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Rationale for the Parameters of Comprehensive Selective Reliability Testing Plans for Single-Use Items

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Abstract:

The article presents a mathematical model for comprehensive reliability testing of single-use items. The model makes it possible to incorporate both prior reliability information obtained from the operational experience of items of the same type and their components, as well as the results of stand-alone tests of the components of single-use items. The application of this model is particularly relevant when assessing the reliability of structurally complex single-use items that have been in service or storage for extended periods.

Keywords:

selective reliability testing, consumer risk, reliability coefficient

1 Overview

Ensuring an acceptable level of confidence in decisions regarding the reliability of batches of highly reliable items requires extensive reliability testing of samples drawn from those batches. Furthermore, reliability tests of single-use items are destructive by nature, as they result in the irreversible loss of the tested items, making such testing costly. Reducing testing costs therefore requires minimizing the number of tests performed. This can be achieved by incorporating operational data from the items themselves, their components, or analogous items, as well as the results of stand-alone tests (or inspections) of the items' components. In some cases, stand-alone tests of the components of single-use items may also be non-destructive, for example, by verifying the operability of radio-electronic equipment, hydraulic systems, pneumatic systems, and other components.

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2 Relevance

In modern scientific and technical literature, considerable attention has been devoted to planning statistical control and evaluating the reliability of complex technical systems (CTS). The fundamental approaches to mathematical modelling for reliability analysis of technical systems are described in [1, 2]. The applied foundations of reliability theory, which remain relevant today, are presented in [3], while the classical work [4] provides mathematical methods for reliability calculation and maintenance planning. In addition, recent review papers have analyzed modern trends and the evolution of reliability prediction models for CTS in detail [5].

Modern mathematical models address a wide range of complex operating conditions. In particular, reliability assessment based on a dependent two-stage failure process with competing risks is presented in [6]. Monte Carlo methods are widely used to assess network vulnerability under random component failures [7], while cluster-based reliability models employing expectation-maximization algorithms continue to be developed [8]. Researchers have also devoted considerable attention to the reliability of electrical, electronic, and programmable safety-related systems [9], as well as structures operating under stochastic excitation [10]. In addition, methods based on tolerance limits and the Weibull distribution are successfully applied to assess the dependability of highly reliable samples [11].

Regulatory documents and NATO standards, such as [12, 13], establish general guidelines and dependability requirements for complex systems at both the development and operational stages. Reliability and maintainability issues related to surface-to-air missile systems and their mobility platforms are examined in detail in [14, 15]. The modelling of reusable systems with complex operating modes is discussed in [16]. Furthermore, recent studies have proposed methods for determining the probability of failure-free operation of systems operating in two modes [17].

Nevertheless, the specific characteristics of testing single-use items create several unique challenges that are not adequately addressed by traditional approaches. Reliability tests of such items are inherently destructive, significantly increasing the cost of experimental verification, as demonstrated in recent international studies [18, 19].

Furthermore, when a product is a complex hierarchical system, reliability control is performed from the lowest structural level to the highest. This approach applies to both critical control systems [20] and complex maritime transport systems [21]. Modern studies emphasize the importance of assessing CTS reliability using the results of tests performed on individual components and subsystems [22]. Since testing subsystem batches precedes the testing of finished products, the data obtained from stand-alone (including non-destructive) tests of individual components provide valuable information about the reliability of the system as a whole.

Consequently, there is a need to develop a mathematical model for comprehensive sampling tests of single-use items. Such a model should make it possible to combine prior reliability information obtained both from the operational data of similar systems and from the results of preliminary stand-alone tests of individual components, thereby significantly reducing the scope of expensive full-scale testing.

3 Purpose

The purpose of this article is to develop a methodological approach to constructing a mathematical model for comprehensive sampling tests that considers prior reliability

data on products and their components, obtained from previous operational experience and the results of stand-alone component testing.

4 Presentation of the Main Material

Each single-use item (system) can be represented as a set of a finite number of independent, interconnected subsystems. Each subsystem can be regarded as an element of a batch of a given size, from which samples can be selected for testing.

A sample should also be selected from the batch of finished products (systems). Since a product (system) has a defined structure composed of subsystems, and testing these subsystems precedes testing the finished products (systems), the results of subsystem testing provide not only information about their own reliability but also information about the reliability of the product (system) as a whole. Accordingly, this information should also be considered when planning the testing of a batch of products (systems).

