Problems of Designing Transport Systems of «siberian Antrazit»

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Case study

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Abstract

The main aim of this work was to identify an optimal route design for the delivery of coal from the open pit mines to the enrichment plants on the example of the Sibathractic Group's mine "Kolyvansk" and its enrichment plants «Listvjanskaja-1» and «Listvjanskaja-2». The new route would allow the corporation to increase production rates and to reduce the risks associated with the use of motor vehicles. Dynamic programming method, mainly the Bellman equation principle, was chosen as an algorithm for searching for the optimal route from Kolyvansky mine to the «Listvjanskaja-1» and «Listvjanskaja-2». In the course of the study the two possible routes were selected. Further comparison indicated that only one of them - "2nd railway track", corresponded to all the recommended parameters for the delivery route. All the findings are presented in detail in the study.

Key words:

Motor vehicles, mining enterprise, coal delivery, railroad, circular curves, R. Bellman's optimality principle, transport system, economics

1. Introduction

Sibathractic Group is one of the world's largest producers and exporters of ultra-high-quality anthracite and is the largest Russian producer of coking coal. The brand's production grows rapidly with the 30% average annual increase in mineral production. Nonetheless, the future development might get affected by the chosen transportation methods and route design. Right now, the delivery route is 40 km long and the transportation of minerals from the open-pit mines to the enrichment plants requires motor vehicles. We suggest that the construction of the railroad would create a faster delivery method of minerals. New railroad would be only 30 km long and it would reduce the delivery route by 10 km, furthermore, the use of locomotives would create a greater car capacity that would allow to transport more coal. That is why the design of new transportation systems could affect an increase in production rates.

One of the developing mining locations of the Sibathractic Group is Kolyvansky open pit mine, which is located in the Novosibirsk region. The Kolyvansky is divided into two separate areas - the "Severnij"mine and the "Krutchinsky" mine. In 2019 the anthracite mining capacity of the Kolyvansky was estimated to be 8500 thousands tones per year, (Severnij - 8100 thousands tones per year, Krutchinsky - 400 thousands tones per year). The in-depth longitudinal two-breasted extraction system [1] is used for the mineral extraction. After the extraction, the largest part of the anthracite gets transported to the «Listvjanskaja-1» (OF-1) and «Listvjanskaja-2» (OF-2) enrichment plants. There the minerals get processes and prepared to be shipped to consumers via railroads.

In our research we suggest using the dynamic programming method - the new approach toward calculating the optimal route that was never used by coal enterprises as a tool for the route search before. With the help of the Bellman equation we were able to determine the economic efficacy of the project as well as to identify potential dangers associated with the project implementation. Long distance delivery routes as well as emergency situations associated with the dump trucks movements on public highways, might affect the efficacy of the mining location. The new railway route design would allow to minimize the risks of unexpected emergencies and to secure the delivery of minerals.

2. Material and methods

- Before finding an optimal route design, it is important to consider the aggravating exploitation factors of the chosen mining location:
- Distance from the mine to highways
- Lack of the infrastructure in the region
- Distinjunctive dislocation of 14 steeply-dipping coal seams that break the mines into separate 0.5 - 1.0 km long blocks at the depth of 200-300 meters.
- Since 1993 mining and delivery method chosen by Sibathractic Group includes mineral transportation by motor vehicle routes. Nonetheless, the latest techno-economic estimates

indicated the inadvisability of the current delivery method. These calculations together with the special characteristics of the discussed mining location influenced Sibathractic Group's decision to transition to railroad delivery method. This article is going to discuss the issues related to the design of the optimal railroad track from the open pit mine "Kolyvansky" to the enrichment plant "Listvjanskaja". The authors believe that the railroad design would consider the unique characteristics of each mining location and would help to find a solution to the transportation issues.

