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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ
АКАДЕМИЯСЫ» РҚБ

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ИЗВЕСТИЯ

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DIGITAL TRANSFORMATION OF PRODUCTION PROCESSES OF ENTERPRISES FOR THE PRODUCTION OF CONSTRUCTION PRODUCTS

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Abstract. The rapid digitalization of industrial sectors raises important questions regarding the real efficiency, economic impact, and feasibility of implementing digital technologies. This study explores the digital transformation of EcostroyNII-PV LLP, a construction materials enterprise that uses technogenic waste from metallurgical and thermal power plants as alternative raw materials. The novelty of the research lies in the integration of intelligent information technologies with eco-friendly resource utilization in construction manufacturing. A simulation software tool (SMTL), developed in C++, enables dynamic modeling of production processes, raw material optimization, and performance forecasting. Concrete mixtures containing industrial waste fillers were experimentally developed, tested, and classified using statistical and mathematical analysis. The simulation results indicated the production of 1338 split bricks during a standard 8-hour shift, with a detailed breakdown of material requirements. A 5-day simulation projected weekly output at 5975 bricks. The implemented digital system demonstrated high adequacy and precision. As a result of digital integration, the enterprise achieved a 21% increase in production efficiency, a 24% cost reduction, and a 17% decrease in defective products. These findings confirm the practical value and reproducibility of digital tools in real manufacturing settings. The outcomes offer a strategic approach for enterprises aiming to enhance efficiency, sustainability, and decision-making through digital transformation. The research is beneficial for engineers, technologists, researchers, educators, and policymakers involved in construction and industrial innovation.

Keywords. digital technologies, production of construction products, technological process, management efficiency, technogenic waste.

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ҚҰРЫЛЫС БҰЙЫМДАРЫН ӨНДІРУ КӘСІПОРЫНДАРЫНЫҢ ӨНДІРІСТІК ПРОЦЕСТЕРІН ЦИФРЛЫҚ ТРАНСФОРМАЦИЯЛАУ

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Аннотация. Бүгінгі таңда бүкіл әлемде өнеркәсіп пен экономиканың түрлі салаларында цифрлық технологияларды енгізудің өсуі байқалады. Дегенмен, цифрлық технологияны енгізудің әсері бар ма, әлде бұл жай ғана сән инновациясы ма? Егер біз ғылыми ортаны алсақ, онда цифрлық технологияларды құрал ретінде пайдалану есептеу нәтижелерін өткен ғасырмен салыстырғанда әлдеқайда жылдам алуға мүмкіндік береді, сонымен қатар бағдарламалық құралдарды қолдану бұрын жинауға ұзақ

уақыт қажет болған ақпараттық деректерді алуға мүмкіндік беретін өнімдерді жасауға мүмкіндік береді. Әдетте, күнделікті, қол еңбегін болдырмау үшін бізге цифрлық технологиялар қажет. Бірақ сонымен бірге цифрлық технологияларды енгізу, әрине, ірі және шағын, орта бизнес объектілері үшін қажетті іс-шаралар екенін түсіну қажет, олар айтарлықтай үлкен шығындарды талап етеді. Цифрлық технологияларды өндіріске енгізу алынған түпкілікті нәтижелермен қамтамасыз етілуі керек, олардың мұндай іс-шаралардың жекелеген өндірістік объектіде орындылығы мен пайдалылығын бағалауға болады, бұл іс жүзінде әрдайым қол жетімді бола бермейді.

Бұл мақала металлургия секторының, жылу станцияларының қалдықтарын зерттеуге байланысты мақалалардың жалғасы. Техногендік шикізаттан толтырғыштары бар құрылыс бұйымдарын өндірудің технологиялық процесіне ақпараттық-цифрлық технологияларды енгізу нәтижелері бойынша жазылған. Мақала өнеркәсіп пен экономиканың нақты секторына цифрлық технологияларды қолданумен және енгізумен айналысатындардың барлығына, сондай-ақ ғалымдарға, инженерлерге, студенттерге, магистранттарға, докторанттарға пайдалы болады.

