Using genetic algorithms for operational planning of cement mills loading

V I Svetlichnaya¹, E O Savkova¹, O O Shumaieva¹, O V Chengar² and V I Shevchenko²

¹ Donetsk National Technical University, 58, Artyoma Str., Donetsk
² Sevastopol State University, 33, Universitetskaya Str., Sevastopol, Russia

E-mail: ovchengar@sevsu.ru

Abstract. The article discusses the problem automating the construction of schedules for cement production. The necessity using a computer system for planning the loading of technological equipment is substantiated in order to develop the optimal use of available resources for the timely and high-quality execution production tasks. The essence of the problem is shown, which is to allocate resources (cement mills and produced brands of cement) the production system for a given target plan so as to exclude deviations the real plan from the target, as well as to reduce the number of mill switchings to a minimum. The formalization the task planning the loading the mills is carried out and those essential parameters of the process are given, which are selected as the initial data for solving the task planning the operation of grinding mills. The solution to the problem constructing schedules for the operation of cement mills is based on the use of a genetic algorithm, for which an implementation sequence is proposed. The results solving the problem are also presented, which confirm the correctness the chosen method and its implementation.

1. General problem statement

The production building materials is one of those industries that together determine the economic level of the country’s development. A cement industry feature which is part of the building materials industry, is the continuous process of obtaining a homogeneous product in large quantities.

An important role in ensuring the fulfillment of contractual obligations for the supply finished products is played by operational planning production, since it is at this stage that the issue of daily production products in an assortment is resolved, corresponding to the applications-reports accepted for execution and contracts concluded with customers. Cement production planning is carried out according to the orders that the plant receives and which each month can be different. The main parameters of orders are:

- brand of cement;
- the volume the issue;
- date order execution.

In solving such a problem, it is important to develop plans for the production cement, which would provide the required amount products in compliance with the established deadlines. Consequently, the
problem of improving the management system and its main link - planning for the cement industry is urgent [1].

Operational planning in the cement industry is designed to ensure the rational utilization equipment, the continuity the production process, the systematic fulfillment the tasks of contractual obligations for the supply products on the basis uniform, rhythmic work all divisions the enterprise. This, in turn, affects the economic performance the enterprise.

At present, at most cement plants, operational planning the production of cement in the assortment section with an indication the specific load of cement mills is carried out by the plant laboratory. Research at the enterprise shows that in conditions when the output and range products are constantly increasing, when the enterprise is tasked with fulfilling contractual obligations for the supply of products, this planning practice does not meet the requirements the economy [2].

2. Research problem statement

The cement production is organized in such a way that the main production equipment is cement grinding mills. There may be several these mills, depending on the plant's capacity.

The produced product (cement) can be different quality, which is determined by the cement' brand. The number of cement' brands produced is usually larger than the number of mills in production. A feature cement production is that when switching from the production of one cement' brand to the production another, it is necessary to reconfigure the mills. It should also be noted that the switching time of the mill takes up a fairly large part from the total operating time the production complex [3]. This leads to economic losses, which are determined by the downtime of the mills themselves, energy and labor costs, faster wear of individual parts technological equipment. Reducing the number of mill reconfigurations will significantly reduce these losses and, accordingly, increase income from cement production.

Automated control systems existing in the cement industry solve a number of problems operational management, both production' and logistics' character. At the same time, none of them solves the problem drawing up operational plans for the production cement of a given assortment the required volume and in a given time frame. This class tasks is one of the most time consuming in in-plant planning. The complexity constructing an operational plan lies not only in choosing the optimal option for using available resources the timely and high-quality execution production targets, but also in the need to promptly adjust planned targets in accordance with the changed production situation and obtain new versions operational plans. It also determines the direction research to improve the planning of cement plants.

3. Problem solution and research results

Each mill can only produce one grade cement at a time. To change the production of the cement grade, it is necessary to switch and adjust the mill. The amount cement that is produced in excess the plan is stored in the silos. The number tons cement that is allowed to be produced in excess of ordered is set by experts the forecasting department. This expert assessment is taken into account when drawing up a plan for the month. The planning of schedule the mill loading takes place at the end the month.

