RESEARCH IN LOGISTICS & PRODUCTION

MACHINE USE AND THE SUPPLY CHAIN EFFICIENCY IN THE MANUFACTURING COMPANY

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Abstract The increase of machine utilisation in manufacturing companies contributes significantly to improving customer logistics service by ensuring the availability of stocks at the required level. The aim of the article is to present the impact of the improved machine use in the manufacturing plant of the lighting industry on supply chain efficiency. The first part discussed the performance indicators of machine use in the Total Productive Maintenance grasp with suggestions of their improvement. The second part presents the facilitation of the machine use process in the company. It also contains the analysis of the influence of the machine use improvement on shaping the availability of component inventory of the customer.

Paper type: Research Paper

Published online: 30 April 2016
Vol. 6, No. 2, pp. 165-176
DOI: 10.21008/j.2083-4950.2016.6.2.6

ISSN 2083-4942 (Print)
ISSN 2083-4950 (Online)

Keywords: *Total Productive Maintenance, OEE, hidden machine, availability of inventory*

1. INTRODUCTION

The essence of functioning of manufacturing companies on the markets is the focus on the requirements and needs of the customer. Customer's satisfaction can be viewed through the prism of three categories: costs, quality and delivery. Efficient companies seek to provide lower costs, higher quality and shorter delivery than their competitors (Suzaki, 1993). One way to achieve the competition advantage is to increase the efficiency of using the machinery. This allows the manufacturing plants to lower costs, improve quality, and most of all provide better availability of the offered products. Availability of stocks, as well as the rate of their replenishment are some of the key indicators to measure the quality of the logistics customer service (Christopher, 1998); (Ciesielski, 2009). The aim of the article is to present the impact of improving the use of machines in the manufacturing company from the lighting industry on the supply chain efficiency and customer's satisfaction, measured as the inventory availability indicator. The first part discussed the efficiency indicators of machine use in manufacturing companies in terms of Total Productive Maintenance with the proposal for their improvement. The second part presented the facilitation of the machine use process in manufacturing on a practical example. Also the analysis of the impact of machine use improvement on the shaping of component inventory availability of the customer was conducted.

2. MACHINE USE

One of the manufacturing processes improvement philosophies putting a strong emphasis on maximising the machine use in the manufacturing process is Total Productive Maintenance. TPM rules were developed in 1971 by Seiichi Nakajima. They consisted of prolonging the machine life cycle and of improving effectiveness of the whole manufacturing plant (May & Schimek, 2014). Nakajima defines the TPM concept as maintaining productivity by all employees of the company within the operation of small groups of employees. The main objectives of these groups are included in the formula: “No accidents, no failures, no losses”. The main goal of TPM is to strive for manufacturing perfection by reducing accidents, failures and quality losses. It is a kind of perfect state of the company (Koch, 2008). In the initial phase of the existence, actions within TPM focused on the machinery park. Over the years, the concept has evolved and currently it should be characterised more broadly as a comprehensive maintenance of productivity of the whole organisation. Nevertheless, still one of the basic areas of TPM activity is the efficient and effective use of machines.

The basic indicator used within the TPM approach to the effectiveness measurement of using the machinery park is the overall equipment effectiveness indicator OEE. Japan Institute of Plant Maintenance defines OEE as the indicator describing how well the machinery park is used in the manufacturing process. It is measured in relation to losses interfering production efficiency (TPM Encyklopedia, 2007). The basis for OEE calculation is the machine operating time. This time, reduced by losses in the form of: time of changeovers and breakdowns (availability loss), micro stoppages time and speed losses (productivity loss), time during which the machine produces waste and time of additional repairs resulting from bad quality (quality loss), is defined as valuable operating time. The ratio of valuable operating time to the machine operating time is the OEE indicator. Therefore, this indicator is a multiplier of three components: availability, performance and quality.

