Reducing Production and Transportation Costs for the Transportation of Iron Ore Raw Materials from Mining and Processing Plants on the Basis of the Use of an Integer Model

A N Novikov¹, I A Novikov², N A Zagorodnij²

¹Oryol State University named after I.S. Turgenev, 302026, Orel, Komsomolskaya st., 95, RF
²Federal state educational institution of higher education «Belgorod state technological University named V.G. Shukhov» (BSTU named V.G. Shukhov), 308012, Belgorod, Kostyukov st., 46, RF

E-mail: n.zagorodnij@yandex.ru

Abstract. The article considers an integer model for transporting iron ore raw materials with minimal transportation costs. An integer production and transport model allows you to determine the volume of production with the assignment of sites to storage points and distribute the volume of transportation along routes. It is established that the solution of the transport problem allows you to determine the volume of transportation; assign sections to temporary storage points, choose a rational transportation route, minimize transportation costs, assign the required number of dump trucks to excavators, etc.

1. Introduction

Any transport process for transporting iron ore raw materials (food products or household waste) interacts with their production and production (receipt). The interaction of the transportation organization with the production stages is observed. In this regard, any deviation from the established system of transportation entails failures in the production of products and bringing them to marketable form.

Unstable work in the quarry, the lack of constant production of iron ore in the same volumes, high requirements for transport and cargo safety, require changes in the structure of transport flows, regulation of the maximum use of equipment and the organization of the transport process, adapted to the most frequently changing conditions. Special attention should be paid to planning the operation of transport depending on the load, the development of new equipment and improving the system of work in the quarry and on the surface.

When operating the transport complex of a mining and processing plant (GOK), it is necessary to monitor the technical condition of the equipment [2]. The creation of separate repair services and transport workshops at the enterprise would eliminate long transport downtime waiting for labor-intensive repairs [5]. Increase the efficiency of transport operation, timely maintenance and repairs are required, which prevent the occurrence of failures and malfunctions.

For the growth and development of mining and processing enterprises, automation of technological processes with the use of information and telecommunications systems, software products and satellite
navigation is required [1]. Monitoring the operation of the transport complex, transportation along a set route, the volume of cargo transported, and the driver's condition allow you to make a timely decision to eliminate a failure in operation, which prevents a complete stop of the transportation process and saves time [9].

For the development of the transport industry in the quarry and prospects for the future, the task is to reconstruct the mining transport system of the quarry, which will ensure the required volume, quantity and quality of ore charge, and reduce distances regardless of the number of dead-end stations [12,4].

The most common are direct transportation of iron ore [6]. Loading of minerals is carried out by an excavator in a dump truck of various loading capacities, which later transports the ore to a temporary storage point. The disadvantage of this type of transportation is the occurrence of downtime of the excavator. The decrease in the efficiency of transport operation occurs due to the inconsistency of the chain "excavator-dump truck" [7,8]. Based on this, it is necessary to calculate the time and number of dump trucks delivered to the excavator to prevent waiting and loss of time.

When creating a rational organization of the iron ore transportation system, it is necessary to plan the transportation processes based on weather conditions, including paying attention to the load capacity of dump trucks, the productivity of excavators, the capacity of warehouses, free working areas for loading and unloading of minerals. This will have an impact on reducing the probability of downtime of the "excavator-dump truck", loading and unloading downtime, will allow you to calculate the necessary amount of equipment, and, as a result, reduce the cost of production and improve its quality [10,20].

The main goal of any mining and processing plant is to maximize profit and reduce material costs [17]. At most GOK, work is underway to reduce the cost of production by reducing: production costs (blasting); time for loading and unloading and transportation; downtime; ride length; the probability of failure of equipment on the line-monitoring the technical condition of the most important components and aggregates (ice, transmission, tires, etc.) of the equipment, as a result, it is necessary to develop a model for transporting minerals, allowing with minimal costs to produce and transport iron ore raw materials to an intermediate or average warehouse, and then to a processing plant [16].

2. Integer production and transport model for determining the volume of production and transportation of iron ore raw materials, taking into account cost reduction

The integral transport and production model is based on reducing the cost of transporting iron ore raw materials to an intermediate / average warehouse and processing plant, reducing the loss of unprocessed raw materials within the established production schedule [18].

The simplest transport and production models are those that by their content are not only tasks for optimizing the schemes of attaching consumers to suppliers, but which, due to the presence of features of the mathematical formulation, can be reduced to mathematical transport problems and do not require universal linear programming methods to find optimal solutions [3].

