Planning of an experimental research of the organization of townhouses’ construction

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Abstract. One of the most important ways in improving the research’s efficiency is an experiment’s planning. The aim of the study is to identify and study various factors that can affect the productivity of brick layers during bricklaying of townhouses in Iraq. Visual observation, timing and photographs of the working day were carried out during eight working weeks. In the process of daily monitoring, causal relationships of the formation of downtime and overtime work of bricklayers were identified. The most significant factors are untimely delivery of materials and alteration of performed work. The data obtained are the basis for the development of a mathematical model of labor productivity indicators. An analysis of the data on the functioning of the construction technological system for erecting brick walls of buildings shows that its states can be modeled by regular Markov processes. The data obtained are the basis for the development of a mathematical model of labor productivity indicators.

Keywords: experiment's planning, research, factors, methodology.

1. Introduction

Experiment’s planning is a draft of an experimental research that allows you to establish its logical scheme and determine the tasks to be solved at each stage of work. Experiment’s planning is a purposeful choice of the conditions for its conducting, of the systematic impact on the studied object (during an active experiment) or optimization of observations (during a passive experiment). The experimental study is associated with the organization of the experiment. Many experimental studies require a large number of different means, including finance ones. A researcher needs to perform many measurements in the laboratory, in the factory conditions or on the construction site [1-3].

The erection of townhouses with the use of brick laying (masonry) is one of the fastest growing directions of construction in Iraq. The main characteristic of measuring the intensity of work performed is labor productivity. Labor productivity in construction can be represented by the relationship between the result and the data: the number of products produced per unit of working time; labor costs per unit of production or work performed. A significant part of researches is dedicated to labor productivity in construction [4, 5].

Productivity is influenced by many factors and is associated with the implementation of time, cost and quality indicators of [6, 7]. To solve the problems of increasing labor productivity, it is necessary to make its evaluation. Due to the lack of standard assessment methods, it is determined in several ways: calculation of direct specific indicators, percentage alterations, activity levels, production technology, etc. [5, 8, 9]. Each of the methods measures work in different ways and serves as an indicator for understanding of actual labor productivity. Labor productivity in construction depends on numerous influencing variables consisting of subjective and objective factors. One of the main problems in studies of labor productivity is the identification of key influencing parameters. The main tasks of organizing effective management of the factors of labor productivity’s formation include: establishing of factors in the formation of labor productivity; the definition of the source data used to organize the effective management of factors of labor productivity’s formation; grouping of factors of labor productivity’s...
formation into categories; building a model for effective management of factors in the labor productivity’s formation and its verification [10, 11].

1.1. Factors Affecting the Labor Productivity

The factors of formation of labor productivity are divided into groups: material, technical, organizational and socio-economic at the sectoral, design and production levels in different countries [12-14]. The level of labor productivity is influenced by many factors acting simultaneously: the organization and the system of servicing working places; the proportion of main workers in their total number; the number of workers combining several professions; the qualifications of workers [10, 15]; construction and consumable materials [10, 11]; equipment and tools [11, 16]; project management [10, 16]; providing favorable working conditions, etc. [17]. The presence of each of the factors ensures the growth of labor productivity. However, the contribution of each of the factors to the growth of labor productivity is different. Some of the factors have a greater effect on the growth of labor productivity, while others have a smaller effect. A high level of labor productivity at the working place is achieved primarily due to the fact that rational labor techniques and movements with which the schemes of organization and layout of working places are linked, are worked out for each type of work (manual, mechanized and automated ones). Rational planning of the working place gives the worker the opportunity to reduce the time for completion of labor movements by 10-15%. This allows you to increase the labor productivity [18].

In the research works [12, 19-22], labor productivity indicators for masonry were considered. It is difficult to determine the influence of individual factors [23] on labor productivity indicators, since many factors act simultaneously on labor productivity. When determining the influence of separate or several factors on labor productivity indicators, it is advisable to use modeling [12].

1.2. Modeling of labor productivity

Modeling of labor productivity is a difficult task. All the factors of labor organization have a significant impact on the level of labor productivity, not being in functional dependence with it. To determine the quantitative effect of each individual factor and all the totality of factors on the level of labor productivity, methods of mathematical modeling are used [24-26]. Models for calculating indicators of labor productivity in masonry are presented in the studies [12, 19-22].

A review of the literature shows that, despite the differences in the socio-economic conditions of countries, the main factors affecting labor productivity are the lack of materials, the lack of qualified personnel, the lack of proper tools and equipment, and manual labor.

The aim of the study is to identify and study various factors that can affect the productivity of bricklayers during bricklaying of townhouses in Iraq. The data obtained are necessary for the development of a mathematical model of labor productivity indicators.

2. Method of research

A study of the implementation of the technological system for the construction of townhouses was carried out using theoretical, structural, empirical and statistical methods.

