Mathematical modeling of failure of port control systems

Tatyana Khripko

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: ProkhorovaTV@mgsu.ru

Abstract. The need to increase the capacity of ports is due to the development of the Northern Sea Route as a national transport route of Russia in the Arctic, the National Program for the Development of the Far East, in the context of an increase in trade with other regions of Russia, as well as the reorientation of cargo flows from the Baltic ports to Russian ones in Primorsk, Ust-Luga and Vysotske. Increasing cargo turnover and ensuring the strategic economic interests of Russia requires the reconstruction of existing and construction of new modern port-industrial complexes, provided with advanced technologies, including the automation of logistics management processes, production and engineering systems. This article describes a method for mathematical modeling of the failure of control systems for automation of cargo terminals of ports. Since failures in the operation of automation systems lead to an increase in the load of cargo berths (terminals) of both sea and river port complexes, to a violation of logistics schemes, and as a consequence to an increase in costs [11-13]. Modeling is carried out using methods of probability theory, in particular, the Poisson distribution law. A comparison of the empirical and theoretical failure rates of automation is performed using the Pearson criterion. The performed modeling will allow determining the technical and economic indicators of new construction, reconstruction or overhaul, in terms of the engineering systems of the facility, and optimize the automation processes.

1. Introduction

The need to increase the capacity of ports is due to the development of the Northern Sea Route as a national transport route of Russia in the Arctic, the National Program for the Development of the Far East, in the context of an increase in trade with other regions of Russia, as well as the reorientation of cargo flows from the Baltic ports to Russian ones in Primorsk, Ust-Luga and Vysotske. Increasing cargo turnover and ensuring the strategic economic interests of Russia requires the reconstruction of existing and construction of new modern port-industrial complexes, provided with advanced technologies, including the automation of logistics management processes, production and engineering systems. This article describes a method for mathematical modeling of the failure of control systems for automation of cargo terminals of ports. Since failures in the operation of automation systems lead to an increase in the load of cargo berths (terminals) of both sea and river port complexes, to a violation of logistics schemes, and as a consequence to an increase in costs [11-13]. Modeling is carried out using methods of probability theory, in particular, the Poisson distribution law [20-25]. If the number of trials increases, then the number of terms in the binomial distribution also increases. Since the sum of the probabilities of all possible values remains equal to one, the value of the
The probability of each individual value decreases. This explains what Poisson's law is sometimes called the law of rare events. A comparison of the empirical and theoretical failure rates of automation is performed using the Pearson criterion. Pearson criterion is a non-parametric method that allows you to assess the significance of the differences between the actual (identified by the study) number of outcomes or qualitative characteristics of the sample falling into each category, and the theoretical number that can be expected in the studied groups if the null hypothesis is valid. Simply put, the method allows you to assess the statistical significance of the differences between two or more relative indicators (frequencies, shares) [1-5]. The performed modeling will allow determining the technical and economic indicators of new construction, reconstruction or overhaul, in terms of the engineering systems of the facility, and optimize the automation processes.

2. Methods
The research used methods of the theory of probability [6-10]. As the initial data, let us set the empirical distribution of a discrete random variable of the number of failures of control systems \( x_i \). Define the following parameters required for modeling the process:

- \( m_i \) - frequency of the \( i \)-th feature;
- \( P_i \) - empirical probability of the \( i \)-th feature:

\[
P_i = \frac{m_i}{\sum m_i} = \frac{m_i}{n}
\]

- \( P'_i \) - theoretical value of the probability of occurrence of the \( i \)-th feature for Poisson's law:

\[
P'_i = e^{-\lambda} \frac{\lambda^{x_i}}{x_i!}
\]

- \( \lambda \) - average number of failures:

\[
\lambda = \sum P x_i = \lambda
\]

- \( m'_i \) - theoretical value of frequency according to Poisson's law

\[
m'_i = P'_i * n
\]

- \( \chi^2 \) - value of Pearson criterion

\[
\chi^2 = \sum \frac{(m_i - m'_i)^2}{m'_i}
\]

Based on the value of the Pearson criterion, the conclusion is drawn on the possibility of replacing the empirical distribution of the number of failures of control systems with the theoretical Poisson's law. Taking the number of degrees of freedom \( k \):

\[
k = l - 1 - r,
\]

- \( l \) - the number of distinct values \( x_i \) (the number of rows in the previously constructed table), \( l = N + 1 \);
- \( r \) - the number of parameters of the theoretical law. For the law Poisson uses one parameter \( \lambda = M(x) \), that is in this case \( r = 1 \).

By the value of the \( \chi^2 \) criterion and the parameter \( k \) (at their intersection), the value of the Pearson distribution function is read, which represents the "probabilistic degree of distrust" to the hypothesis about the possibility of replacement experimental distribution corresponding to theoretical. In other words, the closer this value is to zero, the better the agreement between the experimental distribution and the theoretical one, the more the hypothesis is confirmed [14-19].

3. Results
In the course of the research, calculations were carried out for the possible number of failures of control systems during the period conventionally taken for a calendar year. Column 1 of Table 1 shows the number of possible repetitions of control system failure. The research results are presented in Table 1.
Table 1.

| $x_i$ | $m_i$ | $P_i$ | $P_i x_i$ | $P_i x_i^2$ | $m'_i$ | $(m_i - m'_i)^2$ | $\chi^2$ |
|-------|-------|-------|-----------|-------------|--------|----------------|--------|
| 0     | 35    | 0.000 | 0.000     | 0.000       | 0.740  | 136,160        | 75.157 |
| 1     | 49    | 0.005 | 0.005     | 0.005       | 0.220  | 40,480         | 72.590 |
| 2     | 45    | 0.011 | 0.022     | 0.043       | 0.030  | 5,520          | 1,793  |
| 3     | 31    | 0.016 | 0.049     | 0.147       | 0.010  | 1,840          | 462.123|
| 4     | 11    | 0.022 | 0.087     | 0.348       | -      | -              | -      |
| 5     | 13    | 0.027 | 0.136     | 0.679       | -      | -              | -      |
|       | n=184 |       |           |             |        | $\Sigma=0.299$| $\Sigma=1.223$| $\Sigma=821.44$ |

The average value of the number of rejects

$\lambda = 0.3$

Dispersion

$D(x) = M(x^2) - [M(x)]^2 = \Sigma P_i x_i^2 - (\Sigma P_i x_i)^2 = 1.134$

4. Discussion

According to the calculated goodness-of-fit criterion, it follows that it is impossible to replace the empirical distribution of the number of failures of control systems with the theoretical Poisson distribution law.

Figure 1 shows graphs of empirical distributions of the daily number of failures of control systems. In this case, along the X axis, the values the number of failures of control systems, and along the Y axis the corresponding frequencies - empirical $m_i$.

![Figure 1 - empirical $m_i$](image)
Figure 2 shows graphs of theoretical distributions of the daily number of failures of control systems. In this case, along the X axis, the values the number of failures of control systems, and along the Y axis the corresponding frequencies - theoretical $m'_i$.

5. Conclusions
The data for determining the probabilities should be carried out according to the empirical probability $P_i$ of the Poisson distribution law. After analyzing the results obtained, we find that the probability that the number of failures of control systems per day will be equal to zero is 0.19. The probability that at least one failure of control systems will occur during the day is 0.81.

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