Supply volume forecasting of building materials

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Abstract. Fault times occur due to the late delivery of building materials for which it is impossible to create a stock on a construction site (for example, a concrete mix) when erecting buildings made of monolithic concrete and reinforced concrete. High reliability of supply volume forecasting of building materials per unit time is required to reduce non-production fault times. Based on the equality intensity of the work performance and the structural materials supply intensity, the goal is to develop a generating forecast method of the demand for building materials, taking into account a given level of organizational and technological reliability. The use of classical methods of probability theory made it possible to develop a non-complex mathematical apparatus, which use reliably ensures high confidence of demand forecasts for building materials. The study results can be used in relation to building materials for which it is impossible to create a stock on the construction site, for example, a concrete mix. The practical application of these research results is capable of developing production plans reflecting the real possibilities of contracting organizations, including the production intensity increase of construction and installation works.

Introduction
The published research results [1] rightly divide building materials into 2 groups according to the stock possibility. The first group consists of materials that are easy to stock in any volume on a construction site. The second group combines materials which stock is not possible (for example, construction solutions). Materials of the first group are stored in the amount necessary and sufficient to ensure a given level of organizational and technological reliability. For materials of the second group, the scope of supply depends on the construction and installation works intensity. In this paper, the materials of the second group are considered in more detail.

The brightest proxy object of the second group are mortars. The largest volume of construction and installation work is performed using concrete mixtures. On this basis, it is necessary to focus on the supply volume forecasting of concrete mixes. It is not required to prove the equality of the work production intensity and the supply intensity of concrete mix to the construction site for the monolithic concrete construction. On this basis, we denote the concrete mix supply intensity and the works production speed (productivity) by the letter "W".

To predict the concrete mix supplies volume, it is sufficient to use the concrete production intensity forecast. The uneven production intensity of construction and installation work per unit time (per hour, more often per shift) was convincingly proved in the works [2]. The unevenness appearance reduces the reliability of forecasts in the consumption volumes of building materials in the short and long term. The accuracy of forecasting is increased by introducing into the indicator calculation "organizational
and technological reliability" [3]. To determine the quantitative value of this indicator use the RCM methodology [4, 5], mathematical modeling [6, 7], fuzzy-set theory [8], probability theory methods [3, 9] and many others.

The purpose of the work is to develop a method for forecasting the demand for building materials with a high degree of the calculated results reliability.

Following tasks are solved to achieve this goal:

- collecting initial information method is developed (the general population formation) on the quantitative value of the work intensity;
- approach to the forecast formation of demand for building materials taking into account a given level of organizational and technological reliability is suggested.

**Research methods**

From an author’s point of view, the highest calculations accuracy achieved using the classical methods of probability theory. Such methods are a sequence of the following actions:

- observation in order to form the initial sample of quantitative values (general population), describing the process behavior during a certain period of time (for example, 100 shifts);
- presentation of the initial values sample in the form of a histogram;
- determination of the intensity of work production (delivery of building materials, \( W \)) corresponding to a given value of organizational and technological reliability;
- numerical simulation on the general population of initial values.

**Research results**

As a result of observations, the accumulated baseline information should provide an acceptable confidence level. Studies performed by the author and with his direct participation indicate that if the array of initial values exceeds 100 observations, then it is possible to expect that the calculation error will not exceed 5% (or the calculations accuracy will be at least 95%). As an example of the initial values array, it is proposed to consider the changes observations distribution (initial data) for example, the intensity change of concreting, which is shown in figure 1a. Task condition stipulates such plan development for increasing the work production intensity, which is able to ensure growth at a level of organizational and technological reliability not lower than the set value of 0.8 (\( p = 0.8 \)).