Based on a theoretical study, an analysis of modern publications on the influence of individual or aggregate factors on labor productivity has been made. Structural analysis was used to assess the significance of each individual factor affecting the effectiveness of the organization of brickwork. The empirical research method made it possible to assess the influence of factors on the productivity of brickwork. The statistical research method was used to analyze the quantitative content of the empirical data.

To obtain reliable data about the studied object, a program of the research has been developed with the justification of the necessary and sufficient number of observations, which provides for the identification of influencing factors and their main parameters; substantiation of the working hypothesis about the studied pattern of behavior of the object; determination of measurement accuracy; determination of the minimum volume of measurements; methodology of mathematical processing of
experimental data and verification of the working hypothesis. To correctly evaluate the data and observations, they were analyzed using mathematical statistics and probability theory [28, 29]. An analysis of the data based on the method of confidence intervals [28, 29] suggests that the true value of the studied quantity is located with probability \( P = \gamma \) in a certain confidence interval between the values that are not significantly different from the true value. Confidence intervals for estimating the average value allow to determine the range of values in which an exact solution is possible to appear. In addition, the confidence interval shows that the true value of the parameter being studied does not go beyond its scope.

Based on the Laplace function, it is written:

\[ P \left[ \left| \bar{x} - a \right| < \delta \right] = 2 \Phi(t) \]  

(1)

where \( t = \frac{\delta \sqrt{n}}{S} \) is the argument of the Laplace function; \( \delta \) is the accuracy of measurements; \( n \) is the sample size; \( S \) is the standard deviation.

The number \( t \) is determined from the equation \( \Phi(t) = P/2 \) according to the table of the Laplace function. The minimum number of measurements \( n \) for evaluating the true value of the studied quantity with a given accuracy \( \delta \) and reliability \( \gamma \) is determined by the formula:

\[ n \geq \left( \frac{t \cdot S}{\delta} \right)^2 \]  

(2)

In the process of the research, especially on a real construction site, not only random errors are possible, but also operator’s errors. These errors should be excluded from the experimental data set. To remove the erroneous data (abnormal values), the distribution of Student was used [28, 29]. This method works well for small volumes of sampling. The essence of the method is that the critical value (\( p \) is the percentage point of the normalized sample deviation) is expressed using the critical value of the distribution of Student \( \tau(p, n) \):

\[ \tau = \frac{t(p, n) \sqrt{(n-1)}}{\sqrt{(n-2) + t^2(p, n)}} \]  

(3)

The value of the observed statistics \( \tau \) is determined by the formula:

\[ \tau = \frac{|x_i - \bar{x}|}{S} \]  

(4)

where \( x_i \) is the extreme (largest or smallest) element of the sampling on which подсчитывались \( \bar{x} \) and \( S \) were calculated; \( \bar{x} \) is the average value of the sample; \( S \) is the standard deviation of the sample; \( \bar{r} \) is the value of statistics calculated with a confidence probability \( q = 1 - p \).

Depending on the ratio of the observed statistics and the normalized value \( \tau(p, n-2) \), a decision is to be made on screening of the error.

The study of brickwork in the conditions of production at various sites and with various teams of bricklayers is associated with many factors that affect the data. This forms different conditions of the production of work, as well as different output under the other equal conditions. The rank correlation methods were used to compare the qualitative characteristics of the production of work on bricklaying. To assess the degree of connection of attributes, Spearman’s or Kendall’s rank correlation coefficient is used [28, 29]. Spearman's rank correlation coefficient is:

\[ \rho = 1 - \frac{6}{n^3 - n} \sum (A_k - B_k)^2 \]  

(5)

where \( A_k \) and \( B_k \) are selective qualitative features of the objects.

To determine the homogeneity of the two samplings, obtained as a result of observations of various teams of bricklayers, their verification should be made using Wilcoxon criterion. If the samples are
homogeneous, then they are considered to be extracted from the same general totality and, therefore, have the same functions of distribution. In this case it is assumed that the volume of the first sampling is less (not more) than the volume of the second one.

As part of the research, the daily observation was carried out during eight working weeks. The data on the work’s performance has been obtained during the bricklaying works of the walls of the townhouses at five different construction sites in the city of El Muthanna in the Southern Iraq. Two-storey residential building of «townhouse» type consists of four sections. Brigades of bricklayers are located on the formed production space (Figure 1). At the two construction sites, work was organized according to the “threesome” system, and on the three construction sites according to the “foursome” system.

![Figure 1. Construction of brick townhouses (a team of bricklayers at the facility).](image)

Statistical information includes the following information: the number of workers in the teams of bricklayers; system of organization of production links; duration of a working day; overtime duration; the presence of downtime and losses of working time; output per brigade and per worker; salary of workers; labor mechanization and technological equipment.

