

Problems of designing transport systems of «Siberian Antrazit»

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Abstract The article discusses the operating conditions of transport systems located in open pit mining of the enterprise of Siberian Anthracite JSC using «Kolyvanskij» opencast mine as an example. The most optimal route for coal supply railway lines from the open pit to the concentration plants was designed, the use of which will increase the enterprise's productivity and reduce the risks of using vehicles. When searching for the optimal route for coal delivery from «Kolyvanskij» open-pit mine to the «Listvjanskaja-1» and «Listvjanskaja-2» enrichment plants, the method of dynamically programming the optimal route (the optimality principle of R. Bellman) was used as an algorithm. The method of dynamic programming is to determine the shortest distance between nodes (places of intersection of the proposed railway tracks), by successive solutions of which, the shortest route is revealed. Based on the obtained parameters, two designed tracks were compared and, as a recommendation for solving technological issues in the design of transport systems of a mining enterprise it was proposed to use the optimal railway from the open-cast mine to «Listvjanskaja» «2 way» enrichment plant.

Keywords motor transport, mining enterprise, coal delivery, railroad, circular curves, R. Bellman's equation

1 Introduction

Siberian Anthracite is the world's first producer of ultra-high quality anthracite and is Russia's largest producer of coking coal. It is one of the fastest growing coal companies in the country. The company has an annual increase in the production of minerals about 30%, and in the future this increase will depend significantly on the decisions made in the design of transport systems.

Three coal mines are being developed in the Novosibirsk region: Kolyvansky, Gorlovsky and Oriental. The design capacity of the Kolyvansky cut for 2019 for production has been adopted equal to 8500 thousand. t anthracite per year (of which 8100 thousand tons/year - the project capacity of the Northern site, 400,000 tons/year - the project capacity of the Krutikhinsky site). The field is developed in an open way using an in-depth longitudinal two-breasted development system (Sysoev 2005).

The main part of the extracted anthracite from slaughter is transported to the industrial site of the processing plants Listvyanskaya-1 and Listvianskaya-2 (further on the text of OF-1 and OF-2). OF-1 and OF-2 receive and enrich the anthracites of the Kolyvan field and ship goods to consumers by rail.

The approaches are defined that comprehensively characterize the economic efficiency of the project using the Bellman principle and reflect the actual and potential damage from its implementation throughout the entire life cycle of a mining enterprise.

The novelty lies in the dynamic programming method, which was not

previously used in enterprises to find the optimal route.

2 Experiments

In determining the current problems of designing transport systems of incisions should take into account the more complex operating conditions of the developed fields of the field due to:

- The distance of the deposit from the transport highways;
- Lack of developed infrastructure and industrial enterprises operating in the region;
- The complexity of the mining, geological and mining conditions of the development of deposits associated with the presence of numerous non-concave violations in 14 steep-falling coal seams, breaking them into separate blocks of 0.5-1.0 km at a depth of up to 200-300 m.

Since 1993 as the main transport system of JSC Siberian Anthracite, the technology of mining operations with the use of vehicles was selected, the use of which, according to the results of technical and economic calculations, is not advisable. As a result, for the mining and geological conditions under consideration, the management of the JSC Siberian Anthracite decided to make the transition from the use of road transport to rail. This article is devoted to the design of an optimal railway from the open pit to the Listvyanskaya concentrator, which, according to the authors, will most radically help to solve transport problems in the

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development of deposits, given that the conditions of each open pit are unique.

As an algorithm for finding the required task, and in the case in question, selecting the shortest distance of the railway from the Kolyvanski mine to OF-1 and OF-2 (Figure 1), the most effective method is dynamic programming (the principle of the optimality of R. Bellman) (Lezhnev 2010) that allows you to find the best option for placing the trajectory of the railway in the conditions of complex surface relief (Tatarinova 2015). The subject of dynamic programming is the study of multi-step tasks and their solutions. Dynamic programming is a way to solve a problem by dividing it into several identical (secondary tasks) recursively related to each other. At the same time, decisions at every step are made on the basis of the interests of the whole process, and not each step individually (Tarasenko and Egorova 2019; Ovchinnikov 2008; Ovchinnikov 2012; Faure et al. 1975; Aho et al. 1983). For the design of the parameters of the railway, 4 main directions or tracks were proposed, with connecting roads (Fig. 1). The application of Bellman's methods

to transport logistics in the development of coal deposits of the Siberian Anthracite is presented as a multi-step decision-making process, which is broken down into seven stages (Figure 2):

