QPI 2020, volume 2, pp. 204-213

IMPROVEMENT OF PRODUCTION SYSTEM RELIABILITY USING SELECTED KPIS

doi: 10.2478/cqpi-2020-0023

Date of submission of the article to the Editor: 07/07/2020
Date of acceptance of the article by the Editor: 31/07/2020

Witold Biały – *orcid id: 0000-0003-2313-0230*
Silesian University of Technology, **Poland**

Abstract: Machine failures in each production system cause an increase in costs and delays in order execution. Therefore, companies decide to introduce solutions that detect and immediately remove worrying symptoms before more serious consequences occur. Unfortunately, not all failures can be avoided – in such cases, the most important thing is the quick reaction of machine operators, maintenance and production managers. This paper identifies reliability indicators and presents the steps and effects of implementing selected KPIs (Key Performance Indicators), which aim at the production process. For the machines in which a failure occurred in the surveyed period, technical availability, Mean Times Between Failures (MTBF), Mean Down Time (MDT), technical object readiness, and the downtime coefficient were calculated.

Keywords: production, failure, reliability, KPI, machine efficiency

1. INTRODUCTION

Each company sets clear and achievable goals. Usually it is a dynamic development, high company profits and a high position on the market. In order to meet the increasing customer requirements, the company must ensure that the production process runs smoothly. Unplanned disruptions in the production process affect the quality and timeliness of tasks performed. Among unplanned production interruptions are those caused by machine/plant failures. Each failure results in additional costs that the company has to bear.

Even the most correct behaviour cannot 100% rule out the possibility of undesired events. Each type of activity is associated with a specific risk – including the risk of failure.

The progress of information and communication techniques using mechanical and electronic systems has introduced “new quality” in the construction and operation of machines. The use of control, monitoring or regulation systems allows for proper performance of production tasks. Monitoring the condition of machines before, during or after operation has become a standard. As a result of these activities, downtimes during the production process have been quite significantly reduced, which has translated into economic effects for companies.

According to the occupational health and safety standard (Niziński, 2002), a failure is "an event occurring as a result of uncontrolled developments during the operation of materials, equipment or installations, leading to the emergence, immediately or with delay, within or outside the organization, of a serious hazard to human health and/or the environment, such as: a high emission of harmful or hazardous substances, fire, explosion, etc." (How to understand the concept of failure).

Machine failures are the main problem of industrial enterprises. They cause unplanned stoppages in production, which may result in increased costs and loss of customers (Kowalski, 2012), (failure definition), (Biały and Rozbarsky, 2018).

Failures are understood as unforeseen damage to machinery, which leads to the state of malfunction of the object and prevents its operation. Such failures occur suddenly and result in its malfunctioning or the complete transition of machine into an unfit state. The duration of failure is impossible to determine and requires corrective and remedial action to rectify the failure and restore the machine to a state of serviceability.

Failure – an unexpected (unplanned), sudden event(s) which causes, or is capable of causing, injury to persons or damage to buildings, plants, materials or the environment.

In order for machines to function properly, it is necessary to organize the process of supervising machines and equipment. The management of machinery park is an essential element of the functioning of a company. All activities are implemented to supervise the efficiency, reliability and readiness of the production machines. The basic element of properly organized process of supervising machines and devices in an enterprise consists in choosing and applying proper management strategy (Legutko, 2009), (Niziński, 2002), (Piersiala and Trzcieliński, 2005), (Biały and Rozbarsky, 2018).

Implemented methods of supervising machines and devices require periodic evaluation of the effectiveness of implemented measures and the technical condition of owned machinery park.

2. KEY PERFORMANCE INDICATORS (KPI)

Every production company must take into account the fact that machines and their parts may failure as a result of continuous operation. In order to avoid additional costs and unexpected downtimes in production, companies more often decide to use methods and tools to support maintenance work. These actions will allow for quick identification of the cause of failure, efficient and quick correction and introduction of corrective and improvement measures.

Therefore, in companies, more emphasis is placed on the efficiency of machinery park – the aim is to achieve zero downtime and zero failures.

