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Satbayev University

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ИЗВЕСТИЯ

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APPLICATION OF THE PRINCIPLE OF SPECIAL STATES IN DEVELOPING SIMULATION MODEL

Abstract. The active development of new bauxite deposits in the Kostanay region will increase the volume of alumina production at the Pavlodar Aluminum Plant, which in turn will lead to an increase in the volume of waste sent to man-made deposits (bauxite sludge). The study of the chemical, strength characteristics of bauxite sludge used as fillers in concrete mixes makes it possible to substantiate the prospects and possibilities for organizing technological systems for the production of construction products based on industrial waste from the Pavlodar Aluminum Plant.

The presented article is a continuation of a series of articles devoted to the study of man-made deposits (storage sites, industrial waste (metallurgical slag, bauxite sludge, fly ash) for subsequent use in concrete mixtures.

Earlier, the article was published with a description of the methodology that allows clustering concrete mixtures using industrial waste (bauxite sludge, metallurgical slag) with different chemical composition and strength characteristics, based on which construction products of various nomenclature were subsequently produced.

This article discusses the application of the «principle of special states» in the development of a simulation model of a technological system for the production of construction products based on industrial waste (bauxite sludge), presents the features of concepts and definitions of complex systems.

The described methods for determining the system time show the difficulties that arise in determining the system time for a real technological system for the production of construction products.

The purpose of the study was to apply the «principle of special states» in the development of a simulation model of the technological system for the production of construction products using industrial waste (bauxite sludge).

The assessment of the adequacy of the developed simulation model shows that the use of the "principle of special states" allows not only to ensure the determination of a reliable and accurate system time for the functioning of each cycle of the technological production process, but also to reduce the error in calculating the system time of the technological process for the production of construction products using waste industrial production.

The algorithm, created with the «principle of special states», made it possible to create a software product that allows you to accurately calculate the performance of process equipment for the calculated simulation interval when using concrete mixtures with various fillers (bauxite sludge).

The graphs described for each cycle of the technological process for the production of construction products using industrial waste (bauxite sludge) clearly represent the «principle of special states», both practically and analytically.

Key words: bauxite sludge, industrial waste, principle of special states, technological system, technological process, simulation model, graph, concrete mixes, simulation interval, system time.

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ИМИТАЦИЯЛЫҚ МОДЕЛІН ЖАСАУ КЕЗІНДЕ «ЕРЕКШЕ КҮЙ ПРИНЦИПІН» ҚОЛДАНУ

Аннотация. Қостанай облысында жаңа боксит кен орындарын белсенді игеру Павлодар алюминий зауытында глинозем өндірісінің көлемін ұлғайтуға мүмкіндік береді, бұл өз кезегінде техногендік кен орындарына жіберілетін қалдықтар (боксит шламы және т.б.) көлемінің ұлғаюына әкеледі. Бетон қоспаларында толтырғыш ретінде пайдаланылатын боксит шламдарының химиялық, беріктік сипаттамаларын зерттеу Павлодар алюминий зауытының өнеркәсіптік өндіріс қалдықтары негізінде құрылыс бұйымдарын өндірудің технологиялық жүйелерін ұйымдастырудың перспективалары мен мүмкіндіктерін негіздеуге мүмкіндік берді.

Ұсынылған мақала кейіннен бетон қоспаларында пайдалану үшін техногендік кен орындарын (қойма орны, өнеркәсіптік өндіріс қалдықтары (металлургиялық қож, боксит шламы, тасу күлі) зерттеуге арналған мақалалар циклінің жалғасы болып табылады.

Бұрын жарияланған мақала Әр түрлі химиялық құрамы мен беріктік сипаттамалары бар техногендік қалдықтарды (боксит шламы, металлургиялық шлак) қолдана отырып, бетон қоспаларын кластерлеуге мүмкіндік беретін әдіснаманың сипаттамасымен, олардың негізінде кейіннен әртүрлі номенклатурадағы Құрылыс бұйымдары шығарылды.