The OEE indicator has many advantages and is extremely useful in raising the productivity of manufacturing plants. Japanese authors (Nakajima, 1988); (Suzuki, 1994); (Yoshida et al., 1990) draw attention to the fact that OEE is a kind of tool for solving problems and driving production towards excellence. It allows you to examine the structure of manufacturing losses on the machine by understanding their size, determining priorities and undertaking attempts to seek the cause of their occurrence. The aforementioned time losses of OEE are often referred to as "Six-Great Losses". In the first phase of OEE implementation the stage of data col-lection is important. Generally, the recording of losses takes place on sheets of paper. Over time, companies begin to use computer systems, facilitating the reporting of OEE results. Identification of main OEE losses is an introduction to the process of seeking root causes. In general, at this state, the tool in the form of "5xWhy" is used, as well as the Ishikawa chart, or P-M analysis. The last one is worth noting. It involves understanding the phenomenon of the physical problem (P from the English word "phenomenon" and "physical") and finding relations of this phenomenon towards the main manufacturing factors (4M from English words: man, machine, method, material). After finding the causes of the creation of losses there is the stage of improvement implementation. At this state we use tools and techniques of autonomous maintenance, SMED and poka-yoke and others, which prevent the formation of so many losses in the future (Productivity Press, 2009).

Some authors point out the weaknesses of the OEE indicator and the wrong use of this indicator in practice of manufacturing management. It seems that in addition to the advantages mentioned earlier, the main drawback of OEE is the fact that it takes into account the effectiveness of the machine work in relation to the operating time, avoiding losses associated with the planned maintenance time and resulting from the inefficiency of the manufacturing system. On the other hand, mistakes in the management practice in using OEE refer to:

- treating OEE as a tool for comparing results (benchmarking) and making flawed judgments on this basis, especially in the case of different machines and technologies,
- interpreting OEE results in isolation from the cost realities,
- using OEE for the superficial assessment of the work effects (Grzybowska &Woińska, 2009); (Koch, 2008).

It should be kept in mind that the OEE indicator should be firstly used as a tool for solving problems. It is not the assessment of its level that is important, but most of all the structure of its main elements and causes behind it.

In the management practice there are used indicators, which more widely grasp the degree of using machine operating time in relation to the total time, such as TEEP (Total Effectiveness Equipment Performance) or the indicator of the actual use of the total time EU (Effective utilization) according to methodology of PAMCO (Grzybowska & Woińska, 2009); (Hrubec & Borkowski, 2006). In order to systematise concepts and bearing in mind the holistic approach postulate of the available time and all losses in the machine use, the author of the paper proposes an approach based on the following machine work use indicators:

- asset utilisation indicator AU,
- line overall efficiency indicator LOE,
- overall equipment effectiveness indicator OEE.

