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Darja Kubečková[1,*], Stanislav Smugala[2]

Determination of construction process duration based on labor productivity estimation: A case study

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Abstract: Monitoring labor productivity and how to decrease construction costs are the key issues in the planning process of a construction project. The CONTEC automated system combined with statistical methods assists in predicting the amount of time required to complete construction works according to the specified number of deployed work crews, technological processes, and labor required for certain production in person-hours. This study applies statistical analyses and probability theories for plastering work, which represents a labor-intensive construction process. The goal of the research is to determine the probability of completion of the construction process based on monitoring the mean value of performance. By application of statistical analyses a decrease in the performance standard has been proved compared with the planned values given in the CONTEC database. The decrease in performance, which was also caused by the number of days with unfavorable climatic conditions and demonstrated by performing interval estimates based on the collection of statistical data, was later confirmed by a relative frequency test. The measures taken were in terms of establishing the required number of personnel capacities for complying with the construction schedule.

Keywords: mean value, standard deviation, productivity, sample relative frequency, probability theory, hypothesis test

***Corresponding author: Darja Kubečková,** VŠB-Technical University of Ostrava, Faculty of Civil Engineering Department of Construction L. Podeště 1875, 708 00 Ostrava-Poruba, Czech Republic,
E-mail: darja.kubeckova@vsb.cz
Stanislav Smugala, Department of Construction, Faculty of Civil Engineering, VŠB – Technical University Ostrava, Ludvíka Podéště 1875/17, 708 33 Ostrava – Poruba, Czech Republic

1 Introduction

The prediction of work productivity is one of the key aspects in the planning process of construction work. Many construction projects today are planned and managed using computer technology. An integral part of this project management is application of the statistical probabilistic method with sophisticated software support. The controlling process of work productivity using statistical methods, combined with application of the construction software tools, enables to achieve not only a decrease in the wage costs but also a reduction of overhead and production costs connected to the fulfillment of shortening the process of building duration. In the past, a number of researchers have studied the productivity of individual types of construction work using construction software, and stochastic methods combined with the use of construction software and simulation technique.

1.1 Related work from literature

Historically, one of the first works dealing with this problem was by Nelson (1990), who created a model that represents a new testing method of assessments. The reduction of the difference between the planned and actual work productivity is the subject of the study published by Thomas et al. (2002). Frequently discussed problems described by Gulezian and Samelian (2003) is a differentiation among labor productivity deviances. Elaboration of the standard performance dates that have been carried out by Briec et al. (2012) and Gouett et al. (2011) is necessary for the prediction of duration of the construction process. The estimation and completion (EAC) index method frequently used in the West is presented by De Marco et al. (2009) and Narbaev and De Marco (2011). The statistical method of the relative importance index and mean score presented by Salunkhe (2018), Salunkhe and Patil (2013), and Asiedu et al. (2017) was used for determining the critical construction delay factors. The Positive impact of Engineering Software on Construction Project Management in Bahrain was presented by Aqlan (2014). Project management in construction using primavera and MS project is the subject of study presented by Saini et al. (2017) and Subramani and Karthick (2018). The construction software proposed by Jarský et al. (2000, 2019) is applied for construction project management at building sites in Central Europe. Similar to the works of Briec et al. (2012) and Gouett et al. (2011), standard performance dates enabling the prediction of project duration have been carried out. The above-mentioned works are based on the use of construction software.

The following literature is focused on describing models representing a combination of statistical methods and the use of construction software. Vermo and Kansal (2020) identified delays in construction projects. The measures to reduce the delays have been suggested by means of various observations. The study published by George et al. (2015) proposed to construct the distribution function of the statistical metric space/statistical semi-metric space (SMS/SSMS) in a natural way to quantify the reliability of the forecast. Stochastic project scheduling simulation (SPSS), proposed by Lee et al. (2005), was developed to measure the probability of project completion in a certain time. This method is one of the following ways of how to predict the construction time period. Nassar et al. (2005) presented the analysis to explore use of the Weibull method in stochastic assessments of a construction project development using the cost performance index (CPI) and schedule performance index (SPI) data files. Lowe et al. (2006) proposed the linear regression models to predict the construction cost of buildings, based on 286 sets of collected data. El-Kholy (2015) presented two models in the study predicting cost overrun percentage in construction projects based on the principle of regression analysis. A parsimonious multiple linear regression (MLR) model for predicting the percentage of cost overruns based on parameters known before as the contract award phase was presented together with the one-factor ANOVA test by Sinesilassie et al. (2016). Shrestha et al. (2013) proposed the investigation of large projects that have a significantly higher cost and schedule overruns than smaller ones. According to a method presented by Druker et al. (2009), a combination of the EAC index method and statistical analysis eliminates the problem by delaying the signal that indicates the cost being exceeded. Application of the EAC index method can cause an omission of some important information related to the volume of the conducted work, according to the study published by Leu and Lin (2008). The result of this research work is an improvement in the traditional earned value management (EVM) method, and the methodology, connected to CPI and SPI, which shows certain limitations in defining the given critical path, work quality, and risk impact. The performance of EVM method was also improved by Lipke (2002) by implementation of the statistical process control (SPC). Many works emphasize the importance of integration of the SPC and EVM, because of the latter's sensitivity to discovering abnormal signals, that is, big differences between the planned and real values (Wang et al. 2006). Another improvement in the EVM method in terms of the prediction ability of abnormal deviance applying mathematical statistics was made by Lipke et al. (2009) by development of another system. The proposed earn value (EV) method by Vanhoucke and Vandevoorde (2007) improves the forecast ability of the total project duration compared with EVM.

A new forecasting method is developed based on the Kalman filter and the earned schedule method of Kim and Reinschmidt (2010), removing poor accuracy of the EVM in predicting project durations. The control analysis completed by Urgilés et al. (2019) compares the efficiency of the EVM technique and its Earned Schedule extension, as means of forecasting costs and deadlines. S curve (SS-curve) as an alternative method in relation to the determining S curve is applied to the control construction process, according to study presented by Barraza et al. (2004). Application of the SS-curve enables to determine the cost over in the required time. San Cristóbal (2017) proposed a system S-curve envelope made up of two curves, which can be used as an early warning system if the actual construction process does not correspond with the time schedule. The probability model developed by Khanzadi and Shahbazi (2018) compares the degree of probability of the predicted and, subsequently, implemented performances in the case of projects implemented in the past and similar projects that are at present time in the planning process. Building the time-period of future projects is predicted on the basis of the probability calculation carried out in the already implemented projects. The principle of Khanzadi's method is comparable with the method presented by Kubečková and Smugala (2020). The difference consists in prediction of the process duration, which is based on the evaluation of real implemented performances at the construction site according to Smugala's solution. The impact of rainy days on labor productivity at the construction site of highway pavement operation is analyzed by Choi and Ryu (2015). Rad and Kim (2018) explored the potential factors having an impact on the construction process. Another method proposed by Khanzadi et al. (2017) models work productivity with the help of a dynamic approach.

Simulation techniques are described by Mizell and Malone (2007) as so-called intermediate construction management development stage between the application of the classic method using construction software and a combination of the statistical methods and construction software. Barber (2005) claims that the EAC index calculation does not consider the consequences of the given future order risk. This shortcoming was removed by Hillson et al. (2004) and El-Maaty et al. (2017), who implemented risk management within the frame of the classic EVM calculation. Internally generated risks in the construction process are explored by Zawistovski et al. (2010), as factors that have an impact on the construction process. Schedule overrun and cost escalation percentages of highway projects are modeled by Minasowicz et al. (2011) using the fuzzy approach. Similar fuzzy optimization of construction project network was presented by Kumar and Faheem (2008). A fuzzy Mamdani inference method was proposed by Plybankiewicz (2018). The model identifies not only cost overrun, but also detailed construction works necessary for completion of a construction project. Simulation applications are the subject of studies proposed by Han et al. (2014), which are based on the real data recorded at the given construction site that were used for the construction process modeling. This system is based on an analogous principle as the model presented by Kubečková and Smugala (2020), which was used in the Czech Republic. Compared with Han's study the method proposed by Smugala explored another type of building and evaluated more construction processes making up the whole structure. Further journal articles, focused on the forecast of construction process of high-rise building construction with the repeated work processes, were published by Ko and Han (2015). The evaluation of mean value of performance of the given construction process is done by application of Bayesian analysis.