- In the first phase of node 0 (OF-1, OF-2) without intermediate nodes, you can only get into nodes 1, 2, 3 and 4;
- In the second stage, nodes 1, 2 and 4 can only be accessed in 5, 6 and 11 knots;
- In the third stage, 5, 6 nodes need to be entered into nodes 7 and 8;
- In the fourth stage of knots 7, 8 and 4 you need to get into 9, 10, 11 knots;
- In the fifth stage, choose the most appropriate distance from node 9 to 14, through nodes 12 and 13;
- In the sixth stage of knots 12, 13, 10 and 11 find the shortest distance to 14, 15 and 16 knots;
- in the seventh stage we get the best way to the cut (node 17) of 14, 15 and 16 knots

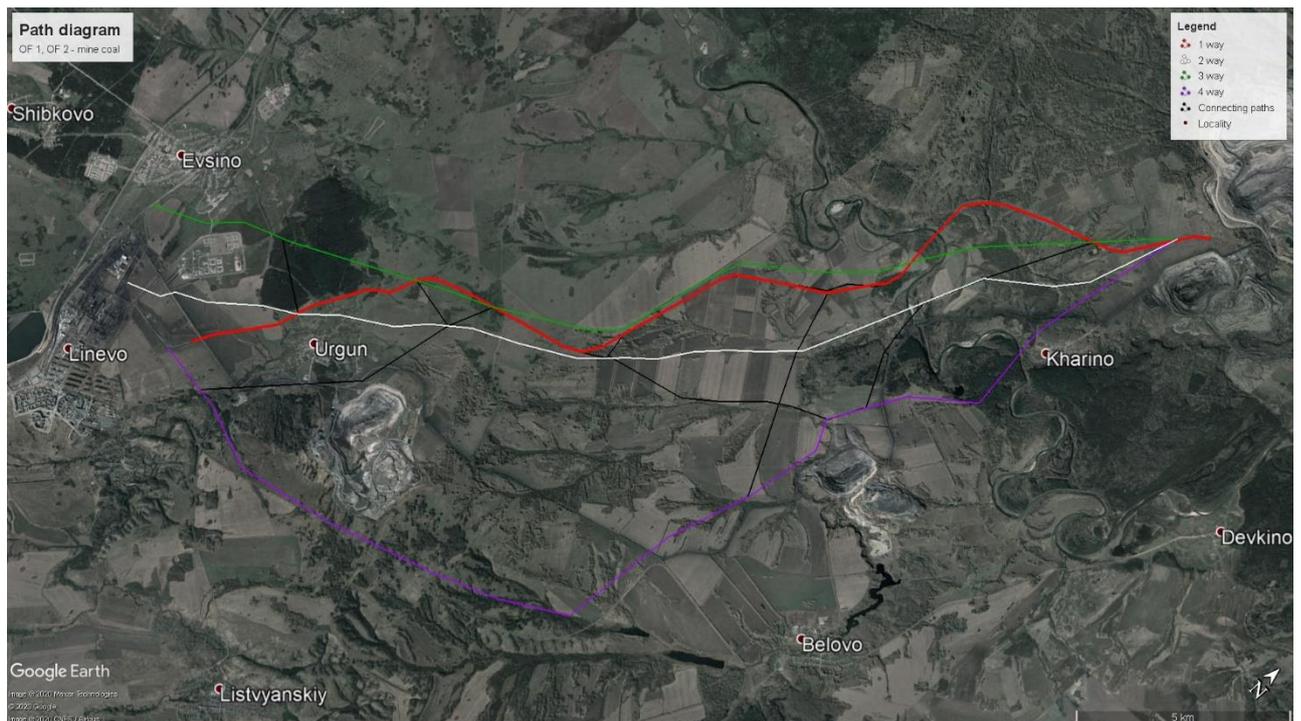


Fig. 1 Scheme of proposed routes

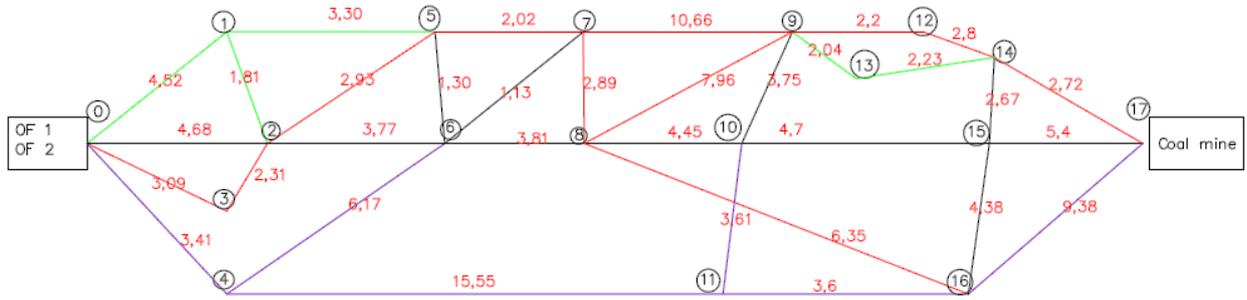


Fig. 2 Shortest Path Finder

By gradually calculating the distances from the nodes of one stage and using the information obtained in the previous stages, it is possible to determine the optimal route of

the access road on the surface of the coal mining complex (2 way). The best path goes through 2,6,8,10 and 15 knots, and the solution below is:

$$f_1(X_2) = \min(f_0(X_0) + U_{02}; f_1(X_3) + U_{32}; f_1(X_1) + U_{12}) = (4,68; 4,52 + 1,81; 4,52 + 1,81) = 4,68 \text{ km}$$

$$f_2(X_6) = \min(f_2(X_5) + U_{56}; f_1(X_2) + U_{26}; f_1(X_4) + U_{46}) = (7,61 + 1,3; 4,68 + 3,77; 3,41 + 6,17) = 8,45 \text{ km}$$

$$f_3(X_8) = \min(f_2(X_6) + U_{68}; f_3(X_7) + U_{78}) = (8,45 + 3,81; 9,58 + 2,89) = 12,26 \text{ km}$$

$$f_4(X_{10}) = \min(f_4(X_9) + U_{910}; f_3(X_8) + U_{810}) = (20,22 + 3,75; 12,26 + 4,45) = 16,71 \text{ km}$$

$$f_6(X_{15}) = \min(f_6(X_{14}) + U_{1415}; f_4(X_{10}) + U_{1015}) = (24,49 + 2,67; 16,71 + 4,7) = 21,41 \text{ km}$$