- The dynamic programming method, mainly Bellman's principle of optimality [2], was found to be the most efficient search algorithm for determining the shortest railroad track from the Kolyvansky open pit mine to OF-1 and OF-2 (fig.1). This method would allow us to make precise calculations of the railway trajectory considering the region's complex terrain [3].
- The dynamic programming method is usually used to study and solve multistep problems. To find a solution, each problem is subdivided into several identical recursively related problems. Each secondary problem gets considered separately, however all the step-by-step interconnected solutions are still aimed at solving the main problem [4-8].
- For this research we used the Bellman equation to analyze the transport logistics used by the Sibathractic Group in the development of the open pit mine. We approached the route design process as a multistep problem. With the help of the chosen method, we identified four possible railway track designs (including their connecting roads) that corresponded to the desired characteristics (fig.1). As a result, the whole task was separated into seven planning steps to find the optimal distance between the route nodes (fig.2):
- Tracks from the node 0 (OF-1, OF-2) to the nodes 1, 2, 3, 4 without any intermediate nodes;
- Tracks from the nodes 1, 2, and 4 to the nodes 5, 6, and 11;
- Tracks from the node 5 and the node 6 to the nodes 7 and 8;
- Tracks from the nodes 7, 8, and 4 to the nodes 9, 10, and 11;
- Tracks from the node 9 to the node 14 through the nodes 12 and 13;
- Tracks from the nodes 12,13,10, and 11 to nodes 14,15, and 16;
- Tracks from the nodes 14,15, and 16 to the open pit mine - node 17.