Evaluation of plastering crew performance is the subject of the study published by Gerek et al. (2016). Data were collected from 40 crews of varying characteristics, and their technical efficiency scores were computed using the banker, charnes, and cooper (BCC) model, which is based on variable returns-to-scale (VRS). The similar problem, that is, investigation of labor productivity data of wall plastering work activity is discussed by Idiake and Ikemefuna (2014). Data used for the study were obtained using the daily method of data collection, which was applied to the evaluation of construction process productivity. Approximately 800 observations were made for the wall plastering activity. Simple regression and correlation analyses were applied to determine the relationships among the research variables. Abdullah et al. (2019) investigated the performance data of gips plastering works according to four buildings of different construction. The overall 11 important factors of 30 practical records on field sites were practically observed. Laborers' efficiency (LE) was measured and divided into three categories, high, medium, and low, for two specific heights, which were 0–2 m and 2–3 m high walls. Labor productivity of wall plastering activity was also explored by Odesola et al. (2015) using Work Study. The determination of building craftsmen productivity in wall plastering activity is documented in this study and the productivity norm is established for accurate estimation of manpower requirements for realization of the projects. The ANOVA test and descriptive statistics were used for analyzing the collected performance data. Another study by Olomolaiye and Ogunlana (1989) achieved surprisingly different results. The results proved not to be such a significant difference in construction labor productivity in terms of wall plastering process across the territory. The labor productivity value of exterior brick wall concrete plastering was investigated by Monkaew and Nawalerspunya (2015). The findings show that the labor productivity rate in concrete plastering of exterior brick wall was at an average of 1.13 m^2/p/h, which is comparable to those achieved in other building sites according to previous publications. This rate includes factors of delays during material preparation, surface repairing, and any accidents.

1.2 Objectives and tasks

The study suggests a system that is determined for the management of construction processes. A computerized system of the construction planning CONTEC combined with a statistical method provides the possibility on the basis of the mean value and standard deviation to determine the probability of construction process completion. The main task is to verify the validity of these performance mean values by collecting real performance data at building sites based on which the entire construction process can be predicted. By creating and updating the performance data, the probabilities of the course of construction processes in similar future construction works may be estimated. The work productivity is influenced by many factors. A drop in the performance is expected due to occurrence of unfavorable weather conditions in the time period December 2020–March 2021. The hypothesis test of relative frequency is carried out to determine if the reduction percentage of fulfillment of the range mean value is statistically significant, whereas zero hypothesis H_0 represents a value not reduced due to work interruptions; alternative hypothesis H_A is a value corresponding to the performance reduction caused by adverse climatic conditions.

2 Statistical methods used

2.1 Estimating mean value μ

In case of calculation of the mean value estimate μ, we start from the assumption of a normal distribution, not knowing the standard deviation σ, that is, deviation of the performance of individual workers per work shift, in the case of construction processes, where it is possible to record the performance of ≥30 workers for a period of 1 day, so that the condition of the procedure according to Lindemberg–Lévy and the Moivro–Laplace theorem is met. Using the Kolmogorov–Smirnov test (see Section 2.7) the assumption of whether the population is subject to a normalized normal distribution will be verified. The following relations (1)–(3) are used to find the appropriate interval estimate (where: σ = s; see Briš and Litschmannová (2004))

$$P\left(\overline{x}-\frac{s}{\sqrt{n}}\cdot z_{1-\frac{\alpha}{2},n-1}<\mu<\overline{x}+\frac{s}{\sqrt{n}}\cdot z_{1-\frac{\alpha}{2},n-1}\right)=1-\alpha \tag{1}$$

$$\overline{x}=\frac{\sum_{i=1}^{5}x_i}{n} \tag{2}$$

$$s=\sqrt{s^2}\cdot s^2=\frac{\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2}{n-1} \tag{3}$$

where P is the interval with a 95% probability; $\overline{x}$ is the sample average; s is the performance standard deviation; s^2 is the sample dispersion; n is the number of workers; $z_{1-\frac{\alpha}{2}}$, is the selected quantile of the standardized; 1 − α is the confidence of interval prediction; and α is the significance level.

2.2 Relative frequency π

For construction contractors, the percentage data is important, such as the probability of meeting the range of the mean value μ pursuant to Section 2.1. A time interval of 1 month was chosen, during which the performance of employees was measured and the percentage fulfillment of the range of the mean value μ was evaluated. The calculation is based on the assumption that the condition of the Moivre–Laplace theorem is met. To find the 95% confidence interval for relative frequency, we use the following relationship (4) (Briš and Litschmannová 2004):

$$P\left(p-\sqrt{\frac{p\,.(1-p)}{n}}\cdot z_{1-\frac{\alpha}{2}}<\cdots\pi\cdots<\cdots p+\sqrt{\frac{p\,.(1-p)}{n}}\cdot z_{1-\frac{\alpha}{2}}\right)=1-\alpha \tag{4}$$

where p is the sample relative frequency and π is the relative frequency.

2.3 Standard deviation confidence interval

The lowest value of worker performance is explored by determination of the 95% estimate of the left-hand side confidence interval for the range and standard deviation of the average of the achieved performance standard. The determination of the left-hand side confidence interval, that is, the lowest deviation of the performance achieved, is calculated according to Eq. (5) (Briš and Litschmannová 2004) as

$$P_1\left(\frac{(n-1)}{x_{1-\alpha,n-1}}\cdot s^2<\sigma^2\right) \tag{5}$$

where P_1 is the left-sided interval with a 95% probability.

2.4 Poisson process

To assess the probability of occurrence of days with unfavorable climatic conditions during the performance of these works, the Poisson process was used, which describes the occurrence of random events in some fixed time interval. Then the probability function of the occurrence of faults is calculated using the following mathematical relationship (6) (Briš and Litschmannová 2004):

$$P(X=k)\frac{(\lambda t)^k\,.e^{-\lambda t}}{k\,!},\quad 0\le k<\infty\ \mathrm{EX}=\lambda t \tag{6}$$

where EX is the mean value; λ is the mean number of events; and t is the time event.

2.5 Test hypothesis on relative frequency

The construction process of a residential complex in Prague 13 Klementova Street is interrupted due to unfavorable weather conditions. We hypothesized a decrease in the relative frequency of compliance with the performance standard assessed by a subsequent net significance test. The determination of the hypothesis consists of the following steps (see Briš and Litschmannová (2004)).

2.5.1 Formulation of null and alternative hypothesis

Zero hypothesis H_0 represents a value not reduced due to work interruptions while alternative hypothesis H_A value corresponding to performance reduction is caused by adverse climatic conditions. It is assumed that the state where mean value $\mu < \mu_0$.

2.5.2 Selection of test statistics

We proceed according to the following relationship (7):

$$T(X) = P_2 = \frac{p-\pi}{\sqrt{\pi(1-\pi)}} \cdot \sqrt{n} \rightarrow N(0.1) \quad (7)$$

where $T(X)$ is the alternative of the statistical characteristic.

2.5.3 Calculation of the monitored value of the test statistics x_{OBS}

p-value is calculating using Eq. (7); later it is decided whether H_0 is rejected or adopted**.**

2.6 Test of mean value hypothesis

Establishing the mean value hypothesis consists of the following process steps.

