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КУРУЛУШ БУЮМДАРЫН ӨНДҮРҮҮНҮН ТЕХНОЛОГИЯЛЫК ЛИНИЯСЫНЫН ИМИТАЦИЯЛЫК МОДЕЛИНИН ШАЙКЕШТИГИН ТЕКШЕРҮҮ

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ПРОВЕРКА АДЕКВАТНОСТИ ИМИТАЦИОННОЙ МОДЕЛИ ТЕХНОЛОГИЧЕСКОЙ ЛИНИИ ПРОИЗВОДСТВА СТРОИТЕЛЬНЫХ ИЗДЕЛИЙ

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CHECKING THE ADEQUACY OF THE SIMULATION MODEL OF THE PRODUCTION LINE OF CONSTRUCTION PRODUCT

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Макалада имитациялык моделдин шайкештиги түшүнүгү, имитациялык моделдердин шайкештигине карата коюлуучу талаптар жана мүнөздөмөлөр баяндалган. Курулуш тармагында колдонулган имитациялык моделдердин шайкештигин жана кемчиликтерин текшерүүнүн статистикалык ыкмаларына талдоо жүргүзүлгөн. Көрсөтүлгөн пайдалануу критерийлерин Фишера жана Стьюдента текшерүү үчүн шайкештик имитациялык моделдер технологиялык өндүрүү линиясын курулуш буюмдарын. Шайкештигин текшерүү имитациялык моделди эсептөөдө алынган натыйжалардын тууралыгын тастыктады. Пайдалануу имитациялык моделдер технологиялык процесстин курулуштук буюмдарын жасоо менен ар кандай технологиялык параметрлери жана аны салыштыруу менен реалдуу процессин аныктоого мүмкүндүк берди минималдуу айырмачылыктар алынган эсептик пайдалануу менен имитациялык моделдер жана реалдуу мааниде алынган эксплуатациялоо процессинде техникалык системасын, деп тастыктайт окшоштук имитациялык моделдер жана реалдуу объекттин. Алынган баа подобия имитационной моделдер болот эске алынууга караштуу тиражировании программалык продуктуну «Курулуш буюмдарын өндүрүүнүн технологиялык линиясынын имитациялык модели».

Негизги сөздөр: *шайкештиги, критерийи, имитациялык модель, параметрлер, статистикалык ыкмалар, сыпайылык, тактык, натыйжалуулук, окшоштук.*

В статье описано понятие адекватности имитационной модели, требования и характеристики, предъявляемые к адекватности имитационных моделей. Проведен анализ используемых статистических методов проверки адекватности имитационных моделей в строительной отрасли их преимущества и недостатки. Показано использование критериев Фишера и Стьюдента для проверки адекватности имитационной модели технологической линии производства строительных изделий. Проверка модели на адекватность, подтвердила, что результаты, полученные при расчете проводимой имитационной модели, являются корректными. Использование на практике имитационной модели технологического процесса производства строительных изделий, с различными технологическими параметрами и сравнение его с реальным технологическом процессом, выявило минимальные расхождения в полученных расчетных с помощью имитационной модели и реальных показателях, полученных во время работы технологической системы, что является подтверждением степени подобия имитационной модели и реального объекта. Полученная оценка подобия имитационной модели будет учтена при тиражировании программного продукта «Имитационная модель технологической линии производства строительных изделий».

Ключевые слова*: адекватность, критерий, имитационная модель, параметры, статистические методы, корректность, точность, эффективность, подобие.*

The article describes the concept of the adequacy of the simulation model, requirements and characteristics of the adequacy of the simulation models. An analysis of the statistical methods used to verify the adequacy of simulation models in the construction industry has been carried out. The use of Fisher and Student criteria to verify the adequacy of the simulation model of the technological line of production of construction products is shown. Checking the model for adequacy confirmed the correctness of the results obtained when calculating the simulation model. The use of a simulation model of the technological process of manufacturing construction products with different technological parameters and its comparison with the real process allowed us to identify minimal differences in the calculated values obtained using the simulation model and the real values obtained during the operation of the technical system, which confirms the similarity of the simulation model and the real object. The obtained assessment of the similarity of the simulation model will be taken into account when replicating the software product «simulation model of the production line of construction products».

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***Key words**: adequacy, criterion, simulation model, parameters, statistical methods, correctness, accuracy, efficiency, similarity.*

The most important requirement for the simulation model is the requirement of its adequacy to the real object under study, relative to the chosen system of characteristics. This is usually understood to mean:

- good qualitative description of the investigated object according to the selected characteristics.

