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THE USE OF SELECTED METHODS IN THE ANALYSIS OF THE EFFICIENCY OF THE MACHINE AND DEVICE – CASE STUDY

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Purpose: The main purpose of the paper was the assessment of efficiency of selected machine and identification of causes of low efficiency.
Design/methodology/approach: During the analysis three main methods were used: OEE, PAMCO and Ishikawa chart. The analysis covers one calendar year. The analysis was conducted for Bole EKH 90 injection molding machine.
Findings: The analysis showed that low utilization of available time of machine was the main problem. It was caused by many factors, three of them are important: employee factor, machine condition and management.
Research limitations/implications: It should be noted that such an analysis should be further explored, using additional assessment methods and tools, which would allow for even more detailed identification of problems in the future.
Originality/value: The paper presents the example that shows that the low efficiency leads to operational losses. However, the proper use of selected methods give possibility to identify factors decreasing the productivity and to make improvements.
Keywords: efficiency, machine and device, OEE, PAMCO, Ishikawa chart.
Category of the paper: research paper, case study.

1. Introduction

One of the most important elements in assessing the performance of any enterprise is the assessing the effectiveness of its operations as a whole and of its individual components. Efficient use of its resources, including machinery and equipment, yields tangible results in the form of reduced production costs and increased profits. Therefore, the concept of efficiency should be defined.

The diversity of existing organizational and management theories means that efficiency is considered from the perspectives of, among others, general knowledge, praxeology, production management, quality management, value-added management, and business informatics (Głodziński, 2015).

The concept of efficiency has evolved over many years, gaining new meanings. It has become so broad that it combines various categories, such as efficiency, effectiveness, competence, functionality, communication skills, morality, and ecology (Tyrańska, 2009).

According to the PWN Dictionary of the Polish Language (PWN, 2026), efficient means "producing good results, effective", while according to the Management Encyclopedia (EZ, 2026): "Efficiency is the result of undertaken actions, described by the ratio of obtained effects to incurred inputs. It means the best results in production, distribution, sales, or promotion, obtained at the lowest cost".

Generally, efficiency is defined by the degree to which a system utilizes its resources. It can be measured using the following relationship (Głodziński, 2015):

$$Efficiency = \frac{\text{Output}}{\text{Input}} \tag{1}$$

In economics and management sciences, efficiency in general can be treated as a positive characteristic of the result of any action (Pszczołowski, 1978). These actions are usually considered from two perspectives: economic or organizational. The economic aspect refers to the allocation of inputs and technical factors, such as pure technical efficiency and scale efficiency. In turn, the organizational aspect encompasses concepts such as effectiveness, expediency, economy, efficiency, functionality, expandability, profitability, rationality, efficiency, motivation, as well as communicativeness, flexibility, interchangeability, competence, common sense, normativity, professionalism, honesty and acceptability (Becla et al., 2024).

The literature offers many approaches to classifying efficiency. The most common classification is based on the aspect being assessed (Kozuń-Cieślak, 2013):

1. Economic efficiency means achieving specific results with the lowest possible inputs or obtaining the highest possible output from given resources.
2. Organizational efficiency is associated with the efficient functioning of an organization, proper coordination of activities, rational division of tasks, and skillful use of resources.
3. Technical efficiency means the ability to achieve maximum production with a given set of inputs or achieve a desired effect with minimal resource consumption.
4. Labor efficiency is the relationship between the results obtained and the inputs incurred to achieve them, in particular working time, effort, and resources used.
5. Social efficiency refers to the social outcomes of activities, such as improved quality of life, increased availability of services or reduced exclusion.
6. Energy efficiency is the ratio of obtained results, services, goods, or energy to the energy input.

Various assessment tools are used to measure efficiency. In the case of technical efficiency, these include productivity indicators, indicators of economic resource utilization, production quality indicators, and productivity audits and benchmarking (Jaki, 2011).

Technical efficiency is assessed by assessing the performance of machines, equipment, and technical systems, human activity, the functioning of the organization and its individual components (e.g., workstations, departments, projects), the state of individual sectors, the overall economy, and socioeconomic systems (Głodziński, 2015).

One important element of assessing a company's technical efficiency is analyzing the efficiency of machinery and equipment used in production processes. This allows for the improvement of these devices' performance and, consequently, the optimization of production costs.

