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Using a modified indicator of overall equipment efficiency for management decision-making

Olena Velyka*
PhD in Economics, Associate Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauky Ave., Kharkiv, Ukraine
https://orcid.org/0000-0002-0072-5867

Inna Kozlova
PhD in Economics, Associate Professor
Simon Kuznets Kharkiv National University of Economics
61166, 9A Nauky Ave., Kharkiv, Ukraine
https://orcid.org/0000-0002-5107-6668

Abstract. The relevance of the study was determined by the need to take into account energy consumption costs, which are a significant item in the cost of production, when making management decisions. The aim of the study was to improve the formation of management decisions based on the assessment of a modified indicator of equipment efficiency, which takes into account the level of energy consumption (OEEe). The methodological basis of the study included the use of methods of analysis and synthesis, comparison and generalisation, visualisation of empirical data based on a diagram of the dynamics of the components of the overall equipment effectiveness indicator using the example of a company that manufactures packaging products for the first half of 2025. This gave grounds to argue that it is necessary to more fully assess the resource and economic efficiency of equipment by introducing an additional component, "E – energy efficiency", which reflects the ratio of minimum and actual energy consumption in the production of a unit of output. Using the example of calculating OEEe for a production line for the manufacture of aluminium tubes, it was established that, with comparable values of overall equipment efficiency, there may be significant differences in specific energy consumption costs, which directly affects the cost and profitability of products. The results of the analysis proved that the main source of energy losses is an increase in the number of equipment changeovers required to fulfil small-volume orders. It is proposed to use the OEEe indicator for making management decisions aimed at optimising the production programme, managing the order portfolio, justifying investment decisions and forming a staff motivation system. The practical significance of the research results lies in the fact that the OEEe indicator can be used as a tool to increase energy efficiency, identify hidden economic losses, and integrate the indicator into the management reporting system

Keywords: management; production cost; equipment performance; changeovers; energy efficiency; specific energy consumption

INTRODUCTION

The main goal of managers of any enterprise is to increase its profits. One of the ways to achieve this in a manufacturing enterprise is to increase performance and production efficiency. Equipment is an important part of the production system, and both the level of labour productivity and the quantity, quality and cost of goods produced on it directly depend on the efficiency of its use. The simplest indicator for assessing the efficiency of equipment use is the ratio of productive equipment usage time to planned production time. However, calculating this indicator does not allow for the identification of production losses and analysis of equipment or production line performance. The overall

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*Corresponding author

equipment effectiveness (OEE) indicator has become more widely used among scientists and managers. OEE tools are widely used as key performance indicators (KPIs), which, in combination with lean manufacturing technologies, allow companies to increase their competitiveness. Scientists L.d.C. Ng Corrales *et al*. (2020) used analysis of information from electronic scientific databases to study the evolution of the OEE indicator, the frequency and results of its use. At that time, they counted 847 documents and scientific articles, which proves the great interest of scientists in this issue. This interest has actively increased since 2015 and has covered not only publications devoted to technology and production issues, but also management, business development, logistics, etc. Over time, companies in various industries have also tried to adapt the OEE indicator to the specifics of their production or developed new modifications of the indicator.

According to researchers F.A.S. Piran *et al*. (2020), increasing the level of equipment utilisation efficiency can also increase the competitiveness of a company. Thus, they proposed comparing the results of a comprehensive analysis of performance and overall production efficiency (DEA/OEE). As a result, they found that managers' actions aimed solely at improving the OEE indicator reduce the efficiency of operations by increasing resource consumption, do not necessarily increase production levels, and may even reduce technical efficiency. Based on the calculation of the OEE indicator, researchers E.T. Prasetio & A. Oktora (2024) proposed to identify the causes of inefficient equipment use and reduced performance when using a moulding machine. To do this, they first used a Pareto chart, which was compiled based on values for six major losses and allowed to establish that in 81.6% of cases, equipment problems are related to breakdowns, reduced operating speed, and equipment configuration issues. The authors then used the principles of cause-and-effect decomposition borrowed from the Ishikawa method and comprehensive analysis to identify the main problems leading to losses in areas such as equipment, methods, personnel, materials and machines. I. Kustiyawan *et al*. (2023) used the OEE indicator to determine the efficiency of automated packaging machines with a tracking system using two-dimensional barcodes and proposed ways to improve it. Their research was conducted for a company that manufactures pharmaceutical packaging. The authors calculated the three main components of the OEE indicator and identified two main problems for each of them. As a result, six major losses were identified: breakdowns, planned downtime, idle time and minor stoppages, speed losses, product shortages, and start-up deviations. Based on the assessment of the values of these losses, the authors constructed a "fishbone" diagram and identified the root causes of problems on the automatic packaging line, which made it possible to reduce its unproductive labour time.

The use of the OEE indicator to reduce costs in additive manufacturing was considered by S. Basak *et al.* (2022). In doing so, they retained the traditional structure of the OEE indicator and adapted it to the specifics of their production. The authors also presented management ideas that can maximise the efficiency of the additive manufacturing process using the OEE indicator. There is also a trend in scientific literature that studies the efficiency of equipment use without the help of the OEE indicator. For example, researchers N. Safonik & V. Vatashchuk (2023) analysed the features of increasing the efficiency of reproduction and use of fixed assets of an enterprise using the depreciation coefficient, suitability coefficient, return on assets, capital intensity and capital-labour ratio indicators. N. Lutska *et al*. (2024) proposed to evaluate the efficiency of the use of fixed assets of an enterprise based on an analysis of their technical condition using the renewal, disposal, growth, depreciation and suitability coefficients, as well as using indicators of return on assets, capital intensity, profitability and net profit. Researcher O. Iastremska (2023) linked the efficiency of equipment use to the number of defective products and the need to manage product quality. Pareto analysis was used to analyse the situation and justify proposals to reduce product defects, and an Ishikawa diagram was used to identify the relationships between factors. Thus, despite the considerable interest of scientists in issues related to the efficiency of equipment operation, a number of issues remain unresolved, namely: the energy consumption of equipment is not taken into account, which is relevant in the context of rising tariffs; many proposals for improving the OEE indicator focus only on the technical aspects of equipment use and do not take into account the fact that problems may be related to imperfect planning of the production programme or insufficient motivation of employees. The aim of this study was to improve the management decision-making mechanism by evaluating a modified equipment efficiency indicator that takes energy consumption parameters into account. Identifying and solving problems related to low levels of this indicator will enable managers to increase labour productivity and equipment efficiency at manufacturing enterprises.