In the fields not prepared for the application of developed quantitative methods, the adequacy of the simulation model is, as necessary, only quantitative, and it is also necessary to understand poor-quality mathematization. In particular, the simulation model can detect significant qualitative characteristics of the object under study and the effect of some characteristics on others. If a simulation model may have low predictive value, but it helps to understand the structure of the problem, that is enough to develop it. Sometimes it may be that the simulation model is quantifiably inadequate due to the complexity of the object under study, but here it is necessary to bear in mind that the detected characteristics of the state help to properly orient the solution of complex tasks. Speaking about the degree of adequacy of the simulation model, it is understood as a proportion of the truth of the simulation model relative to the selected characteristic of the object under investigation, as a coefficient of relationship between the simulation model and the object under investigation. The adequacy of model should be considered only on the certain signs, characteristics taken for the main. If these characteristics are not specified, they should be implied, or clarified during the course of the study.

There is no concept «universal adequacy», because such adequacy would mean the identity of the simulation model and the object under study [1].

An adequate simulation model usually has some side adequacy, in other words it gives a correct description of the quantitative and qualitative characteristics that can be further explored in more detail. The higher the side adequacy, the wider the scope of the simulation model. The side adequacy of the simulation model increases with the enhancement of the real picture of the object under study. Therefore, simulation models with adequate physical patterns in the object under study are most promising. The definition of the adequacy of the simulation model as a scientific category can be given as follows: the simulation model is adequate to the object under study if there is a simulation (similarity) relationship between the simulation model and the object with respect to at least one pair of similar variables.

According to [2-5], the adequacy of the simulation model can be checked in several ways:

1. At the stage of simulation model development in comparison with previous state. This method is in some cases insufficient to verify the adequacy of the model;

2. Control tasks that use real system data. It is applicable when system input and output are available. The complexity and labour intensity of this method is due to the need to obtain the characteristics of a real system. Checking the adequacy of the simulation model in this way allows the developer to better assess his efforts and potential.

Adequacy can be considered as a system of characteristics represented by combinations of two systems of characteristics called correctness and reliability [1].

Correctness describes compliance of the simulation model with some formal, grammatical rules. The adequacy characteristics of the simulation model may include:

- availability of model;
- efficiency of model;
- brevity of interpretation;
- model stability to changes.

Accuracy is the correspondence of estimates of the same-name properties of the object under investigation and the model [6].

When assessing adequacy, there is a concept - the area of adequacy - the area in the parameter space, within which the errors (system of characteristics-validity) of the model remain within the permissible limits [2].

In simulation modeling, it is possible to obtain a large amount of statistical data, which allows to estimate the output data with reliable accuracy. If necessary and reliable experimental data are available or can be obtained, mathematical statistics techniques can be used to verify the adequacy of the models. To date, methods used to assess the adequacy of models in the construction industry do not always provide reliable data. For example, when evaluating discrete selection models, the method of maximum likelihood (MML) is used [1-4]. Due to the fact that the method was designed to evaluate the distribution parameters, which is not always useful for solving the tasks of the construction industry [7].

In practice, Wald criteria, likelihood ratio criteria, Lagrange multiplier criterion, Pearson c^2 criterion, Smyrnov-Kolmagorov criterion are often used to test the adequacy of models.

The Wald criterion, is one of the static tests used to check the execution of constraints on parameters of statistical models evaluated based on sample data. The disadvantage of the Wald criterion is that with a small number of observations there are low values of coefficients [7].

The likelihood ratio criterion has the same disadvantages as MML. With regard to the Lagrange multiplier

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criterion, the comparison procedure is similar to that of Wald [8].

More than 20 experimental data are needed when applying the Pearson c^2 criterion, which is not always feasible [9].

Smyrnov-Kolmagorov criterion should be used for relatively small samples and inefficiency of Pearson criterion c2, which does not always satisfy the needs of the researcher [9].

In this way, the criteria are similar to each other, but the statistics values are not always the same for the final samples. Some of the criteria may reject the hypothesis at the selected level of significance, others may speak in favor of adopting the hypothesis.

We have not found descriptions of the works using statistical criteria to check the adequacy of the object under investigation, the simulation model of the technological line for the production of construction products. In view of the above, it can be concluded that from the existing large number of statistical criteria for testing the adequacy of simulation models in the construction industry, most of them are based on the MML method, or on estimates of the significance of model coefficients, which does not guarantee compliance of the simulation model and its real object.

This makes it necessary to apply other statistical criteria to assess the adequacy of the simulation model, in particular for the object of the technological line of production of construction products.

Verification of the adequacy of the simulation model of the production line of construction products according to the criteria of Fisher and Student's.

