capacity of the equipment and the indicator of the quality level can meet the requirements for compliance with the manufacturing technology. Shown that the sum of the values of the coefficient of "Availability" of the equipment and the value of the "Factor of compaction of working hours" are one. As well as the total value of the indicator "level of quality" and the coefficient of marriage given in the result unit. The measurability of the indicators makes it possible to make a prediction about efficiency of the equipment.

1. Introduction

Production process effectiveness is the most common criteria for the last 50-60 years. Lead time of the production process verification is not a new idea as well as loss criteria accounting for confirmation of effectiveness. Time loss criteria is the most commonly used, the most recent methods define production process through the following parameters:

1. plant and machinery, means of labor (equipment),
2. manufacturing process, the process of labor,
3. product with its accessories, the object of labor, which turns into finished products.

Every element has individual parameters, including effectiveness verification process.

Production facility as individual element accounted as "fixed manufacturing assets". Effectiveness of "fixed asset" accounted by the multiple criteria divided in to the following categories:



- I. General assesses: fixed-asset turnover, capitalization ratio, capital-labor ratio, net profit margin as well as capital-labor ratio effectiveness parameters verses net profit margin at the same period.
- II. Main assets transaction coefficients: input, renewal, outrange, process increments and termination, replacement and extension of production lines.
- III. Assists amortization and replacement criteria
- IV. Manufacturing machines deployment coefficients: intensive and extensive, integral and detrimental, shifts or singular use.

Production process includes such parameters as shift norms, maintenance, labor intensity and production capacity.

Above mentioned Production facility and Production process parameters are well known from the 50-60 years ago.

In this regard an interesting result gives a comparison of a planned manufacturing process in USSR compare to USA customer delivery oriented activities. Manufacturing process were commonly designed on a mass production level for 600-800 thousand norm hours/year. Production design was mainly focused on one man operation per one machine or type of operation. Therefore in the past a full load parameter was a main criterion of production effectiveness.

The article presents the indicators characterizing the main means of production. Among the many indicators highlighted one that uses as features of the equipment loos time, load, and quality of work. Calculation of the elements of this indicator is shown in comparison with the indicators used in the Russian practice. Thus, it is shown two different approaches to the definition of the coefficient of efficiency of the equipment.

2. Comparability of the element base, concepts and terms

Production equipment operation parameters mainly defined by the following coefficients:

- Extensive production equipment load coefficient:

$$C_{Ext} = \frac{F_{act}}{F_{eff-schedule}} \quad (1)$$

where F_{act} – actual time the equipment over the planning period. $F_{eff-schedule}$ – Effective time of equipment working according to the schedule.

The actual time the equipment over the planning period reflects that the equipment "worked" for a certain time and does not answer the question about a full load of equipment, quality products without defects, derogate from the standards, the organization of the maintenance and movement of transport streams. C_{Ext} is used for determination of standard loss level and applied for comparison of the similar production processes within same industry/category. It is widely applied due to its simplicity, however does not give information about cause effect of the detected loss level. In practice it is hard to detect production loss items due to several factors: 1) no motivation of employees of loss recording, 2) no tools for loss recording, 3) no organizational structure for recording, 4) no resources (financial / operational/ infrastructural) for recording. For metal processing equipment C_{Ext} falls within 0.92-0.95 parameters. For equipment with more than 25 years of operations $C_{Ext} = 0.85 \sim 0.88$.

- Next parameters is a coefficient of intensive load of manufacturing equipment.

$$C_{Intensive} = \frac{P_{real}}{P_{declared}} \quad (2)$$

where P_{real} — production machines productivity real; $P_{declared}$ — declared productivity according technical specifications.

This parameter is applied for production process evaluation within industry/ manufacturers with similar production category, however it does not determine routes of the production capacity reduction or change.

Coefficient that includes both C_{Ext} and $C_{Intensive}$ defined as $C_{Integral}$.

$$C_{Integral} = C_{Ext} \cdot C_{Intensive} \quad (3)$$

Value of $C_{Integral}$ is always lower than its components since it includes negative and positive aspects of both coefficients.

Next useful parameter - the shift coefficient of equipment operation - is defined by the following formula:

$$C_{Sh} = \frac{MH_1 \cdot MH_2 \cdot MH_3}{N_{wb}} \quad (4)$$

where MH_1, MH_2, MH_3 - number of Machine hours in shift 1, 2 and 3 respectively; N_{wb} - number of work benches / machines.