Осы мақалада өнеркәсіптік өндіріс қалдықтары (боксит шламы) негізінде құрылыс бұйымдарын өндірудің технологиялық жүйесінің имитациялық моделін әзірлеу кезінде «ерекше күйлер принципін» қолдану қарастырылған, күрделі жүйелер ұғымдары мен анықтамаларының ерекшеліктері келтірілген.

Жүйелік уақытты анықтаудың сипатталған әдістері Құрылыс өнімдерін өндірудің нақты технологиялық жүйесі үшін жүйелік уақытты анықтауда туындайтын қиындықтарды көрсетеді.

Зерттеудің мақсаты өнеркәсіптік өндіріс қалдықтарын (боксит шламын) пайдалана отырып, құрылыс бұйымдарын өндірудің технологиялық жүйесінің имитациялық моделін әзірлеу кезінде «ерекше күй принципін» қолдану болды.

Әзірленген Имитациялық модельдің барабарлығын бағалау «ерекше күйлер принципін» қолдану өндірістің технологиялық процесінің әр циклінің сенімді және нақты жүйелік жұмыс уақытын анықтауға ғана емес, сонымен қатар өнеркәсіптік өндіріс қалдықтарын қолдана отырып, құрылыс өнімдерін өндірудің технологиялық процесінің жүйелік уақытын есептеу кезінде қатені азайтуға мүмкіндік беретіндігін көрсетеді.

«Ерекше күйлер принципі» негізінде жасалған Алгоритм әртүрлі толтырғыштары бар бетон қоспаларын (боксит шламы) пайдалану кезінде модельдеудің есептік аралығы үшін технологиялық жабдықтың өнімділігін дәл есептеуге мүмкіндік беретін бағдарламалық өнімді жасауға мүмкіндік берді.

Өнеркәсіптік өндіріс қалдықтарын (боксит шламын) пайдалана отырып, құрылыс бұйымдарын өндірудің технологиялық процесінің әрбір циклі үшін сипатталған бағандар іс жүзінде де, аналитикалық тұрғыдан да «ерекше күйлер принципін» айқын көрсетеді.

Түйінді сөздер: боксит шламы, өнеркәсіптік өндіріс қалдықтары,» ерекше күй принципі», технологиялық жүйе, технологиялық процесс, Имитациялық модель, график, бетон қоспалары, модельдеу аралығы, жүйелік уақыт.

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ИСПОЛЬЗОВАНИЕ «ПРИНЦИПА ОСОБЫХ СОСТОЯНИЙ» ПРИ РАЗРАБОТКЕ ИМИТАЦИОННОЙ МОДЕЛИ

Аннотация. Активная разработка новых бокситовых месторождений в Костанайской области позволит нарастить объем производства глинозема на

Павлодарском алюминиевом заводе, что в свою очередь приведет к увеличению объема отправляемых в техногенные месторождения отходов (бокситовый шлам и др.). Исследование химических, прочностных характеристик бокситовых шламов, используемых в качестве наполнителей в бетонных смесях, позволили обосновать перспективы и возможности организации технологических систем производства строительных изделий на основе отходов промышленного производства Павлодарского алюминиевого завода.

Представленная статья является продолжением цикла статей, посвященной исследованию техногенных месторождений (места складирования, отходов промышленного производства (металлургического шлака, бокситового шлама, зол уноса) для последующего использования в бетонных смесях.

Ранее опубликована статья с описанием методологии, позволяющей выполнять кластеризацию бетонных смесей с использованием техногенных отходов (бокситовый шлам, металлургический шлак) с различным химическим составом и прочностными характеристиками, на основе которых в дальнейшем производились строительные изделия различной номенклатуры.

В настоящей статье рассмотрено использование «принципа особых состояний» при разработке имитационной модели технологической системы производства строительных изделий на основе отходов промышленного производства (бокситовый шлам), представлены особенности понятий и определения сложных систем.

Описанные способы определения системного времени показывают трудности, возникающие при определении системного времени для реальной технологической системы производства строительных изделий.