Since the relationships among the parameters of the statistical test plans are determined by the known structure of a product (system), consisting of subsystems and components, and operational data are continuously accumulated at each structural level, prior reliability information is available for all levels of the hierarchy.

Consequently, the first stage in solving the problem of planning structural-hierarchical sampling control is to develop a system of interrelated statistical test plans for components, subsystems, and products (systems) as a whole. Because testing at lower structural levels precedes testing at higher levels, the statistical information obtained from testing the lower levels should be incorporated into the planning of tests at the higher levels. This constitutes the second stage of the planning procedure.

Accordingly, the task of planning structural-hierarchical sampling control can be divided into two interrelated subtasks:

- Test planning before subsystem and component testing, when batches of components and subsystems have not yet been tested, their test results are unavailable and therefore cannot be incorporated into the planning process. In this case, only the accumulated prior reliability information for products (systems), their subsystems, and components is taken into account.
- Test planning after subsystem and component testing, when the results of subsystem and component testing are incorporated into the planning process together with the accumulated prior reliability information for the batch of products (systems).

These two subtasks are interrelated because the results of the first provide the basis for solving the second.

Let us consider these subtasks in sequence. The outcome of a single reliability test of a single-use item (system) is one of two possible events: “success” or “failure”. A sequence of n independent tests of such items is referred to in the literature as a “Bernoulli scheme”, and the probability of observing exactly d failures in n tests is described by the “Bernoulli formula” [22]:

$$P(n,d) = C_n^d \, p^{n-d} \left(1-p\right)^d \tag{1}$$

where $C_n^d = \dfrac{n!}{d!(n-d)!}$ – the number of combinations of n taken d at a time (binomial coefficient), p – the probability of ‘success’ in a single test.

Graphically, the process of sequential testing according to the Bernoulli scheme can be represented as a random walk in a two-dimensional coordinate system defined by the number of tests and the number of failures. With each test performed, the trajectory moves one step to the right, while a failure results in an upward step.

In the context of sampling tests, the trajectory of the test process must pass through the points with coordinates (*n, d*), corresponding to the sample size and the acceptance number of failures, and (*N*, *D*), corresponding to the batch size and the defect level. The probability that the trajectory passes through both points is calculated as the product of the unconditional probability of reaching the first point and the conditional probability of subsequently reaching the second:

$$P\left(N,D\big|_{n,d}\right)=C_n^d\,p^{n-d}\left(1-p\right)^d\,C_{N-n}^{D-d}\,p^{N-n-D-d}\left(1-p\right)^{D-d} \tag{2}$$

The conditional probability that the test trajectory (i.e., the random-walk path), having reached the endpoint with coordinates (*N*, *D*), also passes through the point with coordinates (*n*, *d*) is calculated as the ratio of the joint probability of passing through both points to the probability of reaching the endpoint, in accordance with Bayes' formula:

$$P\left(n,d,N,D\right)=\frac{P\left(N,D\big|_{n,d}\right)}{C_N^D\,p^{N-D}\left(1-p\right)^D} \tag{3}$$

It should be noted that, for a constant probability p, summing the probabilities in (3) over all values of d (from zero to the acceptance number of failures) yields the well-known hypergeometric distribution. However, the analysis that follows focuses specifically on the random-walk process of the test trajectory with respect to the random variable *p*. Therefore, classical hypergeometric distribution is not applicable in this case.

The scientific and technical literature [4, 6–8] describes various methods for combining prior information with experimental data. These include the linear combination of unbiased estimates of reliability indicators for similar products, the use of prior estimates obtained from previous tests of equivalent products, the regression-based linear combination of estimates, parameter estimation based on the combination of two samples, the Bayesian approach, and others. The application of these methods (except for the Bayesian approach) requires that the so-called information transfer model, which defines the relationship between the parameters of similar products, be available at the test-planning stage. In addition, most of these methods focus on reliability assessment, whereas issues related to reliability control have received considerably less attention.

If it is assumed that variations in the reliability coefficient (*RC*) among single-use products of the same type operated under similar conditions are negligible, the results of their operation may be regarded as homogeneous.