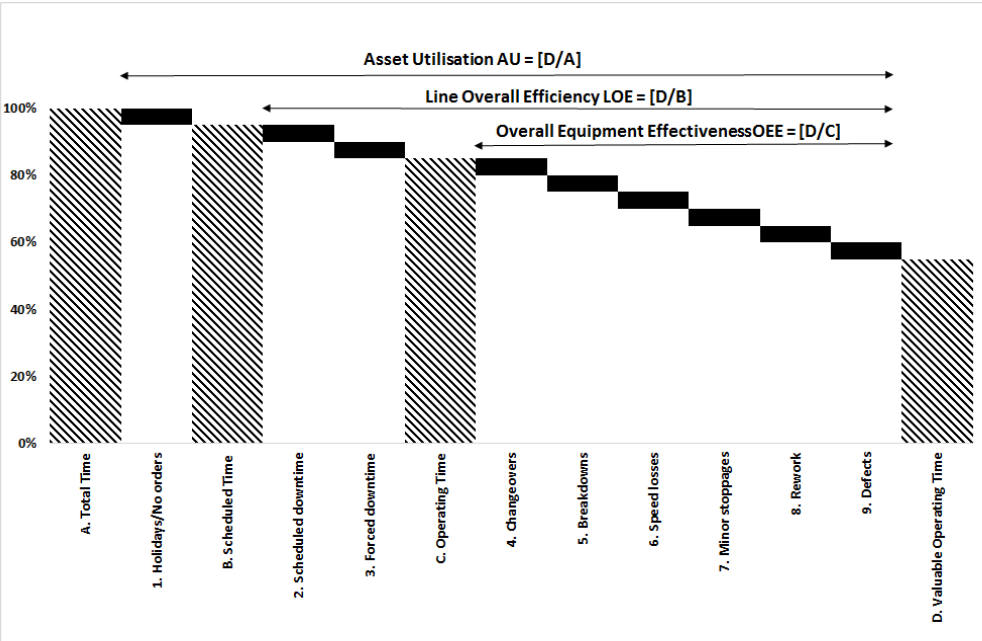

Fig. 1 Machine use efficiency indictors. Own study

These indicators are used in the management practice in many companies, they have also become the subject of professional experiences of the author. It should be noted here that the translation of English terms of "*efficiency*" and "*effectiveness*" can sometimes be confusing, often both these words are used as synonyms. However, the minor differences should be noted. According to what is proposed by Lis and Kosieradzka, efficiency is "a degree to which the system uses resources", while effectiveness is “measured by the degree in which the system implements what has been planned” (Kosieradzka & Lis, 2000). These nuances are very visible in terms of LOE and OEE indicators. The construction of the discussed indicators has been presented in the form of a waterfall chart in Figure 1.

As it can be seen in Figure 1, the indicator which presents the machine use effectiveness in the broadest sense is the AU indicator. It takes into account all possible losses occurring during the machine manufacturing process. A slightly narrower scope is presented by the LOE indicator, which does not take into consideration in its structure the unavailable time (holiday, days off from work) and unplanned time (lack of demand). The narrowest approach is included in the OEE indicator, described in the earlier part of the article.

Table 1 Losses in the machine use process and ways to eliminate them. Own study

Loss	Example	Ways to eliminate losses
Days off Lack of demand	- Holiday - Days off in accordance with the work schedule - Lack of demand and orders from the market	- Changing the work schedule economically justified - Training the reserve crew - Actions aimed at sales growth
Planned stop	- Machine inspections - Planned renovations - Cleaning and inspection - Tests	- Shortening inspection times - Condition Based Maintenance (CBM) - Predictive Maintenance - Implementing steps of autonomous maintenance, shortening cleaning and inspection times
Forced stop	- Lack of materials - Lack of the operator - Lack of tools - Lack of energy factors	- Improving effectiveness of management processes - Reducing employee absences - Preventive measures based on the risk analysis (e.g. FMEA)
Retooling	- Assortment retooling	- SMED - Optimisation of manufacturing planning
Failures	- Machine failures - Tooling damage	- Implementation of steps of autonomous maintenance - Preventive inspections - Eliminating human errors - P-M Analysis - Construction changes - Improving competence of the maintenance services - Acting in accordance with the operational procedures
Speed losses	- Reduced speed - Empty positions	- Eliminating quality problems - Material quality improvement
Micro stoppages	- Minor stoppages - Regulations	- Staff training - Automation
Additional processing and repairs	- Product repairs - Manual installation - Additional control - Other operations aimed to restore quality	- Process control, including SPC - Poka-Yoke solutions - Staff training
Waste	- Process waste - Finished product waste	- Process control, including SPC - Six Sigma - Implementation of quality points (Q-points)

Efficiency indicators of machine use are primarily an important carrier of information about the losses in the manufacturing process. The sum of these losses creates a phenomenon, which by some authors is referred to as the “hidden machine” (Koch, 2008). Eliminations of this phenomenon lies in reducing losses on the machine, which can be achieved in many ways, most of which have their roots in the TPM philosophy. Table 1 presents all losses, supported by practical examples and actions to reduce them.

Methods for eliminating particular machine use losses in the manufacturing process presented in table 1 are not a set of solutions, automatically supplementing the company’s performance. They are an indication and course of action, which should be taken into account in the decision-making process, aimed at improving the economic productivity of the company. Because one should remember the words of Taiichi Ohno, the creator of the manufacturing system for Toyota, that improving efficiency makes sense only if it is related to the reduction of costs (Ohno, 1988).

3. IMPROVING THE EFFICIENCY OF MACHINE USE AND THE AVAILABILITY OF INVENTORY ON THE SELECTED EXAMPLE

Improving the efficiency of the machine use and its impact on the shaping of inventory availability will be presented on the example of the manufacturing company from the lighting industry. It is a leading company in its industry operating globally. One of the manufacturing units of the company producing ceramic components faced the problem of the increased demand for the specific type of assortment. A specific feature of these components was the additional manufacturing process performed on one machine, which is a kind of bottleneck of the process. The management had to choose between two courses of action: investing in a new machine or increasing the manufacturing capacity of the present machine, what in practice meant improving the use efficiency. The primary goal was to ensure the required availability of ceramic components in the inventory in the next manufacturing unit of the group dealing with the assembly of lamps. As a result of preliminary analysis, the unit management decided not to invest in a new machine, and has launched actions to improve the utilisation of the machine.

