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RELIABILITY STUDY OF EMERGENCY MAINTENANCE OF GAS SUPPLY SYSTEMS IN THE PRIDNESTROVIAN REGION (MOLDOVA)

The object of research is the reliability indicators of the Pridnestrovian gas transmission system (Moldova). The conducted research is based on the mass service theory.

This research is aimed at studying reliability indicators in terms of determining the quantitative composition of performers and the period of system failure elimination as the most cost-effective aspects of gas transmission organization activities. Since gas consumption facilities are growing annually, the further improvement of the reliability quality of the maintenance system is required. At the same time, as the service life of existing systems increases, the probability of its elements failure increases, which may result in reduced or complete loss of serviceability. It is the reliability indicator that reflects this process and represents a quality characteristic attributed to time. These questions can be solved by mass maintenance theory by investigating a random process and presenting it with a mathematical model of reliability.

The proposed method of mass service system research reveals that incoming flows can be considered as Poisson's (simplest) models, and in most cases it is possible to obtain satisfactory indicators of accuracy in solving the problem. As a result of the construction of a mathematical model, the analysis of existing failures in work by categories was carried out. Using the Kolmogorov criterion, it was determined that the experimental process for distributing applications is Poisson (the simplest). The average time to eliminate the system failure and the average value of the work performers were obtained, and it was also revealed that the irrational use of the calculated resources can lead to irreversible processes.

Application of the proposed mathematical model for determination of reliability indicators will be effective also at operation not only of engineering systems but also of other objects of heat and power region due to the complex approach to realization of questions on accident-free activity of objects, both at design stage and at operation.

Keywords: *queuing theory, accident stages, troubleshooting team, service time.*

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1. Introduction

The annual increase in the number of gas supply facilities and the length of gas distribution networks leads to a constant increase in the reliability of the system as a whole with the observance of basic parameters in case of accident-free operation [1–3].

The problem of reliability has been repeatedly raised and is being raised by many scientists. Thus, in [4] shown that the technical condition of gas distribution networks is at a high enough level, the problem of ensuring their reliability and efficiency is one of the highest priority problems. And each year becoming more and more relevant, which is associated with the ongoing, aging of gas distribution networks and increasing accidents. The way out of this situation is, first of all, reconstruction and technical re-equipment of gas pipelines and gas regulating stations (GRS). However, it should be noted that reconstruction requires substantial financial and material resources. Under these conditions, along with investments, reliability management tools based on modern technologies of statistical management of operation processes become a means of improving technological reliability of the gas distribution network.

As the system operation time increases, the probability of its elements failure increases, which may lead to a significant reduction or complete loss of serviceability [5]. Reliability [3, 6] reflects this process and therefore represents a quality characteristic attributed to time.

Thus, when planning and organizing the work of objects subordinated to the gas industry of populated areas, there are often tasks that can be solved only with the help of mass maintenance theory [2, 3, 7]. In recent years, the mass service theory has been applied to develop methods for arranging emergency maintenance of gas networks, to calculate the number of emergency teams used to eliminate emergency situations on gas trunklines and distribution pipelines.

To solve such problems, it is necessary to study a random process that runs in the system and describe it mathematically. A random process is that the system passes from one state to another at random moments of time. This transition is made by a jump at the moment when the system receives new requirements.

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Calculations on mass service theory show that incoming flows into the system can be considered as Poisson's (simplest) flows. In this case, a satisfactory solution in terms of accuracy can be obtained in the overwhelming majority. Therefore, the research urgency lies in accident-free operation of the Pridnestrovian gas transmission system. Thus, *the object of research* is the reliability indicators of the Pridnestrovian gas transmission system (Moldova). *The aim of research* is the improving technological reliability of gas distribution networks based on statistical analysis and mathematical modeling.

2. Methodology of research

When studying the reliability of emergency maintenance of gas supply systems, the analytical method of studying the specifics of failures in work was used, as well as the theory of mathematical modeling when compiling the accident-free model of system operation.

These questions were solved by means of mass service theory of the reliability indicators, the random process that runs in the system is investigated and described mathematically.

3. Research results and discussion

Let's consider the action of mass service theory to substantiate the number of emergency crews of the Section of underground networks and structures (hereinafter referred to as SUNandS) and the time allocated for troubleshooting on the example of a branch of «Tiraspoltransgas-Pridnestrovie» LLC in Bendery (Moldova).

The duties of the Branch's underground network and facilities section employees include trouble-free operation of the gas supply system facilities, uninterrupted gas supply to all consumption categories, timely liquidation and prevention of facility failures. The performance indicators of the SUNandS are given in Table 1.