Machinery and equipment efficiency refers to the degree to which machines, devices, and installations are used efficiently, reliably and economically (Productivity Press Development Team, 1999). This is demonstrated by achieving high productivity, minimizing downtime, reducing failure rates, and maximizing the technical capabilities of the equipment (Muchiri, Pintelon, 2008). Machinery and equipment efficiency is also demonstrated by their ability to operate with the lowest possible consumption of energy, consumables and maintenance time (Hedman et al., 2016). In practice, high machine and equipment efficiency increases production, reduces operating costs, and improves the quality of processes [Productivity Press Development Team, 1999; Muchiri, Pintelon, 2008). Machinery efficiency assessment methods include various indicators and analytical tools that allow for the determination of equipment utilization and operational efficiency (Muchiri, Pintelon, 2008). The most commonly used include the OEE (Overall Equipment Effectiveness) indicator, the PAMCO (Plant & Machine Control) machine operating time utilization method, failure rate analysis, production efficiency measurement, product quality assessment, and operating cost analysis (Hedman et al., 2016; Gupta, Garg, 2012). Thanks to these methods, it is possible to detect downtime, losses and irregularities in the operation of machines and then take actions to improve their efficiency and reliability (Muchiri, Pintelon, 2008; Hedman et al., 2016).

The main goal of this paper is the assessment of the utilization of operating time of a selected device operating in a Polish company and to identify opportunities for improving its performance by increasing operating time utilization and efficiency. The article utilizes two methods for assessing machine efficiency: OEE and PAMCO. Additionally, an Ishikawa diagram was used to identify the key factors negatively impacting efficiency. The analysis was based on results collected during one calendar year of operation of the tested device.

2. Characteristics of research object

This paper analyzes the operation of a selected machine operating in an existing manufacturing facility. This machine, the Bole EKH 90 injection molding machine, is a servo-hydraulic injection molding machine with a clamping force of 90 tons. It is designed for injection molds in industries such as automotive, household appliances, electronics, and many others. It features a central toggle system that ensures full utilization of the clamping force, resulting in higher production precision (bole-europe.com, 2026).

Main parameters of the machine (bole-europe.com, 2026):

- clamping force: 90 tonnes,
- drive system: servo-hydraulic,
- power consumption: 3 kWh,
- injection weight: 80 g,
- screw diameter: 32 mm.

Figure 1 presents general view of the Bole EKH 90 injection molding machine.



Figure 1. Bole EKH 90 injection molding machine.
Source: bole-europe.com, 2026.

3. Methodology

The analysis of efficiency of the tested machine was based on the results from existed company. It covers one calendar year. Data collected to the analysis are divided into four quarters. The whole analysis was divided into three parts:

1. OEE (Overall Equipment Effectiveness) analysis.
2. PAMCO (Plant and Machine Control) analysis.
3. Ishikawa chart for the main reason decreasing the efficiency of machine.

The analysis was conducted in one of Polish companies. Due to trade secrets, the name of company is omitted. However, the company operates in the plastics industry, producing household appliances.

3.1. OEE analysis

During the first part of the analysis OEE indicators were calculated. The OEE (Overall Equipment Effectiveness) analysis is a measure of operational efficiency of machines and devices. It is also an indicator-based method that evaluates its basic indicators (Borkowski, Ulewicz, 2008):

- Availability – the machine's operating time.
- Utilization – the percentage of utilization at its maximum capacity.
- Quality – the quality level of the products it produces.

Based on the above-mentioned parameters the OEE indicator is determined, which can be used to assess the total operational efficiency of the machine. Detailed descriptions of the indicators used in the analysis can be found in numerous research papers related to production management and the analysis of machine and equipment performance (Borkowski, Ulewicz, 2008; Kurnia et al., 2022; AlMashaqbeh, Munive-Hernandez, 2024).