MATERIALS AND METHODS

The study was conducted based on the processing of statistical data for "Tube Plant" LLC. The selection of this enterprise is due to the fact that it is one of the most well-known companies manufacturing packaging products for the pharmaceutical and cosmetic industries, not only in Kharkiv but in Ukraine as a whole. Furthermore, the company's products are actively used by European companies located in Spain, Italy, Latvia, and elsewhere. Despite the crisis years, the enterprise not only continues to operate but is also actively developing.

The production line for the manufacture of aluminium tubes was considered as the object of the study. The line consists of seven technological sections that sequentially perform operations (turning, trimming, internal and external lacquering, printing, applying a latex ring, and screwing on caps). Production is small and medium-scale, which is associated with frequent equipment changeovers. To assess the prerequisites for the current level of availability of the production system, retrospective and historical analysis of operational data was used. The analysis covered the period 2019-2023 and was based on the company's internal reporting on the volume and structure of orders, the duration of production cycles and the number of equipment changeovers, obtained by the authors. Particular attention was paid to the period after 2022, which was characterised by the company's entry into European markets and an increase in the share of small-batch orders. Changes in the structure of orders were assessed through a comparative analysis of average batch sizes, start-up frequency and downtime, which made it possible to identify their impact on equipment availability.

The calculations used the following statistical data of the enterprise for the first half of 2025, which made it possible to determine the volumes of high-quality and defective products, the planned and actual operating time of the equipment, and its downtime. The analysis of equipment utilisation efficiency was carried out using the overall equipment effectiveness indicator, which consists of three components: operational readiness (availability) of the working operation, efficiency (performance) of the working operation, and quality coefficient (Chikwendu *et al.*, 2020). The relationship between these components can be represented by the following formula:

$$OEE = A \times P \times Q, \tag{1}$$

where A – availability; P – performance; Q – quality. Operational readiness (availability) of a working operation is defined as the proportion of time when the equipment produced or could have been producing output, i.e. was in working order. Availability makes it possible to compare the time during which the equipment was actually used with the time during which its use was planned. This indicator is calculated using the following formula:

$$A = \frac{t_{actual}}{t_{planned}}, \tag{2}$$

where t_{actual} – actual production time; $t_{planned}$ – planned production time. Efficiency (performance) of the working operation is the proportion of time defined as the actual time spent on production at the maximum (ideal) speed for the given equipment. It can also be defined as the ratio of the quantity of output actually produced to the maximum possible quantity that could have been produced on the given equipment. The performance indicator takes into account losses associated with reduced production speed due to equipment wear, the use of materials of inadequate quality, or the influence of human factors. This indicator is calculated using the following formula:

$$P = \frac{V_{actual}}{V_{max}}, \tag{3}$$

where V_{actual} – the quantity of output actually produced; V_{max} – the maximum possible quantity of output that can be produced on the given equipment. The quality coefficient shows the share of acceptable output in the total production volume of the line. It compares the number of units that have passed quality control with the total number of units produced on the given equipment. This indicator is calculated using the following formula:

$$Q = \frac{V_{quality}}{V_{actual}}, \tag{4}$$

where $V_{quality}$ – the quantity of quality products; V_{actual} – the quantity of products that were actually manufactured. Statistical and economic analysis methods, a systematic approach, and scientific generalisation were used to justify the methodology for calculating the overall equipment effectiveness indicator, taking into account energy efficiency. The efficiency of equipment use was assessed based on a modified overall equipment effectiveness (OEEe) indicator, adapted to the conditions of small-batch production with a high frequency of changeovers. The OEEe calculation was based on the classic OEE structure, but the interpretation scale was adjusted to take into account industry specifics and real limitations of the production system. The efficiency level assessment intervals were determined based on benchmarking analysis of companies with similar types of production, as well as analysis of internal historical dynamics of indicators. In particular, the range of 50-79% was classified as "typical functioning" because, in conditions of high order variability and frequent changeovers, achieving values typical of classic mass production (65-85%) is structurally limited. Values below 50% were interpreted as low efficiency, indicating systemic losses in availability, performance or quality. It is proposed to calculate the "E – energy efficiency" component as the ratio of the minimum required energy consumption per unit of output (under ideal conditions) to the actual energy consumption per unit of output:

$$E = \frac{E_{min}}{E_{actual}}, \tag{5}$$

where E_{min} – minimum energy consumption per unit of output; E_{actual} – actual energy consumption per unit of output. Minimum energy consumption per unit of output is calculated as the ratio of minimum energy consumption to maximum possible output. Actual energy consumption per unit of output is determined as the ratio of energy consumed to actual output. Then the formula for calculating the equipment efficiency indicator, taking into account energy efficiency, is as follows:

$$OEEe = OEE \times E = A \times P \times Q \times E, \tag{6}$$

where $OEEe$ – overall equipment effectiveness, taking into account energy consumption; E – energy efficiency. The global standards for the components of the OEE indicator are as follows: availability – 90%, performance – 95%, quality – 99%, which results in an OEE value of 85% (Chikwendu *et al.*, 2020; Kliment *et al.*, 2020). The calculated value of the overall equipment effectiveness indicator can also be compared with reference values: 100% – ideal level, equipment operates quickly and without errors; 85% – global level, which is a long-term goal for many companies; 65% – typical level, which indicates opportunities for improving equipment utilisation; 40% – low level, which is usually found in companies that have not previously paid attention to equipment utilisation efficiency.

