ITM Web of Conferences **59**, 01008 (2024) https://doi.org/10.1051/itmconf/20245901008
HMMOCS-II 2023

Optimization of the number of repair personnel of the enterprise using the theory of queuing

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Abstract. This article addresses the optimization of maintenance personnel at a wood processing facility. The organization of equipment maintenance in one of the workshops is described, along with an analysis of statistical data on equipment breakdowns and repair work execution. The proposal involves the utilization of a closed queuing system to model the process of repair execution. Based on research results, an application has been developed to calculate key system parameters and assess the efficiency of its operation. The optimality criterion considered is a metric that accounts for the reduction in the production output due to equipment downtime and the labor costs of maintenance teams. The results of calculations determine the optimal number of maintenance personnel for the enterprise's workshop. The proposed methodology can be applied to evaluate the effectiveness of production equipment repair operations.

1 Introduction

Currently, many enterprises in Russia are facing a situation where a significant portion of the utilized equipment exhibits a high level of physical wear and tear. This is due to the intensive use of technological equipment, creating a need for proper operation, regular maintenance, and timely repair work. In this context, the primary goal of the technical maintenance service is to enhance the quality of technological equipment repairs while simultaneously reducing its costs.

The insufficient efficiency of the technical maintenance and repair organization leads to a disruption in the standard sequence of production processes. This results in increased equipment downtime, which, in turn, leads to a reduction in production volumes and the quality of the manufactured products, as well as an increase in repair expenses. One possible cause of prolonged equipment downtimes is an insufficient number of maintenance personnel at the enterprise, surpassing the established time for technical equipment servicing. Therefore, determining the optimal number of repair specialists becomes an important task, allowing for the reduction of equipment downtimes caused by malfunctions.

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2 Methods

Machinery and equipment, being an integral part of fixed assets, constitute the technological backbone of any enterprise [1]. During operation, equipment may experience failures due to wear and tear, insufficient preventive maintenance, and a lack of continuous monitoring of its operation [2]. Equipment failures lead to a reduction in production volume and an increase in production costs. In response, enterprises develop a comprehensive set of organizational and technological measures for maintenance and repair. They establish standards for intervals between repairs, maintenance cycles, downtime, and labor costs for equipment repair, as well as approximate types of repair work for different types of equipment.

Management of these processes should ensure the functionality of the equipment, organization of technical maintenance and repair, and a reduction in downtime. This is achieved by combining technical maintenance with scheduled repairs. Unforeseen breakdowns and emergencies are addressed during unscheduled repairs, aimed at quickly restoring equipment functionality and immediately resuming the production process. To efficiently carry out these tasks, enterprises establish repair services.

To evaluate the effectiveness of its operation and determine the optimal number of maintenance personnel, the application of queuing theory is possible, as each piece of equipment represents a potential service request, becoming a reality as a result of a breakdown [3]. The combination of production equipment and maintenance personnel can be considered as a closed queuing system (CQS).

We will consider a closed queuing system in which the incoming request flow is the simplest, and the service time follows an exponential distribution [4]. The optimal number of employees in the repair service can be determined by solving the problem of finding the minimum criterion that reflects the efficiency of the considered queuing system (CQS) operation. This criterion is the sum of maintenance costs for the repair personnel and losses due to equipment downtime:

$$K_r = S \cdot P/(m \cdot F) + N_C \cdot G, \qquad (1)$$

where:

S is the total downtime of all equipment per year, in hours.

P is the annual volume of commodity production, in thousands of rubles.

m is the number of units of equipment.

F is the annual machine time fund of equipment, in hours.

NC is the number of repair service workers.

G is the annual salary of a worker, in thousands of rubles [5].

3 Results and discussion

The addressed problem has been solved for one of the workshops at a wood processing enterprise in the Krasnoyarsk region. The workshop operates equipment in three shifts with a considerable percentage of physical wear, requiring constant technical maintenance during operation. In case of equipment breakdowns and failures, its operability is restored through repairs.

To perform all types of technical maintenance and repair work on technological equipment, the workshop has repair and standby groups. The repair group handles planned preventive maintenance, while the standby group is responsible for unscheduled emergency repairs caused by random equipment failures at any time during working hours. The standby group operates in such a way that one brigade, consisting of two people, works in each shift.

After analyzing shift log data, it was determined that, on average, two incidents of equipment breakdown and failure occur per shift. Additionally, it was found that the average downtime of equipment due to breakdowns and repair activities is 1.5 hours, representing more than 21% of the total working time.

Possibly, one of the reasons for prolonged equipment downtimes is the insufficient number of repair personnel in the workshop, and the actual time for servicing technological equipment exceeds established norms. This disrupts the rhythm of the production process, leads to excessive consumption of the enterprise's resources, negatively impacts the quality of technical maintenance and repair processes, as well as the overall quality of the manufactured products and the competitiveness of the enterprise.

Therefore, our task is to determine the optimal number of repair personnel for this workshop, where the costs of their maintenance and losses due to equipment downtime will be minimized.

