Methodology For Determining The Reliability Indicators Of Construction Flows By Their Intensity

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Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 10 May 2021

Abstract. This article discusses the problem of improving the reliability of the flow of concrete works based on identifying its patterns. The processing of statistical data on a number of construction sites allowed us to conclude that the changeable intensity of the flow of concrete works obeys the normal distribution law. The sample mean and standard deviation are used as design standards to determine reliability indicators.

Keywords. Reliability indicators, distribution law, approximation, distribution law, intensity, statistical variance, Pearson's test, histogram, probability density, distribution function of a random variable.

1. Introduction

The problem of reliability is typical for all technical and organizational systems and attracts an increasing number of researchers in various fields of science. It is the subject of science - the theory of reliability, which is based on the methods of probability theory and mathematical statistics, linear and nonlinear programming.

Reliability means the ability of the system to perform all the functions assigned to it within a given period of time.

The statement of the problem of the reliability of the construction flow is due to the probabilistic nature of the conditions for its functioning. The main difficulty revealed by the practice of line construction is the discrepancy between the design and actual work schedules. The reasons for these discrepancies are various production problems, the types and likelihood of which have recently been intensively studied.

The task of ensuring the reliability of the functioning of the construction flow is to ensure such effective control when its individual parts (construction processes) are coordinated with each other in time and space and the performance of its functions by the flow as a whole will be ensured. In other words, to ensure the reliability of planning and management.

Improving the reliability of the flow can be achieved in two fundamentally different ways: 1) reducing the negative impact of factors that violate the reliability of the functioning of building systems, using targeted measures; 2) the development of systems that function under the influence of these factors. Both ways are not mutually exclusive and can be used in combination or independently.

To consider the methodology, it will use real data obtained in the practical implementation of the flow of concrete work.

Let's say a series of observations was made over the work of a concrete work brigade during 440 shifts. The observed values of intensities are located approximately evenly, respectively, within the following limits $i_j = 0 \div 260 m^3$ / shift.

To calculate the parameters of the flow reliability, it is necessary to identify the distribution law of the investigated quantity, that is, the intensity. This is necessary at the initial stages of the study, since the intensity for different types of investigated flows can be distributed by different laws: logarithmically normal, normal, beta-law, and others. After the accumulation of a sufficient amount of statistical data for a particular type of work, confirming the approximation of the empirical distribution by the adopted law, there is no need to check the law every time.

To accumulate a sufficient amount of statistical data, it is necessary to organize systematic observations of the practical implementation of construction processes, collect and process statistical data in terms of intensity.

Analysis of these data makes it possible to reveal the real average values of the intensities and assess their deviations from the normal intensity.

In mathematical statistics, it is recommended for large, n> 100 observations, to divide them into 10-14 intervals. For our example, let's take the number of intervals H = 14. The size of the interval W is defined as the ratio of the variation range J_{max}- J_{min} to the number of intervals received

$$W = \frac{J'_{max} - J'_{min}}{H} = \frac{260 - 0}{14} \approx 20$$

Let the sample be given in the form of a distribution of equidistant variants and their corresponding frequencies. In this case, it is convenient to find the sample mean intensity and variance by the product method using the formulas.

$$\bar{J} = M_1 h + C; \qquad D = [(M_2 - M_1)^2]h^2;$$

where h is the step (the difference between two adjacent options); C is a false zero (the option that is located approximately in the middle of the variation series).

$u_i = (x_i - c)/h$ - conditional option; $M_1 = (\sum n_i u_i)/n$ - conditional variant of the first order; $M_2 = (\sum n_i {u_i}^2)/n$- conditional variant of the second order.

Let's make a calculation table 1, for this: 1) write the options in the first column; 2) write the frequencies in the second column, put the sum of frequencies in the bottom cell of the column; 3) as a false zero, we choose the option that has the highest frequency: in the cell of the third column, which belongs to the row containing a false zero, write 0, over the zero sequentially write -1, -2, ... -7, and under the zero 1, 2 , 3, ... 6; 4) the product of frequencies n by conditional options and write it in the fourth column, separately we find the sum of negative numbers and separately - the sum of positive numbers; adding these numbers, we place their sum in the required cell of the fourth column; 5) the product of frequencies by the squares of the conventional version, that is, we write $n_i {u_i}^2$in the fifth column; 6) the product of frequencies by squares of the conditional options, increased by one, that is, $n_i(u_i + 1)$,, we write in the control column.