2.6.1 Formulation of zero and alternative hypothesis

The equilibrium state H_0 corresponds to the value of the standard hour according to the CONTEC database; meanwhile H_A represents real achieved performance which is lower. We therefore assume a state where mean value $\mu < \mu_0$.

2.6.2 Selection of test statistics

When determining the choice of test statistics, we assume that we do not know the standard deviation, just as when calculating the standard deviation estimate (see Section 2.3 Eq. (8)) as

$$T(X) = T_{n-1} = \frac{\overline{x}-\mu}{s} \cdot \sqrt{n} \rightarrow t_{n-1} \quad (8)$$

where T_{n-1} is the random variable with n degrees of leeway; s is the standard deviation and the sample average; μ is the mean value; and n is the number of degrees of leeway (number of workers).

2.6.3 Calculation of observed values of test statistics x_{OBS}

For the calculation, relationship (8) is used, based on which the *p*-value is determined and effective decision is made regarding the acceptance or rejection of H_0 (see Briš and Litschmannová (2004)).

2.7 Interval estimation of the difference between the mean values of two populations

The residential complex in Prague 13 West City is made up of two buildings, J12 and J34. Due to the mutual interconnection of the buildings, it is necessary to perform a statistical comparison of performance by performing the basic characteristics, such as estimates of mean values. In this case, just as in Section 2.1, we assume that the population has a normal distribution with unknown standard deviations. The random variable T_2 with Student's division t with $(n_1 + n_2–2)$ and degree of latitude $t_{n_1+n_2-2}$ has the form of Eqs (9) and (10) (see Briš and Litschmannová (2004))

$$P\left(\overline{x}_1 - \overline{x}_2\right) - s_p \cdot \left(\sqrt{\frac{1}{n_1}} + \sqrt{\frac{1}{n_2}}\right) \cdot t_{1-\frac{\alpha}{2},\, n_1+n_2-2} < (\mu_1 - \mu_2) < s_p \cdot \left(\sqrt{\frac{1}{n_1}} + \sqrt{\frac{1}{n_2}}\right) \cdot t_{1-\frac{\alpha}{2},\, n_1+n_2-2} = 1-\alpha \quad (9)$$

$$T_2 = \frac{\left(\overline{x}_1 - \overline{x}_2\right) - \left(\mu_1 - \mu_2\right)}{s_p \cdot \left(\sqrt{\frac{1}{n_1}} + \sqrt{\frac{1}{n_2}}\right)}, \text{ where} \quad s_p = \sqrt{\frac{(n1-1)^2 s_1^2 + (n2-1)^2 s_2^2}{n_1+n_2-2}} \quad (10)$$

2.8 Kolmogorov–Smirnov's test

The theoretical distribution (normal distribution) of the given population in the case of individual tests is assumed (see previous Sections 2.1–2.7). Good compliance tests are needed to verify that this estimate is correct. The Kolmogorov–Smirnov test is applied to test the agreement between the sample and theoretical distribution. It is used to verify the hypothesis that the selection given comes from a distribution with a continuous distribution function $F(x)$, whereas the function must be fully specified (see Briš and Litschmannová (2004)).

2.8.1 Selection of zero alternative hypothesis

$$\mathbf{H_0}: F(x) = F_0(x)$$
$$\mathbf{H_A}: F(x) \neq F_0(x)$$

where $F(x)$ is the distribution function of separation, from which the random selection derives, representing a theoretical distribution function.

2.8.2 Selection of test statistics *T*(*X*) including zero distribution

The test statistic D_n is defined as the maximum deviation of theoretical and empirical distribution function (see Eqs (11) and (12)). The selective empirical distribution function $F_n(x)$ is given as

$$F_n(x) = 0, = \frac{i}{n} = 1$$

$$T(X) = D_n = \sup|F_n(x) - F_0(x)| = \max\left(D_1^*, D_2^*, \ldots, D_n^*\right) \tag{11}$$

$$\text{where}: D_i^* = \max\left\{\left|F_0(x) - \frac{i-1}{n}\right|, \left|\frac{i}{n} - F_0(x_i)\right|\right\}, \quad i = 1, 2, 3, \ldots, n \tag{12}$$

$$F_0(x) = \frac{\bar{x} - \mu}{s} \tag{13}$$

3 Data measurement, goal setting, evaluation

The duration of the plastering work process depends on the mean value of the performance and its deviation. The aim of the research is to determine the upper and lower limits of performance with 95% reliability on the basis of the collection of a certain number of data.

By evaluation of these random attempts in the form of everyday worker performance, a probability estimate was achieved regarding the completion of the given process. By implementing the lower and upper performance values, we obtain an optimistic and pessimistic performance variant with the shortest and longest duration of the plastering process. The given statistical evaluations are performed at the beginning of the construction processes so that it is possible to implement personnel measures to ensure the originally planned construction deadlines. A typical floor is shown in Figure 1.

3.1 Productivity of plastering works

The subject of the assessment is 15-mm-thick lime–gypsum plaster coatings, which are made on the surfaces of the masonry of the perimeter cladding and internal partitions on the 1st floor–7th floor, whose performance standard, with regard to standardized mean value μ, is based on the CONTEC database (see Jarský (2000), 0.73 m^2/h), which represents an output of 10.95 m^2/shift. Concrete surfaces of ceiling structures and walls are treated with a 5-mm-thick coating, the performance standard of which is 42.1 m^2/shift/work (0.19 Nh/m^2) Since the mutual ratio of the areas treated with a trowel of thickness of 5 mm to the area plastered with lime plaster is about 1:3, the average standard hour is 0.59 Nh/m^2 and the worker's output per shift 13.6 m^2/shift/worker. A total of 32 employees will be deployed to carry out this process, with four plastering platoons with a total number of 16 employees deployed at each of the SO J34 and SO J12 facilities. The minimum work queue is two typical floors, where eight plasterers will work in each of them (see Table 1). The last work queue representing the 7th floor is occupied by eight workers and the rest is deployed in the underground floors to complete residual plastering work.

3.1.1 Estimate of the range of the performance mean value μ including standard deviation *s*

To achieve ≥30 random trials, the performance of 16 workers will be recorded in two consecutive shifts, giving 32 pieces of data on daily performance. As in the case of masonry structures, the plastering works of the SO J34 and SO J12 buildings are carried out simultaneously, therefore different working capacities must be used here, assuming different ranges of mean values μ.

A) Building J34
In Table 2, 32 random trials are recorded in the form of worker performances in two consecutive work cycles. We have available ≥30 random trials, so we can start from the normalized normal distribution and the Moivre–Laplace theorem (see Briš and Litschmannová (2004)).

