Assessment of overall equipment effectiveness according to OEE methodology

A A Mitsel, M V Grirorieva and T Yu Dunaeva
Tomsk State University of Control Systems and Radioelectronics, 40, prospect Lenina, Tomsk, 634050, Russia

Abstract. The article discusses the Overall Equipment Effectiveness indicator, the parameters of which are Availability, Performance and Quality are random variables. Mathematical models are described for calculating the probability density of a random value of Overall Equipment Effectiveness, which characterizes the efficiency of equipment use. The relevance of the study is due to the relevance of methods for assessing the effectiveness of equipment and improving production processes in industrial enterprises.

1. Introduction
The OEE is a combined indicator that includes the availability/equipment operational readiness \( A \) (Availability), its performance, \( P \) (Performance) and the quality factor \( Q \) (Quality) [1]. The overall equipment efficiency index (OEE) measures how efficiently equipment, multi-machine production modules, or complete assembly lines are used.

The OEE equipment overall performance assessment is studied in scientific articles and books by various authors. Thus, the article [2] compares the approaches proposed at different times by domestic and foreign scientists for equipment working time accounting for losses/costs. The element bases coefficients Total equipment efficiency (OEE) and working time compaction are analyzed. The latter is calculated using the working day photo method and other coefficients. It is proposed to classify the equipment operation time losses/costs, according to which the operation and the coefficient OEE labour intensity are further determined.

The article [3] evaluates ways to improve equipment efficiency. A standard has been developed that defines the OEE performance indicator It is proposed to take into account the equipment efficiency as an autonomous system, using the indicator E. Thus, the indicators OEE and E can be distinguished by choosing the time base.

The article authors [4] substantiate OEE methods for assessing equipment management effectiveness. Methods for eliminating wasted time and implementation of the OEE system in stages in an industrial enterprise are proposed.

The article [5] discusses a system for automating the reception, incidents transmission and resolution in the large and medium-sized enterprises management and a superstructure for monitoring performance indicators.

The article [6] describes the OEE introduction at the Valio plant in the Ershovo village, Moscow region, for the Viola processed cheese production. The ISEMRM system, as well as the OEE indicator
monitoring system, was created on the TRIM platform software package - an EAM class program (Enterprise Asset Management - fixed assets' management system).

The article [7] discusses the OEE indicators calculations, the reasons that reduce the equipment efficiency, information systems with implemented modules for the OEE calculation.

The publication authors [8] consider the OEE coefficient as a digital manufacturing process efficiency assessment together with another indicator MCE (Manufacturing Cycle Effectiveness), which characterizes the operating cycle efficiency.

Modern approaches and methods for evaluating the equipment efficiency, including the OEE evaluation system, are described in the article [9] using a paper mill example. The authors propose a new approach for assessing the technical equipment individual pieces effectiveness, which allows highlighting and analyzes key performance indicators at the production process each stage.

Article [10] contains a methodology on how to create and improve production lines. The authors consider the factors influencing the production line efficiency: human and machine, illustrate the OEE indicator application, evaluating the equipment effectiveness, as well as support services.

The OEE indicator allows us to get better information, identify production losses, improve product quality in the improving production process through process optimization [11-13].

In the above works, the parameters A- availability, P- performance, Q- quality are considered as deterministic values. In this article, these parameters are considered as random values, which corresponds to reality.

2. Research methods

The calculation formula is:

\[
\text{OEE} = A \times P \times Q,
\]

where:

- \( A \) (Availability) = \( OT/PPT \);
- \( P \) (Performance) = \( TP/IRR \);
- \( Q \) (Quality) = \( GP/TP \) (table 1).

**Table 1.** OEE elements and losses associated with the equipment functioning peculiarities.

| Total operating time | Unexpected stops |
|----------------------|------------------|
| PPT                  | Scheduled operating time |
| OT                   | Operation time |
| IRR                  | Planned production |
| TP                   | Actual production (net operating time) |
| GP                   | Quality products |
|                      | Processing speed loss |
|                      | Defects |

\(^a\) PPT - Planned Production Time; \( OT \) - Operating Time; \( IRR \) - Ideal Run Rate; \( TP \) - Total Pieces; \( GP \) - Good Pieces [14].

