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Abstract. The effective functioning of the testing institution is related to the systematic, precise and timely tests of weapon specimens and military equipment. The planning of test activities should ensure a continuous process of testing. However, the excessive and uneven arrival rate of specimens for test might adversely affect the planned testing process.

To check the magnitude of the possible impact, the statistical parameters of the input flow of testing requests were calculated. The magnitude of the input flow is determined, the central, second and third moments are calculated, the distribution law of the request rate is determined, the coefficient of variation of the time interval between requests is determined. However, the calculated numerical values of the statistical characteristics of the input flow revealed no significant risks for significantly reducing the efficiency of the testing institution.

Analysis of the statistics revealed some deviation of the actual test time of the separate specimens from the planned value. The study of this deviation revealed the influence of some external and internal factors that accompany the test process. Such deviations can lead to negative effects: delay in the testing procedure of subsequent specimens or the testing institution inoperative in the intervals between tests.

A further solution to the problem of ensuring the effective functioning of the testing institution is to develop a mechanism that allows take into account the factors of influence and determine a priori the test time deviation of a specific specimen from the planned time with some degree of certainty.

Keywords: Testing, Queuing, Weapons and Military Equipment.

1 Introduction

Recently the flow of testing requests for weapons and military equipment has increased significantly. This became a problem because, despite the expansion of the testing organization structure (creation of new specialized units) and the increase in staff, significant time deviations from the basic testing plan started to arise. This turned out to be critical for the organization because it increased the risk of delays in testing other weapons and military equipment. To prevent disruption of the testing, we had to take extreme measures and modes of operation. Further increase in the size of the testing institution was unacceptable because it increased the cost of maintaining it.

In order to stabilize the planned testing process, it was proposed to study all the major processes that accompany the main stages of the testing process: test planning, testing and processing of test results. The purpose of this study was to search for problems that led to deviations from the basic testing plan and development of optimal algorithms for test planning and management. Another reason for investigating the testing processes for weapons and military equipment was the further development of a conceptual model of an automated test planning and quality management subsystem.

After analyzing a set of methods for the study of dynamical systems, we choice for the analytical apparatus of queuing theory, because in its concept it is well suited to the analysis of the system of mass tests, allowing to obtain decisions at the stage of analytical modeling and, eventually, can become the basis for simulation modeling and analysis of testing processes.

2 Background and Related Work

The issues addressed in this paper are the first steps for research and modeling of the testing institution's activities. Nowadays, the queuing theory [1] is a well-known analytical apparatus for the study of dynamic systems [2] that serve mass demand in many practical areas, such as: social infrastructure, education, production [3, 4], telecommunications, computer technology [5], military and defense technologies [6] and the like.

If the testing institution is represented by a queuing system, then the specimens of weapons and military equipment to be tested are considered to be the input flow. Analytical description of the input flow of requests is possible using the methods of mathematical statistics [7]. To do this, you need to have a data set that has the property of consistency [8].

It should be taken into account that the requests are of different importance and urgency, causing ambiguous behavior in the formed queues, which was for example considered in [9].

In [10] it is stated that recurrent Palma input flows with Poisson-like distributed input requests would be the most convenient way to describe processes in queuing systems.

The hypothesis about the nature of the input flow of requests for testing weapons and military equipment was put forward in [11].

Finally, there are many examples of successful application of the theory of queuing systems in military and defense technologies, including modeling of military systems [12, 13], analysis of the effectiveness of combat methods [14], comparative assessment of weapons [15], formation of concepts for building military systems [16], etc.

3 Research Method

3.1 Description of the Object of Study

A special feature of weapon and military equipment testing is the stringent requirements for the reliability of the tests (the accuracy and reliability of the assessments obtained from the tests) and the time limits for testing.

The test process begins with the receipt of a request to test a specific prototype or specimen of weapon or military equipment. The input of requests for testing is massive and continuous in time.

Preparatory measures are taken after the test request is received:

- firstly, the program and test methods are developed, a test plan is drawn up and a test team is formed from specialists;
- then laboratory, measuring equipment and a test site are prepared;
- and eventually training of test staff is conducted.

The preparatory stage has tight time constraints and cannot last longer.

Subsequently, direct tests of a prototype or weapon specimens and military equipment are carried out, which in time is carried out in accordance with a pre-defined test plan.

The test results obtained are processed and a conclusion is drawn on the conformity or non-conformity of the test prototype or weapon specimen and military equipment.