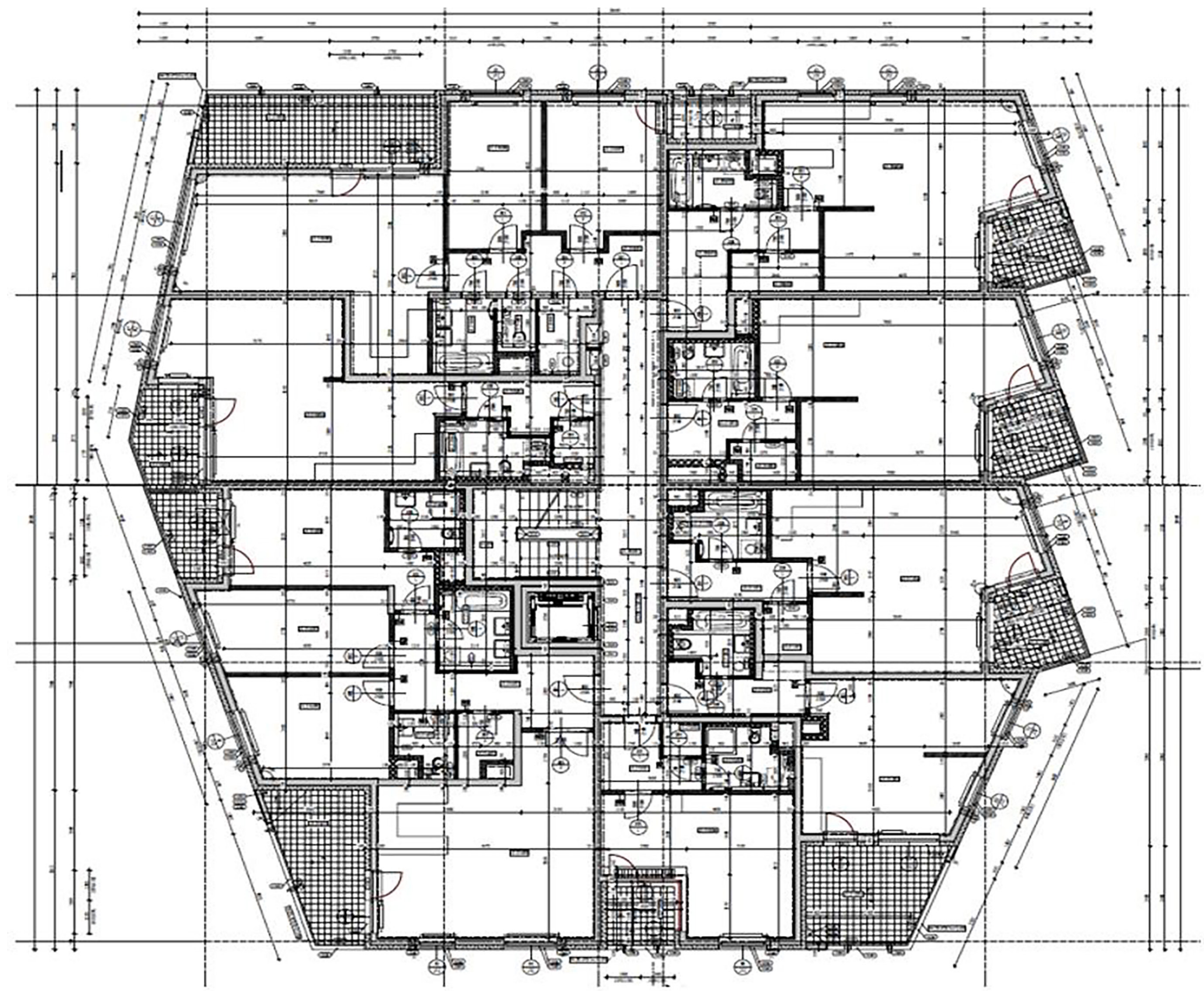

Fig. 1: Type of above-ground floor of building J1–J2.

Tab. 1: Plastering works – Distribution of number of plasterers in work queue no.1

Floor	No. of plasterers	Overall performance plan m²/sm	Overall performance plan m²/month
1	8	87.6	1,752
2	8	87.6	1,752
3	–	–	–
4	–	–	–
5	–	–	–
6	–	–	–
7	–	–	–
Σ	16	175.2	3,504

- **Kolmogorov–Smirnov test**

The theoretical interpretation given in Sections 2.1–2.7 is based on the assumption that the results of randomized trials given according to Table 2 are subject to normal distribution. The proof concerning estimation is that given the subject's normal distribution is decisive of how to choose the way of the respective calculation. With the help of good compliance tests, as it was mentioned, the assumption regarding distribution of the population is to be verified. The application of the Kolmogorov–Smirnov test will prove this assumption to enable calculation according to interpretation according to Sections 2.1–2.7, whose principle is based on hypothesis (see Briš and Litschmannová (2004)).

3.1.1.1. Selection of zero and alternative hypothesis

$$\mathbf{H_0}: F(x) = F_0(x)$$

where $F_0(x)$ is the distribution function of normal distribution with the parameters μ = 11.5; s = 0.83 is based on the assumption that the data are derived from N (11.5; 0.832).

Tab. 2: Plastering works SO J 34

Worker no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Performance/shift	12	11	10	12	11	13	12	11	10	12	11	10	13	10	12	11
Worker no.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Performance/shift	12	11	11	12	11	13	12	11	12	12	11	12	13	12	10	12

$\mathbf{H_A}: F(x) \neq F_0(x)$

where $F_0(x)$ is the distribution function of normal distribution with the $\mu = 11.5$; $s = 0.83$ based on the assumption that the data are not derived from $N(11.5; 0.83^2)$.

3.1.1.2. Selection of the test statistic *T*(*X*) including zero distribution

Test statistic D_n is defined as the maximum deviation of the theoretical and empirical distribution function.

When calculating the values of distribution functions and their deviations given in Table 2, mathematical relations (11)–(13) (Section 2.7) will be used (see Briš and Litschmannová (2004)).

$$F_{1(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 10}{0.83} = 1.807 \tag{14}$$

see label no 1 [16] $\rightarrow 1 - 0.964 = 0.036$

$$F_{2(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 10}{0.83} = 1.807$$

see label no 1 [16] $\rightarrow 1 - 0.964 = 0.036$

$$F_{9(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 11}{0.83} = 0.602$$

see label no 1 [16] $\rightarrow 1 - 0.726 = 0.274$

$$F_{10(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 12}{0.83} = -0.602$$

see label no 1 [16] $\rightarrow = 0.726$

$$F_{11(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 12}{0.83} = -0.602$$

see label no 1 [16] $\rightarrow = 0.726$

$$F_{12(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 12}{0.83} = -0.602$$

see label no 1 [16] $\rightarrow = 0.726$

$$F_{13(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 12}{0.83} = -0.602$$

see label no 1 [16] $\rightarrow = 0.726$

$$F_{14(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 12}{0.83} = -0.602$$

see label no 1 [16] $\rightarrow = 0.726$

$$F_{15(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 13}{0.83} = -1.807$$

see label no 1 [16] $\rightarrow = 0.964$

$$F_{16(x)} = \frac{\bar{x} - \mu}{s} = \frac{11.5 - 13}{0.83} = -1.807$$

see label no 1 [16] $\rightarrow = 0.964$

$$T(X) = D_n = \sup |F_n(x) - F_0(x)| = D_{pro\ i/n = i/n - F(x)} \tag{15}$$

$$= D_1 = 0.063 - 0.036 = 0.027$$
$$= D_2 = 0.125 - 0.036 = 0.089$$
$$= D_{15} = 0.875 - 0.938 = -0.026$$
$$= D_{16} = 1 - 0.964 = 0.036$$

$$T(X) = D_n = \left| F(x) - \frac{i-1}{n} \right|$$

$$= D_1 = 0.036 - 0 = 0.036$$
$$= D_2 = 0.036 - 0.063 = -0.027$$
$$= D_{15} = 0.964 - 0.875 = 0.089$$
$$= D_{16} = 0.964 - 0.938 = 0.026$$

$$D_i^* = \max\left\{ \left| F_0(x) - \frac{i-1}{n} \right|, \left| \frac{i}{n} - F_0(x_i) \right| \right\} pro\ i = 1, 2, 3, \ldots, n \tag{16}$$

$$= \max\{0.036\ ; 0.036\} = 0.036$$
$$= \max\{0.036\ ; 0.036\} = 0.036$$
$$D_9^* = \max\{0.289; -0.226\} = 0.289$$
$$D_{16}^* = \max\{0.036; -0.026\} = 0.036$$

3.1.1.3. Calculation of *p*-value

$\mathbf{H_A}: F(x) \neq F_0(x)$ $p\text{-value} = 2.\min\{F_0(x_{OBS}); 1 - F_0(x_{OBS})\}$

$F_0(x_{OBS}) = F_0(0.289)$

$F_0(0.289) < 0.90$, see label no 4 (see Litschmannová (2015))

$0.1 < 1 - F_0(0.289)$

$p\text{-value} > 0.2$

It follows that the *p*-value is >0.2, that is, we do not reject the zero hypothesis, that is, data in the form of crew performances are subjected to normal distribution. The calculation of selection characteristics will take place in accordance with that given in Section 2.1. In case the normal distribution is not confirmed by utilizing the above mentioned test, it would not be possible to proceed according to the theoretical process stated in Sections 2.1–2.7. The calculation process corresponds to the conclusion of the test concerning the specific distribution (see Litschmannová (2015)).