Table 1: Calculation of parameters of average intensity (¯J) and variance (D)

x_i	n_i	u_i	$n_i u_i$	$n_i {u_i}^2$	$n_i(u+1)^2$
1	**2**	**3**	**4**	**5**	**6**
0	22	-7	-154	1078	22 (36) =792
10	12	-6	-72	432	12·35=300
30	20	-5	-100	500	20·16=320
50	32	-4	-128	512	32·9=288
70	41	-3	-123	369	41·4=164
1	**2**	**3**	**4**	**5**	**6**
90	58	-2	-116	232	58·1=58
110	59	-1	-59	59	59·0=0
130	59	0	-752	-	59 =59
150	43	1	43	43	43·4=172
170	35	2	70	140	35·9=315
190	23	3	69	207	23·16=368
210	20	4	80	320	20·25=500
230	9	5	45	225	9·36=324
250	7	6	42	252	7·49=343
	$n = 440$		349		

$$\sum n_i(u_i + 1) = -403 \sum n_i {u_i}^2 = 4369 \sum n_i(u_i + 1)^2 = 4003$$

To control the calculations, use the identity

$$\sum n_i(u_i + 1)^2 = \sum n_i {u_i}^2 + 2n_i u_i + n$$

4369 + 2(-403) + 440 = 4003

4003 = 4003

The checksums match indicates the correctness of the calculations. Let's calculate the moments of the first and second orders M_1 = -0.916; M_2 = 9.930. The difference between adjacent options is h = 20. Let us calculate the required average intensity, taking into account that the possible zero (the variant with the highest frequency) C = 130.

$$\bar{J} = M_1 h + C = (-0{,}916 \cdot 20 + 130) \approx 112\ m^3/shift$$

The statistical variance of the intensity (estimate of the theoretical variance) is equal to

$$D = [M_2 - (M_1)^2]h^2 = [9{,}93 - (0{,}916)^2 \cdot 20^2 = 3636$$

Let the considered empirical distribution have the form of a sequence of intervals (x_i, $x_{(i+1)}$) and the corresponding frequencies n_i (n is the sum of frequencies that fall into the i-th interval) that is $(x_1;\ \ x_2)(x_2;\ x_3)$ . . . (x_i, x_{i+1}) respectively $n_1, n_2,\ \dots n_i$.

Let's try, using Pearson's criterion, to check the hypothesis that the general population X is normally distributed. To do this: 1) calculate the standard deviation σ, and as a variant x_i^*take the arithmetic mean of the ends of the interval $x_i^* = x_i + x_{i+1}/2$; calculate the theoretical frequencies of intensities $n_i' = nP_i$ where n is the sample size; $P_i = \Phi_{(z_i+1)} - \Phi_{z_i}$the probability of X hitting the intervals (x_i, x_{i+1});

Φ_z- Laplace function; 3) let's compare the empirical and theoretical frequencies using the Pearson criterion. To do this, a) compile a calculation table 2, according to which we find the observed value of the Pearson criterion $\chi^2 = \sum(n_i - n_i')/n_i'$.б. according to the table of critical distribution points χ^2, at a given level of significance α and the number of degrees of freedom $\rho = \text{H}_\text{I} - 3$ (H_I is the number of sampling intervals), we find the critical point of the right-sided critical region $\chi^2(\alpha; \rho)$.. If $\chi^2_{\text{набл}} < \chi_{\text{кр}}$there is no reason to refute the hypothesis of the normal distribution of the general population.

Table 2.