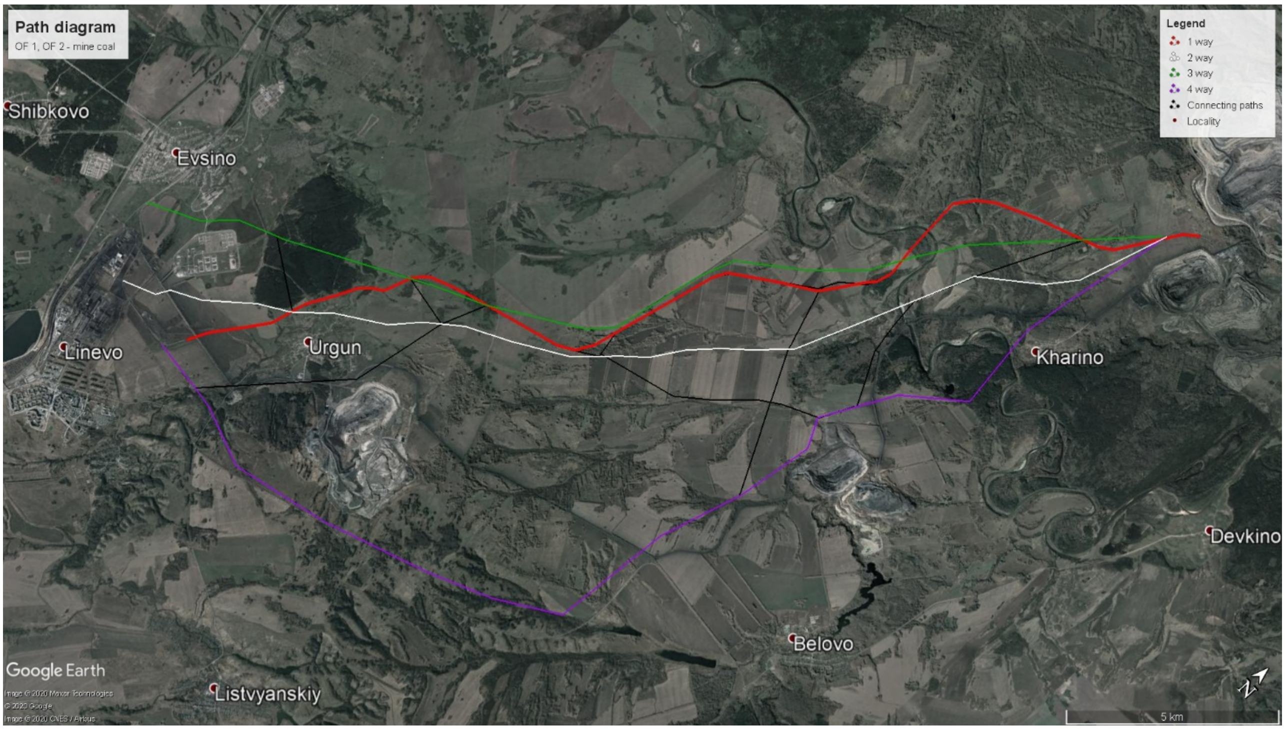

Fig. 1 Scheme of discovered tracks

3. Calculation

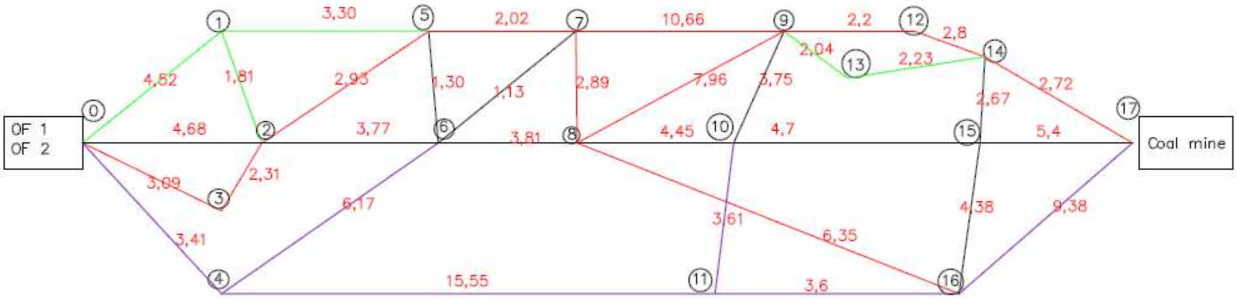

Fig. 2 Shortest tracks calculation scheme

Chosen method allowed us to gradually calculate every next part of the route, considering information obtained in the previous stages. Performed calculations helped us to find the optimal railway tracks design to mining location - the 2nd track that goes through the nodes 2, 6, 8, 10, and 15. All the performed calculations are presented below:

$$\mathbf{f_1(X_2) = min(f_0(X_0) + U_{02};\ f_1(X_3) + U_{32};\ f_1(X_1) + U_{12}) = \left(4,68;\ 4.52 + 1.81; 4,52 + 1,81\right) = 4,68} \text{ km}$$

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

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

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

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

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

In the next part of the paper we will look only into two out of four of the reviewed railway tracks designs - 1st track and 2nd track (fig.1). We decided to consider the 1st track (28.73km) because it was selected by Sibathractic Group for construction, whereas the 2nd track was chosen due to its characteristics - it is the shortest one.

Two route calculating projections were used for the railway tracks design - in profile and plan. Ground profiles of the new route design were characterized by the piecewise broken lines, whereas, the plans of the new railway route design were characterized by the straight and circular lines. At the early stages of development of the route design it is possible to use only straight lines and circular curves for the design plan. Straight lines can be characterized by the two parameters: lengths (L) and direction of the directional angle (α).

The length of the straight trajectory is measured between the ends of the transitioning and circular curves. The direct railway track that would be constructed only with the straight lines could be seen as the most rational and obvious solution. It suggests the shortests route that is associated with the shortest travel distance and that requires minimum expenses. Nonetheless, due to the issues associated with the topographical conditions it is impossible to construct a straight railway track. That is why it is necessary to include circular curves into the track design as they would help to go through the difficult route regions [9-11]. Taking this into consideration, we calculated the distance and directional angles of the destination points using their abbreviated coordinates.

As we determined, circular curves are essential for the unified pairing of the straight adjacent regions of the route (fig.3, a. & b.). There are seven parameters according to which the curves are divided on the ground: T- tangent, R - radius, D – domer, B - bisector, α - angle of rotation, C - the arc length as well as VU - the vertex of the steering angle.