The basis is selection of appropriate measures that are used to assess the key activities carried out as part of the maintenance of machinery and equipment to work effectively. The effectiveness is understood as characteristic of the operation object which determines the level of achievement of the objectives set for the object in specific operating conditions and a specific period of time (Antczak and Gębczyńska, 2016).

In order to assess the effectiveness of machinery operation in the company, various measures should be used, which are selected based on a specific criterion. For the different criteria, different types of indicators are used, which are presented in Table 1.

Table 1
Machinery performance indicators

Lp	Type of criterion	Examples of indicator types
1	Economic	Profitability rate Fixed and variable costs of maintaining machines Capital, mean and current machine maintenance costs rate Cost of maintaining spare parts
2	Technical and operational	Machine reliability indicator Performance indicator Machine downtime indicator Machinery damage and failure rate Technical readiness index Machine utilization rate Changeability index
3	Information and operation	Technical performance indicator Mean age of machines Repair service intensity rate Repair satisfaction rate Employment rate of maintenance services On-time performance of capital, mean, current and maintenance repairs Maintainability indicator
4	Security	Number of accidents in the operation and use of machines Number of hazards arising when operating and using the machines

The meters are used to evaluate the key activities carried out within the machinery maintenance, as well as to control the implementation of activities carried out in the company.

Key Performance Indicators (KPIs) are used in the paper to assess the effectiveness of selected production system. They allow for a comprehensive and objective assessment of the implementation level regarding the organization objectives (Bujanowska and Biały, 2018), (Loska, 2011).

The KPIs are a key success factor in the area of maintenance. The selection of appropriate indicators and their interpretation lead to the successful completion of the improvements introduced in the company, which result in savings as well as organizational and operational benefits. The KPIs allow to use the already collected information on the operation of machines to diagnose the maintenance activities.

KPIs for maintenance have been included in the standard (PN-EN 15341:2007), Maintenance Key Performance Indicators, developed by the European Committee for Standardization (CEN), which contains a uniform set of measures. There are seventy-three KPIs and they should be selected according to the relevant criterion (Bujanowska and Biały, 2018), (Loska, 2011). The KPIs are created and selected on the basis of individual information needs in each operating system (Adamkiewicz and Burnos, 2019). The study was guided by the technical and operational criterion, which is related to the suitability of system elements. These indicators express the influence of technology on the operation of particular technical means and are related to the system elements' functioning, as well as express the influence on the system's ability to function in a given time.

The following indicators are included in the technical and operational criterion (Antosz and Stadnicka, 2015):

- performance indicator,
- coefficient of variation,

- machine damage and failure rate,
- machine downtime indicator,
- machine utilization rate,
- technical readiness indicator.

3. BRIEF DESCRIPTION OF THE COMPANY

The surveyed company is a dominant manufacturer of machinery and equipment for metallurgy and metal processing. Thanks to many years of experience in designing, production, delivery and start-up of equipment and entire process lines, it has a certain position on the domestic market, but also on the foreign market.
The company also employs highly qualified engineers, who consist of a team of experienced design office employees. Thanks to their work, new product designs are developed for the company and for foreign companies.
Main sectors of the company's activity:

- machinery and equipment for the independent metalworking industry,
- machinery and equipment for the iron and steel metallurgy industry,
- machining,
- heavy welded structures of machines and equipment,
- mining and energy industry,
- food industry,
- shipbuilding,
- manipulators and forge hammers.

The aim of conducted studies is to analyze and assess the correctness of using key efficiency indicators of the production process in the surveyed company. The paper analyses selected, four key efficiency indicators such as:

- Boring mill (Figure 1),
- Drilling and milling machine (Figure 2),
- Hobbing machine (Figure 3).