- **Sample characteristics:**

$$\text{Sample average}: \bar{x} = \frac{\sum_{i=1}^{12} x_i}{n}$$

$$= \frac{(12+11+10+12+11+13\cdots13+12+10+12)}{32} = 11.5$$

$$\text{Sample standard deviation}: s = \sqrt{s^2} = \sqrt{0.69} = 0.8$$

$$\text{Sample range}: s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$$

$$= \frac{(1.6-1.61)^2 + (1.5-1.61)^2 + \ldots + (1.5-1.61)^2 + (1.7-1.61)^2}{32}$$

$$= 0.69$$

$$P\left(\bar{x} - \frac{s}{\sqrt{n}} \,.\, z_{1-\frac{\alpha}{2}} < \mu < \bar{x} + \frac{s}{\sqrt{n}} \,.\, z_{1-\frac{\alpha}{2}}\right) = 1-\alpha$$

$$P\left(11.5 - \frac{0.83}{\sqrt{32}} \cdot 1.96 < \mu < 11.5 + \frac{0.83}{\sqrt{32}} \cdot 1.96\right) = 1-\alpha$$

$$11.21 < \mu < 11.79$$

- Reliability of interval estimate: 1–α = 0.95, that is, the level of significance α = 1–0.95 = 0.05, $\frac{\alpha}{2}$ = 0. 025, 1 – α/2 = 0.975, $z_{0.975,}$ = 1.96 (see Table 2). Selected quantiles of the standardized normal distribution (see Litschmannová (2015)).

|AD A) Evaluation

The interval estimate of the range of the mean value with 95% confidence ranges from 11.21 m² to 11.79 m², while the center of this range represents the value of 11.5 m². In relation to the standardized CONTEC database, this value is 15% lower, which requires a reinforcement of two workers, provided that the contractual HMG is complied with.

B) Building J12

To secure the plastering work on this building, 16 workers were deployed in two consecutive work cycles. These are different work crews, so it can be assumed that different ranges of mean values, μ, will be obtained. Even in this case, we can start with respect to the number of recorded powers ≥30 from the standardized normal distribution and the principle of Moivre–Laplace theorem. Based on the calculation of the two-sided interval with 95% confidence, it was proved by calculation that the estimate of the range of the mean value ranges from 10.91 m² to 11.52 m², while the mean of the range relative to the CONTEC database is 17.5% lower. To eliminate this decrease in performance, it is proposed to strengthen the capacity by three plasterers.

3.1.2 Estimate of interval of reliability of standard deviation

In this section, the calculation of the left-hand side interval estimate with 95% reliability for the scattering and standard deviation of the plastering process will be performed, that is, the smallest possible area of plaster performed by one worker per shift. Left-hand deviations will be calculated due to the deployment of different work crews on SO J34 and SO J12 for each building separately.

A) Building J34 – Left-hand interval of reliability of standard deviation

Our starting point follows from the results of the calculation of the range of mean value of performance of plastering works (see Section 2.1. A). The mathematical relationship (5) (see Section 2.3) will be used for the calculation, whereas $s^2 = 0.0061$, $n = 32$:

$$P_1\left(\frac{32-1}{19.3} \,.\, 0.0061 < \sigma^2\right) = 1-\alpha \tag{5}$$

$$P_1(0.0098 < \sigma^2) = 1-\alpha$$

$$(0.099 < \sigma) = 1-\alpha$$

- Reliability of interval estimate: 1–α = 0.95, that is, the level of significance α = 1–0.95 = 0.05, = 0.95, $z_{0.95,\ 31}$ = 19.3 (see Table 3). Selected quantiles χ^2 of distribution with *ν* degree of latitude (see Litschmannová (2015)).

AD A) Evaluation

We can state with 95% reliability that the maximum left-hand side standard deviation of the sample average is 1.053 m². Incorporating this data into the construction software CONTEC, we get the longest period of plaster work,

Tab. 3: Calculation of observed value X_{OBS} – originally wrongly numbered 2

Ordered		Series (i)		(í–1)/n	í/n	*F*(*x*)	*D* pro	*D* pro	D
Values x							i/n	(í–1)/n	
10		1		0	0.063	0.036	0.027	0.036	0.036
10		2		0.063	0.125	0.036	0.089	−0.027	0.089
11	9	0.5	0.563	0.274	0.289			−0.226	0.289
12	10	0.563	0.625	0.726	−0.101			0.163	0.163
12	11	0.625	0.688	0.726	−0.038			0.101	0.101
12	12	0.688	0.75	0.726	0.024			0.038	0.038
12	13	0.75	0.813	0.726	0.087			−0.024	0.087
12	14	0.813	0.875	0.726	0.149			−0.087	0.149
13	15	0.875	0.938	0.964	−0.026	0.089	0.089		
13	16	0.938	1	0.964	0.036	0.026	0.036		

$X_{OBS} = 0.289$.

that is, the latest permissible start of the next process, which are tiling works (see Jarský (2000)).

A) Building J12 – Left-hand interval of reliability of standard deviation

It was proved by calculation with 95% reliability that the maximum left-hand side standard deviation of the sample average is 1.148 m^2. Based on this data, and using the CONTEC construction software, we are able to calculate the latest allowable starts of the following processes, while the earliest possible start of the process would be the result of calculating the right-hand side confidence interval of the standard deviation, as stated in Jarský (2000, 2019).

3.1.3 Relative Frequency

A) Building J 34

This section is dedicated to the investigation of procentual probability of fulfillment the range of mean value μ pursuant to Section 2.1. For the calculation, mathematical formulas will be used (see Section 2.2); see Briš and Litschmannová (2004) as

- Sample sets: $p = \frac{29}{32} = 0.91$
  $n = 32$

$$P\left(0.91 - \sqrt{\frac{0.91(1-0.91)}{32}} \cdot 1.96\right) < \pi < \left(0.91 + \sqrt{\frac{0.91(1-0.91)}{32}} \cdot 1.96\right) = 0.95 \quad (4)$$

$$P\left(0.91 - \sqrt{0.0025} \cdot 1.96\right) < \pi < \left(0.91 + \sqrt{0.0025} \cdot 1.96\right) = 0.95$$

$$0.817 < \pi < 1.008$$

- Reliability of interval estimate: 1–α = 0.95, that is, the level of significance α = 1–0.95 = 0.05, $\frac{\alpha}{2} = 0.025$, $1 - \alpha/2 = 0.975$, $z_{0.975,} = 1.96$ (see Table 2). Selected quantiles of the standardized normal distribution (see Litschmannová (2015)).

AD A) Evaluation

It was proved with 95% reliability that the percentage probability of meeting the mean range estimate values of performance of individual workers for a period of three work cycles – 6 days (see calculation Section 3.1.1. A) ranges from 81.7% to 100.8%, with the middle of this range being 91.2%.

B) Building J12

The test of meeting the range of the mean value of plastering works will also be performed in the case of this building. Based on the data (see Section 3.1.1 B), where the estimate of the range of the mean value μ of output per 1 plasterer and shift is from 10.91 m^2 to 11.52 m^2 of plaster area. The calculation and evaluation methodology is the same as in the previous case. Based on the calculation, the fulfillment of the estimate of the range of the average value of the crew's performance for the period of three work cycles – 6 days ranges from 85.6% to 102.3% with a 95% probability. The middle of this range represents a value of 93.9%, which is an above-average fulfillment of the lower limit of the performance standard. In comparison with SO J34, the fulfillment of the average value of power at this building is higher by 2.7%.