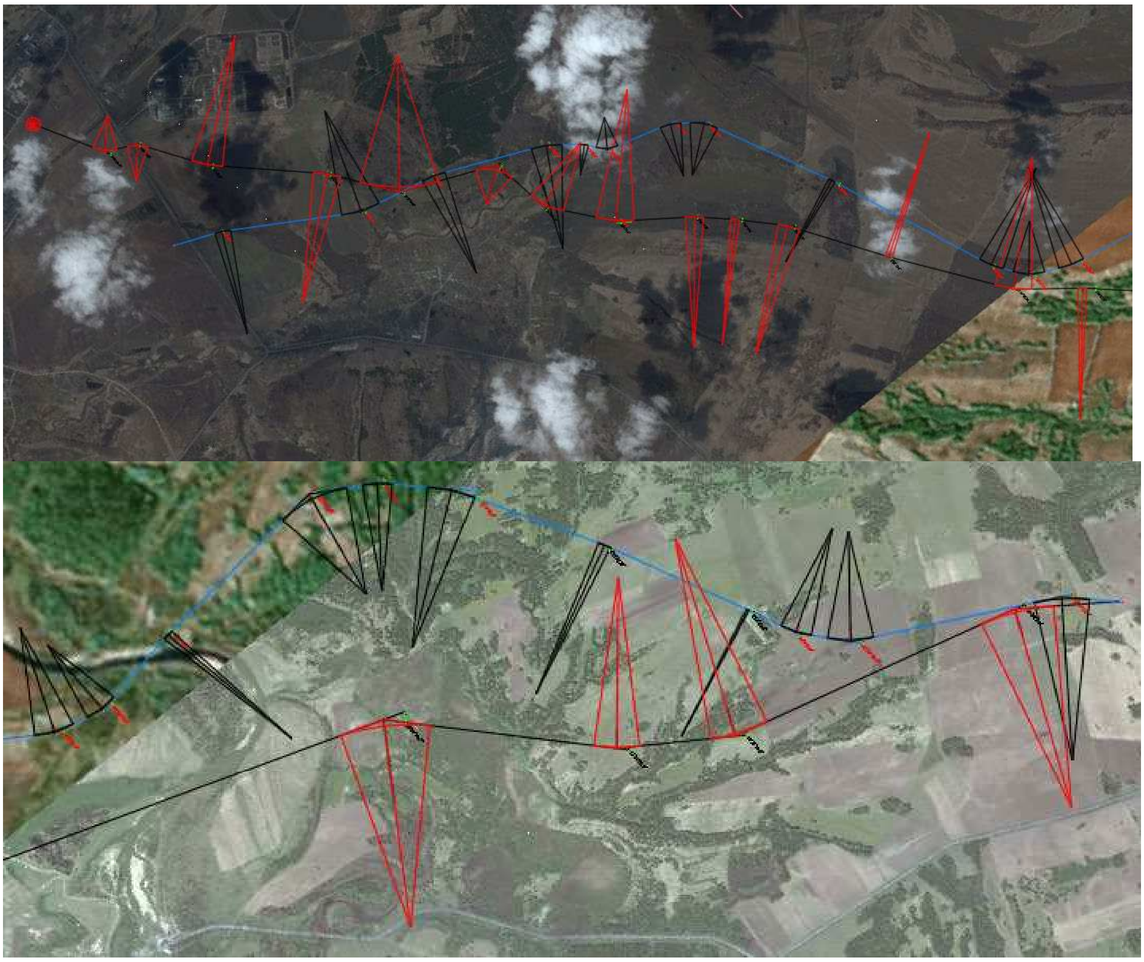

Fig. 3 Circular curves building scheme
(a - route starting point, b - route final destination)

In order to set up two main parameters of the curve - angle of rotation(α) and radius (R) - it is important to consider the efficacy and feasibility of the curves as well as the topographic characteristics of the terrain. Parameters α and R can vary within a certain range. Minimum angle of rotation - αmin can be constrained by special conditions, whereas the maximum angle of rotation, in theory, is not constrained at all [11, 12]. Radius is an essential aspect that helps to find the location of the railway position (2) within the curve. Comfortable motion is the factor that determines the smallest radius.

The rest of the parameters are measured in meters and calculated according to well-known formulas (1-4):

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

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

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

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

4. Results and Discussion

Our calculations of the circular curves and picket values helped to determine the 1st track's mean radius – 926.923 m and the 2nd track's mean radius – 1326.087 m.

Train movement through the curved railway regions influences the development of the centrifugal force that has a negative impact on the increased wear of the truck superstructure and its rolling stock. Furthermore, difficult terrain might affect the underutilization of the bounded slope. In that case there will be a need for construction of the longer railway tracks, which will lead to an increase in excavation work. Whereas the decrease in the train weight (tonnage rating) will lead to an increase in the operating costs of the trains' movements, and it will lead to a decrease in carrying capacity of the road [11, 13].