Analyzing the data in Table 1, it is possible to see that every year the length of gas pipelines of different pressure and purpose, the number of gasified apartments, heating boilers, utility and domestic consumers is constantly growing by 5–10 % on average. The number of gas regulating points has remained unchanged for the last 10 years – 19. Thus, the functional responsibilities of the SUNandS personnel to ensure reliability of facilities operation are increasing.

The main work is performed by repair crews (performers) that work only one shift, lasting 8 hours (not including lunch break).

In case of equipment [3, 8, 9] failure at subordinate objects, employees of the underground networks and structures site, receiving the application, go to the place of emergency. Thus, the total component of all applications received by SUNandS at random moments of time forms an incoming flow with parameters λ Mass Service System, these time intervals are also considered as random values. As a result, the process that has arisen on the investigated object, too, has a random character [3, 7, 10].

In the organization of SUNandS the main task is to determine the exact number of teams. If the number of crews is insufficient, the service will not be able to eliminate a gas leak during the process, which could result in a fire or explosion. Therefore, the number of employees should be determined in such a way that SUNandS can service the networks and facilities under its jurisdiction and satisfy all requests for facilities without waiting and rejection.

In general, when determining the number of performers for liquidation and prevention of failures in gas supply systems in Pridnestrovian region, it is necessary to take into account the average time spent on their elimination.

Let's consider the number of requests (refusals) and the above parameter in terms of time to service one failure during 2017–2019 for the Bendery branch of «Tiraspoltransgaz-Pridnestrovie» LLC.

According to the data provided by the employees of SUNandS for the time period under study were considered about 4000 applications, most of them occurred in 2017.

Outdoor gas pipelines and their facilities were studied. The average time to eliminate failures in the systems was between 55 and 120 minutes. The largest number of failures occurred at building entrances and fittings (mainly leaks).

Thus, it is possible to assume that the emergency messages for the SUNandS are Poisson's (simplest) thread.

In the Poisson's thread, the probability of arrival in the time interval t exactly K requests is determined by the formula:

$$P_k(t)=\frac{\bar{\alpha}^k}{k!}e^{-\bar{\alpha}}, \tag{1}$$

where $\bar{\alpha}$ is the mathematical expectation of the number of requests within a day:

$$\bar{\alpha}=\frac{\sum_{i=0}^{34} t_i n_i}{\sum_{i=0}^{34} n_i}=12 \text{ applications.} \tag{2}$$

By substituting the values $\bar{\alpha}$ in the formula (1), let's obtain the values of probabilities of the number of applications within a day in the Poissonian distribution. Comparing the received data of distribution of number of requests theoretically and actually, let's receive some deviations in values, it is connected with insufficient volume of processed material.

Table 1

Performance indicators of a section of underground networks and structures in Bender

Years	Length of gas pipeline concerning pressure, km			Number of gasified apartments	Number of heating boilers	Number of municipal and domestic consumers	Number of hydrofracturing stations
	High pressure	Medium pressure	Low pressure				
2017	19,315	107,033	186,287	47,095	385	353	19
2018	19,315	107,033	187,071	47,177	387	359	19
2019	19,315	107,681	187,561	47,235	391	365	19

Based on the results obtained, for further research let's use the Kolmogorov criterion, according to which the probability $P(\lambda)$ indicates that the experimental distribution is Poissonian, according to the law of distribution of the number of applications.

If the incoming flow is the simplest, the law of interval time T distribution between arbitrary two adjacent applications is indicative, the density of which is determined by the formula:

$$f(t)=\lambda e^{-\lambda t}. \quad (3)$$

Mathematical expectation of the value of T will be:

$$m_t=\frac{1}{0.57}=1.75 \text{ hours, i. e. 1 hour 45 min.} \quad (4)$$

The received applications are served by five teams of the underground networks and structures section.

Let's consider the following parameter – the time, which is allocated for gas supply system operation failure elimination, is also of random nature, as it depends on the location of the emergency object and the type of accident. The service time includes the total index from the moment the work failure is received until the executors return directly to the branch of the organization.

Taken in consideration that Bendery is not a metropolitan area, the time to move to and from the facility to the branch within 20 minutes, the time for inspection is given no more than 10 minutes. Thus, it is possible to obtain the value of the parameter on time 2 hours and 7 minutes.

In order to assess the efficiency of a section of underground networks and structures, it is also necessary to determine the probability of employment or free condition of all crews (employment and idle time coefficients).