Through the analysis of statistical data on the receipt and servicing of requests for repair work, the average number of breakdowns per shift and the average repair time for a unit of equipment have been determined.

For mathematical modeling of the considered queuing system (CQS), it is necessary to know the distribution of the time interval between the arrival of requests and the distribution of the number of requests received over time t. To establish the distribution of a random variable, a check is conducted using the χ^2 test for the statistical hypothesis about the assumed distribution [6].

As a result, it is concluded that the service time distribution follows an exponential law, and the number of breakdowns (service requests) follows a Poisson law.

Figure 1 shows the service time distribution density, and Figure 2 illustrates the probabilities of the number of breakdowns per shift. As the data analysis revealed, the incoming request flow satisfies all the properties of a simple flow: it is stationary, ordinary, with no aftereffect.

Based on the conducted statistical analysis, an application has been developed that allows for the computation of efficiency indicators for the considered queuing system.

The dependency of the optimality criterion on the number of repair brigades is shown in Figure 3.

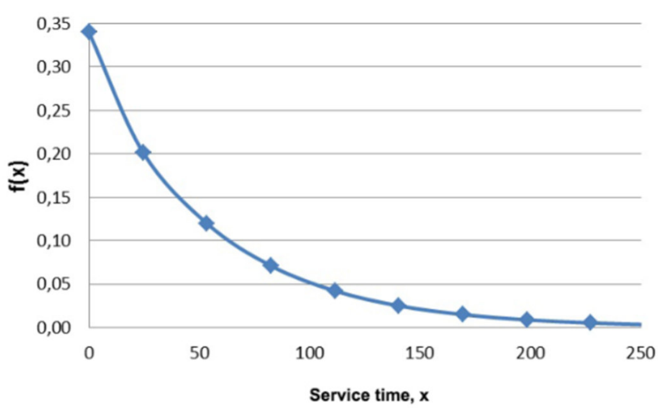

Fig. 1. Service time distribution density requirements.

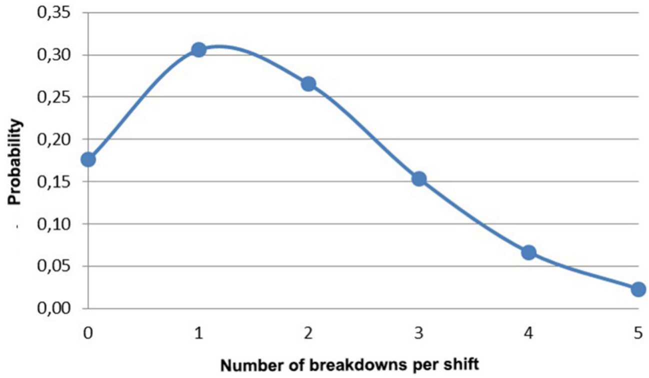

Fig. 2. Probabilities of the number of breakdowns per shift.

The results of calculations for the optimality criterion at various numbers of repair brigade workers are presented in Table 1 and Figure 3.

Table 1. Results of calculation of the optimality criterion.

Characteristic	**Number of people in the team**			
	1	**2**	**3**	**4**
Optimality criterion Kr, rub.	1469.49	1189.56	1157.1	1188.85

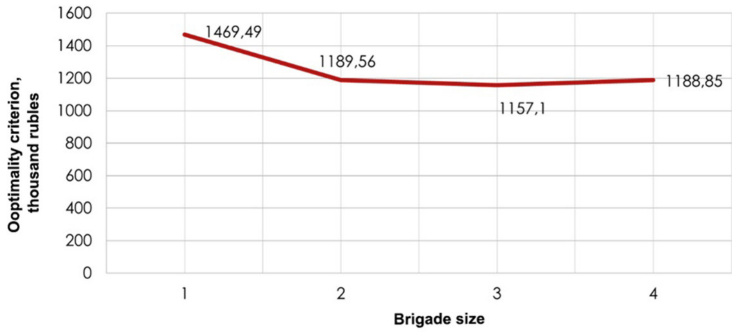

Fig. 3. Dependence of the optimality criterion on the number.

Based on the analysis of the obtained results, it can be concluded that the minimum value of the considered indicator Kr is achieved with a repair brigade personnel of 3.

4 Conclusions

The most crucial conditions for enhancing the efficiency and quality of the production process are minimizing losses associated with equipment downtimes and optimizing the expenditure of working time on its repair.

This paper proposes the application of a queuing system to model the process of conducting repair work in a wood processing enterprise workshop. Based on the conducted research, an application has been developed that allows for the evaluation of the efficiency of this system's operation. The application also provides the ability to determine the average number of pieces of equipment awaiting repair, the average number of pieces of equipment awaiting maintenance and undergoing maintenance, the average waiting time for the start of repairs, equipment downtime, as well as the value of the criterion reflecting the efficiency of the queuing system's operation.

Based on the calculation results, the optimal number of repair personnel has been determined.

The proposed methodology can be applied to calculate the number of repair personnel for enterprises in various industries.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Grant No. 075-12-2022-1121).

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