3.2. PAMCO analysis

During the second part of analysis PAMCO method was used. It helps to analyze the efficiency of time of work of machine more detailed. The PAMCO (Plant and Machine Control) method, also known as the machine resource utilization assessment method, involves a ratio analysis of machine operating time, dividing these times into types related to its active operation and interruptions resulting from various groups of factors. The analysis includes eight main indicators expressing the ratio of the duration of various types of activities to total time (related to the length of the analyzed period), available time (reduced by interruptions resulting from the machine's work schedule), or production time (reduced by interruptions related to unused or non-operational time) (Borkowski, Ulewicz, 2008):

- Production Efficiency indicator (PE).
- Operational Efficiency indicator (OE).
- Available Utilization indicator (AU).
- Asset Availability indicator (AA).
- Asset Utilization indicator (Aut).
- Operational Utilization indicator (OU).
- Production Utilization indicator (PU).
- Effective Utilization indicator (EU).

Detailed descriptions of the indicators used in the analysis can be found in numerous research papers related to production management and the analysis of machine and equipment performance indicators (Borkowski, Ulewicz, 2008; Borkowski et al., 2014, Ingaldi, 2015).

3.3. Ishikawa chart

The cause analysis was made for the most significant reason of decreasing efficiency of the machine. Ishikawa chart was used in the paper. The Ishikawa diagram is a graphical analysis of the influence of various factors and their interrelationships that cause a specific quality problem and an analysis of the results (effects) caused by the operation of these interrelationships. All causes identified in the work were grouped according to the traditional classification, the so-called 5M: Manpower (Man), Methods, Machinery (Machine), Materials, Management (Wong et al., 2016; Botezatu et al., 2019).

4. Results

The analysis of efficiency of selected machine was made. It was divided into two part: OEE (Overall Equipment Effectiveness) and PAMCO (Plant and Machine Control). According to the results of this analysis the main reason of decreasing efficiency of the machine was identified. The, the cause analysis was made for this reason using Ishikawa chart.

It must be underline that the during the study period the following values of production parameters were recorded:

- Average working time fund – approx. 130 000 min.
- Average planned working time found – approx. 110 000 min.
- Average time of downtime (planned and unplanned) – approx. 45 000 min.
- Average quarterly production – approx. 17 000 pieces.
- Average quality level percentage of defects– approx. 2%.

4.1. OEE (Overall Equipment Effectiveness) analysis

First step of the analysis was using OEE method to the estimation of efficiency of the tested machine. The main indicators were calculated. The results are presented in Table 1.

Table 1.
Results of OEE analysis of efficiency of the tested machine.

	Availability, %	**Utilization, %**	**Quality, %**	**OEE, %**
Quarter 1	82.8%	78.6%	98.3%	64.0%
Quarter 2	85.0%	82.1%	97.4%	68.0%
Quarter 3	84.2%	80.7%	97.9%	66.5%
Quarter 4	80.2%	75.2%	98.2%	59.2%
World class value (Borkowski, Ulewicz, 2008; Kurnia et al., 2022; AlMashaqbeh, Munive-Hernandez, 2024)	**90%**	**95%**	**99.9%**	**85%**

Source: Own study.

According to results of the analysis presented in Table 1, it can be said that:

- The availability indicator was in the range from 80.2 to 85% and it was lower than the preferred value of 90%. The highest value was noticed in the second quarter while the lowest – in the fourth.
- The utilization indicator was in the range from 75.2 to 82.1% and it was lower than the preferred value of 95%. The highest and the lowest value was noticed in the same quarters as previous indicator.
- The quality indicator was in the range from 97.4 to 98.3% and it was a bit lower than the preferred value of 99.9%. Diversity of values was very small, the lowest values were noticed in the middle of analyzed time.
- The OEE indicator was in the range from 59.2 to 68% and it was much lower than the preferred value of 85%. The highest and the lowest value was noticed in the same quarters as availability and performance indicators.
- It should be underline that problems with utilization of the machine was the biggest cause of low efficiency of the machine.

4.2. PAMCO (Plant and Machine Control) analysis

The PAPMCO analysis was made in the next step. The purpose of this method is to analyze use of machine operating time. Main indicators were calculated. The results are presented in Table 2.

Table 2.
Results of PAMCO analysis of efficiency of the tested machine.