**Figure 1.** The values distribution nature of the work production intensity: a) sample of the original values; b) accumulated probabilities curve for the initial and planned values samples.
The plan construction procedure to increase the production intensity of construction installation works constitutes the following sequence of simple operations:

1. During the initial values (observations) distribution, the quantitative value of the studied indicator change interval is determined (for this example, the «production intensity of works») for which the occurrence probability of the calculated value will be at least 80%. For the distribution shown in figure 1a, the second interval does not satisfy this condition (the probability that the intensity of the work will exceed $I_{\text{min}} + \Delta I$ is no more than 78%).

2. In order to apply the values lying in the first interval in the calculations, it is necessary that the values number of this interval does not exceed 20% of the sample values. Consequently, the actually observed values of the «production intensity of works» should fall beyond the right boundary of the first interval. On the supposition that it is necessary to determine the number of such values that fall, for example, in the interval 2, then the expression should be used:

$$N_k = \frac{\sum_{i=1}^{k} n_i}{1 - p}$$  \hspace{1cm} (1)

where $N_k$ is a number of values in the sample that can provide the specified significance level (level of reliability) of the «production intensity of works» calculated value (it is important to emphasize that the values number increase in the sample relative to the original array should be done solely due to the indicators which value exceeds the right boundary of the interval «$k$»);

- $k$ is a number of the sample interval under study;

- $\sum_{i=1}^{k} n_i$ is the sum of the values number that fell into the $k$-th interval, as well as all the intervals preceding the $k$-th;

- $p$ is the specified level of reliability (validity) of the indicator calculated value «production intensity of works».

For the sample considered as an example (refer with Figure 1a), the condition of the confidence growth in the reliability of the «production intensity of works» indicator in the first interval is the procurement at least 10 values exceeding the value of the right interval border ($W_{\text{min}} + W$, where $W_{\text{min}}$ is the minimum value in the initial array, and $W$ is the interval length, or the histogram step).

3. The actual observations number, which addition is ensured by a given level of reliability (confidence of calculations) is the difference between the calculated sample size ($N_k$) and its initial or previous value ($N_{k-1}$):

$$\Delta n = N_k - N_{k-1}$$  \hspace{1cm} (2)

where ($N_k$) is an estimated value of the sample;

- ($N_{k-1}$) is the initial or previous value (size) of the sample.

Thus, the practical application of expressions 1 and 2 can provide the construction of such a plan, which provides the intensity of work production increase, which will ensure the level of organizational and technological reliability of at least 80%. For the initial sample of work intensity values, shown in figure 1a, such a plan is given in table 1, and a graphical interpretation of the change in the sample of initial values is shown in figure 1b.

**Table 1.** The intensity increase plan of the production work in the construction process

| № int. | Orig. Interval numbers (steps) |
|--------|-------------------------------|
| g.     | 1    2    3    4    5    6    7    8    9 |
| 1      | 2    3    4    5    6    7    8    9    11 |
The plan is a diagonal (numbers in bold), which shows the number of actual (observable) values of the “production intensity of works”, which should be provided during construction and installation work on the building or structure construction. The calculated values are given in table 1 are calculated on the basis of the condition that the set value of the “production intensity of works” is exceeded within the adjacent interval. If the actual values of the indicator will fall into other intervals located to the right, then the calculated values of the plan to increase the indicator value decrease. According to the results given in table 1, it is not difficult to construct a graph of the growth dependence of the “production intensity of works” (W) on the observations number (N), providing the value of organizational and technological reliability not lower than the given one - p = 0.8 (refer with Figure 2).

![Figure 2. Intensity increase of the work performances, depending on the implementation of the planned work amount in a shift](image)

**Summary**

The obtained results prove conclusively the possibility of the scientifically based long-term plan construction of «production intensity of construction installation works» increase while ensuring that the value of organizational and technological reliability is not lower than specified.

Actual values addition to the sample used to describe changes in the quantitative values of indicators provides a reasonable adjustment possibility in the planned indicators.
Scientifically based planning of the production intensity in construction and installation works contributes to the establishment of rhythm and proportional processes in construction of buildings and structures.

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