The initial data for solving the problem planning the operation of grinding mills is information from the database, namely:

1. An array clients \( C = (1..n) \) and their status \( R_j = (0; 1) \);
2. An array of prices per ton each brand cement \( P_{R_i} \). Cement prices are set by the sales specialists.
3. Numbers brands \( M_k = [1; 12] \), their names.
4. Types brands \( T_{ipM} = [1; 3] \), which determine the productivity of each brand \( P_{roizv} = [20; 30] \) tons / hour.
5. An array of loading silo in tons \( S_l = (0 ... 2550) \);
6. Arrays of customer orders:

   - the number tons of cement to must be produced;
the time after which it is necessary to ship the finished product.

7. Constants used in calculating costs and planning mill loading:

- the cost of electricity, kW / hour;
- the cost of replacing the reductor;
- downtime when switching the mill;
- capacity of silos;
- mill working hours per day, taking into account the technological features of the mill.

Thus, the essence the problem is that for a given target plan, it is necessary to distribute the resources the production system (cement grinding mills and produced cement grades) so that there are no deviations of the current plan from the target, and also to reduce the switching mills to a minimum. The solution to the problem of constructing schedules for the operation cement mills is based on the use a genetic algorithm [4, 5].

The procedure for developing a schedule can be represented as the following sequence of actions:

Step 1. Initialization the initial population of individuals. The creation the initial population is very important and one of the determining factors the genetic algorithm [4]. When choosing an encoding, several options were considered:

1. Coding the brand number and the number the mill, which will produce this brand of cement. It was assumed that each chromosome is an m-dimensional vector, the elements of which are integers from 1 to n. The integer in the j-th place means the number of the brand to be produced.

2. The use of the following values as initial data: the amount cement of a given grade produced for a given period time (for example, an hour), the operating time the mills, the lead time the order, and the downtime.

3. Breaking of a given amount cement into 10 parts for flexibility in manipulating genes in the chromosome. Each gene contains the number of tons cement (or the time it takes to produce that number of tons cement) that needs to be produced.

4. Encoding with the presentation of the order in the form of a gene with its own serial number. A modification of this view is the representation of the gene as a structure, which imaging the mill number and the order being executed. In this case, crossing over occurs within the structure, i.e. inside the mill.

As a result of studies of possible options, a coding option was chosen in which each chromosome is represented by a set of gene's pairs:

- The first gene of a pair — defines the number the corresponding order Zi;
- The second - determines the operating mode of the mill Sj.

Thus, the chromosome can be represented by the formula (1):

\[(Z_1S_1) (Z_2S_2) (Z_3S_3) (Z_4S_4) ... (Z_nS_n)\]  

Each gene sequence is formed from operations that can be scheduled. Since the sequence of operations corresponding to the genes of the chromosome must adhere to a given set execution of orders, the initial population is generated randomly only from the set of admissible options that can be performed in the schedule [6].

Step 2. Assessment of the fitness of individuals in the population.

To assess the efficiency of the cement mill loading schedule, it is necessary to select the target function and constraints to find the optimal solution. The main costs of the enterprise associated with switching mills and drawing up a non-optimal mill loading plan include:

- costs for mill downtime;
- electricity costs;
• costs associated with the repair of the gearbox;
• costs associated with exceeding the time of cement production;
• costs in case of overfulfillment of the cement production plan [7].

Considering the possible costs and the limitations below, the type of fitness function is represented by the formula:

\[ \min Z = \sum_{i=1}^{m} (t_{ni} \ast (S_n + S_3) + Sp) + K \ast R_q \ast S_{ui} \]  

where: Z - the total amount of economic losses;
Sn - the sum costs of one hour of mill downtime;
Sc - the amount of electricity costs;
Sp - the cost of gearbox wear at one mill changeover;
Stsi - the cost of 1 ton cement of the i-th grade;
K - the number tons that did not have time produced to the q-th client within the specified time;
Rq - client status.

The minimization the time spent on switching mills can be represented using formula (3).

\[ t_n = \sum_{i=1}^{m} t_{ni} \rightarrow \min \quad t_{ni} = \sum_{j=1}^{n_i} \tau_{ij} \]  

where: \( \tau_{ij} \) - the switching time of the i-th mill for the j-th time;
\( t_n \) - the total switching time of the mills.

Considering that the switching time of one mill has a relatively small spread, it can be considered conditionally constant. Then the minimization of switching costs can be interpreted as minimizing the number of switching.