Calculation of intervals z_i and z_{i+1}

H_i	Interval boundaries		$x_i - J$	$x_{i+1} - \bar{J}$	Interval boundaries	
	x_i	x_{i+1}			$z_i = \frac{x_i - \bar{J}}{\sigma}$	$z_{i+1} = \frac{x_{i+1} - \bar{J}}{\sigma}$
1	0	0	-	-112	-	-1,87
2	0	20	-112	-92	-1,87	-1,53
3	20	40	-92	-72	-1,53	-1,2
4	40	60	-72	-52	-1,2	-0,87
5	60	80	-52	-32	-0,87	-0,53
6	80	100	-32	-12	-0,53	-0,2
7	100	120	-12	8	-0,2	0,13
8	120	140	8	28	0,13	0,47
9	140	160	28	48	0,47	0,80
10	160	180	48	68	0,80	1,13
11	180	200	68	88	1,13	1,47
12	200	220	88	108	1,47	1,8
13	220	240	108	128	1,8	2,13
14	240	260	128	-	2,13	-

Find the intervals $z_i; z_{i+1})$,, taking into account that $\bar{J} = 112$, $\sigma = \sqrt{D} = \sqrt{3636} = 60$. To do this, let's make a calculation table 3. The left end of the first interval is assumed to be equal - ∞, and the right end of the last interval is ∞.

We build a histogram of the empirical distribution of the intensity value in relative frequencies. The construction results can be seen in Fig. 1.

A qualitative analysis of the histogram indicates the possibility of putting forward a hypothesis about the normal distribution of variable intensities based on the nature of the distribution of intensity values over individual intervals.

Table 3: Calculation of the theoretical probability of interchangeable intensities and their parts

	Interval boundaries		$\Phi(z_i)$	$\Phi(z_{i+1})$	$P_i(\Phi_{z+1}-\Phi_z)$	$n=440P_i$
	z_i	z_{i+1}				
1	$-\infty$	-1,87	0,5000	0,4693	0,0307	13,508
2	-1,87	-1,53	0,4693	0,4370	0,0323	14,212
3	-1,53	-1,2	0,4370	0,3849	0,0521	22,924
4	-1,2	-0,87	0,3849	0,3078	0,0771	33,924
5	-0,87	-0,53	0,3078	0,2019	0,1059	46,596
6	-0,53	-0,2	0,2019	0,0793	0,1226	53,944
7	-0,2	0,13	0,0793	0,0517	0,1310	57,64
8	0,13	0,47	0,0517	0,1808	0,1291	56,804
9	0,47	0,8	0,1808	0,2881	0,1073	47,212
10	0,8	1,13	0,2881	0,3708	0,0827	36,388
11	1,13	1,47	0,3708	0,4292	0,0584	25,696
12	1,47	1,8	0,4292	0,4641	0,0349	15,356
13	1,8	2,13	0,4641	0,4834	0,0193	8,492
14	2,13	∞	0,4834	0,5000	0,0166	7,304

We will test the null hypothesis about the normal law of distribution of intensities according to the criterion according to mathematical statistics - the Pearson criterion. The calculation of the χ^2 criterion is summarized in Table 4.

Table 4: Calculation of the χ^2 criterion and the ordinates of the curves of the differential and integral intensity distribution functions.

№	n_i	n_i'	$n_i - n_i'$	$(n_i - n_i')^2$	$(n_i - n_i')^2 n_i'$	n_i^2	n_i^2/n_i'
1	2	3	4	5	6	7	8
1	22	13,508	8,492	72,114	5,339	484	35,831
2	12	14,212	2,212	2,893	0,204	144	10,132
3	20	22,924	2,924	8,550	0,373	400	17,349
4	32	33,924	1,924	3,702	0,109	1024	30,185
5	41	46,596	5,596	31,315	0,672	1681	36,076
6	58	53,944	4,056	16,451	0,305	3364	62,361
7	59	57,64	1,36	1,85	0,032	3481	60,424
8	59	56,804	2,196	4,822	0,085	3481	61,251
9	43	47,212	4,212	17,741	0,376	1849	39,162
10	35	36,388	1,388	1,927	0,053	1225	33,625
11	23	25,696	7,268	0,283	0,283	529	20,587
12	20	15,356	4,644	21,567	1,405	400	26,049
13	9	8,492	0,508	0,258	0,030	81	9,538
14	7	7,304	0,304	0,092	0,0130	49	6,709

$$\chi^2 = 9{,}279 \sum n_i^2/n_i' = 449{,}279$$

Control: $\sum(n_i^2/n_i) - n = \chi^2$; 449,279-440=9,279.. The calculations are correct.