Цель исследования заключалась в применении «принципа особых состояний» при разработке имитационной модели технологической системы производства строительных изделий с использованием отходов промышленного производства (бокситовый шлам).

Оценка адекватности разработанной имитационной модели показывает, что использование «принципа особых состояний» позволяет не только обеспечивать определение достоверного и точного системного времени функционирования каждого цикла технологического процесса производства, но и снизить погрешность при расчете системного времени технологического процесса производства строительных изделий с использованием отходов промышленного производства.

Алгоритм, созданный на основе «принципа особых состояний», позволил создать программный продукт, позволяющий достаточно точно рассчитать производительность технологического оборудования за расчетный интервал моделирования при использовании бетонных смесей с различными наполнителями (бокситовый шлам).

Описанные графы для каждого цикла технологического процесса производства строительных изделий с использованием отходов промышленного производства (бокситовый шлам) наглядно представляют «принцип особых состояний» как практически, так и аналитически.

Ключевые слова: бокситовый шлам, отходы промышленного производства, «принцип особых состояний», технологическая система, технологический процесс, имитационная модель, граф, бетонные смеси, интервал моделирования, системное время.

Introduction. Pavlodar Aluminum Plant (PAP) produced the first batches of alumina in 1964. Alumina is a source of aluminum production. At present, PAP is supplied with bauxite ore from two deposits: Torgaiskoye (almost depleted) and Krasnooktyabrskoye, which is the main supplier. To date, 2 more bauxite deposits have been discovered, with explored reserves of bauxite ore up to 37.5 million tons, which allow increasing the volume of alumina production and the life of ore deposits (https://kz.kursiv.media/2020-05-31/kak-alyuminievyy-klaster-pavlodarskoy-oblasti-privlekaet-investicii).

The amount of alumina produced by PAP alumina today is 1.4 million tons per year [https://www.google. com/search?client=avast-a-1]. The bauxite ores of the Krasnooktyabrskoye deposit are not rich enough; on average, the content of aluminum $Al_2 0_3$ is less than 20% (https://metalspace.ru/education-career/osnovy-metallurgii/proizvodstvo-tsvetnykh-metallov/540-proizvodstvo-alyuminiya.html).

Obtaining alumina on the PAP is carried out on the basis of the Bayer method:

$$Al_2O_3 \cdot nH_2O + 2NaOH = 2NaAlO_2 + nH_2O$$

Aluminum is obtained from the obtained sodium aluminate by hydrolysis.

$$NaAlO_2 + 2H_2O = NaOH + Al(OH)_3$$

Crystals of aluminum hydroxide $Al(OH)_3$ precipitate, which is filtered, washed and calcined to obtain pure alumina (Al_2O_3).

As a result, 200 kg of alumina is obtained from 1 ton of Krasnooktyabrskaya ore, the rest is bauxite sludge. The estimated amount of bauxite sludge at the man-made PAP deposit is presented in Table 1 (Tulegulov, 2022).

Table 1 - Estimated amount of bauxite sludge stored at man-made PAP deposits

Company name	Year of opening of the enterprise	Quantity of produced alumina, thousand /ton	Amount of bauxite sludge, thousand /ton
Pavlodar aluminum plant	1964	60000	240000

The chemical composition of bauxite sludge is shown in Figure 1. Bauxite sludge is a red-brown friable mass, particle size analysis shows that when sieved, minimal particles can be sifted through a 0.05 mesh sieve (figure 2).