To form a scale for determining the level of production efficiency based on the OEEe indicator, the method of structural-parametric synthesis was used. This method is based on the structure of OEEe as the product of the elements of availability, performance, quality and energy efficiency. Since each of these elements is limited to the range [0;1] and does not reach its maximum in real conditions, the upper limit of OEEe was determined as the limit value corresponding to the minimum technological and energy losses. On this basis, high, medium and low OEEe intervals were identified, reflecting different types of losses and equipment operating modes. As already noted, each component A, P and Q has its own stable range. The maximum value of the energy efficiency component E is 95% (Patterson *et* *al.*, 2023). It follows that even with good production organisation, the maximum achievable value of OEEe can be:

$$OEEe_{max} = 0.90 \times 0.95 \times 0.99 \times 0.95 = 0.80.$$

Thus, an OEEe value above 0.80 corresponds to modes with minimal energy and time losses, while values below 0.50 indicate the presence of systemic losses. The resulting scale is the result of a parametric interpretation of the OEEe model, rather than an empirical comparison, which makes it reproducible and applicable to different types of equipment. The main purpose of calculating the OEEe indicator is not so much to compare its value with the proposed standards, but rather to identify the reasons for the low efficiency of equipment use at the enterprise and to formulate management decisions to improve the situation. Thus, it is necessary to constantly monitor the dynamics of this indicator, identify the causes of losses and respond to them promptly. The information obtained should be accumulated and provided to the enterprise manager for analysis in the form of graphs.

To determine the factors that influence the level of the OEEe indicator and its components, the principles of cause-and-effect analysis based on the logic of the Ishikawa methodology were used. Classic graphical "fishbone" diagrams were not constructed because many factors are interrelated and may influence several components of the OEEe indicator simultaneously. However, the structure of factors was formed according to similar principles of cause decomposition, which made it possible to systematically identify the key loss factors for each component and show their interrelationship. To establish the correspondence between the results of the OEEe calculation and management decisions, a method of analysis and synthesis was used, which took into account the factors affecting this indicator and the results of observations of equipment operation. For each component of the OEEe indicator, typical situations that affect its value were identified. The method of analytical generalisation was used to establish possible causes and practical management measures that reflect the relationship between changes in the OEEe indicator and decisions that managers can make to improve equipment performance.

RESULTS

The overall equipment effectiveness indicator allows for the analysis of performance losses and the identification of problem areas in production. It provides an answer to the most important question for a company manager: how to quickly and significantly increase output without increasing production capacity. The OEE indicator can be used in established operating modes, mainly for mass, large-scale and serial production. The advantage of using this indicator is its comprehensive nature and the ability to identify the causes of low equipment efficiency. The overall equipment effectiveness indicator can also be used to track changes in its dynamics, compare its values for different similar types of equipment, or compare its values for the same type of equipment but in different shifts. Calculations of the overall equipment effectiveness indicator for one of the enterprise's production lines (Fig. 1) showed that it corresponds to typical production (for typical production, the indicator values should be between 65% and 85%).

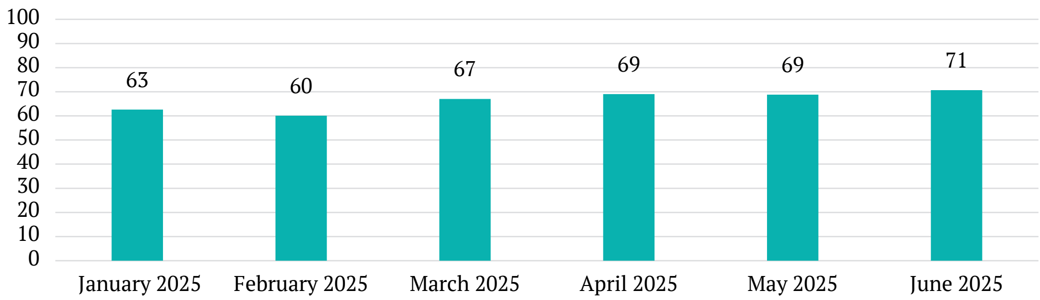

Figure 1. OEE – overall equipment effectiveness for "Tube Plant" LLC, %

Source: developed by the authors

Considering the individual components of the overall equipment effectiveness indicator (Fig. 2), it can be seen that the highest values were for the "*Q* – quality" component. The share of quality products in the total production volume is 95-96%, i.e. 4-5% of products are defective. It should be noted that during the production process, at various stages, part of the manufactured products (about 2%) was selected for quality control, which is a requirement of the technological process. Thus, the actual amount of products manufactured that were of inadequate quality accounted for 2-3% of total production. The "*P* – performance" component also had quite high values, amounting to 92-98%, i.e. 2-8% of time losses were associated with short downtimes that did not require the intervention of repair personnel (minor malfunctions, material interruptions, tool cleaning, etc.) or with natural factors reducing performance (fatigue deformation of parts, equipment wear, i.e. everything that reduced the rated performance).

