Scheduling on the basis of the research of dependences among the construction process parameters

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Abstract. The dependences among the construction process parameters are investigated in the article: average integrated value of qualification of the shift, number of workers per shift and average daily amount of completed work on the basis of correlation coefficient are considered. Basic data for the research of dependences among the above-stated parameters have been collected during the construction of two standard objects A and B (monolithic houses), in four months of construction (October, November, December, January). Kobb-Douglas production function has proved the values of coefficients of correlation close to 1. Function is simple to be used and is ideal for the description of the considered dependences. The development function, describing communication among the considered parameters of the construction process, is developed. The function of the development gives the chance to select optimum quantitative and qualitative (qualification) structure of the brigade link for the work during the next period of time, according to a preset value of amount of works. Function of the optimized amounts of works, which reflects interrelation of key parameters of construction process, is developed. Values of function of the optimized amounts of works should be used as the average standard for scheduling of the storming periods of construction.

1 Introduction

Construction process is the difficult system, which values of parameters constantly changes in time and depend on a huge number of factors. Organizational-and-technological reliability of construction process (OTRCP) is directly connected with the decisions, made when scheduling construction. Therefore scheduling always needs special attention. Matters of the increase in OTRCP of construction always were relevant. The necessary OTRCP level is provided with the factors, connected with organizational, technology, technical, economic solutions. Therefore, consideration of the applied methods of management of such factors is also very important.

The increase in efficiency of processing of statistical information on parameters of construction process is an important task for establishment of dependences between processes of construction system and further forecasting of her behavior. Important feature of the parameters of construction process investigated in work is shift of these parameters in time. The models describing the temporary ranks formed by values of the studied parameters represent difficult dependences. For identification of such dependences it is necessary to use such mathematical apparatus, which could reveal the moments of emergence of such dependences and their frequency with the maximum reliability. It is especially important to reveal minor changes in the parameters of the construction system, which sometimes can lead to critical deviations of parameters of construction from preset values, for example, the increase in
duration of construction. The research of temporary ranks is the relevant task of the analysis and forecasting of dynamics of shift of characteristics of construction process.

Organizational-and-technological reliability (OTR) is the ability, the existing probability of the designed decisions relating to costs planning of resources including labour, to determination of duration of construction of a separate object or complex in general, to be executed within the established concept of the construction project and with the set level of quality [1-5]. Numerous works of the famous scientists [1, 3, 5-14] are devoted to the matter of increase in OTR of construction system (in general and its components of elements), however this question remains relevant and today. In works [3-6] it is noted that the construction process always has probabilistic character, since work flow is influenced by various random factors having the diverse nature and various consequences all the time.

2 Materials and Methods

The authors carry out the research of dependences among three parameters of construction process: the average integrated value of qualification of shift [15, 16], the quantity of workers in shift and average daily amount of completed work (the daily volume of the concreted designs taking into account plates of overlappings, m³). Basic data for a research of dependences between the above-stated parameters have been collected during construction of two standard objects A and B (monolithic houses), in four months of construction (October, November, December, January). Statistical data on construction of facilities A and B for October are presented in Table 1. The authors consider the production Kobb-Douglas function, which appearance is the following:

\[ Q = AK^\alpha L^\beta, \]  

(1)

where \( K \) – expenses of work/volume of labour forces in value terms, or in natural quantity (for example, quantity of workers);  
\( L \) – expenses of the capital/volume of funds or in value terms, or in natural quantity;  
\( A \) – the positive production coefficient describing the proportionality of all the functions;  
\( \alpha, \beta \) – the coefficients of elasticity of output on expenses of the capital and work;  
\( Q \) – production in value or natural terms.

Thus, the Kobb-Douglas production function can be characterized as the function describing dependence among factors of production and the greatest possible volume of the product made by this set of factors. Analyzing the coefficients of elasticity it is possible to allocate the following types of Kobb-Douglas production function [17, 18]:

1. in proportion increasing, if \( \alpha + \beta = 1 \);  
2. disproportionately increasing, if \( \alpha + \beta > 1 \);  
3. decreasing, if \( \alpha + \beta < 1 \).

If we transform the Kobb-Douglas production function for the establishment of dependences among the considered parameters: the average integrated value of qualification of change, the quantity of workers in shifts and average daily amount of completed work, it will take the following form:

\[ Z = AX^\alpha Y^\beta, \]

(2)

where \( Y \) – the average integrated value of qualification of the shift;  
\( X \) – the number of workers in shift;  
\( A \) – the coefficient describing the proportionality of all functions;  
\( \alpha, \beta \) – coefficients of elasticity of average daily amount of completed work by the number of workers in shift and to the average integrated value of qualification of the shift;  
\( Z \) – average daily amount of completed work.