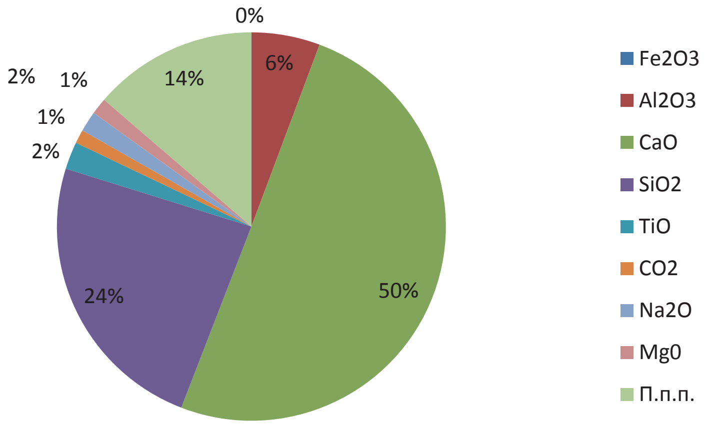


Figure 1 - Chemical composition of bauxite sludge

Figure 2 - Granulometric analysis of bauxite sludge

The study of bauxite sludge, chemical, strength characteristics made it possible to develop a fairly large number of concrete mixtures. Laboratory and field tests allowed to obtain real statistical results allowing the use of the developed concrete mixtures based on man-made waste (bauxite sludge) for the production of construction products. Further work was carried out in relation to the adaptation of the “principle of special states” to develop a simulation model of the technological system for the production of construction products using industrial waste (bauxite sludge).

Designing and subsequent implementation in production of studies related to the modeling and operation of complex systems is not only an urgent task, but also practically necessary, especially at the present time, when the number of complex objects is only increasing. Such complex systems include technological systems for the production of construction products, including those using waste from industrial enterprises. When developing and researching complex systems, the designer needs to solve many tasks based on knowledge of not only quantitative, qualitative and other patterns characteristic of the systems under study (Ryzhikov, 2004); (Pichitlamken, 2002).

Considering as a system, a technological line for the production of construction products using waste is separate components, for example: a mixer for preparing a concrete mixture, a conveyor for supplying raw materials, a matrix press for forming construction products, etc. As a basis, such properties of a system element are taken that interact with other elements of the system, and also impose restrictions on the properties of the system as a whole. Today's promises in the development of complex systems require a fundamental change in the entire technology of designing systems development. The main feature is the presence and wide choice of modern methods and ways of presenting and processing information, which allows the developer to reveal all his creative potential. In today's world, complex systems under investigation require the creation of prototypes or simulators of complex systems-simulation models, which are a set of algorithms and programs capable of displaying the system under study and its behavior in the virtual space of a computer system.

The proximity of the real system and the simulated system is based on the use of common information data and common patterns. But at the same time, ideal conditions are created for the simulation model, which do not always take place in a real system (Karpov, 2017; Ostaukh, 2009; Ivaev, 2011). It turns out that the nature of the simulation model does not fully correspond to the nature of the real system, for the same patterns. One of the solutions for discrete complex systems is the application of the principle of special states for each element of the system, which allows you to determine the system time as accurately as possible and, accordingly, bring the behavior of the developed simulation model closer to the graying of the real system.

Research methods. In practice, when developing simulation models, two methods can be presented: *"the principle of special states and the principle t"*. For each case, the task is to determine the system (model) time T for the studied (simulated) system, where T is taken as the interval of "real computer time", from the beginning of the simulation and at the same time, "calendar time t_r" in the simulated system. The relationship between them can be represented as:

$$t_r = M^* T \tag{1}$$

where M is the scale factor.

In the process of modeling complex systems, the concept *of "interval of modeling" is adopted* - the interval of "real calendar time t_m", for which the behavior of a complex system is studied. It can be any period of a year or more. The simulation time may depend only on the capabilities of computer technology, the developed modeling algorithm and the given *"simulation accuracy"*.

As a rule, during the simulation process using modern computer systems, the system time changes intermittently (discretely), and the real time is continuous.

For the *"principle t"* the "discrete step of the system time T_d" is first set, while the system time is determined by the expression:

$$T = T + Td, \tag{2}$$

where, T = T (0) to start the simulation.

Calculation according to formula 2, allows you to view all events in the interval T_d with subsequent changes in the system. But for this principle, there is a problem that for events occurring "close in time from each other", the value of T_d taken less (usually

T_d<<t_m), while increasing the time of the modeling process, which does not provide high efficiency.

Research results. In our study, to model the "technological process for the production of construction products using industrial waste" as a complex system, we will apply *the "principle of singular states"* as the most practical and accurate description of the behavior of a real system. In Figure 3, we are presented with a developed, functional model of the "technological process for the production of construction products based on industrial waste."