In general, the number of worked machine-hours is a positive indicator; it shows the effective use of the general composition of the workshop equipment. However, in this indicator it is difficult to understand of the reasons for the poor performance, the reasons of the downtime. From this general indicator it is possible to go to a private - for one machine and as an indicator only one particular machine is considered. In this case, the "shift coefficient of equipment operation", as a factor for the machine, is already close to the indicator of "Machine Load coefficient".

Machine Load coefficient:

$$C_{Load} = \frac{L_{\Sigma}}{F_{eff-schedule}} = \frac{N_{wb(calc)}}{N_{wb(real)}} \quad (5)$$

где L_{Σ} is a total laboriousness all parts, $N_{wb calc}$ is a calculated number of work benches $N_{wb real}$ - is a real number of work benches implemented in the production process - it is accepted, rounded parameter of $N_{wb calc}$.

$$N_{wb(calc)} = \frac{\sum_{i=1}^m (t_{item-calc i} \cdot N_{ai} \cdot C_{incomplete})}{F_{eff-schedule} \cdot C_{plan compl} \cdot N_{e/wb} \cdot 60} \quad (6)$$

where $t_{item-calc i}$ - item-calculated time, is a time from production table for development of item/part of unit the product with count number i, with preparation and ending time. This is base time labor intensity.

N_{ai} - annual program per production plan, counted in units,

C_{incomp} - coefficient of in complete production,

$C_{plan completion}$ - coefficient of the production plan completion,

$N_{e/wb}$ - number of employees per 1 work bench,

m - number of operations.

Labor coefficient is widely used for calculations. This coefficient calculated by two methods:

1. "Stopwatch study" method,
2. "Motion study" method (Production daily log).

Both methods are used for more than 50 years [1], however still applied in TQMS or other management systems.

First method is focused on determination of $t_{op i}$ the operational time of production equipment. Elements of the method are shown in Figure 1 as below.

"Motion study" method based on determination of type of operations. Maintenance condition of production machines were identified in two categories: time of operations and time of standby. Based on that time of standby were subjected for cause analysis that lead for correction.

Time compression rate coefficient drawn from the motion study methods as below [2, 3]:

$$C_{comp.r} = \frac{T_{shift} - (t_{p.e} + t_{op} + t_{maintenance} + t_{op.m} + t_{wp})}{T_{shift}} \quad (7)$$

where $C_{comp.r}$ time compression rate coefficient. T_{shift} - observation time or time of one shift.

This coefficient helps to determine proportional workforce productivity.

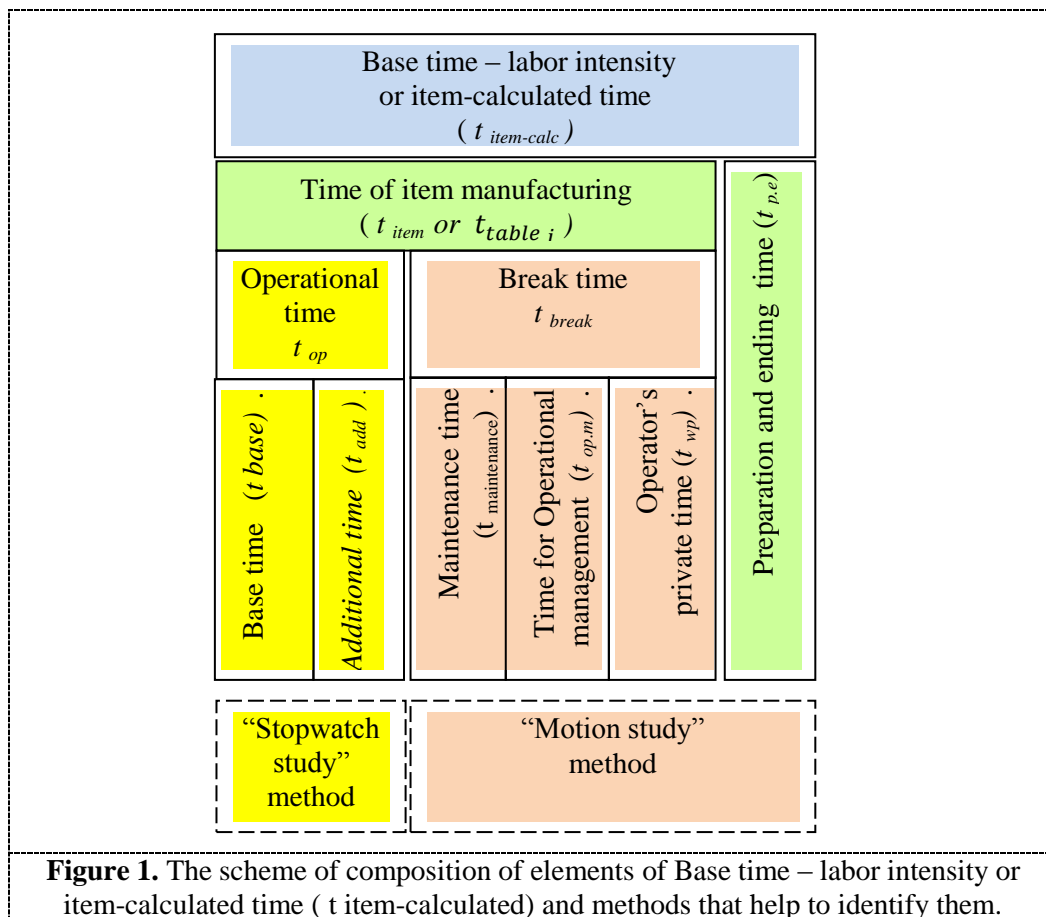
$$C_{WP} = \frac{C_{comp.r}}{1 - C_{comp.r}} \quad (8)$$