The advantage of this model is that it considers the process of mining and transporting iron ore at the same time, and also offers a solution to the problem, taking into account the performance of the transport complex of mining and processing enterprises.

Minimization of production and transport costs can be achieved by determining the volume of production and throughput capacity of warehouses with the required number of dump trucks assigned to the excavator for load capacity and production capacity of the processing plant.

To determine the volume of transported minerals, taking into account the preservation of quality and organization of the transportation process, an integer transport and production model is selected. It will allow you to create a rational organization of the transportation process, operational planning stages, and reduce the cost of transporting raw materials [19]. The selected model allows the calculations to take into account options for transporting raw materials by an integer number of dump trucks.
The integer transport and production model explicitly displays production costs, as well as defines production plans and schemes for attaching iron ore deposits to warehouses and processing plants.

The task of organizing the process of transportation and distribution of traffic flows from the production site to the temporary storage facilities taking into account the reduction of transport costs for transportation of iron ore, is achieved based on the data throughput of the warehouses, the existing cost for transportation and production facilities of the enterprise [13].

The choice of the optimal option for the volume of transportation of iron ore raw materials and the distribution of transport flows is made in accordance with the cost minimization:

$$
\sum_{i=1}^{n} \sum_{l=1}^{l_i} (c_{il} p_{il} + \sum_{h=1}^{d} Q_{hil} \delta_{mh} c_{ih}) + \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{K} t_{ijk} V_{ijk} \Rightarrow \min,
$$

$$
\sum_{i=1}^{n} a_{il} p_{il} - \sum_{k=1}^{K} V_{ijk} \geq 0
$$

$$
\sum_{i=1}^{n} p_{il} \leq 1,
$$

$$
\sum_{i=1}^{n} V_{ijk} \geq b_{ik},
$$

$$
V_{ijk} \geq 0,
$$

where \( \sum_{i=1}^{n} \sum_{l=1}^{l_i} c_{il} p_{il} \) - iron ore production costs for the \( l \)-th option on the \( i \)-th site;

\( \sum_{h=1}^{d} Q_{hil} \delta_{mh} c_{ih} \) - the cost of losses of the unearthed volume of iron ore raw materials on the \( i \)-th site in the \( l \)-th variant of cleaning;

\( \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{K} t_{ijk} V_{ijk} \) - the cost of transporting \( j \)-type iron ore from the \( i \)-th site to the \( k \)-th point of the processing plant;

\( j \) – ore raw materials \((j=1,\ldots,m)\);

\( k \) – concentrating factory \((k=1,\ldots,K)\);

\( i \) – production site \((i=1,\ldots,n)\);

\( l \) – mining option \((l=1,\ldots,L_i; i=1,\ldots,n)\);

\( c_{il} \) – total costs (gross cost) associated with the extraction of iron ore for the \( l \)-th option on the \( i \)-th site;

\( p_{il} \) – the desired intensity of use of the \( l \)-th production option on the \( i \)-th site, while \( p_{il} \in \{0;1\} \). If \( p_{il} = 1 \), the solution, then the option is included in the optimal plan, and \( p_{il} = 0 \) means that it is not included. Each object has only one option;

\( Q_{hil} \) – the volume of iron ore raw materials not extracted at the \( i \)-th site in the \( l \)-th variant of production;
\( \delta_{hi} \) - underworking of iron ore raw materials in shares on the \( i \)-th site;
\( c_h \) - cost per ton of iron ore;
\( d \) - number of days after the end of the planned month;
\( t_{ijk} \) - the cost of transporting a ton of \( j \)-type iron ore from the \( i \)-th site to the \( k \)-th point of the processing plant;
\( V_{ijk} \) - the required volume of transportation of \( j \)-type iron ore from the \( i \)-th site to the \( k \)-th point of the concentrator;
\( a_{ijk} \) - the volume of production of the \( j \)-th type of product from the \( i \)-th site to the \( k \)-th point of the processing plant;
\( b_{jk} \) - total demand for \( j \)-type iron ore in the \( k \)-th point of the processing plant.

If \( p \) satisfies formulas 1-5, then the components \((p, V)\) are called the production and transport plan.