Consider a functional model in the form of state graphs:

// OA $_0$ – object class Z $_0$

// 0 - free and can dry mix

// 1 - the formation of the dry mix without cement is completed and you can

// transfer dry mix to Z_1, transfer time ordered

// 2 - idle, transfer impossible, Z_1 is busy mixing the mixture, supplying cement, lime, plasticizer

// 3- simple, some component ended.

Figure 4 shows the state graph of the object Z_0. In states 0 and 1, the object is included in the list of events. In other states, the object is excluded from the list of events. In state 3, the model stops working, because there is no procedure for adding components. The transition <1, 0> is carried out if the dry mixture is transferred to the object Z_1. The transition <1, 2> is carried out if the dry mixture is not transferred to the object Z_1 due to its busyness. The transition <2, 0> is carried out by a signal from the object Z_1 at the time when it goes into state 0, i.e., is released.

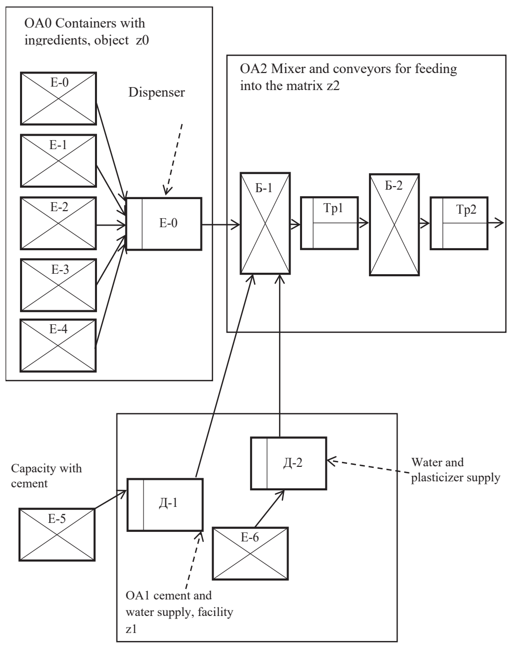
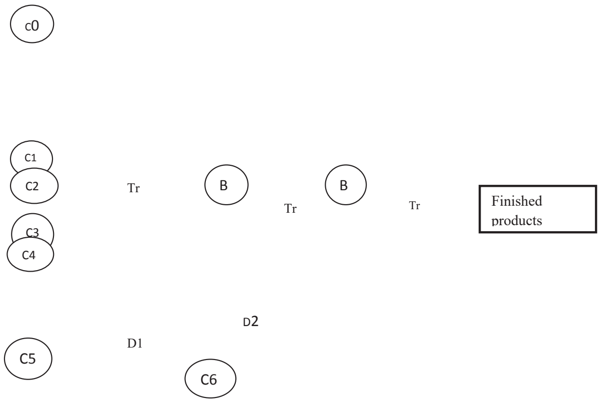


Figure 3. Functional process model



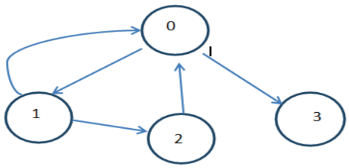


Figure 4. State graph of the object Z_0

//OA_1 – Z_1 object class
// 0 - free and can take dry mix
// 1 – dry mix is transferred to object Z_1, end of transfer time ordered,
// 2 - the machine is involved in mixing, adding cement, water, plasticizer and mixing, mixing end time is ordered,
// 3 - the time of transfer of the mixture to the matrix is ordered,
// 4 – simple, failed to transfer the mixture to the matrix, Z_2 is busy.

Figure 5 shows the state graph of the object Z_1. In state 0,1,2,3 the object is included in the list of events. In state 4, the object is excluded from the list of events. The transition < 0, 1> is carried out if the dry mixture is transferred to the object Z_1 and the transfer end time is ordered. The transition <1, 2> is carried out if the dry mixture is transferred to the object Z_1. The transition <2, 3> is carried out if the object Z_1 is busy mixing the mixture and adding cement, water and plasticizer and the end time of this process is determined. The transition <4,1>> is carried out by a signal from the object Z_2 at the time when it goes into state 0, i.e., is released.