The biggest problems at the enterprise that led to a decrease in equipment efficiency were identified in component "*A* – availability". The availability indicator was 67-78%, meaning that 22-33% of time was not spent on direct production, but was lost due to unscheduled and scheduled downtime. Unplanned downtime at the enterprise included stoppages for tool and fixture replacement, equipment breakdowns, lack of materials, the need to replace paint or printing plates due to poor-quality printing, and similar issues. Planned or start-up downtime included line stoppages for changeovers to produce items of different sizes.

Since 2022, following the company's entry into new European markets, the number of small-volume orders has increased, each requiring time for changeovers. This became the main reason for the low values of the "*A* – availability" component, leading to less efficient use of equipment. It should also be noted that the equipment was not switched off during changeovers and continued to consume electricity, the share of which in production cost was relatively high, amounting to 11-14%. The overall efficiency of the equipment does not directly take into account electricity losses. However, as a result of downtime, shortages or re-adjustments (i.e. when any of the OEE components decrease), specific energy consumption increases because electricity is used inefficiently. That is, when assessing the efficiency of equipment use, it is also advisable to consider energy efficiency as another aspect of losses, along with losses in availability, performance and quality.

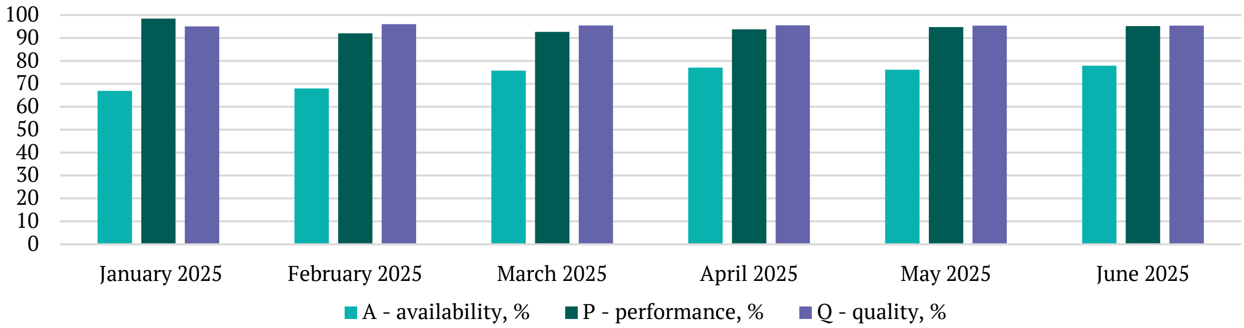

Figure 2. Components of overall equipment effectiveness for "Tube Plant" LLC

Source: developed by the authors

If only the OEE indicator is used to assess the efficiency of equipment, it is possible to take into account losses in time, speed or quality. However, in modern production conditions, it is also necessary to take into account resource losses associated with energy consumption. A critical situation for management is when the share of electricity costs in the cost structure is constantly growing, not only due to the constant increase in tariffs, but also due to the inefficient use of equipment, which leads to an increase in energy consumption. If energy consumption costs are not taken into account when calculating OEE, this can lead to a situation where two production periods with the same OEE values can have completely different financial results due to different specific energy costs. In other words, the overall equipment effectiveness indicator does not provide a complete picture, limiting managers' ability to assess the real impact of production decisions on costs and profits.

Taking into account the "*E* – energy efficiency" component when calculating OEE made it possible to integrate another key factor into the production management system – the energy component of the cost price. This gave managers the opportunity to evaluate production efficiency not only in terms of volume and quality, but also in terms of production costs. They were also able to identify hidden financial losses associated with the irrational organisation of equipment operation (e.g., as a result of frequent changeovers), justify changes in the policy of forming the order portfolio and production plan taking into account energy efficiency, and make investment decisions based on more comprehensive indicators. Thus, the transition from the OEE indicator to the overall efficiency indicator, which takes into account energy costs, is a logical development of the equipment efficiency assessment methodology. This has ensured a closer link between production indicators and the strategic management goals of the enterprise. It was proposed to use the following scale to determine the level of production efficiency based on the obtained OEEe values (Table 1).

Table 1. Scale for determining the level of production efficiency based on the OEEe indicator

Level	OEEe	Energy efficiency characteristics
Perfect production	100%	Ideal equipment operation without energy losses
World-class production	80-99%	Equipment operates with minimal energy losses; settings, loading and planning are optimal
Typical production	50-79%	Moderate energy losses associated with changeovers, downtime or unstable loading
Low level of production efficiency	30-49%	Systemic energy losses, high proportion of long changeovers and frequent transitions between orders

Source: developed by the authors

To calculate the OEEe value for the production line, the minimum energy consumption per unit of output was first determined. For the enterprise under review, the term "energy consumption" refers to electricity consumption, i.e. the consumption of electrical energy in kW per hour. This approach was due to the fact that the production line uses electricity as its main energy source, while other types of energy (heat, gas, steam) are not used in the production process. Accordingly, when calculating E_{min}, the best operating conditions of the equipment were taken into account, namely, the adjustment of the line for the production of one order and its continuous production during two shifts. Under these conditions, the highest energy consumption occurred during the warm-up and adjustment of the equipment, which lasted an average of two hours. Then, energy consumption decreased and averaged 150 kW per hour. The maximum possible output was determined taking into account the speed of the equipment (80 units/min) and the operating time of the line. As a result, it was determined that in the analysed period, the overall efficiency of the equipment, taking into account energy efficiency, was 41-52%, which corresponds to a low level of production efficiency (Fig. 3). That is, if the OEE values indicated that the production level was typical, the OEEe values already indicate its low level. This is due to the low values of the "*E* – energy efficiency" component, which ranged from 60 to 83%.

