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Recent Application of Dijkstra's Algorithm in the Process of Production Planning

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Abstract: This paper aims to develop a method that could serve as a tool for evaluating extracted raw materials in terms of use by considering the place of extraction and consumption. Dijkstra´s algorithm solves many of the shortest path problems observed in the production planning of raw materials. The algorithm requires knowledge of the relative distance between the vertices and the definition of the Euclidean distance of the vertices from the target vertex. The algorithm scans all of the paths and chooses the one with the minimum distance. At the same time, it would be able to identify the places of sale of raw materials and transport sites for the transportation of raw materials. It would have a database of point and line sources of occurrence (mining, deposit), places of transport (transmission network), and points of sale (seller). At present, geo-statistics is becoming an essential tool for solving various problems in modern deposit geology. Its results are used to calculate reserves and the economic valuation of the deposit. In the process of production planning, it is necessary to constantly process and analyze the geological information obtained during the mining survey.

Keywords: Dijkstra's algorithm model; production planning; raw materials; efficiency

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1. Introduction

The planning process requires making several important decisions about goals and ways to achieve them, the resources needed, and the required use of the company's resources. Decision-making requires having several options and alternative solutions [1]. Their creation is based on information about possibilities and abilities [2]. An important part of management is also information and decision-making, which create the preconditions for the implementation of planning and the initial function of management [1]. In organizations, planning is a very important activity and a priority management function, and according to the plans, managers manage the organization. As a process, planning involves setting goals, setting the means to achieve the goals, and identifying ways and means to achieve the goals. The result of planning is a plan focused on the purpose of the organizational unit, the business entity, and the determination of procedures and means for achieving it by the set deadline and at the required level [2].

Planning has a direct impact on [3]:

- Increasing efficiency: To a large extent, successful business activity depends on planning. For these activities to be as effective as possible, it is necessary that the objectives are set as clearly as possible and that the optimal options for achieving them and the evaluation criteria are defined.

- Risk reduction: Risk in the organization can be eliminated by good planning. Planning makes it possible to identify risks in various business activities and can thus reduce their negative impact on them.
- Successful organizational changes: The better managers' ideas about organizational change are, the easier it will be for them to cope with the consequences. Successful adaptation in the organization is not possible without a good planning process.
- Development of managers: The most positive impact on the development of managers, but also the organization, comes from the analysis of the development of the internal and external environment, finding the problem and subsequent problem solving, and accepting permanent changes [2,3].

Figure 1 shows the relationship between the first two most important functions in management, namely the relationship between planning and control.

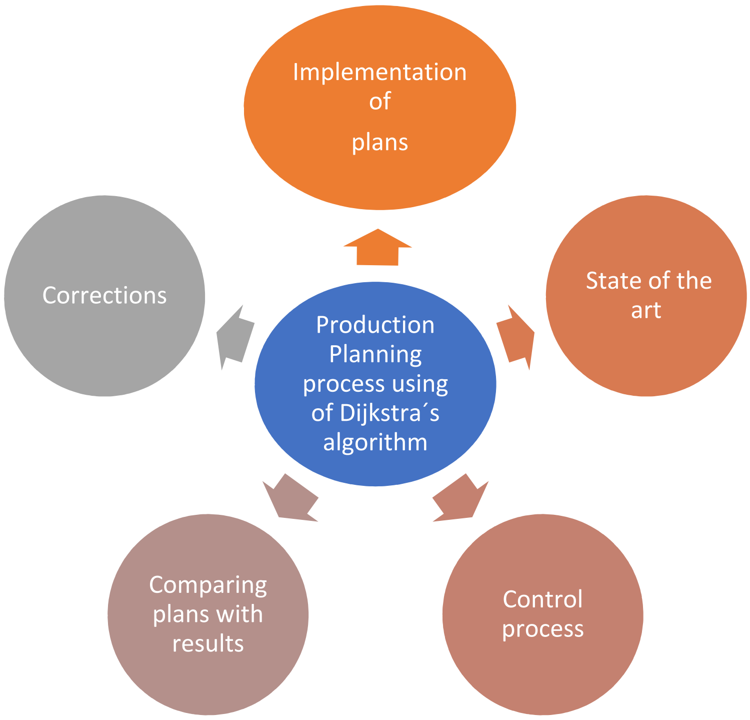

Figure 1. The relationship between important functions in the company management [Authors own processed].