Түйін сөздер: цифрлық технологиялар, құрылыс бұйымдарын өндіру, технологиялық процесс, басқару тиімділігі, техногендік қалдықтар.

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ЦИФРОВАЯ ТРАНСФОРМАЦИЯ ПРОИЗВОДСТВЕННЫХ ПРОЦЕССОВ ПРЕДПРИЯТИЙ ПО ПРОИЗВОДСТВУ СТРОИТЕЛЬНЫХ ИЗДЕЛИЙ

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Аннотация. На сегодняшний день во всем мире наблюдается рост внедрения цифровых технологий в различных отраслях промышленности и экономики, что очень позитивно. Тем не менее, часто мы можем слышать как из средств массовой информации, так и от простых обывателей, есть ли эффект от внедрения цифровых технологий, или это просто модная фишка? Если брать научную среду, то использование цифровых технологий как инструмента, позволяет получать результаты вычислений намного быстрей, по сравнению с прошлым веком, более того, применение программных инструментов дает возможность создания продуктов, позволяющих получать информационные данные, для сбора которых ранее требовалось продолжительное количество рабочего времени. Как правило, цифровые технологии нам нужны для исключения рутинного, ручного труда. Но при этом необходимо понимать, что внедрение цифровых технологий – это, разумеется, необходимые мероприятия для объектов как крупного, так и малого, среднего бизнеса, они требуют достаточно больших финансовых затрат. Внедрение цифровых технологий в производство должно обеспечиваться полученными конечными результатами, по которым можно было бы судить о целесообразности и полезности таких мероприятий на отдельно взятом производственном объекте, что на практике не всегда достижимо. Представленная вашему вниманию статья есть продолжение статей, связанных с исследованием отходов металлургического сектора, тепловых станций, написана по результатам внедрения информационно-цифровых технологий в технологический процесс производствастроительных изделий с наполнителями из техногенного сырья. Статья будет полезна всем, кто занимается использованием и внедрением цифровых технологий в реальный сектор промышленности и экономики, а также ученым, инженерам, студентам, магистрантам, докторантам.

Ключевые слова: цифровые технологии, производство строительных изделий, технологический процесс, эффективность управления, техногенные отходы.

Introduction. Today no one has heard of the term ‘digitalization’. Even the company taking place in Ukraine did not do without the use of ‘digital technologies’, providing an advantage for one of the parties.

Digital technologies are necessary, their use is effective and has good prospects. From the usual point of view, digitalization is a remote control for TV, air conditioner, the ability to determine the location of your loved ones, etc. This raises interest in the application of digitalization in the real economy, how effective it is, whether the stated goals have been achieved, etc. After all, often in practice, in pursuit of new-fashioned innovations, the whole meaning of the ‘work’ carried out is lost, the goals of which were initially not achievable. The mass media of Kazakhstan quite often provide data on the number of new production facilities launched, the type of products manufactured, and the number of personnel employed, but there is no data on digital technologies introduced and used at these enterprises, production efficiency, and other key indicators.

Therefore, the authors of the article have the opportunity to share with potential readers the results of the use of digital technologies at a single enterprise for the production of construction products EcostroyNII-PV LLP under the grant subproject #APR-SSG-17/0290P 'Innovative technologies for the use of solid technogenic waste from thermal power and metallurgy enterprises of Pavlodar region in the production of construction materials', funded under the Project 'Stimulating Productive Innovations' supported by the World Bank. Production of volume of manufactured construction materials of various nomenclature is worthwhile. The Law of the Republic of Kazakhstan 'On Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan on Stimulating Innovations, Development of Digitalization, Information Security and Education', adopted in 2022, provides an incentive for further development and implementation of digital technologies in the real sector of the economy.

Data for 2021 on the use of digital technologies allow us to talk about the increasing trend of introducing industry achievements in various business processes (Akishev, et al, 2024).

Purpose of the study. The research aims to improve methodological and system principles of digital transformation of enterprises of Kazakhstan for the production of construction products based on wastes of the metallurgical sector, and thermal power plants, through the introduction of information intelligent technologies.