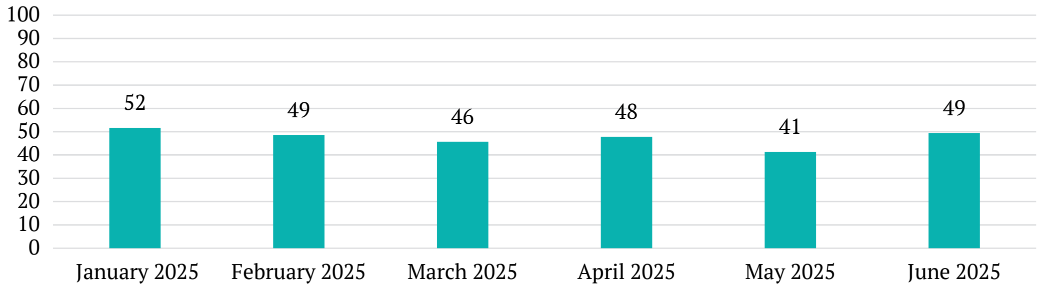

Figure 3. OEEe – overall equipment effectiveness taking into account energy efficiency for "Tube Plant" LLC, %
Source: developed by the authors

To determine the reasons for the deterioration in OEEe values, changes in each of its components were examined, as well as the factors that influenced them. To this end, it is proposed to use the diagram shown in Figure 4.

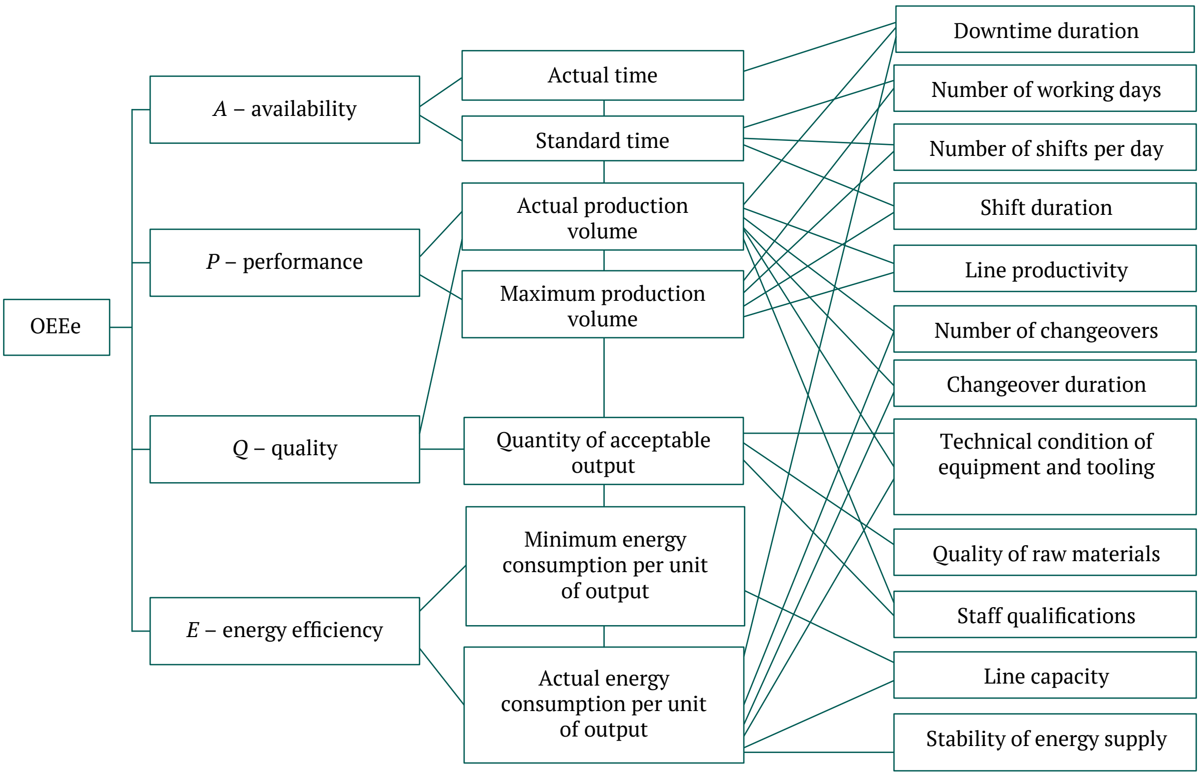

Figure 4. Factors affecting the level of OEEe
Source: developed by the authors

The above factors prove that changes in the overall efficiency of equipment, taking into account energy efficiency, are directly related not only to the technical parameters of the equipment itself, but also to the organisation of the production process. It is important for managers to translate the calculated values of the indicator into practical actions. For this purpose, it is advisable to use Table 2, which shows the relationship between the results of the OEEe calculation, the identified key problem areas of OEEe, and possible management decisions that can be made on their basis.

Table 2. Key management decisions based on OEEe calculation results

Problems	Interpretation	Management decision
Decrease in OEEe value with stable OEE level	The equipment formally operates without downtime or defects, but actual energy consumption exceeds the norm (e.g., due to frequent changeovers or partial loading)	review the order portfolio in favour of consolidating batches, combining small orders by type and size; optimise the production programme to reduce the number of changeovers; introduce the "energy load" criterion when planning the production programme
Increase in OEEe value after combining orders or changes in production schedules	Improvements in the organisation of the production process have reduced specific energy consumption	approve the new planning algorithm as a standard; introduce OEEe into the KPI system for economists in the planning department and line managers; use OEEe calculations to justify minimum order sizes
Different OEEe values on different machines or lines	Identification of "energy-intensive" areas where actual specific energy consumption is higher	optimise the production programme to maximise the utilisation of energy-efficient machines and lines; consider the feasibility of replacing equipment with low OEEe with more efficient equipment; use OEEe to justify investment projects
Correlation between OEEe level and product cost	The increase in production costs is associated with increased energy consumption, rather than direct production losses	include the OEEe indicator in the management reporting system; take energy costs into account when calculating the cost of production; consider the OEEe indicator as a factor of competitiveness, especially in the context of rising electricity tariffs
Lack of OEEe use in employee motivation system	OEEs makes it possible to consider not only the volume and quality of output, but also the rational use of resource	introduce a bonus scale for achieving OEEe targets; motivate economists in the planning department and line managers for rational planning of the production programme; combine OEEe growth with the company's energy conservation programmes