Making up equations 6, 7, which indicate production and transport costs in the implementation of the plan, it is necessary to focus on the terms of the target function 2.

\[
\begin{align*}
 f_2(V) &= \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{K} t_{ijk} V_{ijk}, \\
 f_1(p) &= \sum_{i=1}^{n} \sum_{l=1}^{L} (c_{il} p_{il} + \sum_{h=1}^{d} Q_{il} \delta_{ih} c_h),
\end{align*}
\]

where \( p \) - production plan;
\( V \) - transport component (transport plan).

Problem 1-5 is a partially integer linear programming problem and has the following features:
1. Each variable of the \( V_{ijk} \) type is included in 2 restrictions: with a coefficient of +1 and with a coefficient of -1;
2. The set of variables of the \( V_{ijk} \) type is divided into several groups depending on the number of products produced from iron ore raw materials;
3. Integer variables take the values 0 or 1;
4. Variables are divided into groups based on the number of production points at the processing plant. In a group, one variable can be different from zero [14,15].

The solution to the problem of minimizing costs for the transportation of iron ore raw materials and the distribution of transport flows is based on the study of the production and transport components. When studying the total demand for each site as a load the production model is presented as:

\[
\begin{align*}
 f_1(p) &= \sum_{i=1}^{n} \sum_{l=1}^{L} (c_{il} p_{il} + \sum_{h=1}^{d} Q_{il} \delta_{ih} c_h) \Rightarrow \min.
\end{align*}
\]

As the volume of deliveries, it is possible to use the volumes of iron ore extraction, which were discussed above. Determining \( m \) by the number of sections of transport problems is only possible when solving this model.

Accept: \( P^0 = \{ P_{il}^0 \} \) - the optimal plan for the production model:

\[
\sum_{l=1}^{L} d_{il} P_{il}^0 = A_{il}, \quad j=1,...,m; \quad i=1,...,n;
\]

where \( A_{il} \) - the production volumes of the \( j \)-th type of iron ore raw material on the \( i \)-th site and can be formed for \( j=1,...,m \) transport problems of the form:
\[ f_{j0}(p_0) = \sum_{i=1}^{n} \sum_{k=1}^{K} t_{jk} V_{jk} \Rightarrow \min. \]  

After solving the transport problem production and transport tasks are defined:

\[ F_0 = f_i(p_0) + \sum_{j=1}^{m} f_{j0}(p_0). \]  

The solution to the problem of minimizing cost involves the construction of production plans, so that when you add production and transport costs, their sum is minimal.

According to the model described above, with the established production plan, the cost of production from iron ore raw materials is reduced. According to equation 16, the reduction of total production and transport tasks is possible when the production plan is reduced, but at the same time, transport costs are saved.

Based on the use of dual permissible systems of transport problem potentials, when considering ways to exclude production plans that do not lead to saving transport costs, it is possible to determine additional linear restrictions. If the production plan does not meet these restrictions, it is not possible to reduce transport costs. Therefore, when solving a transport problem, it can be excluded, because it is unpromising.

Accept:

\[ F^* - \text{total production and transport costs at this current step, after solving a series of transport tasks;} \]

\[ G_{ik} - \text{dual variable corresponding to restrictions 12 in the same step;} \]

\[ S_{ij} - \text{dual variable of the transport problem corresponding to restrictions 13 at the same step.} \]

The dually valid systems of transport problem potentials, taking into account transformations and transfer of terms independent of the production plan to the right side of the equation, are written as:

\[ \sum_{i=1}^{n} \sum_{l=1}^{L_i} (c_{il} - \sum_{j=1}^{m} a_{ij} s_{ij} ) p_{il} < F_0 + \sum_{j=1}^{m} \sum_{k=1}^{K} b_{jk} G_{ik}; \]  

\[ \sum_{i=1}^{n} \sum_{l=1}^{L_i} c_{il} p_{il} - \sum_{i=1}^{n} \sum_{l=1}^{L_i} a_{ij} p_{il} s_{ij} < F_0 + \sum_{j=1}^{m} \sum_{k=1}^{K} b_{jk} G_{ik}; \]

The validity of solutions to dual transport problems does not depend on the established production plan.

Since \( p_{ic} \in \{0;1\} \), then there will always be a number \( \lambda > 0 \) something that meets production plans (1 and 6).

\[ \sum_{i=1}^{n} \sum_{l=1}^{L_i} (c_{il} - \sum_{j=1}^{m} a_{ij} s_{ij} ) p_{il} \leq F_0 + \sum_{j=1}^{m} \sum_{k=1}^{K} b_{jk} G_{ik} - \lambda. \]

3. Conclusion

Solving transport problems based on established production plans allows you to minimize production and transport costs. Potential systems obtained as a result of solving transport problems are used for constructing additional linear constraints (cut-offs), which are used for screening out "unpromising" production plans [11, 14].