Materials and methods. Methods of system analysis, statistical analysis, mathematical and simulation modeling, theory of automatic control, and modern methodologies of management and production organization were applied. The material of research in the article are ash and slag wastes from thermal power plants used as an active mineral admixture in the composition of heavy concrete. The study is aimed at evaluating the effect of these wastes on the physical and mechanical characteristics of concrete (including compressive strength), in order to utilise the TPP wastes and improve the environmental friendliness of construction materials.

Results and discussion. To evaluate the results of the use of digital technologies at the enterprise for the production of building products, let us consider several stages.

The stage of development of concrete mixture composition. Note that the process of production of construction products begins with the development of concrete mixture composition. Currently, various sources describe a large number of software tools for the automatic development of concrete mix composition. Therefore, we do not emphasize the methodology of concrete mix design.

It should be realized that concrete mixtures developed in this way do not provide strength or other indicators of concrete mix quality. These data can only be obtained experimentally using existing methodologies.

In our study, we have developed concrete mix compositions using various fillers, including wastes from metallurgical enterprises and thermal power plants.

Testing stage of the developed concrete mixtures.

For each composition of concrete mixtures experimental samples of cubes were made for testing (Fig.1) according to (GOST 25192-2012, GOST 10180-2012, GOST 10060-2012, GOST12730.3-78).

We would like to note that experimental samples of concrete mixtures with fillers from metallurgical sector waste, and thermal power plants, unlike samples based on natural raw materials, should be investigated more carefully and responsibly.

Figure 1: Experimental samples of concrete compounds

The data on composition, strength (Fig. 2a), moisture absorption (Fig. 2c), frost resistance (Fig. 2c) tests of concrete compounds were recorded using the form shown in Table 1 (Akishev, et al, 2019).

a) strength   в) water absorption   c) frost resistance

Figure 2 - Testing of experimental samples

The prepared data in Table 1 were further used to classify concrete compounds into classes and then used in the production process of the company.

Table 1 - Form of presentation of concrete mix composition

№	Состав бетонной смеси					
	Traditional fillers (cement, sand, crushed stone)	Metalslag g/%	Slurrybauxite g/%	Chemicaladditive g/%	Water/ Cementratio g/%	Milk of lime in % to cement

1. Distribution of developed concrete mixes by classes.

At many enterprises producing construction products, usually, concrete mixes of the same grades are usually used, so the issue of analyzing the qualitative characteristics of concrete mixes is not relevant.

But when the company uses a wide range of manufactured building products, different nomenclature is necessary for each technological process to apply a particular composition of concrete mixes.

In these cases, to analyze the qualitative characteristics of concrete mixtures, there is a need for effective and prompt results.

In our study, statistical methods of analysis are used to evaluate the quality characteristics of concrete mixes. The task is to distribute a sufficiently large number of concrete mixtures with different quality characteristics and to distribute them into classes with the closest indicators.

To realize the task of distribution of concrete mixes into classes, a mathematical formulation has been performed, the aim of which is to ensure the most uniform and qualitative distribution into classes, formula 1 (Akishev, et al, 2019).

$$F(C_k,C_l) = 1/(N_k*N_l)*\sum_{SiCk} \sum_{SjCl} f(Si,Sj) \quad (1)$$

Where: N_k, N_l – number of concrete mixes, C_k, C_l – distribution classes, $f(Si,Sj)$ – a potential function that provides an optimal measure of similarity between concrete mix compositions.

In other words, each distribution class contains concrete mixes with the closest possible quality parameters, but the concrete mixes of each class are different from each other.

The process of class distribution of concrete mix compositions itself was carried out using software tools and methodology (Akishev, et al, 2019). The results of classing the concrete mixes are shown in Figure 3, each class has its color.