Note: KPI – key performance indicators used to measure and achieve the strategic goals of a company or a specific employee
Source: developed by the authors

Thus, the overall equipment effectiveness indicator, taking into account energy efficiency, is transformed from a technical indicator into a management tool. It allows for improved planning and management of orders at the operational management level and will serve as a basis for justifying investments and a source of cost optimisation at the strategic management level. At the analysed enterprise, the overall efficiency of equipment, taking into account energy efficiency on the production line, decreased significantly in May compared to April (Fig. 3). Analysis of the reasons for this decrease showed that the values of components A, P and Q remained almost unchanged during this period. The deterioration in energy efficiency had the greatest impact on the decline in the overall efficiency of equipment use.

The energy efficiency indicator depends on the minimum and actual energy consumption per unit of output. The minimum value for "Tube Plant" LLC was unchanged and depended on the capacity of the line and the duration of its operation. Actual energy consumption depended on the actual volume of products manufactured and the actual amount of electricity consumed. In turn, these indicators depended on the number of orders requiring equipment changeovers on the line and their complexity. In May, the company had many small-volume orders that required equipment changeovers. During changeovers, the line was not switched off and continued to consume electricity without producing finished products. The line also operated irregularly, with frequent stops for adjustments, which prevented it from reaching an energy-efficient operating mode and increased specific energy consumption.

As a result of calculating the OEEe indicator and analysing the factors that caused its deterioration, the company's managers identified the main problem, namely a reduction in energy efficiency at a fairly stable OEE level. To solve this problem, the following management decisions were proposed. The quality of order portfolio management needs to be improved. The main problem is that the greater the number of small orders processed by the company, the more frequent the changeovers become, which increases downtime, raises energy consumption and reduces OEEe. To overcome this issue, the planning department's economists should take a more thorough approach to grouping orders, taking into account tube diameter and length, type of raw material, thread type, cap type and colour, printing complexity, etc. At the same time, order fulfilment times and possible energy costs should also be taken into account. It is also advisable to set an economically justified minimum order size. If the customer's order volume is lower than this, either refuse the order or significantly increase its selling price. It is also necessary to investigate the feasibility of modernising equipment. Since the OEEe indicator varies across different production lines, especially due to the energy efficiency component, this may be an indicator of the need to make a decision on re-equipping or modernising the line.

It is also necessary to introduce a system of motivation for economists in the planning department and line managers not only for the quantity of products manufactured, but also for the achieved OEEe level. This is because the higher the OEEe value, the lower the losses of the enterprise, including energy consumption, and the higher the contribution of production line employees to the financial result. This measure will contribute to the formation of a reasonable order priority, coordinate changeovers, prevent defects and improve work planning. In the future, this may become the basis for the formation of KPIs for economists in the planning department and production line employees. The use of a modified overall equipment effectiveness indicator that takes energy efficiency into account has made it possible not only to more accurately assess the technical efficiency of equipment, but also to link the performance of the production line to the economic and financial indicators of the enterprise. Including OEEe in the management analysis system will provide managers with more reliable information for decision-making. It will also make it possible to use OEEe as a management reporting tool and as a basis for KPI development.

DISCUSSION

Calculations of the proposed OEEe indicator, which is a modification of the overall equipment effectiveness indicator and takes energy consumption into account, have revealed a number of features that are not reflected in the calculation of the classic OEE indicator. In particular, with comparable OEE values across different shifts and production lines, significant differences in specific energy consumption were identified, which led to a reduction in the OEEe value. This proves the necessity of including the "*E* – energy efficiency" component in the system for assessing overall equipment effectiveness.

An analysis of data from the manufacturing enterprise showed that the main source of additional energy losses was the increase in the number of changeovers caused by the reduction in order sizes. As a result, the equipment operates at less than full capacity, and the electricity consumption per unit of output increases. This directly affects the cost and profitability of products, confirming the importance of the OEEe indicator for management decision-making. Assessing the efficiency of equipment use based on the proposed OEEe indicator, which takes into account the level of energy consumption of the enterprise in the production of products, will allow for a comprehensive analysis and identification of the main problems associated with the inefficient use of equipment. Based on the analysis of the values obtained for both the indicator itself and its components, enterprise managers will be able to make management decisions aimed not only at improving the efficiency of equipment use, but also at improving the economic and financial performance of the enterprise, reducing its costs and increasing profits. The results obtained were based on current scientific developments in the field of efficient equipment use. According to R.M. Nachiappan & N. Anantharaman (2006), measuring the efficiency of individual equipment in a factory is insufficient because the production system is focused on a production line consisting of mass-produced machines. They proposed using the Overall Line Effectiveness indicator in a continuous flow production system.