The Bayesian method for incorporating prior information is the most general approach to combining homogeneous information [6–8]. Therefore, it is particularly well suited for solving reliability control problems involving single-use products. In this approach, statistical information about the unknown value of the controlled reliability coefficient (*RC*) is represented by prior distribution, its numerical characteristics, and other relevant parameters. Since the value of a specific *RC* is unknown, it can formally be treated as a random variable. Accordingly, the prior

distribution reflects the degree of confidence in the value of the *RC* at the beginning of the testing process.

The reliability characteristics of the test results are determined using the operating characteristic [5, 6], which is a function of the test plan parameters. At a fixed sample size, the confidence level γ for the event that the true value of the probability-type *RC* exceeds the corresponding one-sided lower confidence limit is determined by the sum of the probabilities that the test trajectory passes through the points whose abscissas correspond to the test duration and whose ordinates correspond to the number of failures, ranging from zero to a predetermined value [2–7].

$$1-\gamma=\sum_{i=0}^{d} C_n^i \underline{p}_\gamma^{n-i}\left(1-\underline{p}_\gamma\right)^i \tag{4}$$

where n is the number of individual tests conducted, d is the number of failures observed during testing.

The probability that the test trajectory passes through a specific point can be determined as the difference between the probabilities of the events that the true value of *RC* does not exceed the corresponding one-sided lower confidence limit, calculated for the same test duration but for two successive numbers of failures differing by one.

Thus, the probability of observing exactly d failures in n tests is equal to

$$P(n;d)=\sum_{i=0}^{d} C_n^i \underline{p}_\gamma^{n-i}\left(1-\underline{p}_\gamma\right)^i-\sum_{i=0}^{d-1} C_n^i \underline{p}_\gamma^{n-i}\left(1-\underline{p}_\gamma\right)^i \tag{5}$$

The following equality can be demonstrated to hold:

$$\frac{\int_0^{\underline{p}_\gamma} C_{n-1}^d x^{n-d-1}(1-x)^d\,\mathrm{d}x}{\int_0^1 C_{n-1}^d x^{n-d-1}(1-x)^d\,\mathrm{d}x}=\sum_{i=0}^{d} C_n^i \underline{p}_\gamma^{n-i}\left(1-\underline{p}_\gamma\right)^i \tag{6}$$

An approach analogous to that described by equation (6) is presented in [6–8], where a relation is derived for determining the confidence probability at a fixed test volume, given the prior probability density distribution of the *RC* and its one-sided lower confidence bound. This relation has the following form:

$$1-\gamma=\frac{\int_0^{\underline{p}_\gamma} C_{n-1}^d x^{n-d-1}(1-x)^d\, f_a(x)\mathrm{d}x}{\int_0^1 C_{n-1}^d x^{n-d-1}(1-x)^d\, f_a(x)\mathrm{d}x} \tag{7}$$

where $f_a(x)$ is the prior probability density distribution of the value of the probability-type reliability coefficient.

To simplify the record, enter the function $G(p, n, d, f_a(x))$

$$G\left(p, n, d, f_a\left(x\right)\right)=\frac{\int_0^p C_{n-1}^d x^{n-d-1}\left(1-x\right)^d f_a\left(x\right)\mathrm{d}x}{\int_0^1 C_{n-1}^d x^{n-d-1}\left(1-x\right)^d f_a\left(x\right)\mathrm{d}x} \tag{8}$$

in which $G(p, n, d, f_a(x))$ – the confidence probability that, given test results (n, d) the unknown value of the probability type *RC* belongs to the interval (0, p).

Considering (5), the probability of completing the tests with a result (n, d), where the *RC* level is equal to p is equal to the results (n, d), can be determined as

$$P_a\left(p, n, d, f_a\left(x\right)\right)=G\left(p, n, d, f_a\left(x\right)\right)-G\left(p, n, d-1, f_a\left(x\right)\right) \tag{9}$$

While $d=0$ in relation (9), the subtrahend is equal to 0, therefore

$$P_a\left(p, n, 0, f_a\left(x\right)\right)=G\left(p, n, 0, f_a\left(x\right)\right) \tag{10}$$