$$f_7(X_{17}) = \min(f_6(X_{14}) + U_{1417}; f_6(X_{15}) + U_{1517}; f_6(X_{16}) + U_{1617}) = (24,49 + 2,72; 21,41 + 5,4; 22,56 + 9,38) = 26,81 \text{ km}$$

Of the proposed 4 railway tracks (Figure 1) in the future will be considered 2 way and 1 way, as 2 path, based on the decision, is the shortest, and 1 track (28.73km) was selected by the Siberian Anthracite as the main route for construction.

When designing the route of railway tracks, the calculation of the track is designed in two projections - in profile and plan. The ground profiles of the new route are piecemeal broken lines. New rail route plans are a family of straight lines and curves. When designing a plan for the new railroad track in the early stages, you can limit yourself to presenting the plan only by straight and circular curves. There are two parameters that directly characterize the length of the L and the direction determined by the directional angle α .

The length of the straight trajectory is measured between the ends of the transitional

or circle curves. The rationality of direct lanes is obvious, as the shortest distance is provided and on this basis the minimum mileage and operating costs are provided. However, in difficult topographical conditions, bypassing obstacles causes you to deviate from the shortest direction, so the circular curves are projected (Loktev et al. 2015; Sychev et al. 2016; Gavrilentov and Perelennikov 1984). For the priority 2 paths, calculations of abbreviated coordinates of the main points, distances and directional angles were calculated.

For the uniform pairing of adjacent straight sections of the path, there are circular curves (Figure 3, a, b). Curves are divided on the ground by parameters: T - tangens, R - radius, D - domer, B - bisectrix, α - angle of turn, C - the length of the curve. VU is the top of the corner of the turn.