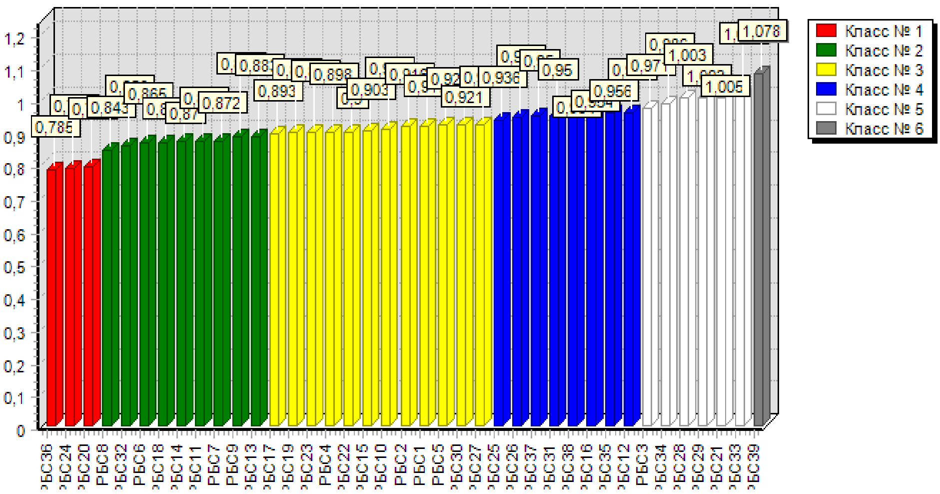

Figure 3 - Results of concrete mixes distribution by classes

As can be seen from Figure 3, all concrete mixes are in classes with the closest qualitative characteristics. We would like to note that the process of distribution into classes does not take much time, and the result allows us to talk about a fairly high accuracy.

This stage is very important, as any distortion resulting from poor quality distribution of concrete mixes, causes in the future, when using the composition of concrete mixes of this class in the technological process of the enterprise, the defect of products.

So, we have developed concrete mixes, conducted tests, and obtained a qualitative analysis of the characteristics and distribution by class of optimal compositions.

If we take a real production enterprise, we can start the technological process of production of building products.

To organize the technological process it is necessary to work out the following questions:

- what quantity of raw materials should be in production?
- what is the productivity of technological equipment for a given composition of concrete mix?
- how to calculate the production plan for the month, quarter, etc.?
- what are the optimal operating parameters of the process equipment?
- How much does the introduction of additional equipment affect productivity?

It became possible to answer these questions after the development of the program 'Simulation model of the technological line for the production of building products using waste from industrial enterprises' by the authors (Akishev, et al, 2019), hereinafter referred to as SMTL.

1. Use of simulation modeling to ensure the functioning of the production enterprise for the production of construction products.

Further, we will show the features and purpose of the software tool to ensure the functioning of the production enterprise for the production of building products.

To begin with we would like to say that this program is written in object-oriented language C++, in Russian, which allows us to talk about the possibility of scientists of the former USSR countries to develop products with practical application.

The methodology of the development of simulation models for various processes of the construction industry and some operations of concrete production technology is presented in (Ryzhikov, et al, 2004, Babina, et al, 2004, Borschev, et al, 2008).

The possibilities and advantages of the developed SMTL program will be discussed below. Currently, the SMTL program has been upgraded and has a more extended interface and functionality, the principle of the program operation is discussed in sources (Akishev, et al, 2019).

The SMTL program is designed as a real technological line for the production of construction products, including the use of waste from the metallurgical sector and thermal power plants. Currently, there are no analogs of the SMTL program.

Let's proceed to the practical implementation of our stage.

This stage will be interesting both for producers of construction products and for students, masters, and doctoral students within the educational process.

Let's imagine that you have an enterprise for the production of building products, you have worked out compositions of concrete mixtures, and technological equipment, and you need to know what quantity of building products can be produced per working shift, what quantity of raw materials should be in your warehouse, can you fulfill the order of a potential customer?

Recall that you know the compositions of developed concrete mixtures, class, and grade, and you know for which building products they are used.

So, enter the data for modeling the technological process of production of building products, for example - split bricks, Figure 4.