Several restrictions have been introduced:

• Restrictions on the volume of cement production:

\[ V_{pli} = V_{fi} \]  

where \( V_{pli} \) - the planned volume cement production of the i-th grade;
\( V_{fi} \) - the actual volume cement production of the i-th grade.

Moreover:

\[ V_{fi} = V_{fi} + \alpha \]  

where \( \alpha \) - the percentage of possible deviation from the plan, which depends on the popularity of the brand order at the moment, forecast, and previous planning. This percentage is calculated by experts and is already taken into account in the order when drawing up a plan.

Cement produced in excess the plan is stored in the silos and can be used in the next scheduling of the mill load.

• Limitations on the timing of cement production

\[ T_{pli} \geq T_{fi} \]  

where \( T_{pli} \) - the planned production time of the i-th cement grade;
\( T_{fi} \) - actual production time of the i-th cement grade.
Constraint (5) guarantees the production the number tons of cement to be produced according to the plan. Constraint (6) guarantees the production of cement on time. Exceeding the term entails losses for the enterprise.

As a result of the performed assessment individuals, the best chromosome is selected.

Step 3. Selection of individuals for crossing, which selects chromosomes for their further reproduction in accordance with the values of their fitness function. Gene selection is performed by the tournament selection method [4].

Step 4. Generation of the offspring genotype using the crossing operator PPC (precedence conservative crossover) - the so-called crossing operator for representing mutations with repetitions [4].

Step 5. Mutation with probability Pm based on the "order-based mutation" method. The mutation operator in this work was specially modified so that it could preserve the specified sequence restrictions in the execution of operations.

Step 6. Checking chromosomes and, in some cases, correcting them, which is associated with the obligatory observance of the given order of execution orders. Selecting an individual and replacing it with a descendant. Then are need to update the current population by adding the best chromosome to it.

Step 7. Evaluation of the fitness offspring, after which the average fitness the population is recalculated and the vector fitness of individuals is calculated. Go to step 3.

In the process testing the proposed algorithm for constructing a schedule of loading cement mills, a series studies was performed. The studies were carried out with the following parameters:

- The population size is 100;
- 1000 generations was considered in each process of evolution;
- The probabilities of mutation and crossing were selected experimentally.

Each process was repeated 10 times and the average result was calculated. The result is presented in the form of graphs and tables with the final best schedule option. An example of the resulting graph is shown in figure 1.

![Monthly schedule of loading mill No. 4](image)

**Figure 1.** Monthly mill schedule.

### 4. Conclusions

A modified genetic algorithm has been developed, which allows to distribute the load of cement mills over time and produced cement brands in such a way as to minimize the switching mills to a minimum and at the same time prevent deviations from the set plan.

The research of the proposed genetic algorithm was carried out, which allowed to determine its optimal parameters.
The developed genetic algorithm, when used in an automated subsystem for cement production control, allows you to build optimal production plans, taking into account restrictions on volumes and terms, which contributes to an increase in equipment productivity and a decrease in production costs.

**Reference**

[1] Kolosova O S 2018 *Production automation: a textbook for open source software* (Moscow: Yurayt Publishing House) Series: Professional education the general ed O S Kolosova p 291

[2] Grishkovets V A and Svetlichnaya V A 2011 *Planning the load of cement mills on the basis of a portfolio of orders Information control systems and computer monitoring (IUS KM - 2011): II All-Ukrainian scientific and technical conference of students, graduate students and young scientists* (Donetsk: Donetsk National Technical University) 1 p 60-4

[3] Alekseev B V 1980 *Cement production technology* (Moscow: Higher School) p 263

[4] Skobtsov Yu A 2008 *Fundamentals of evolutionary calculations: a textbook* Ministry of Education and Science of Ukraine (Donetsk: Donetsk National Technical University) p 326

[5] Skobtsov Yu A 2019 *evolutionary algorithms and object-oriented models in optimization of production schedules In the collection: Ninth All-Russian scientific-practical conference on simulation modeling and its application in science and industry* (Donetsk: Donetsk National Technical University) p 206-10

[6] Skobtsov Yu, Sekirin A, Zemlyanskaya S, Chengar O, Skobtsov V and Potryasaev S 2016 *Application of object-oriented simulation in evolutionary algorithms advances in Intelligent Systems and Computing* DOI: 10.1007/978-3-319-33389-2_43 466 p 453-62

[7] Krichevsky M L 2005 *Intellectual methods in management* (SPb: Peter) p 304