Fig. 1. Boring mill. Source: (Zamet Industry)

Fig. 2. Drilling and milling machine. Source: (Zamet Industry)

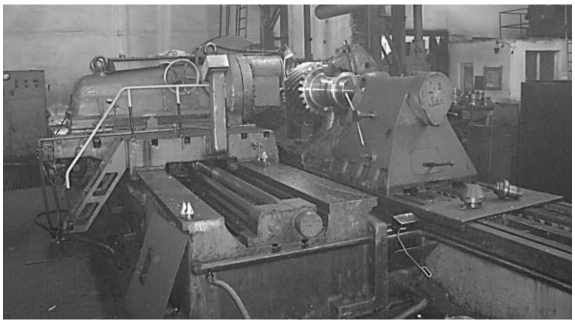

Fig. 3. Hobbing machine. Source: (Zamet Industry)

4. DETERMINATION OF SELECTED KPIs

In order to determine the system's reliability it is necessary to determine the reliability of each technical object. The rules of preparing technical documentation of maintenance services provide for a 20-day work cycle of selected machines. The system components operate in series during two eight-hour shifts. Reliability was calculated on the basis of technical object tests in one month, which had 28 days, excluding Saturdays and Sundays.

The presented paper determines (calculated) reliability indicators in order to obtain data on the efficiency of components operation of the analyzed equipment.

All calculated indicators should be analysed by tracking their trends at equal intervals. It is then possible to deduce whether the implemented measures are achieving the intended effect. The indicators shall be calculated and measured to plan the time of maintenance and replacement of parts, to verify the performance of maintenance services, to measure the progress in reducing the time to repair failures. These indicators are related to failure analysis, it is worth to use them to draw conclusions and implement actions aimed at reducing the failure level and reducing the failure duration (Bujanowska and Biały, 2018), (Macha, 2002).

1. Technical availability

$$A_t = K_g = \frac{T_1}{T_2} \quad (1)$$

where:

T1 – Actual operating time

T2 – Expected operating time

Boring mill

Actual operating time (total): T1 = 224 h

Estimated operating time: T2 = 320 h (8 h during each shift)

Readiness index for boring mill:

$$A_t = K_g = \frac{224}{320} = 0.709 \cdot 100\% \ = 70\% \tag{2}$$

Readiness index for boring mill in one month was 70%

Drilling and milling machine

Actual operating time (total): T1 = 256 h
Estimated operating time: T2 = 320 h (8 h during each shift)
Readiness index for drill and milling machine:

$$A_t = K_g = \frac{256}{320} = 0.8 \cdot 100\% \ = 80\% \tag{3}$$

Readiness index for drilling and milling machine in one month was 80%

Hobbing machine

Actual operating time (total): T1 = 320 h
Estimated operating time: T2 = 320 h (8 h during each shift)
Readiness index for hobbing machine:

$$A_t = K_g = \frac{320}{320} = 1 \cdot 100\% \ = 100\% \tag{4}$$

Readiness index for hobbing machine during the month in question was 100%

2. Mean Times Between Failures (MTBF)

$$\mathrm{MTBF} = \frac{T_z}{N} \tag{5}$$

where:
Tz – total time of the object's correct operation at time t
N – number of the object's damage (failures) at time t

Boring mill

Total time of the object's correct operation at time t:

$$Tz = 320\ h - 96\ h = 224\ h \tag{6}$$

Number of the object's damage (failures) at time t: N = 2
MTBF indicator for boring mill:

$$\mathrm{MTBF} = \frac{224}{2} = 112\ \mathrm{h} = 6720\ \mathrm{min} \tag{7}$$

Mean operating time between boring mill damage in one month was 6720 min.

Drilling and milling machine

Total time of the object's correct operation at time t:

$$Tz = 320\ h - 64\ h = 256\ h \tag{8}$$

Number of the object's damage (failures) at time t: N = 1
MTBF indicator for drilling and milling machine:

$$\mathrm{MTBF} = \frac{256}{1} = 256\ \mathrm{h} = 15360\ \mathrm{min} \tag{9}$$

Mean operating time between drilling and milling machine damage in one month was 15360 min.

Hobbing machine

For hobbing machine, this indicator has not been calculated because in the month in question, there was no failure of this machine – MTBF = 0.