To solve the task of the research, a list of factors affecting the labor productivity indicators has been made: limitation of the storage area for materials; untimely supply of materials or absence of some other necessary resource (electric energy, water, etc.); low mechanization of labor; the use of a large amount of manual labor; downtime of the brigade and loss of working time; manufacturing defects; organization of the production process; uneven rate of the production work; qualification of production personnel.

These features emphasize random errors that are caused by many and, as a rule, uncontrollable factors. Random errors cannot be eliminated in principle.

3. Results and their discussion

The construction of townhouses is one of the most popular ways of housing in the towns of modern Iraq. This makes it necessary to solve the problem of optimizing the organization of building production. The creation of rhythmic technological flows assumes their stable operation under the influence of random factors.

Daily monitoring of the construction sites revealed the factors affecting the productivity of brick layers. It should be noted that it is possible to take into account a huge number of factors. However, this research is based on the data available at the design stage of the experiment. Attention is focused on the use of a large amount of manual labor: almost all the operations are performed without the use of mechanization. The scope of work includes unloading and supplying materials to workplaces, preparing mortar, laying bricks, and related operations. Due to interruptions in the supply of electricity, the preparation of mortar is carried out without the use of special mixers. Portland cement or dry mixes are available in the amount needed for one to three days of work, which leads to shutdowns and losses of
working time.

The productivity of the team of bricklayers depends not only on the rhythm of work, but also on the organization of the production process. In the process of observation, it was found that brickwork is being done very unevenly by time. Uneven work is observed not only on individual days during the week, but also on weeks during the month. Failure to meet planned tasks is a consequence of the impact of internal and external factors. One of the most significant internal factors is qualification of the production personnel: in the process of performing the work, a lot of working time is used to eliminate the appeared defects. An external factor is the irregular supply of material. Significant losses of time are associated with lack of materials.

In the process of the research work, production stops and loss of working time, including downtime, were identified. Figure 2 shows the distribution of losses of working time.

![Figure 2. Distribution of losses of working time.](image)

The largest number of production shutdowns occurs in the period from 0.5 hours to one hour, respectively 42.4% and 16.5%. Downtimes with duration of 2, 3, and 6 hours are 9.4%, 8.2%, and 7.1%, respectively. Downtimes of 4, 5 and 8 hours are 4.7%, 4.7% and 2.4%, respectively. A causal relationship between the output and rhythm of the work of the brigade of masons was revealed. It was established that the losses of working time directly affects the amount of production output. Analysis of the amount of brickwork during the month showed that the output is 37.9% below the norm. The production output in the brigades of “threesome” type and “foursome” type is formed unevenly. To compare the efficiency of work production by the brigades, an analysis of production output per worker was performed. Fig. 3 shows the distribution of labor productivity per worker per ordinary working day.

The productivity of the “threesome” type of brigades is lower on average by 13.8% than for the “foursome” type brigades. A rank correlation analysis of their indicators has been made to compare the production of brigades with organizational forms of production of the “threesome” type and the “foursome” type. Based on the criterion of Spearman (0.69<1.66 with a significance level of γ=0.01), it was found that the rank correlation between the qualitative characteristics of labor productivity in the two types of masons’ brigades is insignificant. This means that the analyzed data in the studied brigades of masons are independent of each other. Based on the Wilcoxon criterion (23<37<55, with a significance level of γ=0.01), it was found that labor productivity in the studied types of masons’ brigades is statistically homogeneous.
Figure 3. The distribution of labor productivity per worker in the brigades of bricklayers.

However, both types of brigades do not complete the daily task. To fulfill the schedule of work on the construction sites they have to use overtime work. It lasts 2-3 hours. Figure 4 shows the distribution of labor productivity during periods of overtime.

Figure 4. Labor productivity during overtime.

An analysis of the data shows (Figure 4.) that the productivity of a “threesome” brigade is lower than that of a “foursome” brigade. The difference is on average 23.1%. Labor productivity in overtime for the both types of brigades’ organization is 15-17% lower than in ordinary working hours. At the same time, labor productivity in overtime is 10-15% lower than on a normal working day (27). The reduced labor productivity from forced downtime on working days can reach 26% (22). The data obtained shows that in only 72% of the working time were used for the manufacturing of construction products. At the
same time, 28% of working time relates to downtime and overtime.

An analysis of the data during the construction of the brick walls of townhouses shows that its condition can be modeled by regular Markov processes. The technique is based on a quantitative analysis of the conditions of a technological system. This provides a minimal impact of subjective assessment factors.

4. Conclusion
The study of the influence of various factors of a causal nature on the formation of labor productivity of bricklayers in the construction of townhouses has been made. The analysis takes into account the factors affecting the productivity of bricklayers during a regular working day and in overtime. The data obtained are the basis for the development of a mathematical model of labor productivity in bricklaying works during construction of townhouses.

5. Acknowledgments
The publication has been prepared with the support of the «RUDN University Program 5-100».

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