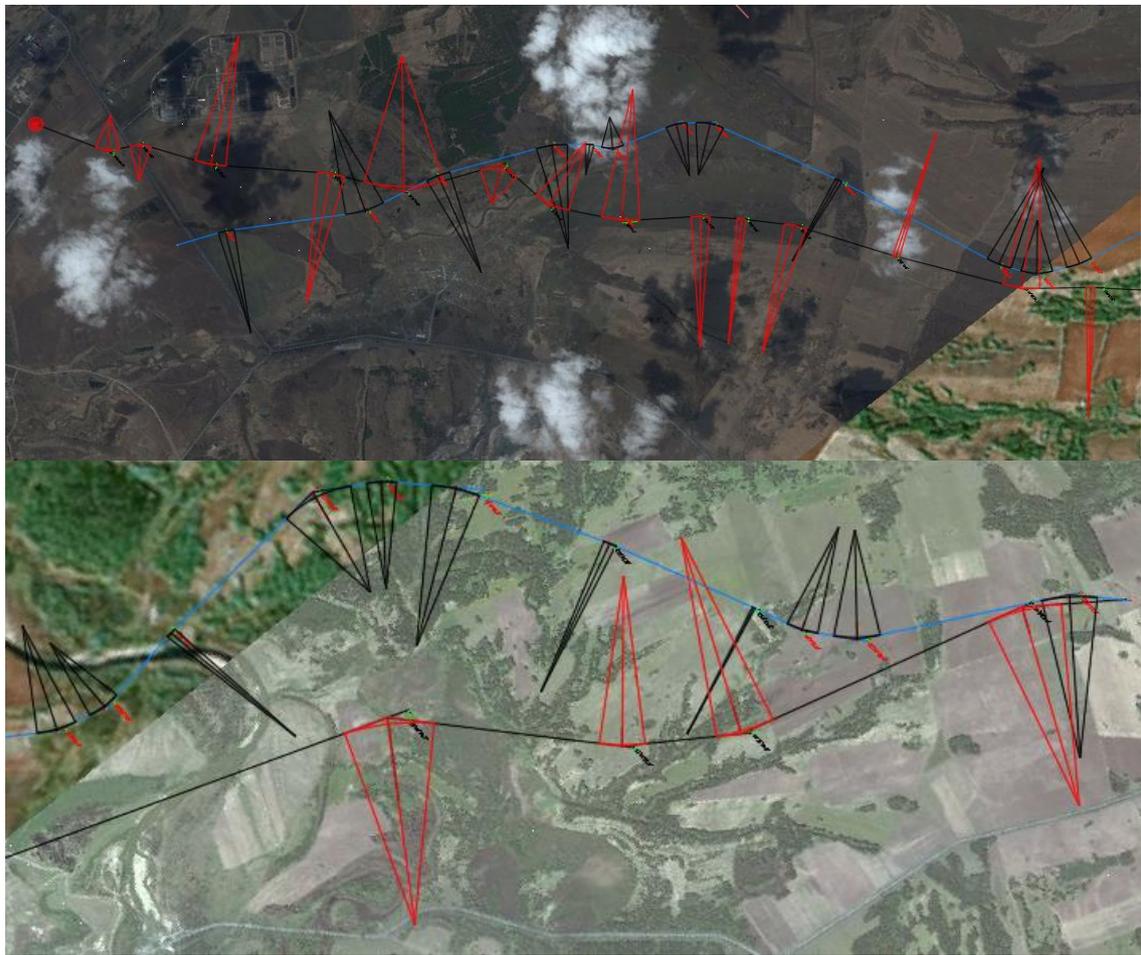


Fig. 3 Scheme to build circular curves
(a - the beginning of the path, b - the end of the road)