The authors offer to call the received function (2) the development function. For finding of coefficients \( A, \alpha, \beta \) it is necessary to define logarithm for the equation (2):

\[ \ln Z = \ln A + \alpha \ln X + \beta \ln Y, \]  

(3)
Table 1. Basic data for objects A and B for October

| Number of the shift | x (quantity of workers) | y (the average integrated value of qualification of shift) | z (average daily amount of completed work, m³) |
|---------------------|-------------------------|----------------------------------------------------------|---------------------------------------------|
|                     | Facility A | Facility B | Facility A | Facility B | Facility A | Facility B |                     |
| 1                   | 26        | 26        | 1.92       | 1.84       | 40.85      | 35.31      |                     |
| 2                   | 29        | 25        | 1.72       | 1.75       | 40.25      | 46.91      |                     |
| 3                   | 27        | 27        | 1.58       | 1.80       | 40.75      | 33.91      |                     |
| 4                   | 25        | 29        | 1.74       | 1.83       | 36.75      | 31.21      |                     |
| 5                   | 27        | 24        | 1.81       | 1.83       | 31.90      | 45.51      |                     |
| 6                   | 30        | 23        | 1.75       | 1.78       | 33.90      | 32.31      |                     |
| 7                   | 25        | 28        | 1.69       | 1.62       | 32.00      | 42.71      |                     |
| 8                   | 28        | 30        | 1.86       | 1.73       | 36.00      | 47.50      |                     |
| 9                   | 26        | 31        | 2.01       | 1.91       | 37.00      | 37.00      |                     |
| 10                  | 30        | 28        | 1.79       | 1.72       | 42.70      | 45.00      |                     |
| 11                  | 22        | 25        | 1.72       | 1.72       | 35.00      | 47.03      |                     |
| 12                  | 26        | 24        | 1.80       | 1.74       | 28.00      | 41.33      |                     |
| 13                  | 25        | 24        | 2.04       | 1.85       | 38.75      | 50.13      |                     |
| 14                  | 31        | 24        | 1.76       | 1.80       | 29.85      | 55.50      |                     |
| 15                  | 30        | 29        | 1.69       | 1.73       | 40.25      | 54.80      |                     |
| 16                  | 29        | 31        | 1.85       | 1.77       | 37.25      | 48.60      |                     |
| 17                  | 31        | 25        | 1.89       | 1.82       | 41.05      | 53.50      |                     |
| 18                  | 27        | 19        | 1.78       | 1.85       | 37.35      | 37.15      |                     |
| 19                  | 27        | 21        | 1.67       | 1.78       | 33.75      | 33.95      |                     |
| 20                  | 30        | 25        | 1.83       | 1.68       | 36.25      | 33.95      |                     |
| 21                  | 33        | 26        | 1.86       | 1.70       | 42.70      | 38.55      |                     |
| 22                  | 34        | 26        | 1.77       | 1.67       | 41.60      | 39.95      |                     |
| 23                  | 34        | 28        | 1.65       | 1.70       | 32.20      | 39.15      |                     |
| 24                  | 31        | 24        | 1.83       | 1.73       | 40.20      | 42.35      |                     |
| 25                  | 32        | 21        | 1.85       | 1.86       | 24.70      | 34.35      |                     |
| 26                  | 24        | 20        | 1.78       | 1.92       | 28.80      | 26.75      |                     |
| 27                  | 31        | 24        | 1.63       | 1.72       | 42.80      | 29.75      |                     |
| 28                  | 34        | 27        | 1.81       | 1.70       | 41.80      | 51.50      |                     |
| 29                  | 36        | 27        | 1.86       | 1.79       | 41.10      | 58.70      |                     |
| 30                  | 33        | 22        | 1.70       | 1.77       | 42.40      | 31.50      |                     |
| 31                  | 30        | 18        | 1.66       | 1.71       | 37.33      | 49.50      |                     |

The authors calculate all the necessary coefficients. Values of coefficients $A$, $\alpha$, $\beta$, as well as the values of coefficients of correlation, calculated on the basic data, presented in Table 1 are presented in Table 2.
Table 2. The coefficients, calculated for the function of production of the facilities A and B

| Facility  | Coefficient of Correlation | β        | α        | lnA | A       |
|-----------|---------------------------|----------|----------|-----|---------|
| Facility A| 0.999114684               | 0.618180881 | 0.9631855 | 0   | 1       |
| Facility B| 0.998322433               | 0.502499011 | 1.06052978 | 0   | 1       |

Values of coefficients of correlation both for the facility A, and for the facility B are close to "1" that makes possible to accept function (2) as the function describing the considered parameters: the average integrated value of qualification of change, the quantity of workers in shift and the average daily amount of completed work. For the facility A function (2) will take the following form:

\[ Z = X^{0.9631855} Y^{0.618180881}, \]  

(4)

For the facility B function (2) will take the following form:

\[ Z = X^{1.06052978} Y^{0.502499011}, \]  

(5)

Mathematical models of functions of development for the facility A (4) and the facility B (5) describe that for identical standard facilities different dependences appear. The elasticity coefficients for function of development of the facility A and the facility B are various, however they have the identical order. The difference among coefficients of elasticity of \( \alpha \) for objects A and B matters 0.097, the difference among coefficients of elasticity of \( \alpha \) for objects A and B matters 0.12. The sum of coefficients of elasticity of \( \alpha \) and \( \beta \) for object A is equal 1.58, for an object B – 1.56. The difference in mathematical models of functions of development for the facility A and the facility B is caused by various schedules of work of crews, and respectively, a daily quality of people on the construction site and also various volume of the performed daily works.