The authors developed the software product «Simulation model of the technological line of production of construction products», the program menu in Figure 1 [10]. The result of the program calculation is the calculation of productivity of the process line of production of construction products, the need for raw materials for production of the finished product.

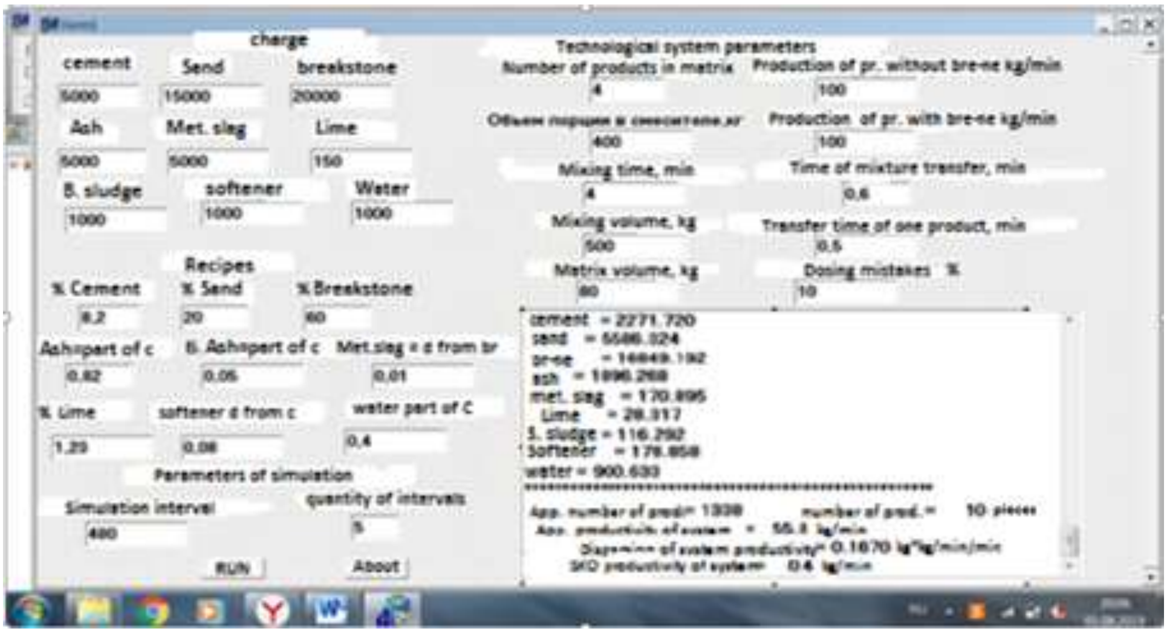

Figure 1. Menu of simulation model of process line for production of construction products.

To check the adequacy of the simulation model, use the results of operation of the software product «Simulation model of the technological line of production of construction products», window on the right in the menu, Figure 1:

Average quantity of products = 1338 pieces

Mean square deviation of products = 10 pieces

Average productivity of a system = 56.0 *kg/min*

Dispersion of productivity of a system = 0.4 *kg/min*

System performance mean square deviation = 0.*2 kg/min*

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Production characteristics of the technological line for production of construction products Table 1, hollow wall stone, were obtained during pilot production, on the process line for production of construction products in Pavlodar on the site of «Ecostronii-PV» LLP.

Table 1

Production characteristics of the technological line of construction products

Data	**Duration period, min**	**Made products, kg**	**Productivity of the line, kg/min**
22.07.19	420	23352	55,6
23.07.19	360	20124	55,9
24.07.19	360	20052	55,7
25.07.19	420	23268	55,4
26.07.19	360	20232	56,2
		Average value of productivity	55,8
		Mean square deviation of performance	0,3

Let us estimate the average value of x having a normal distribution as a result of the simulation. For calculation $M[x]$ in the model, values of random value *y*, also having normal distribution, are obtained. In this case, the simulation model will be considered adequate if in the total population $M[x] = M[y] \quad u \quad \sigma[x] = \sigma[y]$. The Fisher criterion is used to test the variance equality hypotheses, and the *t*- criterion is used to test the average equality hypothesis.

Let be obtained n_1 values of magnitude *x* and n_2 values of magnitude *y*, having a normal distribution.