3.2 Modeling

The baseline of the testing process at the institution is represented by the context diagram in Fig. 1 [11].

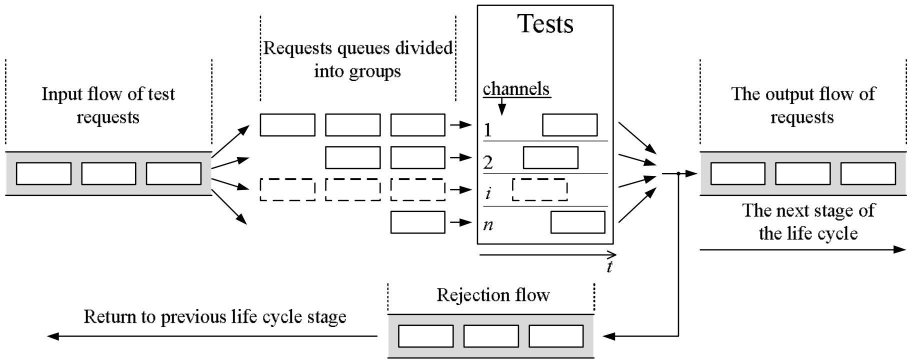

Fig. 1. Context diagram of the testing institution queuing system.

The following points are important for modeling processes in a testing institution and for analyzing problems encountered when planning and performing large amounts of tests:

- description of the parameters of the input flow of test requests;
- queue formation and order of servicing test requests;
- procedure for the distribution of test requests across the system servicing channels;
- description of the service parameters - testing of a prototype or a weapon specimen and military equipment.

The idea of modeling using a queue system is to evaluate the effectiveness of the testing institution through the utilization coefficient [6],

$$\rho = \frac{\lambda}{C}, \tag{1}$$

where λ is the intensity of the input flow of test requests and C is the traffic capacity of the testing institution. When $\rho \to 1$, we obtain the maximal usable coefficient fully using the workforce and means of the testing institution (test teams, or channels in the context diagram of Fig. 1). The mode with constant input flow and constant traffic capacity will be as close as possible to the optimum.

However, there is always a risk associated with the non-stationarity of the input flow, e.g. when there is an increase in λ, herewith $\lambda \gg C$. In this case, there will be a "congestion" on the servicing of the system, and if the request queueing time exceeds a certain limit, there is a risk of failure of the state task. As practice has shown, the risk was insignificant when the growth in λ was short in time, the channel capacity C has enough reserves to cover the peak values λ.

The worst cases were when the growth in λ was spread out in time and the reserves C were too small, then the risk of failure of the state task was great. Accordingly, the task of determining and analyzing a set of parameters of the input flow of test requests was set.

3.3 Input Flow of Test Requests

Forming a List of Input Flow Parameters. Input flow parameters were determined and analyzed with statistics using the totality of the available reporting data over three years. To estimate the parameters of the input flow, we needed the following statistical characteristics:

- the intensity of testing requests λ [1];
- the mathematical expectation value $M^*[X]$, variance $D^*[X]$ and standard deviation $\sigma^*[X]$ and the number of test requests received over a period of time t [7, 8];
- the coefficient v of the interval's variation between moments of occurrence of an event (the deviation of time intervals between test requests) [6],

$$\nu = \frac{\sigma_{\text{int}}}{\tau_{\text{int}}}, \tag{2}$$

  where σ_{int} is the standard deviation and τ_{int} is the mathematical expectation value for the length of the interval between requests;
- the distribution law for the number of test requests received per unit of time.

Set the Time Interval for Analysis. To obtain reliable data from the analysis of statistical information, we needed to have a general data set that had the property of consistency. According to the law of large numbers [9-11], the statistical frequency of an event observation approaches the probability of an event occurring $P^*[X] \to P[X]$, if the total number of events $n \to 500$ [8]. That is, ideally, the number of time intervals for analysis (when a certain number of events occur) should be at least 500. The standard time units of the year are a month, week, day, and in three years only the number of days exceeds 500. However, when analyzing statistical material, the number of requests received more than one per day was extremely rare: as a rule, either one request per day or no request at all was received. Therefore, choosing a time interval of one day would not be indicative. If the requirement $n_t \geq 500$ is met, we are only satisfied with a two-day interval, and given the five-day workweek (established by national labor law), every fifth interval would be broken by the weekend.