Taking into account Eqs (2), (3), (9), and (10), the relation for determining the probability of observing exactly d failures when testing a sample of n products selected from a batch of N products with a defect rate of D, while considering the a priori distribution of the unknown value of the *RC*, is as follows:

$$P_a\left(p, n, d, N, D, f_a\left(x\right)\right)=\frac{P_a\left(p, n, d, f_a\left(x\right)\right)\cdot P_a\left(p, N-n, D-d, f_a\left(x\right)\right)}{P_a\left(p, N, D, f_a\left(x\right)\right)} \tag{11}$$

Assuming that d_{gr} is the maximum permissible (acceptable) number of failures during testing, then, considering Eqs (4) and (11), the probability of completing the tests with an acceptable number of failures is determined by the following relation

$$P_a\left(i\le d_{gr}\middle| p, n, i, N, D, f_a\left(x\right)\right)=\sum_{i=0}^{d_{gr}} P_a\left(p, n, i, N, D, f_a\left(x\right)\right) \tag{12}$$

In this case, the expected value of the consumer's risk β, is calculated as the probability of deciding that a batch of products conforms to the reliability requirements on the basis of the sample testing results (12), according to the following relation

$$\beta=P_a\left(i\le d_{gr}\middle| p=p_{gr}, n, i, N, D, f_a\left(x\right)\right)=\sum_{i=0}^{d_{gr}} P_a\left(p_{gr}, n, i, N, D, f_a\left(x\right)\right) \tag{13}$$

where p_{gr} – the maximum permissible value *RC* of the probability type, which is defined as

$$p_{gr}=\frac{N-D}{N} \tag{14}$$

A decision on the adequacy of the sample testing volume is made if the expected value of the consumer's risk β, does not exceed the specified value of the consumer's risk β_{sp}. That is, the following inequality shall hold:

$$\beta_{sp}\ge\beta \tag{15}$$

The methodology for determining test plan parameters involves the following steps:

- determination of initial data values for test planning (volume N of a batch of products, defect level D of a batch of products, specified consumer risk β_{sp}),
- determination of the maximum permissible value of the probability-type reliability coefficient p_{gr} (ratio (12)),
- selection of the maximum permissible (acceptable) number of failures d_{gr} in sampling tests, initial value of sample size

$$n = \frac{d_{gr}}{1 - p_{gr}} \tag{16}$$

- calculation of consumer risk value β (ratio 6-11) for selected values of d_{gr} and n,
- verification of the compliance with inequality (13) with completion of calculations upon its compliance or, in case of non-compliance, with an increase in the sample size n and subsequent recalculation of the consumer risk β relative to the new value.

A graphical representation of this method in the form of a block diagram is shown in Fig. 1.

Considering relations (6)–(16), the sample sizes were calculated for various values of the uniform prior distribution of the unknown reliability coefficient (*RC*). The choice of a uniform distribution is based on the fact that, within the specified interval, it represents the least informative prior distribution (any other distribution within the same interval would provide more informative prior knowledge and, consequently, better results). The values of the remaining initial parameters were as follows: $N = 100$; $D = 5$; $\beta = 0.2$. The calculation results are presented in Tab. 1.

Tab. 1 shows that, as the width of the prior distribution interval of the reliability coefficient decreases, the required sample size for making a decision with a given level of confidence can be reduced by more than 50 % compared with the case where no prior information is available (corresponding to a uniform prior distribution of the RC over the interval from 0 to 1, i.e., the first row of the table).

Relations (6)–(16) constitute a mathematical model for testing samples of single-use products. This model generalizes the known testing model based on the hypergeometric distribution of the number of failures used in reliability inspection of batches of technical objects and, as a special case (when the prior distribution of the unknown value of the *RC* is uniform over the interval from 0 to 1), reduces to that model.