Authors A. Agárdi & K. Nehéz (2021) considered the task of production planning, which depends on the type of equipment and changeover time and is limited by time parameters regarding available time and maintenance time. They chose to minimise changeover time as the objective function and the number of orders, the number of machines, their production capacity, order setup time, etc. as the constraints of the function. To solve the optimisation problem, the authors used a so-called genetic algorithm based on partial search. It starts with a population of random solutions and iteratively creates elements of the next population through mutations. Indeed, the efficiency of equipment use depends on the type of equipment and its capacity. Changeover time affects the efficiency of equipment use because no production takes place during this time and performance decreases. Moreover, equipment usually continues to operate and consume electricity during changeovers. This made it possible to formulate and substantiate the hypothesis that equipment effectiveness is influenced not only by its availability and the quantity and quality of output, but also by the energy consumption associated with setting up and producing an order. If energy consumption per unit of output increases, this may indicate a growing number of small orders requiring frequent changeovers, a decline in the skill level of line workers leading to longer setup times, or a deterioration in the condition of the equipment itself, which, due to wear, requires more time for maintenance.

The problems between the number of changeovers and the need to increase production flexibility were explored in an article by L. Van De Ginste *et al*. (2022). Modern customer requirements increasingly complicate performance indicators, because the constant change of products at production stations leads to a decline in the "A – availability" component of the OEE indicator due to the growing number and duration of changeovers. The authors proposed that, when assessing equipment effectiveness, flexibility indicators should also be taken into account through the calculation of the OEE_{flex}, indicator, which includes elements such as mobility, homogeneity and range. Mobility is related to the time spent on changeovers. The higher the mobility, the faster the equipment can be reconfigured to produce new products. It is debatable whether it is appropriate to single out mobility as a separate element of OEE or whether it is sufficient to take into account the time for changeovers when calculating the "A – availability" component when determining the planned production time. If the changeover time is mandatory for product manufacturing, then the planned time should not be calculated as the product of the number of work shifts and their duration, but should be reduced by the time required to change over the equipment to order, provided that the production plan is optimal.

M. Braglia *et al*. (2008; 2021) believed that the overall efficiency of OEE equipment can only be used to evaluate the performance of individual equipment, which does not allow for the evaluation of the efficiency of the production system as a whole when the machines are connected in a production line. To overcome this problem, they proposed a comprehensive approach to assessing line performance based on the calculation of an object-oriented modelling indicator. The authors developed a classification of losses depending on whether they are associated with specific equipment or distributed throughout the line. That is, according to the authors, the OEE indicator cannot be used to evaluate the efficiency of the entire line. Indeed, the classical version of OEE calculation is intended only for a single machine and allows its performance and bottlenecks to be identified. However, the OEE indicator can also be used to assess the effectiveness of the entire production line, taking into account the following features: availability is calculated not for individual machines but for the whole line; performance is taken at the level of the slowest machine in the line; and quality is determined by the final quantity of output at the end of the line. Accordingly, the OEE value for individual equipment reflects its own effectiveness, whereas the OEE value for the production line reflects the coordination of equipment operation and the absence of losses between them. At the same time, the overall OEE for the line is usually lower than that of the best individual machines. C. Phukapak *et al*. (2024) used the OEE indicator as one of the factors influencing the optimisation of the fruit juice manufacturing process. To do this, they examined the juice production process and used the OEE indicator to identify its bottlenecks. Although the authors provided values for labour, raw materials, packaging, overhead costs, and downtime costs, their research focused more on technical than managerial issues of production improvement, namely the response of equipment to changes in temperature conditions and load settings.

M. Zubair *et al*. (2021) used the OEE indicator to identify key factors that could improve overall equipment effectiveness and performance in the pharmaceutical industry. They calculated the OEE for three main types of equipment and compared their values with each other. This allowed the authors to determine which equipment was used least efficiently and led to a decrease in the performance of the entire line. The main problems that led to low equipment efficiency were unplanned downtime and poor quality parts. It is debatable whether it is possible to compare three types of equipment that are completely different in terms of purpose, performance and speed using the OEE indicator. The article by P.H. Tsarouhas (2020) presents the results of an analysis of the OEE level for an ice cream manufacturing company. Using the Pareto method, the author identified six main losses that lead to equipment downtime, namely: equipment failure, setup and adjustment, downtime, speed reduction, and defects in the production process. A distinctive feature of the study is that the author calculated the OEE indicator not only for a month, but also for each working day and week. This made it possible to identify problems with the use of equipment in a specific period.

F. Kechaou *et al*. (2024) found that, since the introduction of the OEE indicator, several main methods for its calculation have emerged. As a result, somewhat different outcomes may be obtained, leading to slightly different conclusions about how to improve equipment effectiveness. In some cases, an inappropriate choice of calculation method may lead to incorrect or less effective improvement measures. Thus, the authors devoted their study to comparing the main measurement systems used in industry and identified and justified the key characteristics that should be considered when selecting an OEE measurement system. In other words, the authors focused more on the choice of the measurement system for overall equipment effectiveness than on identifying ways to improve it through specific managerial decisions. On the one hand, it can be agreed that accurate measurement not only allows the OEE value to be determined correctly, but also helps to identify appropriate ways of improving it. On the other hand, if a company's management decides to use the OEE indicator for decision-making, it is likely to apply the calculation method that best reflects the specific nature of the company's operations, or to adapt existing methods accordingly.