Consider various options for calculating a random variable OEE probability density. Based on the known probability density, it is possible to calculate numerical characteristics, such as mathematical expectation and variance [15], which characterize the equipment use efficiency.

Let \( OT, TP \) and \( GP \) be independent random variables. These values ranges are \( OT1 \leq OT \leq OT2, TP1 \leq TP \leq TP2, GP12 \leq GP \leq GP2 \).

We introduce the following notations:

\[
x = OT/PPT, y = TP/IRR, z = GP/TP.
\]

These values ranges will be \( 0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq z \leq 1 \).
2.1. Model 1
Let all three quantities $x$, $y$, and $z$ have a uniform distribution with densities

$$f_x(x) = f_y(y) = f_z(z) = \frac{1}{1 - 0}.$$

It is necessary to find the random variable probability density $r = x \cdot y \cdot z$, which characterizes the using equipment efficiency.

Consider a random variable $v = x \cdot y$. This value range is $0 \leq v \leq 1$. Let's calculate the probability distribution density $f_v(v)$.

$$f_v(v) = \int_v^1 f_x(x) \cdot f_y(v/x) \frac{dx}{x} = -\ln(v), 0 \leq v \leq 1.$$

Next, consider the value $r = v \cdot z$, $0 \leq r \leq 1$. The probability density is

$$f_r(r) = f_r(f_v(v) \cdot f_z(r/v) \frac{dv}{v} = f_v^1 \left( -\frac{\ln(v)}{v} \right) \frac{dv}{v} = \frac{1}{2} (\ln(v))^2, 0 \leq r \leq 1 \quad (1)$$

In figure 1 is the function graph $f_r(r)$.

![Figure 1](image)

Figure 1. Density graph $f_r(r)$ (model 1).

We obtain the random variable numerical characteristics $r$ with density $f_r(r) = 1/2 (\ln(v))^2$. The mean and standard deviation are $mr = 0.125, \sigma r = 0.146$.

Of undoubted interest is such a characteristic as the probability that the equipment' using efficiency will be at least a given value. For example, the probability that the random variable $r$ (equipment utilization efficiency) will be at least 0.7 is equal to

$$P = 1 - \int_0^{0.7} f_r(r) \cdot dr = 0.006.$$

The value $Q = 1 - P$ can be used as an equipment' inefficient use risk measure. In this case, the equipment inefficiency risk is 0.994.

An analysis of the equipment utilization efficiency numerical characteristics shows that this model is pessimistic and can be used to assess the equipment efficiency lower bound.

2.2. Model 2
Let all three quantities $x$, $y$, and $z$ have a form inverted truncated exponential distribution
\[ f_x(x) = \frac{\lambda_x}{1 - e^{-\lambda_x}} \cdot e^{-\lambda_x(1-x)}, 0 \leq x \leq 1; \]
\[ f_y(y) = \frac{\lambda_y}{1 - e^{-\lambda_y}} \cdot e^{-\lambda_y(1-y)}, 0 \leq y \leq 1; \]
\[ f_z(z) = \frac{\lambda_z}{1 - e^{-\lambda_z}} \cdot e^{-\lambda_z(1-z)}, 0 \leq z \leq 1. \]

It is necessary to find the random variable probability density \( r = x \cdot y \cdot z \), which characterizes the using equipment efficiency.

Consider a random variable \( v = x \cdot y \). This value variation range is \( 0 \leq v \leq 1 \). Let's calculate the probability distribution density \( f_v(v) \) of the random variable \( v = x \cdot y \).

\[
f_v(v) = \int_0^1 f_x(x) \cdot f_y(v/x) \frac{dx}{x}.
\]

Let's move on to the value \( r = v \cdot z, 0 \leq r \leq 1 \).