3. Mean Down Time (MDT)

$$\mathrm{MDT} = \frac{\sum \mathrm{MDTi}}{\mathrm{n}} \tag{10}$$

where:
∑MDTi – sum of downtimes caused by all failures
n – number of failures

Boring mill

Sum of downtimes caused by all failures
∑MDTi = 96 h
Number of failures
n = 2
Calculation of MDT index for boring mill:

$$\mathrm{MDT} = \frac{96}{2} = 48\ \mathrm{h} = 2880\ \mathrm{min} \tag{11}$$

Mean downtime caused by machine failure in the analysed month was 48 h, i.e. 2880 min.

Drilling and milling machine

The sum of the downtimes caused by all failures
∑MDTi = 64 h
Number of failures
n = 1
Calculation of MDT index for drilling and milling machine:

$$\mathrm{MDT} = \frac{64}{1} = 64\ \mathrm{h} = 3840\ \mathrm{min} \tag{12}$$

Mean downtime caused by machine failure in one month was 64 hours, or 3840 min.

Hobbing machine

This indicator has not been calculated for the hobbing machine, as there was no failure of this machine during the month in question. MDT = 0.

4. Technical object readiness

$$\mathrm{G} = \frac{\mathrm{MTBF}}{\mathrm{MDT} + \mathrm{MTBF}} \cdot 100\% \tag{13}$$

where:
MTBF – Mean Times Between Failures
MDT – Mean Down Time

Boring mill
MTBF = 6720 min
MDT = 3h= 2880 min
Calculation of the technical readiness index (G) for boring mill:

$$G = \frac{6720}{6720 + 2880} \cdot 100\% = 70\% \quad (14)$$

Technical readiness indicator for boring mill is 70%

Drilling and milling machine
MTBF = 15360 min
MDT = 2h = 3840 min
Calculation of the technical readiness index (G) for drilling and milling machine:

$$G = \frac{15360}{15360 + 3840} \cdot 100\% = 80\% \quad (15)$$

Technical readiness indicator for drill and milling machine is: 80%.

Hobbing machine
Readiness of the hobbing machine in the surveyed period of time was 100%.

5. Downtime rate

$$Kp = \frac{T_2}{T_1 + T_2} \cdot 100\% \quad (16)$$

where:
T1 – Total operating time
T2 – Operational availability, determined by dependency (time of suitability at time t):

$$A_0 = \frac{T_z}{t} \cdot 100\% \quad (17)$$

Determination of the dependency (time of suitability at time t):
For boring mill:

$$A_0 = \frac{224}{320} \cdot 100\% = 70\% \quad (18)$$

For drilling and milling machine:

$$A_0 = \frac{256}{320} \cdot 100\% = 80\% \quad (19)$$

For hobbing machine:

$$A_0 = \frac{320}{320} \cdot 100\% = 100\% \quad (20)$$

- Downtime rate for boring mill:

$$Kp = \frac{70}{320 + 70} = 0.179 \approx 0.18 \quad (21)$$

The value of downtime rate for boring mill is 0.18.

- Downtime rate for the drilling and milling machine:

$$Kp = \frac{80}{320 + 80} = 0.2 \quad (22)$$

The value of downtime rate for drilling and milling machine is 0.2.

- For the hobbing machine, no downtime rate was calculated because no failure occurred during the period considered – the rate is 0.

Table 2 shows the calculated values of all selected indicators.

Table 2
Calculated performance indicators

Component / Indicator	Technical availability	Mean operating time between MTBF failures	Mean downtime due to MDT failure	Technical object readiness	Downtime rate
Boring mill	70%	6720 min	48 h	70%	0.18
Drilling-milling machine	80%	15360 min	64 h	80%	0.2
Hobbing machine	100%	0	0	100%	0
∑		22080 min	112 h		0.38

5. CONCLUSION

Production systems require an efficient operating economy to provide products of appropriate quality. Machines must not only run smoothly, but also produce high quality products. Each order accepted by the company has a specific execution time. In case of failure, the time is prolonged, which involves customer dissatisfaction and additional costs. Therefore, maintenance methodologies and tools have a very important role in the production company. Thanks to cause-effect analyses it is possible to quickly find the cause of failure and avoid further downtimes.