The study by P. Dobra & J. Jósvai (2022) was not aimed at determining the level of OEE achieved by a company, but rather at establishing its forecast value. According to the authors, accurate forecasts contribute to more efficient use of resources and the timely fulfilment of orders. They proposed making such forecasts not only with mathematical models based on previous-period results, but also through human forecasting based on surveys of machine setters. On the one hand, this approach is reasonable, because people may anticipate problems that could arise during order execution but have not yet appeared in previous OEE calculations. On the other hand, the authors did not assess the level of experience of the machine setters or the consistency of their opinions, apart from stating that they should have many years of experience. Moreover, even surveying machine setters did not always make it possible to identify the problems that led to a decline in overall equipment effectiveness. The main issues that made OEE forecasting impossible were unpredictable shortages of raw materials, equipment breakdowns, poor-quality materials, urgent orders, and similar factors. Thus, the reviewed studies are based on the calculation of OEE components and the search for ways to improve their values, taking into account the specifics of the production process, operating conditions, and the parameters of particular equipment. Thus, the results of these studies cannot be directly applied to companies operating in other industries, producing different products, or using different types of equipment. Wherever possible, the findings should be adapted to the specific features of a particular enterprise. The analysis of recent studies on overall equipment effectiveness has demonstrated the advisability of modifying its calculation to reflect the characteristics of a production enterprise that consumes large amounts of electricity. It can be concluded that existing approaches to OEE calculation should be supplemented with an energy-efficiency component. This would make it possible to account for energy consumption not only during production, but also during equipment setup for orders or during downtime. It would also help to identify problems of inefficient resource use even when overall equipment effectiveness indicators appear satisfactory. As a result, this provides a basis for managerial decisions aimed at reducing production costs and increasing company profits through improved equipment utilisation.

CONCLUSIONS

Despite its widespread use, the overall equipment effectiveness (OEE) indicator has limitations – it does not reflect resource losses, primarily those related to energy consumption, which is a significant item in the cost of production of a manufacturing enterprise. To overcome this shortcoming, it is proposed to use a modified OEEe indicator, which includes an "*E* – energy efficiency" component that compares minimum and actual specific energy consumption. The calculations of OEEe showed that, with the same OEE values, different production periods can have significantly different energy costs, which confirms the need to take into account the energy component when assessing the efficiency of equipment.

A common factor in the decrease in OEEe at the studied enterprise was an increase in small orders, which increased the number of changeovers and led to an increase in energy costs and production costs. The use of the OEEe indicator will improve the effectiveness of management decisions at the operational level (it will allow optimising the order portfolio, production programme and taking into account the results when forming the employee motivation system) and at the strategic level (calculating the cost of production, establishing the main directions for equipment modernisation and justifying investment decisions). The inclusion of the OEEe indicator in the management accounting system will ensure a more comprehensive assessment of the efficiency of the enterprise's production activities and will allow the technical efficiency of equipment to be linked to its economic and financial indicators.

Thus, the use of the OEEe indicator allows for the identification of hidden energy losses, which is relevant for enterprises where the share of energy consumption costs in the cost price is high. Managers will be able to identify ways to save resources not only by optimising time, but also by reducing energy consumption. They will be able to see how much electricity is consumed above the minimum required level and identify the reasons for excess consumption. Based on this, a motivation system can be introduced for various employees involved in planning and executing production plans. For example, it is possible to make changes to the enterprise's pricing policy and significantly differentiate sales prices depending on order volumes in order to encourage buyers not to split one large order into a bunch of small ones throughout the year.

Thus, the OEEe calculation will allow not only to directly determine the overall efficiency of the equipment, but also to establish the reasons for its deterioration and, on this basis, to make management decisions to improve the situation, reduce specific energy consumption, reduce unproductive losses, which in turn will reduce the cost and increase the profit of the enterprise. The current version of the OEEe calculation takes into account only one type of resource – electricity. In the future, it is advisable to develop the use of OEEe taking into account various types of energy resources (heat, gas, steam), which will allow creating a universal indicator for comprehensive assessment of the energy efficiency of equipment use. This will improve the effectiveness of management decisions at enterprises that consume various types of energy and whose share in the cost of production is significant.

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CONFLICT OF INTEREST

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Використання модифікованого показника загальної ефективності обладнання для формування управлінських рішень

Олена Велика
Кандидат економічних наук, доцент
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0002-0072-5867

Інна Козлова
Кандидат економічних наук, доцент
Харківський національний економічний університет імені Семена Кузнеця
61166, просп. Науки, 9А, м. Харків, Україна
https://orcid.org/0000-0002-5107-6668

Анотація. Актуальність дослідження зумовлена необхідністю врахування при прийнятті управлінських рішень витрат на енергоспоживання, що є значущою статтею у собівартості продукції. Метою дослідження було удосконалення формування управлінських рішень на основі оцінювання модифікованого показника ефективності використання обладнання, якій враховує рівень енергоспоживання (OEEe). Методична основа дослідження включала застосування методів аналізу і синтезу, методу порівняння та методу узагальнення, візуалізації емпіричних даних на основі діаграми динаміки складових показника загальної ефективності обладнання на прикладі підприємства, що виробляє пакувальну продукцію за перше півріччя 2025 року. Це дало підстави стверджувати, що необхідно більш повно оцінювати ресурсну та економічну ефективність роботи обладнання за допомогою введення додаткової складової «Е – енергоефективність», яка відображає відношення мінімального та фактичного енергоспоживання при виробництві одиниці продукції. На прикладі розрахунку OEEe для виробничої лінії з випуску алюмінієвих туб було встановлено, що при зіставних значеннях загальної ефективності обладнання можливі значні розбіжності у питомих витратах на енергоспоживання, що напряму впливає на собівартість та прибутковість продукції. Результати аналізу довели, що основним джерелом енерговтрат є збільшення кількості переналадок обладнання для виконання невеликих за розмірами замовлень. Запропоновано використання показника OEEe для прийняття управлінських рішень, спрямованих на оптимізацію виробничої програми, управління портфелем замовлень, обґрунтування інвестиційних рішень та формування системи мотивації персоналу. Практична значущість результатів дослідження полягає у тому, що показник OEEe можливо використовувати як інструмент для збільшення енергоефективності, встановлення скритих економічних втрат та інтеграції показника до системи управлінської звітності

Ключові слова: менеджмент; собівартість продукції; продуктивність обладнання; переналадки; енергоефективність; питоме енергоспоживання