The density is

\[
f_r(r) = f_v^1 f_v(v) \cdot f_z(r/v) \frac{dv}{v}.
\]  \hspace{1cm} (2)

In this case, the density \( f_r(r) \) can only be calculated numerically. This function example for parameters \( \lambda_x = 2, \lambda_y = 5, \lambda_z = 5 \) is shown in figure 2.

![Figure 2. Density graph \( f_r(r) \) for \( \lambda_x = 2, \lambda_y = 5, \lambda_z = 5 \) (model 2).](image)

Numerical characteristics of the random variable \( r \) with density \( f_r(r) \) (2) for \( \lambda_x = 2, \lambda_y = 5, \lambda_z = 5 \) are equal: \( m_r = 0.427, \sigma_r = 0.227 \); the probability that the random variable \( r \) (equipment utilization efficiency) will be at least 0.7 is equal to

\[
P = 1 - \int_0^{0.7} f_r(r) \cdot dr = 0.134.
\]

And the equipment inefficient use risk will be 0.866, which is slightly less than for the first model.

The numerical characteristics value analysis shows that statistical model 2 is more realistic than the first model. Also, this model provides three input parameters \( \lambda_x, \lambda_y, \lambda_z \), which can be used to simulate various scenarios for assessing the equipment use effectiveness.
2.3. Model 3

Let all three quantities have a truncated Laplace distribution with probability densities:

\[
\begin{align*}
    f_x(x) &= \frac{\lambda_x}{2 - e^{-\lambda_x \beta_x} - e^{-\lambda_x (1 - \beta_x)}} \cdot e^{-\lambda_x |x - \beta_x|}, 0 \leq x \leq 1; 0 \leq \beta_x \leq 1; \lambda_x > 0 \\
    f_y(y) &= \frac{\lambda_y}{2 - e^{-\lambda_y \beta_y} - e^{-\lambda_y (1 - \beta_y)}} \cdot e^{-\lambda_y |y - \beta_y|}, 0 \leq y \leq 1; 0 \leq \beta_y \leq 1; \lambda_y > 0 \\
    f_z(z) &= \frac{\lambda_z}{2 - e^{-\lambda_z \beta_z} - e^{-\lambda_z (1 - \beta_z)}} \cdot e^{-\lambda_z |z - \beta_z|}, 0 \leq z \leq 1; 0 \leq \beta_z \leq 1; \lambda_z > 0
\end{align*}
\]

Random variable probability density \( r = x \cdot y \cdot z \)

\[
f_r(r) = \int_0^1 f_v(v) \cdot f_z(r/v) \frac{dv}{v}
\]

is shown in figure 3.

![Figure 3](image)

**Figure 3.** Density graph \( f_r(r) \) for \( \lambda_x = 8, \lambda_y = 10, \lambda_z = 8; \beta_x = 0.9, \beta_y = 0.9, \beta_z = 0.9 \) (model 3).

The mean and standard deviation for the specified parameter values \( \lambda_x = 8, \lambda_y = 10, \lambda_z = 8; \beta_x = 0.9, \beta_y = 0.9, \beta_z = 0.9 \) are equal to: \( mr = 0.596, \sigma r = 0.15 \).

The probability that the random variable \( r \) will be at least 0.7 is equal to

\[
P = 1 - \int_0^{0.7} f_r(r) \cdot dr = 0.265.
\]

The equipment' inefficient use risk for this model will be 0.735.

In figure 4 shows a random variable OEE three statistical models numerical characteristics' comparison. It can be seen that the third model gives the highest average and lowest risk of equipment inefficient use.
3. Conclusion

The proposed statistical models for assessing the equipment use overall efficiency make it possible to reveal a loading technological equipment problem to study new aspect at enterprises. Using the second and third models, you can simulate different scenarios for evaluating performance. The first model can be used to estimate the lower bound of efficiency, and the third model to estimate the upper bound.

The modeling the equipment use OEE overall efficiency indicator assessment results can be useful for managers at management different levels in process and batch production as analytical information for improving production.

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