Unfortunately, not all failures can be avoided. In such cases, the most important thing is a quick reaction of machine operators, maintainers and production managers.

In this paper, KPIs have been determined (calculated) to improve the reliability of machines. For machines in which a failure has occurred during the period under consideration, technical availability, Mean Times Between Failures (MTBF), Mean Down Time (MDT), technical object readiness, and the downtime factor have been calculated.

Each employee was trained to operate the machinery in the company's fleet and was informed of the need to notify the production manager of any change in the operation of a given machine that was noticed. Employees were involved in the planning, design and maintenance of machines. The lifespan of production machines was also extended thanks to the development of maintenance system. The company constantly strives to achieve the effect of three zeros: zero failures, zero shortages, zero accidents at work. Efficient machinery and high product quality contribute to more customers and along with higher revenues for the company. It should be remembered that maintaining the achieved effects requires the continuous involvement of all employees, control and systematics, as the lack of continuous improvement leads to the loss of all previously undertaken steps.

ACKNOWLEDGEMENTS

The research was conducted with the support of the statutory work titled "The use of modern methods and tools for developing the priority research areas of the Faculty of Organization and Management at Silesian University of Technology", project number 13/030/BK-20/0059

REFERENCES

Adamkiewicz, A., Burnos, A., 2019. *Kluczowe wskaźniki efektywności w utrzymaniu silników spalinowych w układach energetycznych jednostek pływających*. Zeszyty Naukowe Akademii Marynarki Wojennej, rok LIII, 2(189).

Antczak, A., Gębczyńska, A., 2016. *Analiza efektywności procesu produkcyjnego za pomocą kluczowych wskaźników (KPI) na przykładzie firmy XYZ*", Wyższa Szkoła Bankowa we Wrocławiu, Instytut Logistyki.

Antosz, K., Stadnicka, D., 2015. Evaluation measures of machine operation effectiveness in large enterprises: study results. *Eksploatacja i niezawodnosc – Maintenance and Reliability*, 17 (1), 107-117.

Biały, W., Ruzbarsky J., 2018. *Breakdown couse and effect analysis. Case study*. Management Systems in Production Engineering, 26(2), DOI 10.1515/mspe-2018-0013, 83-87.

Bujanowska, A., Biały, W., 2018. *Infrastruktura techniczna w szpitalu. Wspomaganie procesów eksploatacji*, Wydawnictwo CeDeWu, Warszawa.

Durlik, I., 2006. *Inżynieria zarządzania. Strategia i projektowanie systemów produkcyjnych*. Agencja Wydawnicza, Placet, Gdańsk.

Failure definitione https://sjp.pwn.pl/slowniki/awaria.html [Accessed 3 Feb 2020].

How to understand the concept of failure https://www.prawo.pl/kadry/jak-rozumiec-pojecie-awarii,192696.html [Accessed 25 May 2020].

Kowalski, K., 2012. *Nieuszkadzalność, gotowość i obsługiwalność systemów uzbrojenia*, Postępy Nauki i Techniki, 12.

Legutko, S., 2009. *Trendy rozwoju utrzymania ruchu urządzeń i maszyn*, Eksploatacja i Niezawodnosc – Maintenance and Reliability, 2.

Loska, A., 2011. *Przegląd modeli ocen eksploatacyjnych systemów technicznych*, Komputerowo zintegrowane zarządzanie, 25, 37-46.

Macha, E., 2001. *Niezawodność maszyn*, Oficyna Wydawnicza Politechniki Opolskiej, Opole.

Niziński, S., 2002. *Eksploatacja obiektów technicznych*. ITE, Radom.

PN-EN 15341:2007 Obsługiwanie- Kluczowe wskaźniki efektywności obsługiwania

Zamet Industry http://www.zamet-industry.com.pl [Accessed 12 May 2020].