We can see that the first activity that the company performs is planning. Functional departments or company management initially prepare plans, which are then implemented. After their implementation, another phase occurs, namely the control phase, which aims to determine whether all of the company's projects have been fulfilled. It can be said that the task of management is to reach the achieved goals with the planned objectives and to find out whether the plans were met, to what extent, and if not, which factors caused them to not be completed [3]. Production planning in the area of mineral resources form the basis of production in the metallurgical, electrical, chemical, construction, ceramic, and glass industries as well as in other industries, and represent one big group. A significant part is the extraction of non-metallic, construction, and energy raw materials [3]. The production of most non-metallic and building materials (limestone, dolomite, magnesite, gypsum, building stone, etc.) substantially covers their domestic consumption [4,5]. Reserved mineral deposits represent the state's mineral wealth and are owned by the state: the deposits of reserved minerals are part of the land for state deposits of non-reserved minerals (e.g., gravel, brick raw materials, etc.) [6,7].

The raw materials policy includes all activities by which the state influences and defines the goals of society through the use of domestic mineral resources [4]. It builds on the long-term societal needs of economic and social development regarding the environmental aspects of sustainable development related to geological research and exploration and the use of proven reserves of minerals and obtaining raw materials abroad to ensure the stability of the economy [4].

2. The Work Methodology

The aim of the present paper is the optimization of the production process and the presentation of the selected idea for an algorithm. Specifically, Dijkstra's algorithm, which we will use for the construction sector, considers the place of extraction and the consumption of raw materials [3,6].

We aimed to develop a method that would optimize the model of economic feasibility of raw material sales based on certain inputs, sources of building materials, and general characteristics. In the paper, we used Dijkstra's algorithm (Figure 2) [5], which is an algorithm for finding the shortest path between nodes in a graph.