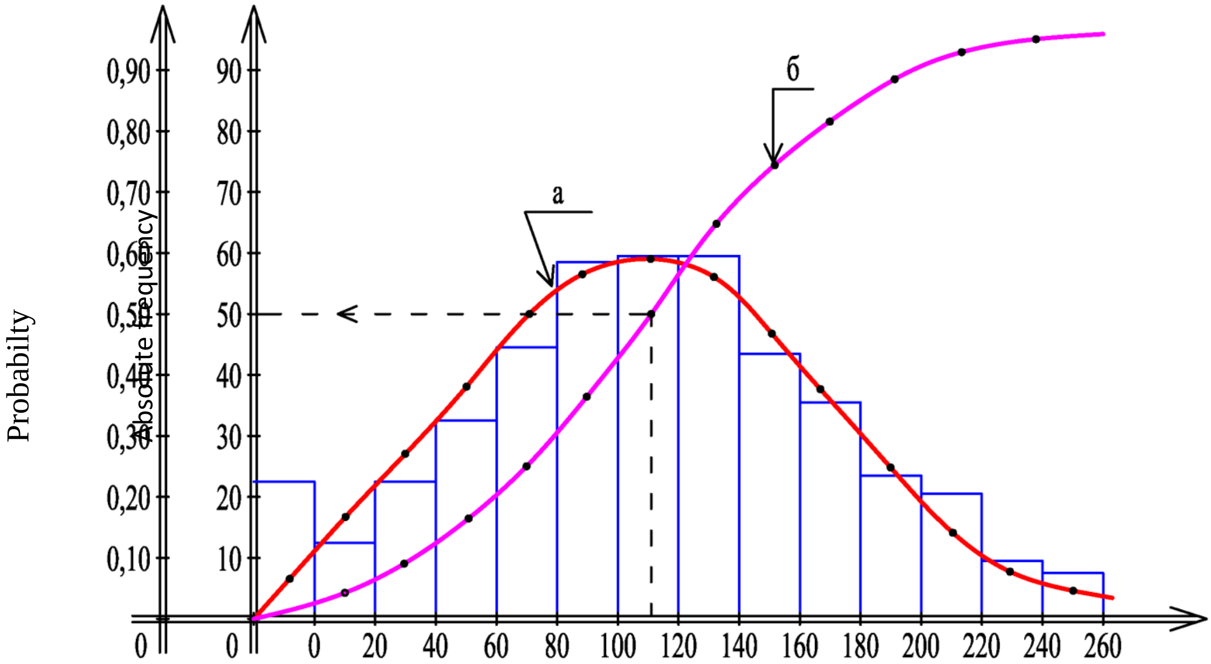

Fig. 1. a) the distribution of the size of the shift work of teams (histogram and probability density). The numbers in brackets are the absolute frequency. B) the distribution function of the random variable.

According to the table of critical distribution points χ^2 in terms of significance levels α = 0.05 and the number of degrees of freedom, we find and compare the calculated value $\chi^2 = 9.3$ with the corresponding theoretical value taken from tables of mathematical statistics. We pre-calculate the number of degrees of freedom ρ for our empirical distribution $\rho = \text{H}_1 - \eta - l$, where $\text{H}_1$is the number of distribution intervals adopted in the calculation of the criterion χ^2..

When testing the null hypothesis by the χ^2 criterion, intervals containing a small (n≥5) number of values of a random variable must be combined with adjacent ones; η is the number of distribution parameters (J and D); l is the number of links imposed on the statistical set.

$\rho = \text{H}_1 - \eta - l = 14 - 2 - 1 = 11.$

$$x^2 = 9{,}3 \leq [x^2_{(\rho)} = x^2_{(0{,}05)}(11) = 19{,}7]$$

Thus, the null hypothesis of the normal distribution of shift intensities J is not rejected by the significance level α = 0.05.

Studies have shown that during the functioning of the construction flow, many production interruptions occur, which by their nature refer to random variables, that is, these interruptions are the result of random causes and occur at random times. These interruptions are a consequence of the stochasticity and probabilistic nature of construction, therefore, the solution to the problem of the normal functioning of continuous construction lies in ensuring the required level of reliability of construction flows.

The main element in determining the reliability indicators is the regularity of the distribution of changeable intensities. The processing of statistical data on a number of construction projects allowed us to conclude that the changeable intensity of the flow of concrete works obey the normal distribution law. Sample mean ‾J and standard deviation σ are used as design standards to determine reliability indicators.

2. References

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