The authors construct dot charts of dependence of values of development (ordinate axis) on the quantity of workers (abscissa axis) (Figures 1, 2). From the schedules it is visible that with increase in number of workers decrease in development both for the facility A, and for the facility B is observed. The nature of these dependences can be described on the basis of the approach offered in work [19] in which it is also noted that at reduction of quality of crew development grows and at increase in quality of crew falls.

Figure 1. Dependence of production on the quantity of workers for the facility A
Analyzing Figures 1 and 2, the authors describe the dependences among the parameters graphically in the form of a hyperbole. On the basis of the approach described in [19] the authors define the coefficients of the hyperbolic equation of regression:

\[ y = a + \frac{b}{x}, \]  

(6)

where \(a, b\) – equation coefficients which can be found, using the following system of the equations:

\[
\begin{align*}
11 & \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i \\
1 & \sum_{i=1}^{n} \frac{1}{x_i} = \sum_{i=1}^{n} \frac{1}{y_i},
\end{align*}
\]  

(7)

where \(n\) – quantity of values of a number of data.

Let us assume, that \(x\) is specific relative quantity of workers \(N_{i0}\), calculated as:

\[ N_{i0} \frac{N_i}{N_{cp}}, \]  

(8)

where \(N_i\) – quantity of workers for the \(i\)-th day of the period;
\(N_{cp}\) – the average quantity of workers in the considered period. The authors treat 4 months of work of crews at the facility A and facility B as the period (October, November, December, January).

Then values of the specific production (on the 1st worker) can be determined according to the formula (6), having substituted the calculated values of coefficients \(a, b\) and parameter \(x\) in a formula. The calculated coefficients \(a\) and \(b\) for two facilities are specified in table 3.

**Table 3. Coefficients of the equation of hyperbolic regression**

| Facility  | \(a\)  | \(b\)  |
|-----------|--------|--------|
| Facility A | 0.50   | 0.80   |
| Facility B | 1.35   | 0.25   |
Values of the optimized amounts of works will be defined multiplying of the specific production and the actual quantity of workers per a day.

3 Results
The authors construct and compare schedules for the facilities A and B during the time, equal to four months (figures 3, 4): the schedule of the actual amount of works which values are determined by collected statistical data (in drawings it is demonstrated in pink color); the schedule of amount of works which values are calculated by the formula of function of production (2) (in drawings it is demonstrated in blue color); a function graph of the optimized amounts of works which values are received on the basis of application of the approach offered in work [19] and formulas (6) and (7) (in drawings it is shown in green color). From summary schedules of the amounts of works presented in the figure 3 it is visible that the maximum fluctuations and dispersion of values are observed on graphics of the actual amount of works both for the facility A, and for the facility B.

The schedule of the amount of works calculated by the formula of function of development (2) corrects values of the schedule of the actual amounts of works, however fluctuations and dispersion of values nevertheless are well noticeable. For example, on graphics of the amount of works calculated by the formula of function of development (2), constructed for the facility B fluctuations of values of amounts of works at the end of January are even higher, than fluctuations of values of the actual amounts of works in the same period.

**Figure 3.** Summary schedule of amounts of works for the facility A

**Figure 4.** Summary schedule of amounts of works for the facility B
The function graph of the optimized amount of works has the smallest fluctuations and dispersion of values in comparison with the schedule of the actual amount of works and the schedule of the amount of works calculated by a formula of function of production (2). The values of amounts of works received as the result of creation of the function graph of the optimized amount of works are the best and can be established as the average standard values. It is possible to tell that the function graph of the optimized amount of works constructed taking into account specific development is the population mean reflecting interrelation of key parameters of construction process.

4 Conclusions
Thus, after each temporary working period, for example, month of works, it is possible to analyze the deviations of the actual values of amounts of works from standard (optimum for this period) according to the summary schedule of amounts of works and also to establish borders of tolerances of values of the actual amounts of works, having set certain threshold values. For example, having established threshold values of deviations, equal 10% of values of function of the optimized amount of works, authors analyze zones of critical deviations. Fluctuations of values of the actual amount of works can be in range between threshold values of deviations of amounts of works, at the same time critical fluctuations of values of the actual amounts of works are inadmissible. At identification of such fluctuations it is necessary to analyze the reason of their emergence connected with the external, or internal factors influencing construction system.

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