Solving the problem of organizing the transportation process and distributing transport flows from the mining site to temporary storage points, taking into account the reduction of transport costs for the transportation of iron ore raw materials, allows you to obtain:

1. production Volumes, i.e. what volumes of iron ore raw materials and from which sites should be transported first;
2. Assigning sites to intermediate warehouses (temporary storage points), taking into account the capacity of warehouses;
3. Rational routing of road transport of iron ore raw materials inside and outside the quarry with minimal costs;
4. Determination and reduction of costs for the extraction and transportation of iron ore raw materials, taking into account the remaining raw materials, according to the established plan, for each production option.

4. References

[1] Abroskin A S 2015 Application of modern automation systems in open-pit mining Proceedings of Tomsk Polytechnic University Georesources engineering Vol 326 12 pp 112-130
[2] Agafonov D V 2017 Technological motor transport of the Lebedinsky GOK Gorny Zhurnal 5 pp 38-41
[3] Blam Yu Sh, Mashkina L V 2008 Models and methods of applied analysis (production systems): studies' method complex to the course (NSU, Novosibirsk) http://econom.nsc.ru/efnsu/Mimpa2.htm
[4] Gavrishev S E 2002 Organizational and technological methods for improving the reliability and efficiency of quarries: monograph (Magnitogorsk: MSTU) 231 p
[5] Nesterenko A V 2017 Repair service of the combine Mining journal 5 pp 42-45
[6] Semykina A S 2017 Analysis of types of iron ore raw materials and the process of their transportation Scientific and technical aspects of innovative development of the transport complex: collection of scientific papers on the materials of the III International scientific and practical conference on may 25, 2017 Ministry of education and science of the DPR and others-Donetsk: DAT pp 27-31
[7] Semykina A S 2017 Identification of problems of the transport complex of mining and processing enterprises New materials, equipment and technologies in industry: materials of international cooperation. scientific-technical Conf. young. scientists Ministry of education of the Republic of Belarus, Ministry of education and science of the Russian Federation Federation Belarusan (Mogilev: Byelorus)
[8] Semykina A S 2018 Improving the efficiency of automobile career transport Student scientific forum http://www.scienceforum.ru;
[9] 1996 Modern software systems of the Modular Mining company for managing mining equipment at quarries journal "Mining industry" 4 p 46 https://mining-media.ru
[10] Tarikov D Sh 2012 Analysis of production activities of a mining enterprise and development of methods for optimizing the transport and cargo complex Actual problems of modern science, technology and education-Magnitogorsk: Magnitogorsk state technical University (Nosov University) Vol 1 pp 96-99
[11] Taha Hemdi A 2005 Introduction to the study of operations, 7th edition [Text]: TRANS. from English (M.: Publishing house "Williams") 912
[12] Lepetyukha S V, Yakushev A S 2007 State and prospects of development of technological motortransport at Lebedinsky GOK (Gorny Zhurnal) 7 pp 25-27
[13] Paley L M 2014 Managerial and engineering support of open pit mine production phase I at v. grib mining and progressing combine Eurasian mining 2 pp 20-22
[14] Chun-xiu Wu, T Song, P Zhang, S C Wong 2012 Phase-plane analysis of preserved higher-order traffic flow model Applied Mathematics and Mechanics 1505 -1512 p
[15] Trapeznikova M A, Furmanov I R, Churbanova N G, Lipp R 2012 Simulating multilane traffic flows based on cellular automata theory Mathematical Models and Computer Simulations pp 53-61
[16] Trapeznikova M A, Furmanov I R, Churbanova N G, Lipp R 2012 Simulating multilane traffic flows based on cellular automata theory Mathematical Models and Computer Simulations pp 53 - 61
[17] Novikov A N 2006 Ecological monitoring of the impact of vehicles on the acoustic environment of the city Repair. Recovery. Modernization 6 pp 33-34
[18] Novikov A N 2009 The choice of factors that determine the quality of car service by the program-target method *Bulletin of transport information* 8(170) pp 36-40

[19] Novikov A N 2010 Optimization of the number of diagnostic lines for technical inspection of vehicles on the example of the Oryol region *Bulletin of transport information* 5(179) pp 31-33

[20] Shavol G 2007 New service of DBT firm in Russia: provision of mining equipment for rent *Mining industry* 4(74) pp 36-37