or

$$C_{WP} = \frac{t_{loss}}{T_{shift} - t_{loss}} \quad (9)$$

where t_{loss} - down time loss, $t_{loss} = T_{shift} - (t_{p.e} + t_{op} + t_{maintenance} + t_{op.m} + t_{wp})$

In the mordent techniques OEE parameter (Overall Equipment Effectiveness) is the most commonly used [4, 5]. OEE has been proposed in 1960s by Seiichi Nakajima [6], however become widely applied in 80s and was populated in 90s by Robert Hansen. [7].



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).

$$OEE = A \cdot P \cdot Q \quad (10)$$

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 is calculated by [6, 7, 8, 9]:

$$A = \frac{OT}{PPT} = \frac{PPT - DTL}{PPT} \quad (11)$$

Where OT - *Operating Time* (reducing stand by time), DTL - (*Down Time Loss*) all stand by or non-operational time by all reasons. PPT - (*Planned Production Time*).

Formula (12) can be drawn in accordance with the parameters commonly used in Russian manufacturing practice:

$$A = \frac{T_{shift} - t_{loss}}{T_{shift}} \quad (12)$$

It is clear to show a correlation of “Availability”.

$$A = \frac{T_{shift} - t_{loss}}{T_{shift}} = 1 - \frac{t_{loss}}{T_{shift}} \quad (13)$$

$$C_{comp.r.} = \frac{T_{shift} - (t_{p.e} + t_{opr} + t_{maintenance} + t_{wp})}{T_{shift}} = \frac{T_{shift} - t_{effectiv}}{T_{shift}} = \frac{t_{loss}}{T_{shift}} \quad (14)$$

$$A = 1 - C_{comp.r.} \quad (15)$$

$$A + C_{comp.r.} = 1 \quad (16)$$

From formula (16) and Figure 2 as below it is clearly shown that both A and $C_{comp.r.}$ are completely opposite by meaning and at the same time compose one integration unity.

If we analyze OEE's parameter of *Performance* (P) [3], that is determined as

$$Performance = P = ICT / (OT/TP) \quad (18)$$

$$or \quad P = (TP/OT) / IRR \quad (19)$$

where: ICT (*Ideal Cycle Time* for production of 1 item and IRR – *Ideal Run Rate*, theoretical maximum of production, reverse to ICT ; OT – (*operating time*), TP – (*Total Pieces*), produced by the time of OT .

Stand by time should be removed, including low speed operations. If we try to draw above parameters with commonly used theoretical base applied in Russia it can be shown as below:

$$PI = ICT / (OT/TP) = \frac{t_{item-calc.}}{t_{base(i)} / 1 \text{ part}} = \frac{t_{item-calc.}}{t_{base.i}} \quad (20)$$

In total, while for production ($N_{real(i)}$) of items (i) of work benches :

$$P_N = ICT / (OT/TP) = \frac{\sum t_{item-calc.i}}{\sum t_{base(i)} / \sum N_{real(i)}} = \frac{\sum N_{real(i)} \cdot t_{item-calc(i)}}{\sum t_{base(i)}}$$

$$\frac{N_{real(i)}}{\sum t_{base(i)}}$$

$$P_N = (TP/OT) / IRR = \frac{N_{real(i)} \cdot t_{item-calc(i)}}{\sum t_{item-calc(i)}} = \frac{\sum N_{real(i)} \cdot t_{item-calc(i)}}{\sum t_{base(i)}}$$

or

$$P = ICT / (OT/TP) = (TP/OT) / IRR = \frac{\sum N_{real(i)} \cdot t_{item-calc(i)}}{\sum t_{base(i)}} \quad (21)$$

Third parameter of OEE defined a quality level or (Q), by the following formula [1, 2]:

$$Q = \frac{N_{\text{produced (i)}} - N_{\text{non-conforming (i)}}}{N_{\text{produced (i)}}} \quad (22)$$

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.