Otherwise, the week unit has the characteristic feature of five working days and two weekends. In addition, the analysis of the statistics revealed a certain correlation of the receipt of applications on certain days of the week (which is related to the procedure of issuance by the top management of the order for conducting the tests). Therefore, for a time interval for analysis, to a certain extent neglecting the rule $n_t \geq 500$, a week was selected, the total number of which in three years was $n_t = 156$.

Analysis of Results. As a result of processing a set of statistics, the following parameters of the input flow of test requests were obtained:

- the intensity of testing requests $\lambda \approx 1,87$;
- mathematical expectation value for the number of test requests per week $M^*[X] = 1,79$, variance $D^*[X] = 1,93$ and standard deviation $\sigma^*[X] = 1,39$;
- the standard deviation of the length of the interval between requests $\sigma_{\text{int}} = 4,12$, mathematical expectation value $\tau_{\text{int}} = 3,79$, according to (2), the coefficient of variation of the intervals between the test requests is $\nu = 1,08$.

It was important for further modeling to establish the Poisson character of the distribution law for test requests, which would further substantially simplify the simulation process itself. We have constructed a statistical function of the distribution of the requirements for the Poisson law for $\lambda = 1,87$

$$P_x(\Delta t) = \frac{(\lambda \Delta t)^x}{x!} e^{-\lambda \Delta t}; \; x = 0,1,... \tag{3}$$

The function graph is shown in Figure 2.

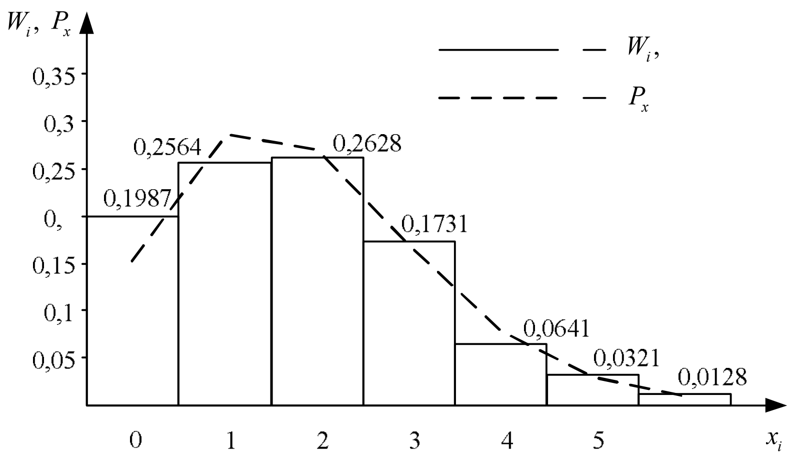

Fig. 2. Input flow parameters: W_i - histogram; P_x - statistical distribution function.

As can be seen from Figure 2, the built-in statistical function of the distribution of test requests by Poisson's law (3) converges well with the empirical histogram, which is built on a variation series of relative frequencies W_i of the number of test requests per week x_i.

Despite the importance of the input flow numerical data obtained for further modeling of processes in the testing institution, we did not detect significant deviations in the number of test requests per week x_i from their mathematical expectation value $M^*[X]$. There were also no significant prolonged periods of large increase in λ that could have a big impact on the deviation from the test organization plan, and the coefficient of interval variation between requests was too small to assert a significant effect of the input flow irregularity.

4 Discussion

The conducted studies of the parameters of the input flow of test requirements did not reveal any significant risk for deviation from the test plan. But, looking at (1), we paid attention to the channel capacity of the testing institution, namely its behavior over time during the tests.

Based on the analysis of the statistical material, we have seen periodic time deviations of tests of certain samples of weapons and military equipment from the planned time indicators, which were expressed in the extended or postponed time of testing. As stated in the reports, the reasons for shifted tests were different, for example: defects of specimens discovered during the test process, weather conditions, unpreparedness of a polygon base or laboratory-measuring equipment, etc. It should be noted that the causes have both an internal character of influence (depending on the institution) and an external character of influence (independent of the institution). In addition, different time requirements for the preparatory stage were observed, which depended on the complexity of the specimen, the development of the methodological base of tests, the training of specialists and so on.

Therefore, taking into account the reasons for the time lags would allow adjustments to be made to the plans and to stabilize the institution's activities both when planning tests of a specific specimen of weapons and military equipment and planned activity of the institution as a whole at the prospective planning stage.

The problem is that, for the most part, the influx of causes, which can be called the factors of the shift in test time, is unpredictable at the test planning stage. Therefore, to further address the problem of stabilization of the planned test process, it is necessary to investigate and establish a correlation between the reasons that may affect the test process and the magnitude of the time shift of the test process.