3.1.4 Interval estimate of difference between mean values of two populations

The subject of this section is the assessment of the differences in the mean values achieved in the execution of plastering work on buildings SO J34 and SO J12. In view of the shortfall of mainly tiling capacity, it is necessary to verify to what extent the calculated estimates of the range of mean values according to Section 3.1.1. A), B) may affect the possible start of works on the following construction processes. As can be seen from these calculations, the middle of the range of the mean value of the workers performance on SO J34 is 2.5% higher than the middle of the range on SO J12. The task of the interval difference test is to evaluate whether this is a statistically significant difference, and thus to confirm the legitimacy of the proposed capacity reinforcement in relation to compliance with the commencement of PSV work. The following procedure is in accordance with Section 2.7, according to the mathematical relations (9) and (10) as

- Sample sets: $n_1 = 32$, $s_1^2 = 0.69$, $n_2 = 32$, $s_2^2 = 0.82$, $\bar{x}_1 = 11.5$, $\bar{x}_2 = 11.2$

$$s_p = \sqrt{\frac{(n_1-1)^2 . s_1^2 \; + (n_2-1)^2 . s_2^2}{n_1+n_2-2}} = \sqrt{\frac{(32-1)^2 . \; 0.69 + (32-1)^2 \; .0.82}{32+32-2}} = 4.84 \tag{9}$$

$$P(\bar{x}_1-\bar{x}_2)-s_p \cdot\left(\sqrt{\frac{1}{n_1}}+\sqrt{\frac{1}{n_2}}\right)\cdot t_{1-\frac{\alpha}{2}\,,\, n_1+n_2-2} < (\mu_1-\mu_2) < (\bar{x}_1-\bar{x}_2)+s_p \cdot\left(\sqrt{\frac{1}{n_1}}+\sqrt{\frac{1}{n_2}}\right)\cdot t_{1-\frac{\alpha}{2}\,,\, n_1+n_2-2} = 1-\alpha \tag{10}$$

$$P(11.5-11.2)-4.84\left(\sqrt{\frac{1}{32}+\frac{1}{32}}\right). \; 1.998 < (\mu_1-\mu_2) < (11.5-11.2)+4.84.\left(\sqrt{\frac{1}{32}+\frac{1}{32}}\right). \; 1.998 = 0.95$$

$$P(0.3-4.84. \; 0.25. \; 1.998) < (\mu_1-\mu_2) < (0.3+4.84. \; 0.25. \; 1.998)$$

$$-2.12 < (\mu_1-\mu_2) < 2.72$$

- Reliability of interval estimate: $1-\alpha = 0.95$, that is, level of significance $\alpha = 1-0.95 = 0.05$, $\frac{\alpha}{2} = 0.\ 025$, $1 - \alpha/2 = 0.975$, $t_{0.975,\ 62} = 1.998$. Selected quantiles of Student's distribution with □ degree of latitude (see Litschmannová (2015)).

3.1.4.1. Evaluation

If the value of the difference $(\mu_1 - \mu_2) < 0$, it can be stated that the mean value of the output of one worker/shift, in our case the number of plastered areas square meters of walls/shift is lower on SO 34. The opposite case is when the value of the difference $(\mu_1 - \mu_2) > 0$ would then prove a higher performance of one worker/shift, the number of performed square meters of plasters on SO J34 (see Briš and Litschmannová (2004)). The interval achieves both negative and positive values, so we cannot clearly prove which of the mean values of the range of plastering work on SO J34 and SO J12 is higher. Based on the mutual ratio of the range of negative and positive values of the interval estimation, we can estimate with 95% probability the magnitude of the mean values μ_1 and μ_2. The mutual ratio of the negative and positive parts of the interval is very tight. The negative values occupy 43.8% of the range of the interval estimate of the difference between the mean values. With 95% reliability, we can therefore say that the size of the range of mean values of plaster work performance on SO J34 will reach slightly higher values than on SO J12, which corresponds only a slight increase in capacity on SO J12 by one worker.

4 Climatic impacts on work productivity

In the next steps of the process, an estimate of the probability of occurrence of days with unfavorable climatic conditions in one of the months December 2020–March 2021 will be made. Based on meteorological data for the past 5 years, we must consider the existence of the number >2 days or >3 days, especially in January 2021 and February 2021, where due to lower temperatures work will be interrupted, resulting in a decrease of the middle of the mean range μ in the given months. Based on the thus calculated probability of possible interruption of work, personnel measures will be proposed to ensure achievement of the milestones of the construction.

4.1 Probability of occurrence of days with unfavorable climatic conditions

To calculate the probability of occurrence of days with unfavorable climatic conditions, the Poisson process was applied, which describes the occurrence of random events during a fixed time interval (see Briš and Litschmannová (2004)). The subject of the calculation of the probability of occurrence of days with temperatures lower than −5°C will be the period from December 2020 to March 2021. Using the application of the mathematical relation (6) (see Section 2.4), the probability of an interruption in work due to adverse climatic influences will be calculated as

- Mean value: EX = λt = 13/4 = 3.25
- Probability function:

$$P(X \geq 3) = 1 - P(X < 3) = 1 - [P(X=0) + P(X=1)]$$
$$= 1 - \sum_{k=0}^{1} \frac{(\lambda t)^k . e^{-\lambda t}}{k\,!} = 1 - \frac{3.25^3 . 2.718^{-3.25}}{3!} = 71.5\% \quad (6)$$

4.1.1 Evaluation

The probability of occurrence of >3 days in one of the months between December 2020 and March 2021 is 71.5%, which confirms the need for a drastic increase in capacity in January 2021 to February 2021. For these reasons, it is proposed to strengthen the work capacity at SO J34 and SO J12 from January 2021 to February 2021 by three plasterers to ensure time slippages caused by interruption of construction for days with unfavorable climatic conditions. In December 2020, an increase in capacity will suffice for reasons of an 80.8% probability of interruption of work >2 days by only two workers, when working hours will reduce work hours by approximately 10% as a result of days with unfavorable climatic conditions.

5 Test of hypothesis

In this section, the hypothesis test will decrease the performance of the plasterer in the month December 2020–March 2021, when it is expected, based on the probability calculation (see Section 2.4) of a greater number of days with unfavorable climatic conditions, if this is a statistically significant reduction in the range of the mean value μ. In the case of the test of the relative frequency hypothesis, the zero hypothesis H_0 represents the equilibrium state, which corresponds to the calculation (see Section 3.1.3. A), the alternative hypothesis H_A and then the value, which corresponds to the decrease in the fulfillment of the mean value in the winter months. The performed test of the mean value hypothesis compares the zero hypothesis H_0 corresponding to the performances according to the CONTEC database with the alternative hypothesis H_A equal to the calculated value of the estimate of the mean range according to Section 2.1. A), B)., for individual buildings SO J34 and SO J12, where deviations of performance are recorded due to the deployment of different work crews.

A) Test of hypothesis of relative frequency

For calculation of the probability of occurrence of unfavorable climatic conditions (see Section 2.4) demonstrated in the months of December 2020–March 2021, a 71.5% probability of occurrence of >3 days with a temperature of < −5°C, which represents an approximately 15% interruption of total working hours per month, if we assume the number of 20 shifts/month. For the SO J34 building, as stated in Section 3.1.3. A), the relative frequency of fulfillment of the mean value μ ranges from 81.7% to 100.8%. The middle of the range of the relative frequency of filling the mean value μ is 91.25%. Theoretically, the middle of the relative frequency range can then decrease by 15% from 91.25% to a value of about 77.6% due to a work break >3 days due to unfavorable climatic conditions. These decreases will be verified by a pure significance test, whether it is a statistically significant figure requiring capacity increasing.