These indicators are derived from the Erlang's formula:

$$P_k=\frac{\alpha^k}{k!}P_0, \quad (5)$$

where P_0 – probability that all of the brigades are free to serve; k – number of teams (k=0.1, 2, 3, 4, 5);

$$\alpha=\frac{\lambda}{\mu_{cal}}=\lambda m t_{ser}, \quad (6)$$

where λ – parameter for the incoming requests flow. For Bender λ=0.57 applications/h; μ_{cal} – calculated value of the parameter reflecting the performance of the system; t_{ser} – average order processing time:

$$\mu_{cal}=\frac{1}{\bar{t}_{ser}^{cal}}, \quad (7)$$

where $\bar{t}_{ser}^{cal}$ – estimated service time of one request.

Taking into account the statistical data, as well as the fact that all leaks are independent events $\bar{t}_{ser}^{cal}$ can be determined by the formula:

$$\bar{t}_{ser}^{cal}=\bar{t}_{ser1}\beta_1+\bar{t}_{ser2}\beta_2+\bar{t}_{ser3}\beta_3+\bar{t}_{ser4}\beta_4, \quad (8)$$

where β_1, β_2, β_3, β_4 – frequency of occurrence of individual events; $\bar{t}_{ser1}, \bar{t}_{ser2}, \bar{t}_{ser3}, \bar{t}_{ser4}$ – respectively, the average time of service value of one application.

There is:

$$\bar{t}_{ser}^{cal}=0.81 \text{ h}, \quad (9)$$

then

$$\mu_{cal}=1.23 \text{ 1/h}.$$

On the basis of the obtained values, it is possible to determine the probability that all the teams are free, i. e.:

$$P_0=\frac{1}{\sum_{k=0}^{n}\frac{\alpha^k}{k!}+\frac{\alpha^{n+1}}{n!(n-\alpha)}}=0.29. \quad (10)$$

Knowing the probability P_0, it is possible to determine the average number of free and maintenance crews:

$$N_0=\sum_{k=0}^{n-1}\frac{n-k}{k!}\alpha P_0=3.61; \quad (11)$$

$$N_3=\sum_{k=1}^{n}KP_K=0.08. \quad (12)$$

Correspondingly, let's obtain the teams' idle time and load factor:

$$K_n=\frac{N_0}{n}=0.722;\ K_3=\frac{N_3}{n}=0.016. \quad (13)$$

Taking into account the fact that gas supply system failures in the Pridnestrovian region are very dangerous because gas accumulation in premises and malfunctions (such as leaks) can lead to irreversible processes and human casualties. Using the Erlang formula, the probability of servicing requests without waiting will be P=0.9999.

For the possibility of using Poisson distribution tables let's write Erlang formula in this form:

$$P_k=\frac{P(k,\alpha)}{R(n_p,\alpha)+P(n_p,\alpha)\frac{\alpha}{n_p-\alpha}}, \quad (14)$$

where n_p – estimated number of crews.

Taking into account the normalizing condition and accepting the probability of P=0.9999:

$$\sum_{k=0}^{n_p-1}P_k=0.9999. \quad (15)$$

Having analyzed such reliability indices at operation of underground gas pipelines and structures on them, as necessary number of executors on elimination of failures, and also time, allocated for elimination of damages, let's receive probability of elimination of failure according to mass service system P=0.9999 at structure of executors in number of 6 teams.

Based on the so-called conventional units, the number of SUNandS performers varies within the range of 40 people. Let's accept no more than 4 people in a single team, but with the calculated data the organization will have approximately 10 teams, which is more than the number calculated in accordance with the theory of the mass service system.

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4. Conclusions

This article addressed the issues of ensuring the reliability of the gas transmission system by choosing the right number of performers and the accident elimination period. A mathematical model based on mass service theory has been developed to determine the above mentioned parameters. Its peculiarity is a random process that occurs at the moment when the system receives new failure requirements. The proposed mathematical model will determine the need not only to ensure the reliability of the system by timely repair work, as at the time of design, as well as during the operation of the object, but also the correct choice of the quantitative composition of performers to ensure the reliability index $P=0.9999$ and the time allocated to eliminate the failure of the system.

The research results will be useful in the operation of absolutely any engineering system, in any branch of national economy to choose the optimal number of repair workers, without exaggeration to ensure reliability. The time of failure elimination is also a necessary condition, as delay in accident elimination can lead to irreversible processes. If this system is used qualitatively in practice, it is possible to organize any service in many areas of not only heat and power industry, but also the national economy as a whole economically without losses.

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