We calculated the value of the centrifugal force on the circular curve. The mean value of the centrifugal force of the 1st track is 658.517 N/m, and the mean value of the centrifugal force of the 2nd track is 352.5 N/m. The average height of the rail elevation for the 1st track is 105.083 mm and 78.567 mm for the 2ndt rack. Conducted calculations allowed us to categorize the described railway tracks. The categories differ according to the tracks' annual net load densities and the maximum train speed. The 2nd railway track that the authors believe to be the most efficient, was assigned the II category. The annual net load density of the II category tracks might reach around 15-30 million tons/km on the 10th year of exploitation, whereas the motion speed of the train can reach 160 km/h [14]. Whereas, the 1st railway track that was chosen by Sibathractic Group for construction was assigned the III category. The annual net load density of the III category tracks ranges between 8-15 million tons/km, whereas the maximum motion speed of the train reaches not more than 120 km/h.

Categorization of the railway routes required evaluation of the rail tracks quality [15-25]. We compared the rail tracks according to the following characteristics:

1) Sum of lengths of the straight lines and curves (table 1);
2) Percentage of curves (table 2) calculated by formula (5):

$$100\sum C /\ \sum P + \sum C \tag{5}$$

3) Number of curves per 1 km (table 3) calculated by formula (6): where n - the total number of curves;

$$\frac{n}{\sum P + \sum C} \tag{6}$$

4) Minimum radius of the curve - Rmin (table 4);
5) Percentage of the curves with Rmin (table 5) calculated according to following formula: sum of angles of rotation that have the Rmin is calculated formula (7): (the sum of angles of curves with Rmin):

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

6) Mean radius of the curve (table 6) calculated by by formula (8):

$$R = \frac{180*\sum C}{\pi*\sum \alpha}. \tag{8}$$

Table 1. *Calculating the sum of curves ∑C and straight lines ∑P*

Direction	*1st track, km*	*2nd track, km*
∑C	*6,640*	*7,989*
∑P	*19,188*	*18,169*

Table 2. *Percentage of curves*

1st track, %	*2nd track, %*
41	*52*

Table 3. *The number of curves by 1 km*

1st track	*2nd track*

0,89	*0,87*

Table 4. *Minimum radius of the curves*

1st track, m	*2nd track, m*
350	*400*

Table 5. *Percentage of curves with a Rmin*

1st track, %	*2nd track, %*
10	*26*

Table 6. *Mean radius of curves*

1st track, m	*2nd track, m*
959,614	*1326,087*

5. Conclusions

Based on the results of the conducted study, we determined that the construction of the 2nd railway track design would be the best solution for the transportation issues of the Sibanthracite Group mining location. With the help of the Bellman principle of optimality we determined that the 2nd railway track would have better characteristics such as annual net load density and the maximum train speed, which makes it a more productive and reliable means for mineral transportation from the open pit mine to the enrichment plants.