5 Conclusions and Future Work

5.1 Conclusions

The clear and stable operation of the testing institution in the context of an intensive flow of weapons and military equipment testing requires careful planning, consideration of all relevant baseline data and analysis of all the processes that accompany the test activity. Applying queuing theory apparatus can facilitate the process of finding optimal algorithms and test planning methods to ensure a stable test process is possible.

Based on the existing statistical material, we have analyzed the parameters of the input flow of test requests and its possible impact on the occurrence of extreme situations that threaten the planned test process. Despite some positive aspects of the study, which are related to the established parameters of the input flow requests and the distribution law of test requests, there are no high risks that would explain the extreme modes of the institution.

However, from the analysis of the statistical material, deviations in the time of testing of certain specimens of weapons and military equipment, which were caused by various internal and external factors, were revealed.

5.2 Future Work

For further research, it is necessary to formulate an approach that will allow to take into account numerically the magnitude of the influence of external and internal factors on the course of testing and to obtain an a priori assessment of the real testing time of specific weapon specimens and military equipment in specific conditions.

References

1 Kleinrock, L.: Queueing systems - Volume I: theory, John Wiley & Sons, New York (1975).
2 Kleinrock, L. and Gail, R.: Queueing systems : problems and solutions. A Wiley-Interscience publication. New York, NY [u.a.]: Wiley (1996).
3 Matveev, V.F. and Ushakov, V.G.: Queuing Systems: Manual on a special course “Applied mathematics”, p. 239. Moscow State University (1984) (in Russian).
4 Bocharov, P.P. and Pechinkin, A.V.: Queueing Theory: The textbook, p. 529. University under P.Lumumba (1995) (in Russian).
5 Allen, A.: Probability, Statistics and Queuing Theory with Compute Science Applications, Academic Press Inc., Second Edition (1990).
6 Kazachinsky, V.Z. and Levitsky, G.E.: Mathematical methods for solving military special tasks. p. 292. Kiev Higher Air Force Academy (1980) (in Russian).
7 Cramer, H.: Mathematical Methods of Statistics. Princeton University Press, Princeton (1946).
8 Ventsel, E.S.: The Probability Theory. 3rd Edition, Nauka, Moscow (1969) (in Russian).
9 Saaty, T.L.: Stochastic network flows: advances in networks of queues. In: Smith, W.L., Wilkinson, W.E. (eds.) Congestion Theory, pp. 86–107. University of North Carolina, Chapel Hill (1964).
10 Gnedenko, B.V. and Kovalenko, I.N.: Introduction to Queuing Theory. LKT, (2012).
11 Korniienko, I., Korniienko, S., Pokhodenko, O., Kaznachei, S., and Rudenko, O.: Graphical representation of the model of the testing organization functioning. Scientific works of State Scientific Research Institute of Armament and Military Equipment Testing and Certification, 2 (2), 91-98 (2019) (in Ukranian).
12 Nikolić, N.: Monte Carlo Modeling of Military Queueing Systems - Challenge of the Initial Transience. Belgrade: Andrejevic Endowment/Strategic Research Institute, (2008).
13 Jenkins, P.: Using Markov Decision Process with Heterogeneous Queueing System to Examine Military MEDEWAC Dispatching Policies. MSc thesis in Operations Research. Ohio, USA: Air Force Institute of Technology - Wright-Patterson Air Foce Base (2017).

14 Li, L., Liu, F., Long, G., Zhao, H. and Mei, Y.: Performance Analysis and Optimal Allocation of Layered Defense M/M/N Queueing Systems. Mathematical Problems in Engineering, 2016, pp.1-21 (2016), https://doi.org/10.1155/2016/5915918, last accessed 2020/04/15.
15 Mao, Z., Yu-juan, W., Chao, W. and Sheng, H.: Analysis on Aircraft Sortie Generation Rate Based on Multi-class Closed Queueing Network. In: Proceedings 2nd International Conference on Computer Science and Electronic Engineering, ICCSEE. pp.1877-1880 (2013).
16 Leonhard, R.R., Buchanan, T.H., Hillman, J.L., Nolen, J.M., and Galpin, T.J.: Concept for Command and Control. John Hopkins APL Technical Digest, 29(2); pp. 157-170 (2010), https://www.jhuapl.edu/Content/techdigest/pdf/V29-N02/20-02-Leonhard.pdf, last accessed 2020/04/15.