The main parameters of the curve - the angle of the turn and radius of R - are appointed when developing a plan based on their feasibility and efficiency, as well as dictated by the topographical forms of terrain and the planned situation. The parameters of the q and R may change in certain ranges. The minimum α_{min} of the turn is limited depending on the conditions, and the maximum - theoretical is not limited (Gavrilenkov and Perelennikov 1984; Loktev and Loktev 2015). The radius largely determines the position of the road within the curve. The smallest radius is determined by the ride comfort. The rest of the parameters are measured in meters and calculated according to well-known formulas (1-4):

$$\text{Tangens curve: } T = R * \operatorname{tg} \frac{\alpha}{2} \quad (1)$$

$$\text{Length of curve: } K = \frac{\pi * R * \alpha}{180^\circ} \quad (2)$$

$$\text{Bisectri s curve: } B = \left(\frac{T}{\sin \frac{\alpha}{2}} \right) - R \quad (3)$$

$$\text{Domer curve: } D = 2 * R * \left(\operatorname{tg} \frac{\alpha}{2} - \frac{\pi * \alpha}{360^\circ} \right) \quad (4)$$

3 Results and Discussion

The calculations of the circular curve and picket values were made. The average curve radius for the 1st track was 926,923 m., and for 2 - 1326,087 m.

When the train moves along curved sections, a centrifugal force arises, which results in a negative impact on the increased wear of the track superstructure and rolling stock. In difficult terrain, underutilization of the limiting slope can significantly lengthen the track or increase the volume of earthworks, and a decrease in the weight rate (train mass) leads to an increase in operating costs for train traffic and a decrease in the carrying capacity of the road (Gavrilenkov and Perelennikov 1984; Bestem'yanov 2015). Indicators of centrifugal force on a circular curve are calculated. The average value of the centrifugal force along 1 and 2 tracks, respectively, was 658.517 N/m and 352.5 N/m, the average height of the rail elevation, respectively, 105.083 mm and 78.567 mm. These calculations made it possible to assign categories to the projected railway tracks. The categories differ in the calculated annual net load density and the maximum speed of movement along it. The railroad chosen by the authors (2 way) was assigned the II category. For category II, the calculated annual reduced load intensity in the freight direction for the

tenth year of operation can be over 15 to 30 million tons / km, and the speed of the train can reach 160 km/h (SNiP 1995). Unlike the presented one (1 way), which is assigned category III, with a load capacity of over 8 to 15 million tons / km, and a permitted maximum speed of up to 120 km/h.

The quality of the paths has been assessed for the category (Loktev and Loktev 2015; Loktev et al. 2015; Khusainov and Ozhereleva 2019; Ricketts et al. 2017, 2019, 2020, 2018, 2015). The paths were compared by the following metrics:

1) Amounts of lengths of curves and straight (table.1);

2) Percentage of curves (table 2) is calculated by formula (5):

$$100 \frac{\sum C}{\sum P + \sum C} \quad (5)$$

3) The number of curves per 1 km (table 3) is calculated by formula (6), where n - total number of curves;

$$\frac{n}{\sum P + \sum C} \quad (6)$$

4) Minimum radius of the Rmin curve (table 4);

5) Percentage of curves with a minimum radius (table 5) is calculated by formula (7) ($\sum \alpha_{\min}$ the sum of angles of curves with Rmin);

$$\frac{100 \pi R_{\min} \sum \alpha_{\min}}{180 * (\sum P + \sum C)} \quad (7)$$

6) The average radius of curves (table 6) is calculated by formula (8):

$$R = \frac{180 * \sum C}{\pi * \sum \alpha} \quad (8)$$

Table 1 Calculating the amount of curves $\sum C$ and direct $\sum P$

Direction	1 way, km	2 way, km
$\sum C$	6,640	7,989
$\sum P$	19,188	18,169

Table 2 Curve Percentage Calculation

1 way, %	2 way, %
41	52

Table 3 Calculating the number of curves by 1 km

1 way	2 way
0,89	0,87

Table 4 Calculating the minimum radius of the Rmin curve

1 way, m	2 way, m
350	400

Table 5 Calculating the percentage of curves with a minimum radius

1 way, %	2 way, %
10	26

Table 6 Calculating the average radius of curves

1 way, m	2 way, m
959,614	1326,087

4 Conclusions

Thus, as a recommendation to solve technological problems in the design of transport systems of the siberian anthracite mining plant, it is proposed to use 2 way to deliver coking coals from the cut to the processing plant. This is due to the fact that the bandwidth of the 2 way, which was calculated on the principle of optimality of R. Bellman, is 15 million tons/km higher with the prospect for the tenth year of operation.

Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

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