Tab. 1 Required sample size for deciding whether a batch meets reliability requirements

Lower bound of the one-sided interval of the prior distribution of the reliability coefficient	Acceptable number of failures d_{gr}			
	0	1	2	3
0.00	27	49	67	83
0.50	27	49	67	83
0.80	27	48	62	72
0.85	25	43	55	65
0.90	12	26	32	43

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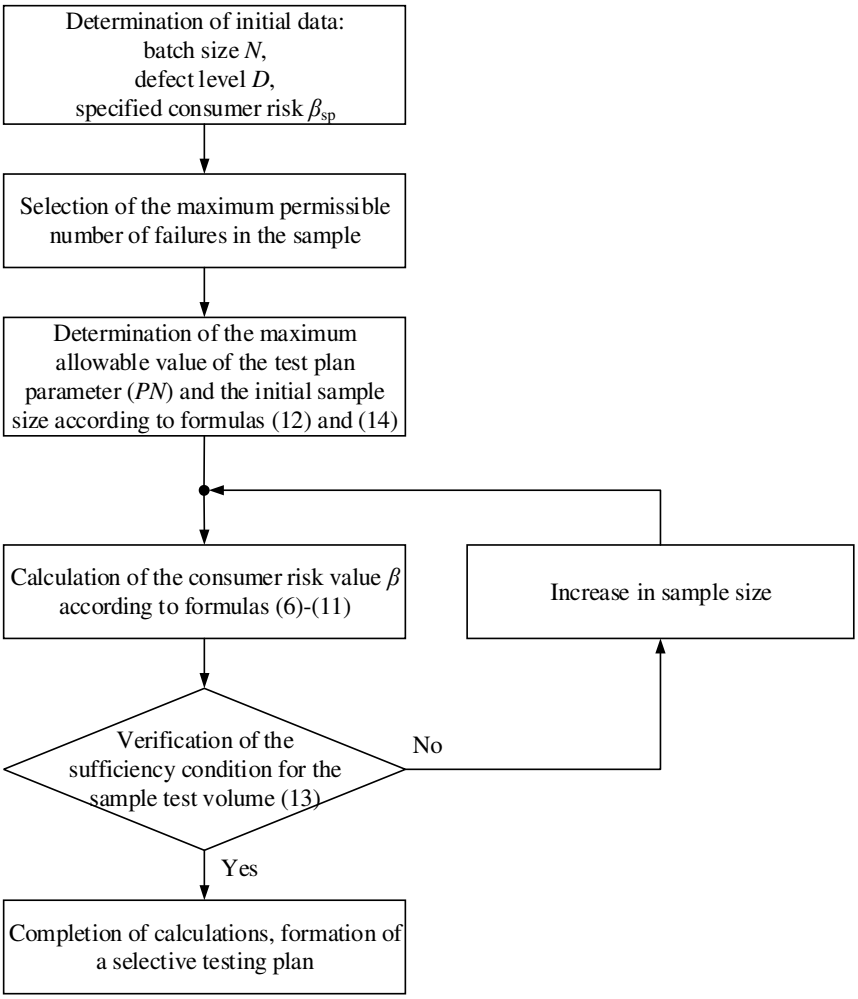


Fig. 1 Block diagram of the methodology for determining the parameters of sampling test plans for single-use products, considering a priori information

Let us now consider the solution to the second subtask in detail.

The process of selective reliability control of products regarded as complex technical systems proceeds from the lowest structural-hierarchical level to the highest. Therefore, by the time a batch of products (systems) is inspected, statistical information on their reliability is already available in the form of the results of inspections of samples of their subsystems.

Since each product (system) has a specific structure consisting of subsystems, and the inspection of these subsystems precedes the inspection of the products (systems), the results of inspections of batches of subsystems contain not only information on their reliability but also information on the overall reliability of the product (system). Analytically, this information can be taken into account when planning the inspection of a batch of products (systems) through the consumer's risk associated with testing that batch. Thus, the consumer's risk associated with the

inspection of a batch of products (systems) is a function of the consumer's risks obtained from testing the subsystems during the preceding inspections of batches of those subsystems.

This means that the probability of accepting a batch of products (systems) depends not only on the sample size drawn from that batch, the reliability level of the products (systems), and the specified requirements, but also on the corresponding probability of accepting batches of subsystems and on the structural configuration of the product (system) composed of those subsystems.

At the same time, the probabilities of accepting batches of subsystems depend on the extent of their inspection, the reliability of the subsystems, and the specified requirements.

The above considerations apply to products regarded as complex technical systems that may have any structure composed of subsystems and components.

Below, we examine the functional relationship between the probabilities that a batch of products (systems) and a batch of subsystems satisfy the reliability requirements for different structural configurations.