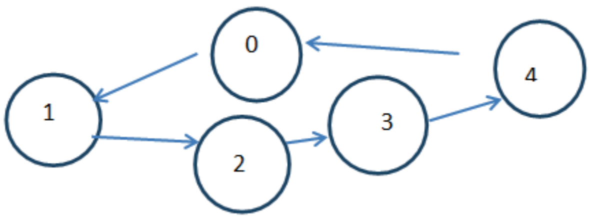


Figure 5. State graph of object Z_1

// OA2 – Z_2 object class

// 0- free and can accept ready mixes,

// 1 - busy with the transfer of ready-mixed concrete, from production waste (Kamenev, 2011; Banks, et al, 2003; Yusupov, et al., 2008; Preston, 2016).

// 2 - received the mixture, ordered the end time of the transfer ready products.

The state graph of the object Z_2 is shown in Figure 6.

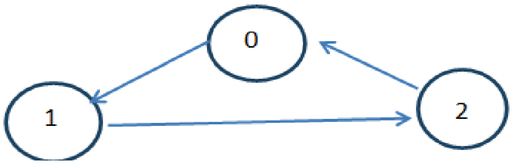


Figure 6. State graph of object Z_2

Object Z_2 in state 0 is disabled from the list of events. The transition <0,1> is carried out by a signal from the object Z_1. The transition<0,1> is carried out if there is a mixture in the object Z1 for transfer to the forming matrix. In this case, the end time for transferring the mixture to the matrix is ordered. The transition <1,2> is carried out at the end of the transfer of the mixture to the forming matrix. In state 2, the time for the transfer of finished products is ordered. At this moment, the transition to state 0 is carried out and the object Z_2 is excluded from the list of events.

Thus, in our case, four events are allocated, stored in the events array:

//ST[4] - event array:

// ST[0] – release of the block Z_0: completion of the mixture formation by the machine Z_0 and transfer to mixing;

// ST[1] – release of the block Z_1: the end of mixing, pouring water, transferring the wet mixture to the vibropress and the molding matrix,

// ST[2] – release of the block Z_2: finishing and molding, production of finished products Z_2

// ST[3] – end of simulation interval

// T_t - system time, in minutes.

Actually the very principle of special events (states) is as follows: the system time each time is adjusted to the nearest event. After processing this event, the system adjusts to the next nearest event, etc. The formula for setting the system time is as shown in formula (3):

$$T_i = min\ MS(i) \qquad (3)$$

where i = 1..N; N – the number of all special events in the system.

For our case MS(3) = 480 min.

Usually, in addition to events that change the state of the system, the number of events also includes the achievement of the system time value corresponding to the specified simulation interval t_p. Since all special events are tied to active blocks, the number of events Ns in the modeling system can be determined by the formula (4):

$$N_s = N_a + 1, \quad (4)$$

where N_a is the number of active blocks.

Thus, for the functional model shown in Figure 1, $N_s = 4$.

The use of graphs to represent simulation models provides a practical way to analyze these models, both analytically and numerically, to improve the accuracy of estimates, simulation modeling must be used.

Results discussion. The use of "principles of special states" in practice is used to model discrete processes in various sectors of the economy (Sullivan, 2017; Akishev, et al., 2022) until today, in the construction industry, the "principle of special events" has not been used to develop simulation models.

Conclusions: The application of the "principle of special events" in the development of a simulation model of a technological system for the production of construction products using industrial waste allows you to accurately determine the "working" time of the main technological operations, depending on the accuracy of setting the dispensers and transfer equipment, and when the equipment is idle, it is excluded from the list of events and is not taken into account when forming the total system time - this ensures reliable and high-quality behavior of the developed simulation model, close to the behavior of the real system, and also takes into account what type of technogenic raw material is used as a filler, which greatly affects the performance of the technological system in in general.

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