Figure 4 - Split Brick

The data for modelling the technology of production of construction products based on anthropogenic waste are entered manually into the SMTL program depending on the quantity and type of construction products to be produced, Figure 5.

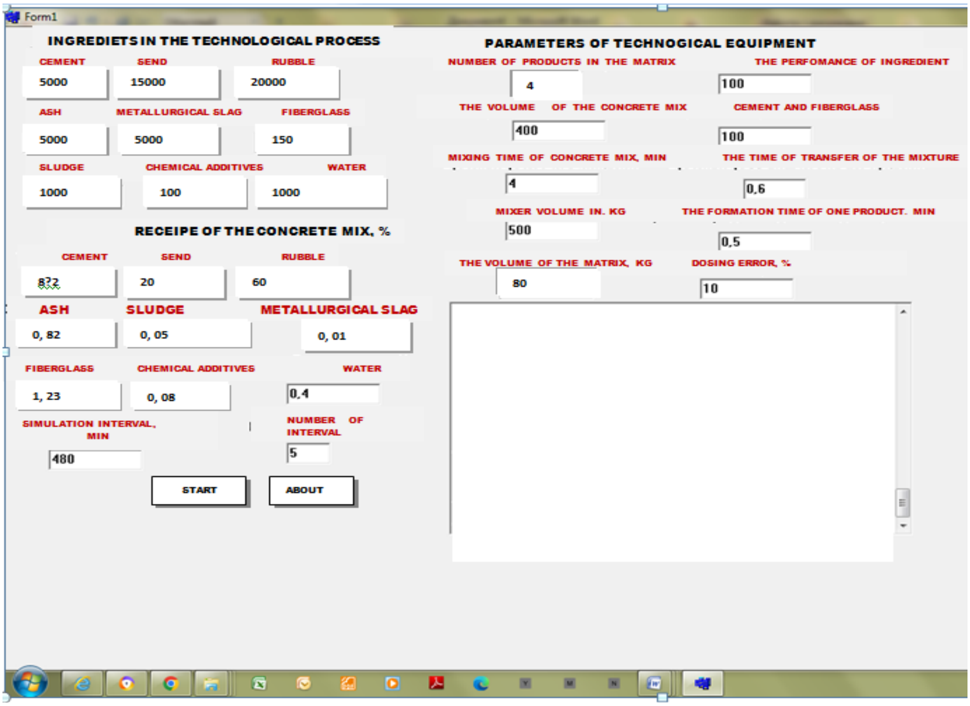

Figure 5 - Input data for modelling the split brick production process

The data for raw materials are approximate, as the necessary quantity of raw materials will be adjusted automatically. In the production of products from heavy concrete, the weight of wall partition bricks is 20 kg, in the matrix can be simultaneously formed 4 bricks, the volume of the mixer 0.5 m3, pressing time, and speed of conveyors - according to the manufacturer's passport data.

Modeling of the technological process of wall partition brick production takes place according to the technical regulations, all time intervals of operations correspond to the real production.

We apply the modeling interval for a working shift of 8 hours (or 480 minutes).

We press the 'Start' button and start to perform the virtual process of production of wall partition bricks. Figure 6 showstheresultofthisvirtualprocess.