If a product (system) has a series structure, i.e., it consists of independent subsystems connected in series, then the product (system) fails if at least one subsystem fails. Therefore, the probability that such a batch of products (systems) satisfies the reliability requirements is

$$P_{\text{sqn}} = \prod_{i=1}^{n} P_i \tag{17}$$

where n is the number of serially connected subsystems, P_i is the probability that the i subsystem meets the reliability requirements.

If a product (system) consists of independent redundant elements, then the failure of the product (system) will only occur when all elements fail. In this case, the probability that such a batch of products (systems) meets the reliability requirements is

$$P_{\text{prl}} = 1 - \prod_{i=1}^{m} \left(1 - P_i\right) \tag{18}$$

where m is the number of parallel connected subsystems.

If a product (system) has a mixed structure, each set of parallel-connected elements (subsystems) can be represented, in terms of reliability, by an equivalent element connected in series with other equivalent elements and with those subsystems that are originally connected in series within the product (system) structure. Therefore, the probability that such a batch of products (systems) satisfies the reliability requirements is

$$P_{\text{mix}} = \prod_{k=1}^{K} \left(1 - \prod_{j=1}^{m_k} \left(1 - P_{kj}\right) \right) \prod_{i=1}^{n} P_i \tag{19}$$

where K – the number of groups of parallel connected subsystems, m_k – the number of parallel connected subsystems in k group, n – the number of consecutively connected subsystems, P_{kj} – the probability that the j subsystem in the k group of parallel connected subsystems meets the reliability requirements, P_i – the probability that the i sequentially connected subsystem meets reliability requirements.

All the above provides the basis for planning structural-hierarchical control. When planning the selective control of a batch of products (systems), together with the

accumulated prior reliability information available at each structural-hierarchical level, the results of inspections of subsystems and individual elements are also taken into account.

Solving this problem requires determining the values of the consumer's risk, thereby making it possible to take into account the inspection results obtained at lower structural-hierarchical levels when determining the parameters of statistical control plans at higher structural-hierarchical levels.

The following considerations apply to the probability of a Type II error. By definition, this probability is the product of the probabilities of the following two events:

- the batch of products does not satisfy the reliability requirements,
- based on the test results, a batch that does not satisfy the reliability requirements is accepted as satisfying the reliability requirements.

Since the batches of subsystems have already been accepted on the basis of the results of autonomous tests before the planning of comprehensive tests of the products (systems), the probability of the second event is equal to one.

In this case,

$$\beta_i = 1 - P_i, \text{ or } \quad P_i = 1 - \beta_i \tag{20}$$

where β_i – the consumer risk value obtained from the results of autonomous tests of i subsystem, P_i – the likelihood that the i subsystem meets reliability requirements.

Taking into account Eqs (17)–(19), the ratio for calculating the II-type error (consumer risk β_{con}), which will be obtained based on the results of autonomous tests of subsystems and the product (system) as a whole, shall be as follows:

- for a product (system) with a sequential structure

$$\beta_{con} = \left(1 - P_{sqn}\right)\beta_{sys} = \left(1 - \prod_{i=1}^{n}\left(1 - \beta_i\right)\right)\beta_{sys} \tag{21}$$

where β_{sys} – the level of risk to the consumer that will be obtained based on the results of testing the product (system);

- for a product (system) with a parallel structure

$$\beta_{con} = \left(1 - P_{prl}\right)\beta_{sys} = \left(\prod_{i=1}^{m}\beta_i\right)\beta_{sys} \tag{22}$$

- for a product (system) with a hybrid structure

$$\beta_{con} = \left(1 - P_{mix}\right)\beta_{sys} = \left(1 - \prod_{k=1}^{K}\left(1 - \prod_{j=1}^{m_k}\beta_{kj}\right)\prod_{i=1}^{n}\left(1 - \beta_i\right)\right)\beta_{sys} \tag{21}$$

It is evident that the expressions in square brackets in relations Eqs (21)–(23) are less than one. Therefore, conducting preliminary selective reliability testing of elements (subsystems) reduces the value of the posterior consumer's risk, β_{con}. This makes it possible to relax the requirements imposed on the consumer's risk β_{sys}. Consequently, conducting preliminary inspections of batches of subsystems makes it possible to reduce the sample size required for testing products (systems).