Conflicts of Interest

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

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Figures

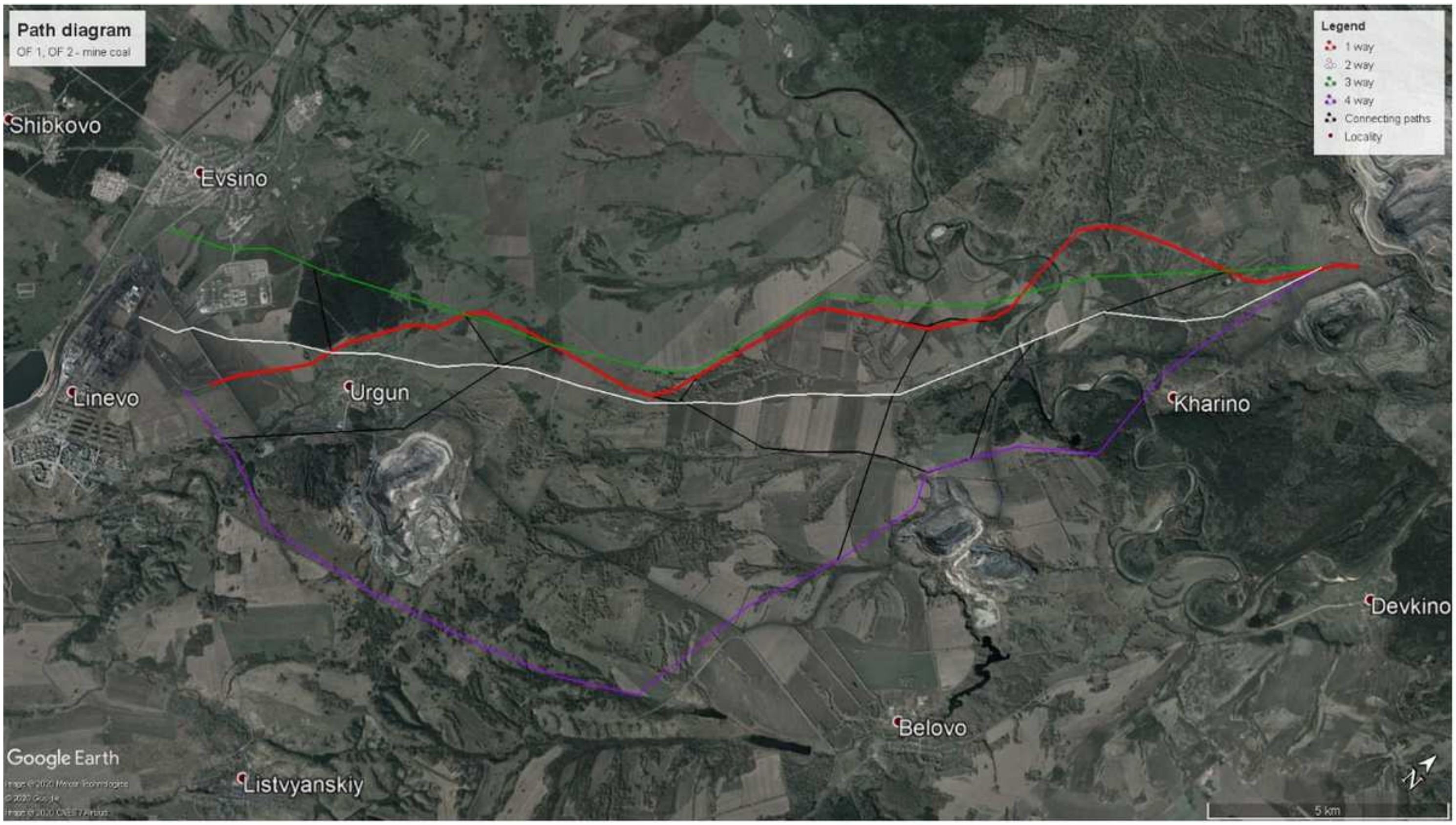

Figure 1

Scheme of discovered tracks