In the months of December 2020 and March 2021, it is assumed that work will be interrupted for >2 days with a probability of 80.8% (see Section 2.4). This interruption of work represents a decrease in the relative frequency of achieving the range of the mean value by 10%. The middle of the range of the mean value represents a value of 91.25% according to Section 3.1.3 A), a reduction of the middle of the range by 10% then represents a value of 82.1%. Both decreases in the relative frequency of 10% and 15% will be verified by a pure test of significance, to see whether this is a statistically significant figure compared with the middle of the range of relative frequency (see Section 3.1.3 A), which confirms the need to implement crew measures. We assume that the relative frequency is subject to a normal distribution, then the calculation will be performed in accordance with Section 2.5 using mathematical relations (7). To illustrate, the decrease in the relative frequency of performance the range of the mean value is given as μ by 10%.

a) Decrease by 10%

- Input data: $p = 82.1\% = 0.821$, n = 32
- Setting of zero and alternative hypothesis.
- H_0: π = 0.912 – zero hypothesis (balanced state), H_A: π < 0.912 – alternative hypothesis.
- Choice of test criterion and determination of its zero distribution (see Eq. (7)):
- Calculation of the value of test statistics – x_{OBS}.

$$x_{OBS} = P_{1H0} = \frac{p - \pi_0}{\sqrt{\pi_{0(1-\pi_0)}}} . \sqrt{n} = \frac{0.821 - 0.912}{\sqrt{0.912(1-0.912)}} . \sqrt{32}$$
$$= \frac{-0.091}{\sqrt{0.08}} . 5.66 = -1.821$$

- Calculation of p-value.

$$H_A = p < 0.912 \; p\text{-value} = F_0\left(x_{OBS}\right)$$

p-value = ϕ (–1.821) = 1 = ϕ (1.821) = 1–0.966 = 0.03, ϕ (0.03) = 0.997 viz. Table 1 (see Litschmannová (2015)).

Distribution function of standardized normal distribution.

$$\phi\ (x) \text{ pro } x > 0,\ 0.01 < p\text{-value} < 0.05$$

Evaluation AD A)

In the case of a decrease of the mean value range by 15%, based on the calculation of p-value = 0.003 < 0.01, it was proved that the decrease in the mean value range of the relative frequency of fulfillment of the mean value from 91.2% to about 77.6% is statistically significant. For these reasons, the strengthening of plastering capacities by 15% in January and February 2021 is a necessary step, from the original 18–21 workers on SO J34 and from 19–22 plastering workers on SO J12, so that the original partial deadlines according to the Construction Schedule are met.

For a decrease in the middle of the mean value range of 10% (see Section 2.5), we do not reject the zero hypothesis because of the value of p-value = 0.03 which lies in the middle of the interval (0.01 < p-value < 0.05) (see Litschmannová (2015)). By extending the scope of the examined population by adding data collection from the next cycle of 32 random trials (3 shifts, n = 64), where the relative frequency of fulfillment of the mean value range remains unchanged, we get x_{OBS} = –2.57 sp – value = 0.005 < 0. From this, it follows that the decrease in the mean value of the range of relative frequency of fulfillment of the mean value 91 from 91.2% to the value of about 82.1% represents a statistically significant value, confirming the need to implement personnel measures, as proposed in the previous sections. It is therefore necessary to step up the strengthening of plastering capacities in January 2021 and March 2021, from the original 18 to 20 at SO J34 and 21 workers at SO J12, so that the original construction deadline is met.

B) Test of mean value hypothesis

In this subsection, due to the shortening of the scope of calculations, only the mean value of the worker's performance on SO J34 is tested, the mean of which is 2.5% higher compared which SO J12. If the performed hypothesis test proves that the data calculated based on an estimate of the range of the average value of the performance of a plasterer at SO J34 (according to Section 3.1.3 A) represent a statistically significant decrease, then the hypothesis test examining the object SO J12 will no longer be performed. The course of the population of mean values μ of the object SO J34 has a normal distribution. According to the standardized CONTEC database, the standardized mean value μ for plastering work represents a capacity of 13.6 m^2/shift. A sample average of the output of 32 masons was calculated by random sampling $\overline{x}$ = 11.5 m^2 with a standard deviation s = 0.83. The equilibrium state H_0 equal to the worker's output of 13.6 m^2/shift is compared with the alternative hypothesis H_A representing the value of the sample average = 11.5 m^2 of worker's output per shift. The result of the test will be a decision as to whether the value of the sample average is a statistically significant decrease, requiring capacity strengthening. Calculations will be performed according to Section 2.1, 2.7 and mathematical relations (8)

Evaluation AD B)

Using the test hypothesis of the mean value for plastering work, the p-value = 0.9995 < 0.01 was calculated. In accordance with the provisions of Section 2.6, we reject the zero hypothesis. We can therefore state that the worker's performance of plastered surface per shift compared with the standardized mean value according to the CONTEC database is a significantly statistically lower value. This test confirms the need to bolster plastering capacities according to Section 3.1.1 A), to ensure that the work is performed according to the time schedule dates of work.

6 Comparison planned and real values of productivity

The decrease in labor productivity was proved to be statistically significant (see the research in Section 5 A) and B), therefore the data of labor productivity were implemented into the construction software CONTEC in order to determine the key delay. It was proved that the optimistic performance variants of plastering execution evince a decrease of 11% compared with the time standard of the CONTEC database.

Figure 2 shows the duration difference of the individual processes among the optimistic, pessimistic, and planned variants of execution according to the construction software CONTEC. The performance decrease has been identified in the case of other processes studied – masonry, tiling, and facade work; this causes an extension of the duration of these processes which influence the construction deadline (see Figure 2). If the personnel

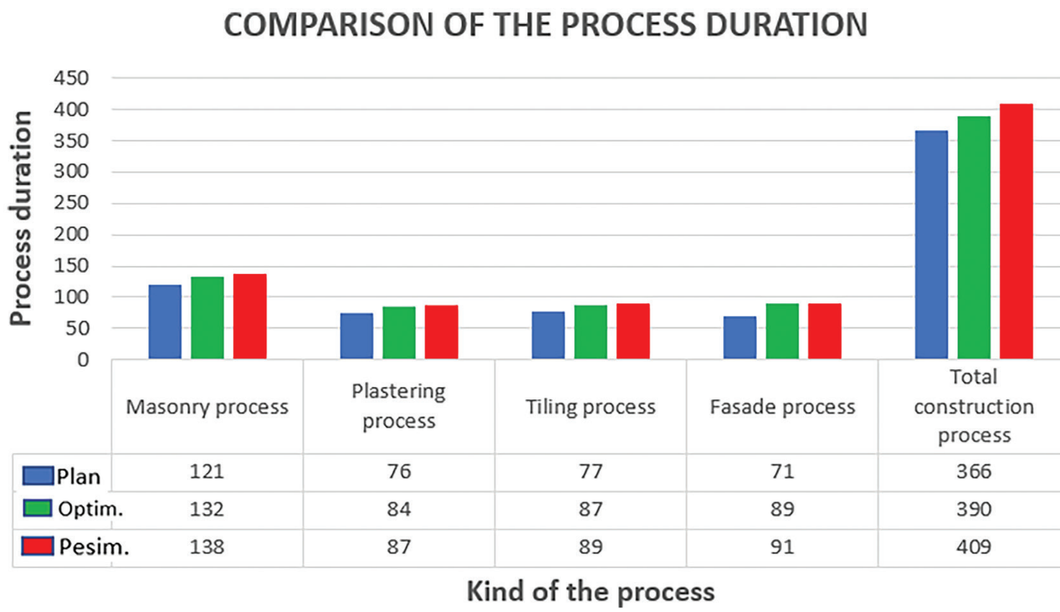

Fig. 2: Comparison of process duration.

measures – increase of capacity in compliance with the calculation results of the statistical analyses implemented into the construction software CONTEC – were not taken, the total duration of the residential complex in Prague 13 West City, Klementova Street would be extended by 24 days (see Figure 2).