In the case considered, the calculated value of *t* - criterion is determined by the formula:

$$t_p = \frac{\max\{x_{cp}, y_{cp}\} - \min\{x_{cp}, y_{cp}\}}{D\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (1)$$

where,

$$x_{cp} = \frac{\sum_{i=1}^{n_1} x(i)}{n_1},$$

$$y_{cp} = \frac{\sum_{i=1}^{n_2} y(i)}{n_2},$$

$$D(x) = \frac{\sum_{i=1}^{n1} (x(i) - x_{cp})^2}{n_1 - 1},$$

$$D(y) = \frac{\sum_{i=1}^{n2} (y(i) - y_{cp})^2}{n_2 - 1},$$

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$$Z = \frac{D(x)(n_1 - 1) + D(y)(n_2 - 1)}{(n_1 + n_2 - 2)}$$
$$D = \sqrt{Z}$$

Max{x_{av}}, min{ x_{av}} - respectively the maximum and minimum value of x_{av} и y_{av}..

The hypothesis is checked $H_0: M\left| x_{av} \right| - M\left| y_{av} \right| = 0$.

In general, against the alternative hypothesis $\max\{M[x], M[y]\} > \min\{M[x], M[y]\}$. The calculated value of the criterion t_p is compared to the table t^T (1-α, $n_1 + n_2 - 2$). Если $t_p > t^T(1-\alpha, n_1 + n_2 - 2)$, that the hypothesis H_0 is rejected . Otherwise, hypothesis H_0 it is not rejected and it can be considered that the average values of the model is adequate to the real system. Table value of t - criterion is given in [11]. This table has two parameters α - level of significance and number of degrees of freedom: $n_1 + n_2 - 2$. Level of significance α means the probability of rejecting the hypothesis while it is true. Usually is accepted α=0.05.

The Fisher-*F* criterion verifies the dispersion equality hypothesis. In our case, the calculation value of the Fisher criterion is carried out according to the formula:

$$F_p = \frac{\max\{D(x), D(y)\}}{\min\{D(x), D(y)\}} \quad (2)$$

The main hypothesis is made H_0 on the equality of dispersions in the general population $H_0 : D(x) = D(y)$.

The calculated value determined by formula (1) is compared to the table. $F^T(\alpha, n_1-1, n_2-1)$. If $F_p > F^T(\alpha, n_1-1, n_2-1)$, then the variance equality hypothesis is rejected and an alternative hypothesis is accepted H_a:

$\max\{D(x), D(y)\} > \min\{D(x), D(y)\}$.

And so we have data:

Model *X* = {55.8, 56.1, 56.1, 56,3,55,7>, *Xav* = 56.0, *ASD*=0.2, *D(x)*= 0, 04, n_1=5

real *Y* = <55.6, 55.9, 55,7,55.4,56.2>, *Yav* = 55.8, *ASD* = 0.3, *D(y)*=0,09, n_2=5

$$F_P = 0.09/0.04 = 2.25$$

From Appendix [11] we find the Fisher table criterion value.

$$F^T(\alpha, n_1-1, n_2-1) = F^T(0.05,4,4) = 6.39$$

Since the calculation value of the Fisher criterion is less than the table value (2 .25 < 6.39), the variance equality hypothesis is not rejected and the model can be considered adequate in variance. The advantage of this method is that it imposes only one constraint on the output value - it must obey only the normal law. Disadvantages include low accuracy with small sample.

In order to obtain more accurate calculations, we use the Student's criterion according to the formula:

$$t_p = \frac{\max\{x_{cp}, y_{cp}\} - \min\{x_{cp}, y_{cp}\}}{D\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (3)$$

where,

$$D = \sqrt{Z}$$

$$Z = (D(x)*(n1-1) + D(y)*(n2-1))/(n1+n2-2) \quad (4)$$

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$$Z = (0.04*4 + 0,09*4)/ 8 = 0,065, D = 0.25$$

$$t_p = (56-55.8) /(0.25 * \sqrt{0.4}) = 0.2/0.16 = 1.25$$

From Appendix [11] we find the tabular value of the Student's criterion:

$$t^T (1-\alpha, n_1 + n_2 - 2) = t^T (0.95, 8) = 1.85.$$

As $t_p < t^T$ *(1.25<1.85*), then the average equality hypothesis in the total population is not rejected and the model can be considered adequate by the average value of productivity. This method, based on Fisher 's criterion, is less sensitive to the deviation of the law of output distribution from normal.

The use of Fisher and Student's criteria to verify the adequacy of the simulation model of the process line for the production of construction products made it possible to consider the simulation model adequate to the real process with further use in calculations. The results of our calculations showed that in addition to the classical methods of assessing the adequacy of models, which allow to obtain a description of models within some limits of the law of distribution of the output value, it is possible to use the Fisher and Student criteria sufficiently to check the adequacy of simulation models, the robustness of which in view of the law of distribution is higher.

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