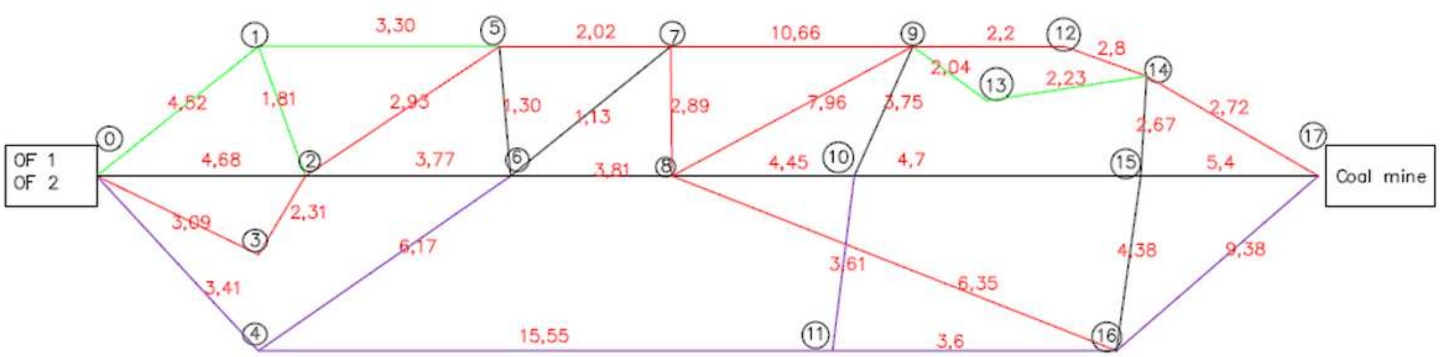

Figure 2

Shortest tracks calculation scheme

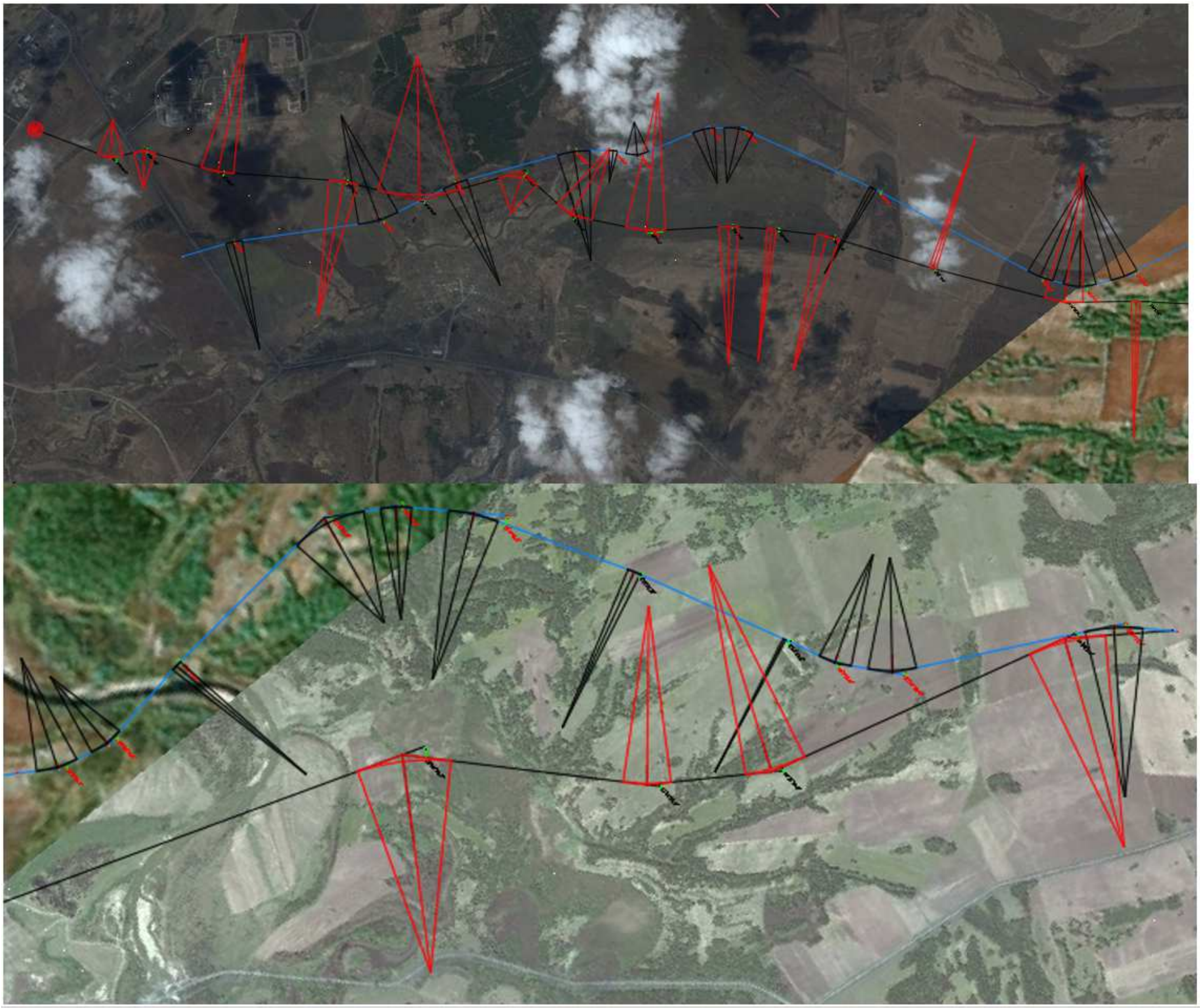

Figure 3

Circular curves building scheme (a - route starting point, b - route final destination)