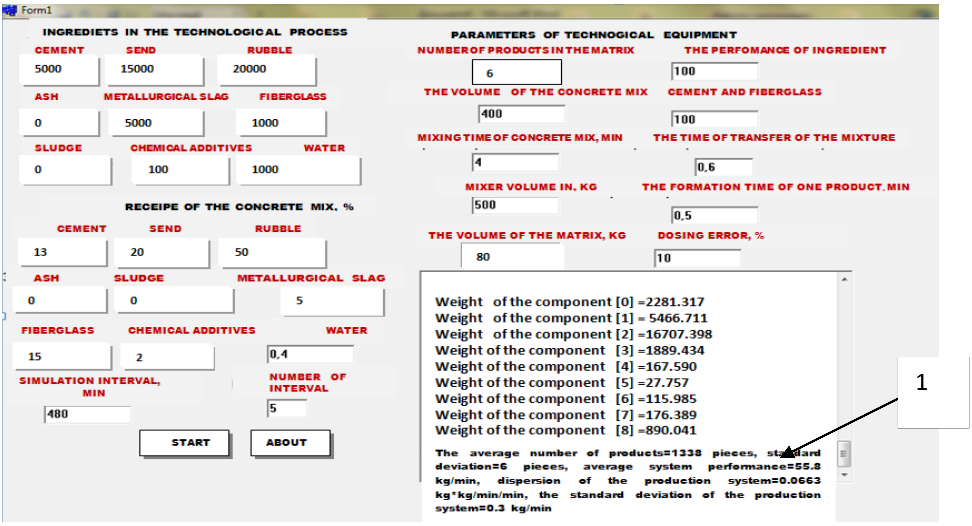

Figure 6 - Modelling of the split brick production process

Let's take a closer look at the simulation results shown in Fig. 7., position 1.

The average number of products=1338 pieces, standard deviation=6 pieces, average system performance=55.8 kg/min, dispersion of the production system=0.0663 kg*kg/min/min, the standard deviation of the production system=0.3 kg/min

Figure 7 - Modelling results

As can be seen from Figure 7, during the simulation period of 480 minutes, 1,338 bricks are formed on the production line, the average square deviation of 6 products, the average productivity of the system is 55.8 kg/min, the dispersion of the production system is 0.0663 kg*kg/min/min, the average square deviation of the production system is 0.3 kg/min

Figure 8 shows the data on the composition of the concrete mix used for the production of split bricks.

THE RECIPE OF THE MIXTURE PER SERVING VOLUME IN THE MIXER

Cement percentage =8.2; weight of cement =32.80 kg
Sand percentage = 20.00; weight of sand =80.00 kg
Percentage of crushed stone = 60.00; weight of crushed stone=240.00 kg
Ash percentage = 6.72; weight of ash =26.90 kg
Percentage of metallurgical slag = 0.6; weight of slag =2.40 kg
Lime percentage = 0.01; weight of lime =0.40 kg
Percentage of bauxite sludge = 0.410; weight of bauxite sludge=1.64 kg
Percentage of plasticizer = 0.656; weight of plasticizer =1.64 kg
Percentage of water= 0.4; weight of water=13.12 kg

Figure 8 - Composition of the concrete mix

According to, the initial parameters needed to perform 5 iterations or simulation cycles of the virtual split brick manufacturing process, as can be seen in Figure 9, all simulation cycles were successful.

Tt=480 Sales=1 Number of products 1339
Capacity kg/min=55.8
Product weight kg=267876.5
USED UP
Weight of the component [0] =2281.317
Weight of the component [1] = 5466.711
Weight of the component [2] =16707.398
Weight of the component [3] =1889.434
Weight of the component[4] =167.590
Weight of the component[5] =27.757
Weight of the component[6] =115.985
Weight of the component[7] =176.389
Weight of the componen [8] =890.041

Tt=480 Sales=2 Number of products 1345
Capacity kg/min=56.1
Product weight kg=26907.5
USED UP
Weight of the component [0] =2244.391
Weight of the component [1] = 5462.532
Weight of the component [2] =16726.175
Weight of the component [3] =1870.677
Weight of the component[4] =168.086
Weight of the component[5] =28.757
Weight of the component [6] =113.853
Weight of the component [7] =179.254
Weight of the component [8] =901.741

Tt=480 Sales=3 Number of products 1342
Capacity kg/min=56.0
Product weight kg=26858.3
USED UP
Weight of the component[0] =2187.342
Weight of the component [1] = 5483.309
Weight of the component [2] =16755.469
Weight of the component [3] =1829.031
Weight of the component [4] =170.454
Weight of the component [5] =28.445
Weight of the component [6] =110.453
Weight of the component [7] =178.394
Weight of the component [8] =872.303