3.1. improving the Asset Utilisation indicator

Improving the AU indicator on the selected machine was carried out in accordance with the PDCA methodology (Deming cycle). In the “Plan” phase the facilitating team has been appointed which collected the data and identified the main losses in the overall machine operating time. Understanding the current losses has become an extremely important task. It was the basis for planning the objective for the AU indicator, focusing powers and planning works and resources of the team on the most important losses according to the Pareto principle. As a result of preliminary analyses the main problems have been identified and defined. These were the losses related to: work interruptions during holiday periods, inefficiency of the planning system, what sometimes resulted in the lack of manufacturing orders, the lack of operators, including absences, breaks and trainings, assortment retooling and process waste. The aim of the team was to achieve the AU indicator at the level of 65% within three months.

During the “Do” phase a series of actions was conducted aimed to reduce the losses identified in the previous stage of the team’s work. In order to increase the available time the continuous work of operators has been ensured within the four shift system and replacements were introduced in case of days off resulting from provisions of the labour code. The operating time was improved by ensuring continuous availability of manufacturing orders. Also a new work system has been introduced, assuming the position rotation. In the absence of the operator in the workplace, related to breaks, trainings or also sickness absences, the machine work was taken by a person from other processes, which were not as critical in the context of their availability. To this end, employees of other processes have been properly trained. In addition, within the steps of autonomic maintenance the machine cleaning time has been shortened, based on simple facilitations related to the 5S system. Effective work time has increased as a result of the use of SMED method for re-ducing changeover time. In this case, after dividing tasks into external and internal, the time of internal tasks has been clearly reduced. This was possible among others thanks to the use of the group retooling “pit stop” formula during the machine stoppage. The operator from another process, which is not a bottleneck, supported the retooling on the facilitated machine. Process losses have also been limited mainly by tightening the process control, what has forced a quicker reaction to the emerging problems.

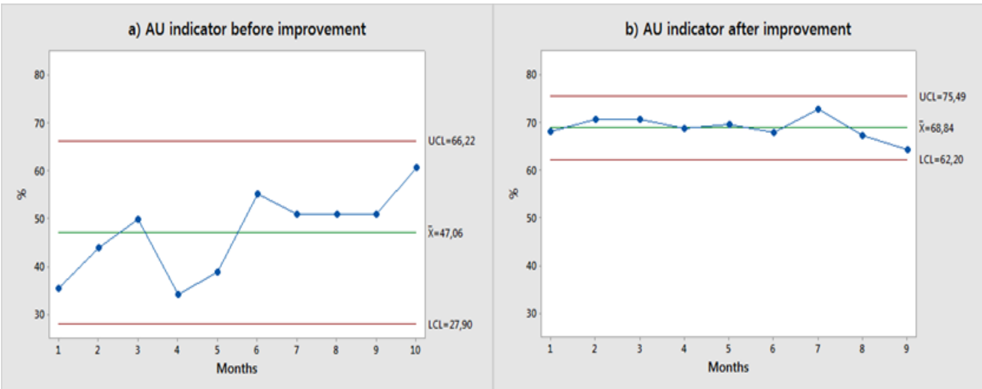

Fig. 2 AU indicator values before and after process improvement. Own study

In the "Check" and "Act" phases, the team has monitored the results of the AU indicator and tried to embed and to modify the adopted solutions. The achieved results were presented in Figure 2.

Data presented in Figure 2 confirm that the undertaken measured have produced a result. The average value of the AU indicator before facilitation was at the level of 47,06%, while after the implemented actions it achieved the value of 68,84%. It is a significant difference, what has been confirmed statistically in the t-Student test, where the statistics T-value was obtained at the level of -7,24, with the 5% significance level. It should be noted that the process has also become more stable, the standard deviation decreased from 8,70% to 2,41%.

3.2. Influence of the AU indicator improvement on the inventory availability

Data and exploratory analysis.

In order to study the impact of the machine use improvement on the inventory availability of the customer the exploratory analysis was carried out based on the collected data. Data relate to two variables:

- AU – the Asset Utilization indicator expressed in the % grasp for the given month,
- SM – inventory availability in the supermarket expressed in the quantity of pieces at the end of the given month.