A decision on the adequacy of the sample size for selective testing of the product (system) as a whole is made if the expected value of the consumer's risk β_{con},

determined from the results of the comprehensive tests, does not exceed the specified value of the consumer's risk β_{sp}. That is, the following inequality shall hold:

$$\beta_{sp} \geq \beta_{con} \tag{24}$$

The methodology for planning structural-hierarchical control involves the following stages:

- determining the structural reliability scheme of the product (system) and the degree of influence of subsystems on the reliability of the product (system) as a whole,
- determining the consumer risk values (II-type errors) of each subsystem based on the results of its autonomous tests,
- determining the initial data for planning tests of the product (system) as a whole (volume N of the product batch, defect level D of the product batch, specified consumer risk β_{sp}),
- determination of the maximum permissible value reliability coefficient (RC) such as 'probability' p_{gr} (ratio (14)),
- selection of the maximum permissible (acceptable) number of failures d_{gr} and the initial sample size for selective testing of the product (system) as a whole;
- the calculation of consumer risk values β_{sys} (ratios (6)–(13)) and β_{con} (ratios (21)–(23)) for the selected value d_{gr} during selective testing of the product (system) as a whole;
- checking the inequality (24) and completing the calculations if it is satisfied or increasing the sample size and recalculating the consumer risks β_{sys} and β_{con} relative to the new value if it is not satisfied.

For example, the test volumes were calculated for the initial data provided below. The single-use product consists of three elements. The reliability structure diagram for this product is sequential. The volume of the batch of products (components) $N = 100$, the acceptable level of product defectiveness $D = 10$, the specified consumer risk value based on the results of comprehensive testing $\beta_{con} = 0.2$. The acceptable level of component defectiveness $D_1 = 5$, $D_2 = 3$, $D_3 = 3$. The component tests proved to be flawless.

A graphical interpretation of this methodology in the form of a block diagram is shown in Fig. 2.

The results of calculations of the volumes of flawless selective tests are given in Tab. 2.

From the data presented in Tab. 2, it can be seen that, for the initial data given above, the sample size required to make a decision with the specified level of confidence can be reduced:

- by more than 50 %, as the width of the prior distribution interval for the reliability coefficient decreases, compared with the case where no prior information is available (corresponding to a uniform prior distribution of the *RC* over the interval from 0 to 1, i.e., the values in column 3 of the table),
- by up to 25 %, as the width of the prior distribution interval for the reliability coefficient of the element decreases, compared with the case where no prior information is available (corresponding to a uniform prior distribution of the *RC* of the elements over the interval from 0 to 1),
- by up to 50 %, as the sample size of previously conducted stand-alone tests of the element increases, compared with the case where no prior information is

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available (corresponding to a sample size of zero for the stand-alone tests of the elements).