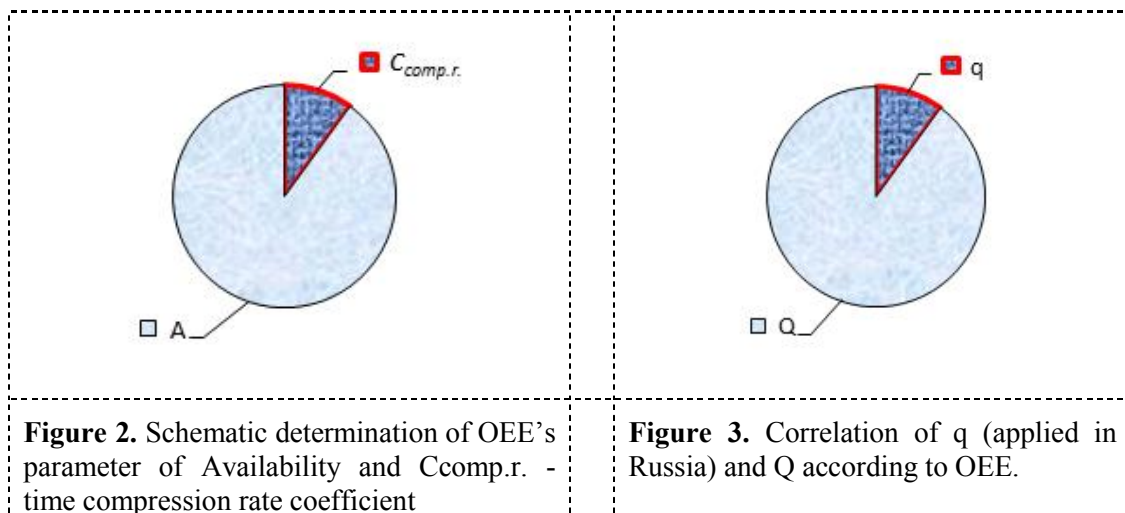
In Russia a similar parameter “output level” is applied together with “level of non-conformities” (q):

$$q = \frac{N_{\text{non-conforming (i)}}}{N_{\text{produced (i)}}} \quad (23)$$

$$Q = \frac{N_{\text{produced (i)}} - N_{\text{non-conforming (i)}}}{N_{\text{produced (i)}}} = 1 - q \quad (24)$$

$$\text{Or} \quad Q + q = 1 \quad (25)$$

On Figure 3 correlations of those parameters drawn on pie chart:



Given the formulas (15), (21), (24) the expression (10), which determines the parameter OEE will be of the form

$$OEE = (1 - C_{\text{comp.r.}}) \cdot \left(\frac{\sum N_{\text{real (i)}} \cdot t_{\text{item.calc (i)}}}{\sum t_{\text{base (i)}}} \right) \cdot (1 - q) \quad (26)$$

3. Conceptual approaches to the prediction of equipment effectiveness criteria:

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 determination of the loss and cost deduction methods.

Determination of loss and cost deduction lead us to a 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 is commonly applied with support of IT and digitalization of 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 an additional loss parameters might be added in the future. According to “Motion study” methods structure is clear 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 OEE, Q, q, Ccomp.r parameters all together production activities can be assessed from different angle by focusing same target of continues effectiveness improvement of production process.

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

4. Summary:

Analysis and comparison of the elemental base of indicators of the efficiency of equipment in the works of American and Russian researchers showed the presence of indicators reflecting the state of efficient and inefficient operation of equipment.

Methods "Stopwatch study" and "Motion study", which allowed determining the elements of the effective operation of equipment, had the goal of rationing the time of work on machines, in order to subsequently pay the main production workers.

"Normalizing" the time of inefficient operation of the equipment requires its classification and purpose.

Strict separation of the effective time of equipment operation time and loss of time associated with the implementation of quality products and the fulfillment of marriage, are shown in figures 2, 3, involves the creation of a clear classification of the elements of effective time loss of time in accordance with the requirements of technology and time, does not comply with these requirements.

Classification of elements of time must reflect the relationship of two directions: the machine work outside the machine, to show the connection with the means of labor and labor process. This will enable you to analyze and control the manufacturing process.

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