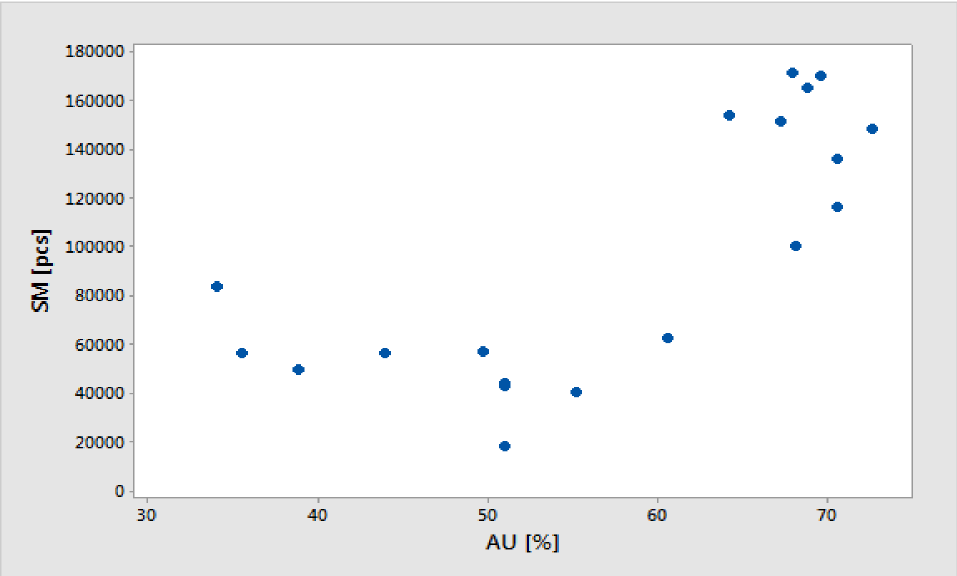

Fig. 3 Dependency between the AU and SM variable. Own study

Data were collected for 18 months and included the period before and after the improvement of the machine use. All calculations were performed using the statistical program Minitab. The exploratory analysis included: data visualisation, study of occurring dependencies and calculation of the correlation coefficient between variables. Data visualisation has been presented in the scatterplot type of chart (Figure 3). The presented data show dependency in the form of a curved line. The Pearson correlation coefficient is 0,748, what indicates a strong positive relation between the variables. Greater values of the AU indicator variable are associated by greater values of the SM inventory availability variable.

Based on the studies from the exploratory analysis a hypothesis has been put forward that the improvement of the AU indicator affects the increase of the inventory availability in the supermarket.

Explanatory analysis

The hypothesis has been verified using the linear regression model. In view of the fact that the data illustrated in figure 3 are clearly curved, the polynomial regression model of the second degree with one explanatory variable has been applied (Aczel, 2005). The level of inventory availability was adopted as the dependent variable measured with the number of components in the supermarket, while the AU indicator was the independent variable. Results of the polynomial regression are presented in Figure 4.