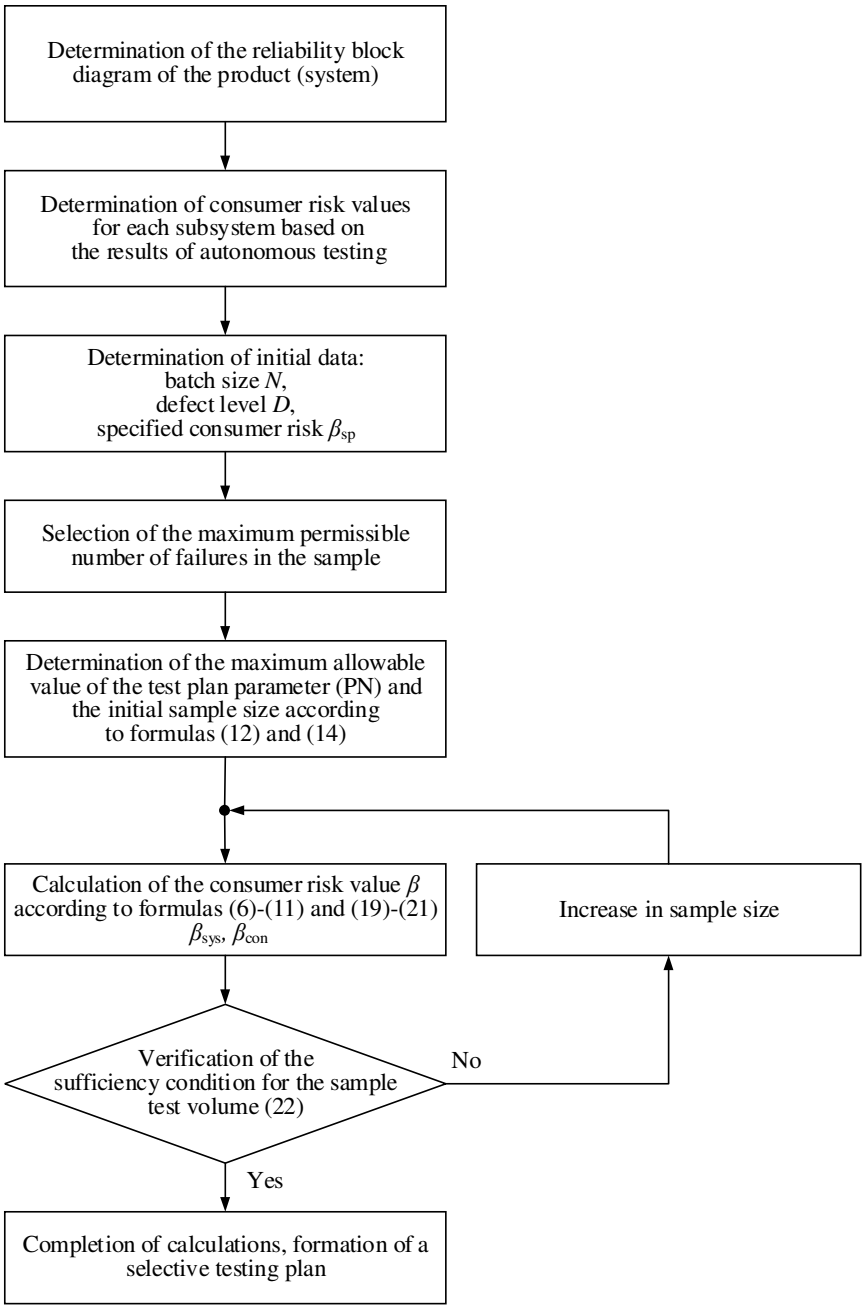


Fig. 2 Flowchart of the methodology for determining the parameters of planned sample tests of single-use products, considering prior information on the reliability of subsystems and their structural configuration

Tab. 2 The necessary amount of product testing to decide whether a batch meets reliability requirements

Lower limit of the prior distribution interval for the reliability coefficient of the elements	Sample size for preliminary autonomous testing of the elements	Lower limit of the one-sided prior distribution interval for the overall reliability coefficient of the product			
		0	0.50	0.80	0.85
0.0	0	15	15	11	6
	10	14	14	11	6
	20	13	13	9	6
	30	11	11	7	6
	40	7	7	7	6
0.5	0	14	14	11	6
	10	14	14	11	6
	20	13	13	9	6
	30	11	11	7	6
	40	11	11	7	6
0.8	0	14	14	10	6
	10	14	14	10	6
	20	13	13	9	6
	30	11	11	7	6
	40	11	11	7	6
0.9	0	12	12	7	6
	10	12	12	7	6
	20	11	11	7	6
	30	7	7	7	6
	40	7	7	7	6

The obtained relationships constitute a mathematical model for comprehensive sample testing of single-use products, which generalizes the existing models used for the reliability control of batches of technical objects and, as a special case, reduces to them.

5 Conclusion

Thus, in contrast to the existing testing model, which does not take into account prior information on the operational performance of products or the results of stand-alone testing of their components, the developed mathematical model describes the process of comprehensive sample testing while incorporating prior information on the reliability coefficients of products and their components accumulated from previous operational data and the results of stand-alone component testing.

The proposed methodological approach is adaptive to the previously accumulated information on the reliability of products and their structural-hierarchical levels, as well as to the results of stand-alone testing of the subsystems and components constituting the products.

The comparative analysis of the sample sizes calculated using the developed mathematical model and those obtained using existing methods confirms that the

required sample sizes can be reduced. The magnitude of this reduction increases as the prior information on the reliability coefficient becomes more accurate and reliable and as the sample size of previously conducted stand-alone tests increases.

The proposed approach can be applied to planning reliability control tests for expensive homogeneous objects, such as anti-aircraft guided missiles.

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