	PE, %	**OE, %**	**AU, %**	**AA, %**	**AUt, %**	**OU, %**	**PU, %**	**EU, %**
Quarter 1	98.92%	77.71%	95.98%	67.96%	65.74%	65.23%	51.25%	50.69%
Quarter 2	99.32%	78.88%	96.99%	69.96%	68.45%	67.86%	53.89%	53.53%
Quarter 3	98.45%	74.41%	96.82%	59.78%	58.65%	57.88%	43.75%	43.07%
Quarter 4	99.29%	74.37%	91.07%	65.40%	59.96%	59.56%	44.61%	44.29%
Optimal value (Borkowski, Ulewicz, 2008; Borkowski et al., 2014, Ingaldi, 2015)	**95%**	**92.5%**	**90%**	**97%**	**65%**	**62%**	**60%**	**50%**

Source: Own study.

According to results of the analysis presented in Table 2, it can be said that:

- Production Efficiency indicator (PE) - the optimal value should be greater than 95%, while results are in the range of 98.45–99.32%. Values are only a bit higher than optimum.
- Operational Efficiency indicator (OE) - the optimal value of approximately 92.5%, results are lower than optimum and in the range of 74.37-78.88%.
- Available Utilization indicator (AU) indicator, with a recommended value of approximately 90%, has values in the range of 91.46-98.93%.

- Asset Availability indicator (AA) indicator, for which recommended value is approximately 97%, has much lower values in the range of 59.78-69.96%.
- Asset Utilization indicator (AUt) - the optimal value is 65%, while results are in the range of 58.65-68.45%.
- Operational Utilization indicator (OU), recommended at approximately 62%, has values in the range of 57.88- 67.86%.
- Production Utilization indicator (PU) – the optimal value above 65%, while results are the range of 43.75-53.89%, below the recommended value.
- Effective Utilization indicator (EU) – the optimal value is approximately 50%, ranging from 43.07-53.53%

Based on the analysis of the results, it can be seen two indicators (PE, AU) were higher than recommended values, while three of them (OE, AA, PU) – lower. In case of three indicators (AUT, OU, EU) values the values fluctuated around the optimal values.

4.3. Ishikawa chart of causes of low utilization of available time of machine

According to the previous analysis the main problem causes low values of efficiency of analyzed machine was problem with low utilization of available time of machine during production process. The analysis of causes of such problem was made. During the analysis Ishikawa chart was used. The results are presented in Figure 2.