7 Discussion

The most common, currently applied way of managing construction production is to monitor its progress using construction software such as Primavera or MS Project. However, this method of management has a number of shortcomings. The main disadvantages include, for example, delayed signaling of abnormal deviations of construction costs from the planned data, which is mainly caused by noncompliance with the performance standard, which is implemented in the above-mentioned construction software.

One of the main objectives of this study is creation and update of database of the desired construction process performance which are implemented into the construction software in such a way that the most precise prediction of duration of the specific process is possible. Based on the measurements and further statistical analysis the productivity of plastering works at SO J34 was minimum 11.21 m^2/shift and maximum 11.79 m^2/shift, which is a 15% lower value compared with the data of the CONTEC database. The productivity at the SO J12 site corresponds to minimum 10.91 m^2/shift and maximum 11.52 m^2/shift. Comparison between the values found in CONTEC and the measured values show that the performance is lower by 17.5%. The mean value of the middle of productivity range is 11.35 m^2/shift – representing a decrease of 16.3% compared with the CONTEC database. A comparison of the achieved productivity of plastering works at the construction sites of the same volume located in the territory of the previous Czechoslovak Republic within the past 5 years has been carried out and approximately the same values have been found. For example, the productivity performance measured at the housing project Jegeho Alej Bratislava is higher by 7% and the productivity measured at the housing project Prosek Praha is 3% higher compared with the productivity achieved at SO J34 and SO J12, Klementova St. Praha. On the other hand, the values measured at the housing project Vsetin, which is of a smaller volume, were 18% lower, which was caused by the above-mentioned volume and lower frequency of repeated works. Studies by Western authors make use of various methods of plastering works productivity measuring, for example, the data envelopment analysis (DEA), described by Gerek et al. (2016), which makes use of a model BCC. The performance of 40 working groups was evaluated using this method and the mean value of performance represents a 45.4 m^2/group/shift, which corresponds to the output of 9.1 m^2/1 worker (in the case of a work group consisting of five workers). If we compare the performance 11.35 m^2 of the construction site Klementova St. Praha, we can see that the productivity performance is 19.9% lower. However, it is necessary to stress out that the productivity of 11.35 m^2 includes plastering of wall and ceiling constructions that were treated with a 5-mm-thick coating with a higher performance value (see Section 3.1). If we evaluate the productivity of wall plastering, as was done by Gerek et al. (2016), the performance value corresponds to 9.08 m^2, which is approximately the same value. Idiake and Ikemefuna (2014) deal with the productivity of plastering works using the conceptual (site-based) model. The statistical analyses proved the fulfillment of the time schedule 1.164/ Nh/m^2; the planned time schedule was equal to 0.84 Nh/ m^2, which is at a 16% lower level of the time schedule compared with the CONTEC database. The achieved productivity of 6.708 m^2/shift represents a 25% lower productivity compared with the performance at the construction sites located in the Czech Republic. Assuming the fulfillment of the time schedule 0.84 Nh/m^2 the performance would be equivalent as in the two previous cases. The equivalent performance of 9.04 m^2/shift was achieved in terms of exterior brick wall plastering, based on the study carried out by Monkaew and Nawalerspunya (2015). Abdullah et al. (2019) evaluate the performance by ANOVA test of the interior gypsum plastering in terms of four different construction units in KRG. The achieved productivity performance 13.3–15.0 m^2/shift corresponds to the performance of a 12-h working time, that is, the performance of 9.3 m^2/ shift corresponding to the standard 8-h working time. The results of performance productivity of plastering in Nigeria deviate depending on the location and qualification of the workers undertaking the works. Based on the work of Olomolaiye and Ogunlana (1989), our performance value corresponding to 8 h of working equals to 9.31 m^2, which matches the previous performance, while Olomolaiye and Ogunlana (1989) found and evaluated using ANOVA test the performance of 2.86 m^2/h, which represents the performance of an almost 20 m^2/shift. Such an exceptional performance might occur, however, depending on many factors such as the type of construction, professional competence of the workers, or the technology of plastering realization. The research available to date shows that the productivity performance of the specific process is about 9 m^2/shift – representing the performance that is necessary to apply in the planning process.

The proposed method of monitoring the construction process eliminates this main shortcoming by being based on the collection of real performance data in the initial phase of the given construction activity, based on which the probability of its completion and thus of the entire construction is predicted with 95% accuracy, using a relative frequency test based on the principle of Bernoulli's theorem. By determining the upper and lower limits of performance, the shortest and longest execution time of a given process can be defined, which is called an optimistic or pessimistic variant of construction execution based on a number of foreign literatures.

8 Conclusion

In this study, statistical analyses of the estimation of the range of the mean value of performance with 95% reliability at the beginning of the plastering work processes were performed, including follow-up tests. The CONTEC-automated construction preparation system, in combination with statistical methods, provides a possibility of determining the probability of construction work completion time, based on mean values of performance and standard deviations and deployed number of work crews, as well as on the basis of technological connections.

The achieved time schedule at the construction site, that is, the mean value of the performance that is implemented into the construction software CONTEC is affected by a variety of factors. A negative factor, affecting the quality and productivity of the undertaken work is decreasing professional competence of the workforce focusing on the plastering works. The results further show that there is a direct correlation between the laboriousness of the construction process and decrease of performance. The main reason for non-fulfillment of the planned values is a high level of laboriousness, especially in the case of two-coat plaster. The decrease in laboriousness of work as well as the increase in the plastering performance can be achieved by a technology modification of plastering work – one-coat plaster replacing a two-coat plaster, increasing the level of mechanization (e.g., machine plastering). In addition to the professional competence, technological procedure, an important role is played by the factor of technical equipment, including transport mechanisms ensuring horizontal and vertical transport (use of crane, hydraulic cart) which directly affect the number of workers undertaking the process and at the same time the productivity performance. The research carried out at the individual construction sites proved that the type and size of the construction unit and climatic conditions influence the mean value of performance.

Based on these facts, it is recommended to the contractor to verify the mean values of data performance in the initial phase of main construction processes to see if the above-mentioned factors, which influence the productivity performance, did not cause a decrease in performance and related non-fulfillment of the time milestones of the construction.

Based on these statistical analyses, it is then possible to determine in sufficient time the measures necessary to meet construction deadlines, which is the main advantage compared with the traditional way of managing projects using only the construction software based on the time standard that is not met at this site. The results of the productivity performance analysis proved the decrease in performance, which meant an increase in personnel capacity, which was done at the beginning of the performance of the process in order to meet the initially planned deadline. Subsequent test of hypothesis of relative frequency rejecting zero hypothesis H_0 evaluated the performance decrease due to work interruptions caused by unfavorable climatic conditions in the period of December 2020–March 2021 as statistically significant, which meant further strengthening of plastering capacities by two workers reaching the final number of 20 plasters at SO J34 and 21 plasters at SO J12. The decrease in productivity performance is a global problem due to the lack of qualified workers.

This paper offers another option on how to increase labor productivity v případě in the case of repeated or long-lasting construction processes. Based on the experiences the increase in the individual construction performance can be achieved by the repeated monitoring, evaluation of statistical data of individual workers' performance, and use of statistical methods combined with an application of construction software. The subject of further research is an expansion of studied processes at the various types of construction. The creation of a data file and its continuous update allows more precise prediction of the time course at the bidding stage. The theoretical probabilistic methods supported by the construction software might contribute to the quality improvement of construction management.

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