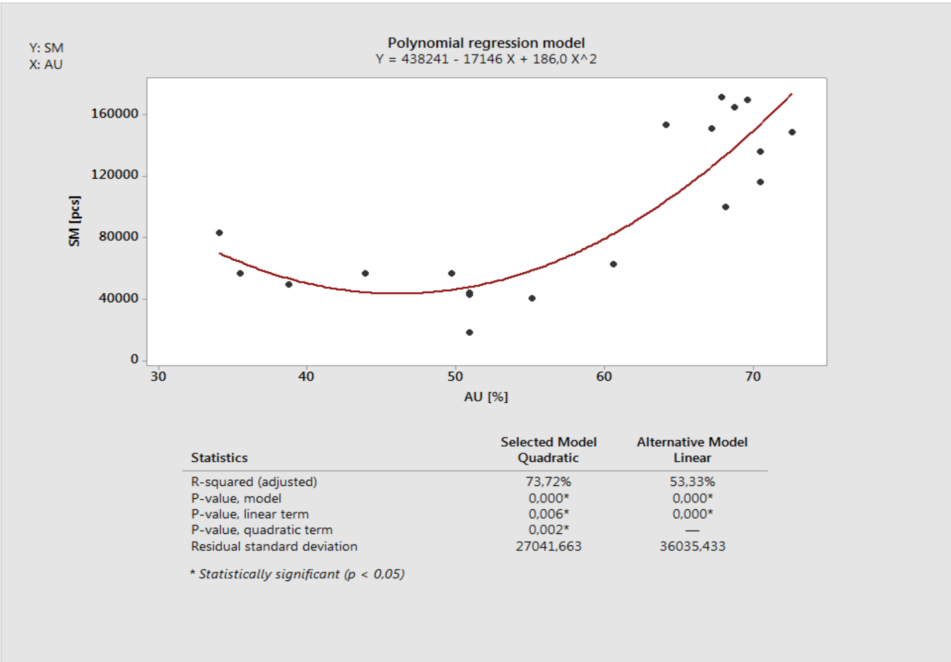

Fig. 4 Polynomial regression model. Own study in the Minitab program

Equation (1) of the polynomial regression model of the second degree took the form of:

$$SM = 438241 - 17146AU + 186AU^2 \tag{1}$$

For the given model the following main statistics have been obtained:
– standard estimation S error at the level of 27041,7;
– determination coefficient R^2 at the level of 76,64%;
– corrected determination coefficient $\overline{R^2}$ at the level of 73,72%;
– p-value equal zero, for the significance level of α=0,05.

Interpretation, practical significance and model limitations

The p-value close to zero informs that the regression model is statistically significant at the 95% confidence level. The determination coefficient R^2 in turn says that the variability of the inventory level in the supermarket can be explained in 76,64% by the impact of the AU indicator variable. Such a result in practice should be considered satisfactory (Aczel, 2005). It is also a confirmation of the hypothesis that the improvement of the AU asset utilisation indicator affected the increase of inventory availability in the supermarket. This condition was, in turn, necessary to meet the customer's requirements and affect his satisfaction, by ensuring the availability of components and continuity of product supply.

The presented regression model brings great practical importance. It may serve as a prognostic tool and it can be used for planning operational actions. For example, in a situation, when the customer expects availability of components in the supermarket at the level of 140 thousand pcs., then the indicator of the asset utilisation should be around 69%. For the management personnel it is a signal to customise the work organisation in order to achieve the assumed level of the AU indicator. These can be decisions affecting the losses limitations in the manufacturing process of the machine use or a specific balance between these losses on the basis of the "trade-off" type of choices. Thanks to the model, the management can proactively plan and implement some preventive measures, which ensure the achievement of the assumed AU indicator level, and thus affect the desired inventory level by the customer.

However, it should be noted that the presented regression model has some limitations. First of all, it can be used to predict the inventory level in the supermarket within the studied AU indicator scope, that is within the range between 30% and 75%. Going beyond these limits may cause the results of the model to slightly differ from reality. Please note that the model has been developed in some permanent external conditions, with the relatively stable and known customer demand for the final product. In the event of changes of these factors, the model results can also change. The value of the determination coefficient at the level of 76,64%, is a satisfactory result. However, this also means that in 23,36% the model variability can be explained by other factors.

3. CONCLUSION

Ensuring the adequate level of machine use in manufacturing plants is a very important task for the company's functioning on the market. First, it enables the increase of productivity by reducing the manufacturing costs in the given area of the manufacturing process. Secondly, it contributes to the increase of customer's satisfaction by guaranteeing the adequate product availability according to the customer‘s requirements. The key elements of the process of machine use improvement in the companies are the measurements of losses, their understanding, and then reduction within the facilitating projects. Very useful in this regard are the machine use effectiveness indicators derived from the concept of Total Productive Maintenance, such as: OEE, LOE and AU. They facilitate the accurate understanding of losses in the manufacturing process on the given machine. After the stage of losses identification, usually the losses reduction process takes place within the facilitating projects. The TPM concept in this respect offers many tools and techniques, which were presented in the content of this article. The experiences of the studied company show that the reduction of losses in the machine use process increases the real manufacturing capabilities, and therefore, affects positively the ensuring of inventory availability in accordance to the customer's requirements. In general, the higher levels of the Asset Utilisation indicator are associated with higher levels of inventory availability in the supermarket, and this in turn translates into greater customer satisfaction.

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