Tt=480 Sales=4 Number of products 1339
Capacity kg/min=55.8
Product weight kg=26793.9
USED UP
Weight of the component [0] =2260.041
Weight of the component [1] = 5593.365
Weight of the component [2] =16806.039
Weight of the component [3] =1855.580
Weight of the component[4] =167.177
Weight of the component[5] =28.530
Weight of the component[6] =115.11
Weight of the component [7] =179.249
Weight of the component[8] =893.306

Tt=480 Sales=5 Number of products 1329
Capacity kg/min=55.4
Product weight kg=265833.2
USED UP
Weight of the component [0] =2281.317
Weight of the component [1] = 5466.711
Weight of the component [2] =16707.398
Weight of the component [3] =1889.434
Weight of the component[4] =167.590
Weight of the component[5] =27.757
Weight of the component[6] =115.11
Weight of the component [7] =176.389
Weight of the component[8] =890.041

Figure 9 - Modelling cycles

Let's take a closer look at the obtained results of modeling the split-brick production process.

As a result of 5 cycles of modeling, we obtained the average value of productivity of the technological line, i.e. for 480 minutes 1338 pieces of split bricks were produced, the standard deviation of products is 6 pieces, the standard deviation of the system is 0.3 kg/min, the average productivity of the technological system was 55.8 kg/min.

The consumption of various raw materials for the production of 1338 pieces of split bricks, were:

- cement - 2281.317kg;
- sand - 5466.711kg;
- crushed stone - 16707,398kg;
- metallurgical slag - 167,590kg;
- ash - 1889,434kg;
- bauxite sludge - 115,985kg;
- mixing water - 890 litres
- milk of lime - 27,757kg;
- chemical additives - 176,389kg.

If necessary, the user can increase the modeling interval and calculate the productivity of technological equipment for a longer time of production of construction products.

Figure 10 shows the result of modeling the split brick production process with a simulation interval of 2100 minutes, a 5-day working week in one shift.

Mass of products =119454.2
CONSUMED in kg
Cement=9874.681
Sand=24032.875
Ash=8149.180
Metallurgical slag=722.084
Lime=120.842
Bauxite sludge=489.643
Plasticizer=788.819
Water=3919.507

Figure 10 - Simulation of the split brick production process with a simulation interval of 2100 minutes.

The SMTL program calculated the productivity of the process equipment in the production of split bricks for a week, it was 5975 pieces, standard deviation 2 pieces. Also calculated the volume of raw materials required for the production of 5975 pieces of split bricks for each nomenclature.

The adequacy of SMTL was evaluated based on statistical methods.

C obtaining modelling data in the SMTL program provides the possibility of outputting the results of modelling directly to the printer, by pressing the key ‘PRINT’, the report comes out as a Word-file, Table 2. The obtained results of modelling are rounded to integer.

Table 2 - Modelling results

Cement	9875 кг
Sand	24032кг
Crushedstone	
Metallurgicalslag	72169кг
Ash	8149кг
Bauxitesludge	490кг
Mixingwater	3920 л
Milkoflime	121 кг
Chemicaladditives	789 кг
Averagenumberofproducts	5975 штук

Conclusion. Analyzing the information presented above, as well as the experience of digital transformation in LLP ‘EcostroyNII-PV’, which is used in the production of construction products as fillers of concrete mixtures wastes from the metallurgical sector, thermal power plants of Kazakhstan, we can draw the following conclusions:

- it is necessary to further promote modern information-intelligent technologies and techniques in the production of construction materials.
- There are prospects of replacement of traditional fillers with technogenic raw materials.

In numerical terms, according to the received statistical data in LLP ‘EcostroyNII-PV’ for the last 2 years, the introduction of digital technologies has provided an increase of production efficiency by more than 21%, reduction of production costs by 24%, scrap of manufactured products by 17%.

We believe that the results obtained from the use of digital technologies in EcostroyNII-PV LLP in the production of construction products in Kazakhstan will resonate both among specialists in the field of digital technologies and the construction industry, which allows us to open a wide discussion on the promotion and implementation of modern digital tools in the construction industry.

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