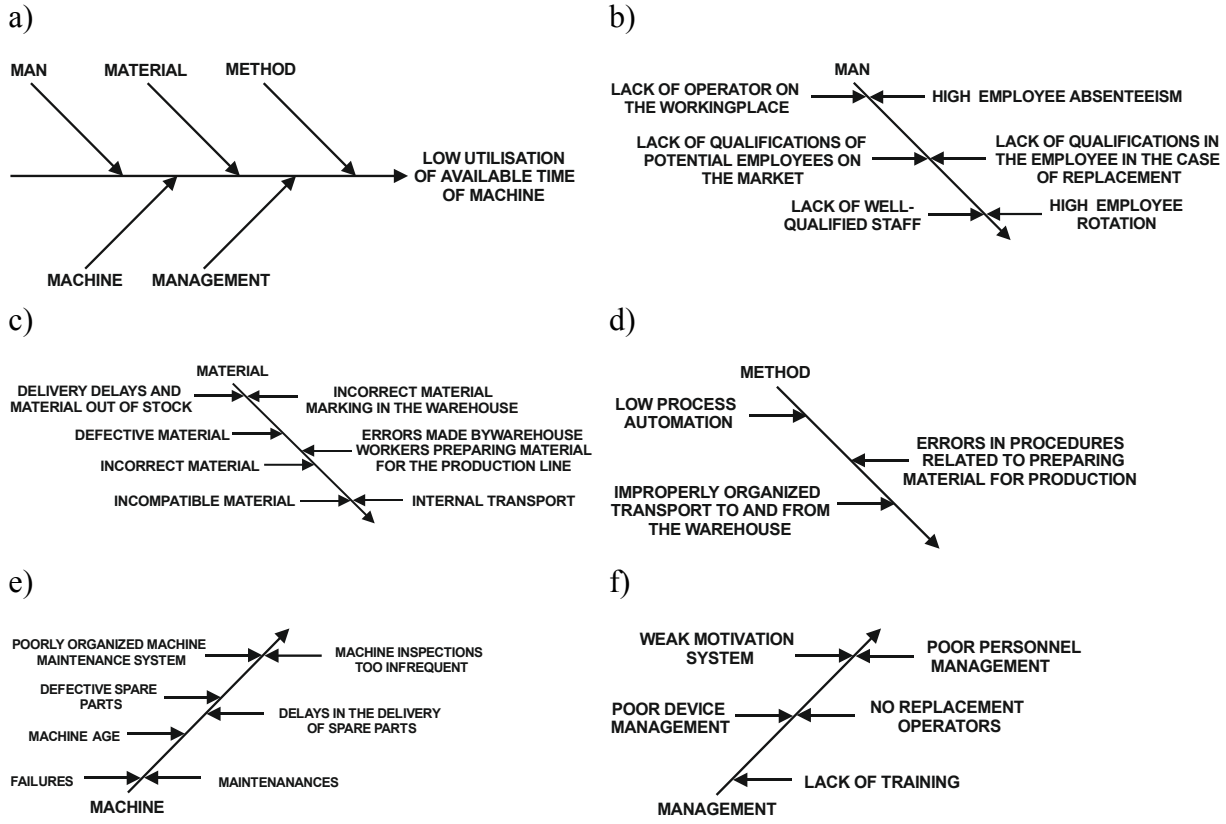

Figure 2. Ishikawa chart for the cause of low values of efficiency of analyzed machine.

Source: Own study.

According to the analysis of Ishikawa chart (Figure 2) it can be said that there are many causes of the problem in the analyzed process. All of them were divided in six groups and it can be observed that some causes in separate group are connected.

5. Discussion of results

It must be said that low efficiency of tested machine is observed. It is caused by many different reasons. Each analysis shows the problem from different point of view.

Based on the result of OEE analysis it can be said that values of the main OEE indicator is on the average level of 64.4% so it is much lower than optimal word class value of 85%. So, it should be concluded that efficiency of analyzed machine is low. The value of the OEE indicator depends on the values of the auxiliary indicators:

- Availability – average value of this indicator for the entire research period was on the level of 83%, while recommended value is 90%. It means that planned stops accounted for 17% of the machine's time fund. It was mainly connected with planned repairs and maintenance.
- Utilization – average value of this indicator for the entire research period was on the level of 79%, while recommended value is 95%. So, it should be concluded that value of this parameter caused the biggest problem in the low value of OEE,
- Quality – average value of this indicator for the entire research period was on the level of 98%, while recommended value is 99.9%.

Based on the result of PAMCO analysis it can be said that main indicator, effective utilization indicator (EU) is, on the average, on the optimal level. Its average value is nearly 48%, while the optimum 50%. However, the analysis of other indicators shows that three of them that:

- Production utilization indicator (PU) - production time accounts for only about 45% of the total time (optimal value 60%). This means that the remaining time includes various breaks when the machine could be used.
- Asset availability indicator (AA) - This indicator is indirectly related to the PU indicator. The average for this indicator is very low, at only 66% (the optimal value is 97%). This is due to only partial utilization of the total machine time. The company operates on a single-shift system, so the device is used only 8 hours a day, the rest of the time is unused.
- Operational efficiency indicator (OE) – the average value of this indicator is on the level of 76% while optimum should be 92.5%. In case of this indicator low operational efficiency results from various types of interruptions during machine operation. These include planned and routine interruptions (maintenance or routine changes to the device).

- The differences between the PU and AA indicators show that the examined enterprise records a very long period of complete machine unusability due to free time, planned and unplanned breaks are a much less significant factor reducing the efficiency of the device.

The Ishikawa helped to analyze the main problem causes low values of efficiency of analyzed machine was problem with low utilization of available time of machine during production process. It shows that main problems are:

1. Man – human resources and manpower:
   - The shortage of machine operators poses a significant challenge in ensuring the machine's continuous operation. A lack of operators leads to production delays and reduces machine efficiency.
   - Frequent employee absences, such as sick leave and vacations, and difficulties in finding replacements.
   - Poorly qualified employees who replace others in their absence can cause numerous errors and downtime during the production process.
   - High demand for specialists in the labor market leads to significant employee turnover, which necessitates hiring people with insufficient qualifications. Difficulties in hiring employees with the appropriate qualifications for a given position, often due to lack of experience.
2. Machine – maintenance of equipment:
   - Poorly organized machine maintenance system.
   - The significant age of the device and its significant wear and tear cause frequent breakdowns and machine downtime.
   - Insufficient machine inspection frequency can lead to more frequent breakdowns, which leads to machine downtime and may also require temporary shutdowns.
   - Lack of regular maintenance action leads to breakdowns and downtime. Insufficient attention to technical condition results in unplanned downtime.
   - Too frequent breakdowns are the result of a lack of proper maintenance and improper equipment management, which directly impacts their availability.
   - Shortages in the supply of spare parts.
   - Defective spare parts.
3. Material – proper parameters, quantity and quality of material in right time:
   - Problems with the supply of materials and spare parts lead to downtime.
   - Inadequate quality of materials used in production also contributes to delays and the need for downtime.
   - Errors when delivering incorrect material to the workstation cause additional downtime: material with incorrect parameters, errors in material deliveries to the production line.

- Failure to follow procedures and employee inattention often result in incorrect preparation of material transferred to the production line.
- Problems with internal transport result in problems with delivering material to the production line and delays in product transport, which can cause unnecessary downtime.

4. Management – personnel management:
   - Poor personnel management, both production staff and warehouse employees, reduces their work efficiency and negatively impacts the production process itself.
   - Inadequate organization of staff work, including the lack of a replacement system in the event of operator absences, contributes to limited availability.
   - Low qualifications of operators, resulting from a lack of appropriate training, contribute to inefficient utilization and an increased risk of failure.
   - Incorrect planning of inspections and incorrect planning of the use of a given device can significantly reduce its efficiency.
5. Method – organization of work:
   - Incorrectly organized transport to and from warehouse.
   - Errors in procedures related to preparing material for production.

According to the analysis presented in this paper it must be said that the relationship between the OEE, PAMCO, and Ishikawa results is consistent. OEE identifies the general problem of low effectiveness, PAMCO shows that the main losses are connected with insufficient use of available time and low asset availability, while the Ishikawa diagram indicates the probable root causes of these losses. This confirms that the problem should not be treated only as a technical failure of the machine. It is also connected with production planning, maintenance organization, staff management, material flow, and work procedures. For this reason, improvement actions should be systemic and should involve both technical and organizational measures.

The first recommended direction of improvement is the development of a more effective maintenance system. Preventive maintenance should be planned on the basis of machine condition, failure history, and production load. Regular inspections, faster access to spare parts, and better documentation of failures could reduce unplanned downtime and improve availability. The second important direction is better organization of labor resources. The company should introduce a replacement system for absent operators, improve training for new and substitute workers, and standardize operating procedures. These actions could reduce interruptions caused by operator shortages and insufficient qualifications.

Another possible improvement is better planning of production time. Since the low AA and PU indicators are strongly connected with the single-shift system, the company should analyze whether extending machine operation to an additional shift would be economically justified. Even partial extension of working time could increase the use of the machine without the need

for new investment in equipment. At the same time, the flow of materials and spare parts should be improved by introducing clearer procedures for material preparation, internal transport, and delivery control. This would reduce the risk of waiting time caused by incorrect or delayed materials.

In summary, the obtained results show that the analyzed injection molding machine has significant potential for efficiency improvement. The production process produces parts of relatively good quality, but the machine is not used intensively enough and is affected by organizational and maintenance-related interruptions. The most important improvement opportunities are connected with increasing utilization, reducing downtime, improving maintenance planning, strengthening operator availability and competence, and ensuring better material flow. Implementation of these actions should lead to higher availability and utilization values and, as a result, to a gradual increase in the OEE indicator.

6. Conclusion

Efficient resource utilization is a key factor influencing a company's success. Low efficiency leads to operational losses and, consequently, reduced profits. This article analyzes the efficiency of a selected machine in a manufacturing company. The analysis revealed that the primary factor reducing the efficiency of the analyzed machine is the inappropriate use of available operating time. Causes that significantly impacted this situation included: employee factor (absenteeism and low qualifications of replacement line workers or new employees), machine condition (age, improper maintenance activities, breakdowns), and poor management. This factor is largely linked to the previous two. Improving employee work organization and machine maintenance will significantly improve its efficiency. However, it should be noted that such an analysis should be further explored, using additional assessment methods and tools, which would allow for even more detailed identification of problems in the future.

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