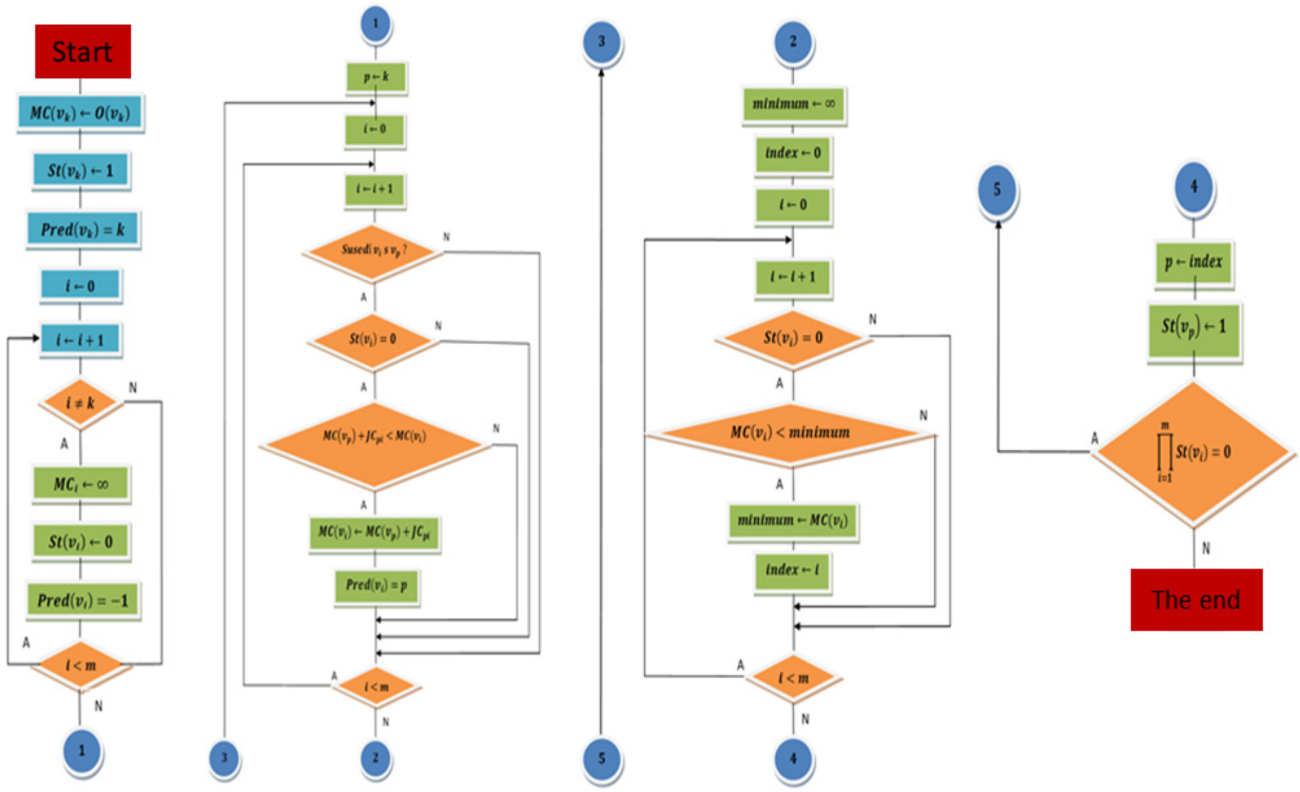

Figure 2. Dijkstra's algorithm [Author own processing].

Dijkstra's algorithm consists of the following six steps:

1. Assign the vertex v_k:
   - The value of minimum path $MC(v_k) = O(v_k)$, i.e., $MC(v_k) = JC_{kk}$;
   - The permanent condition $(St(v_k) = 1)$;
   - The predecessor $Pred(v_k) = k$.
2. Assign to the other vertices v_i, where $i = 1, 2, \ldots, m, i \neq k$:
   - The value of minimum path $MC(v_i) = \infty$;
   - The transient state $(St(v_i) = 0)$;
   - The predecessor $Pred(v_i) = -1$.
3. Choose the vertex v_k as the working vertex v_p (we assigned the value k to the p, i.e., p = k).
4. For each vertex v_i where $i \neq p$, which is adjacent to the working vertex v_k, and whose state is transient, calculate the value $MC(v_p) + O(h_j) = MC(v_p) + JC_{pi}$ (hj is the edge

connecting the working vertex with the vertex vi), and if this value is lower than $MC(v_i)$, then set $MC(v_i) = MC(v_p) + JC_{pi}$ and $Pred(v_i) = p$.

5. For all of the vertices v_i whose state is transient, find the vertex v_l with the lowest value $MC(v_l)$ and
   - Choose the vertex v_l as the working vertex;
   - A it a permanent state ($St(v_l) = 1$).
6. Repeat the procedure in points 4 and 5 until all peaks have a permanent state.

In Table 1, we define the basic parameters of road transport. These data were obtained from freight forwarding companies. For simplicity, the spaces of the individual heights of the adjacent peaks are given in tens of kilometres (Table 1).

Table 1. Distances of neighbouring places along the road.

	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8
v_1	0	5	9	-	22	-	-	-
v_2	5	0	5	8	-	-	-	-
v_3	9	5	0	-	13	-	-	-
v_4	-	8	-	0	-	8	-	-
v_5	22	-	13	-	0	9	-	25
v_6	-	-	-	8	9	0	25	-
v_7	-	-	-	-	-	25	0	3
v_8	-	-	-	-	25	-	3	0

Stocks represent the amount of raw material that will be mined in the future. The present value of a tonne of stocks is lower than the current value of a tonne of stocks currently being extracted [6,7]. The process of valuing mining operations during the early stage of mining affects the long-term value of operations at the deposit, e.g., the initial extraction of higher-quality ore increases the initial profits but reduces the average value of the remaining ore in the warranty, which reduces the life of the mine and of the whole project [8].

The process of valuing mining operations during the early stage of mining affects the long-term value of operations at the deposit [9], e.g., the initial extraction of higher-quality ore increases the initial profits but reduces the average value of the remaining ore in the deposit, which reduces the life of the mine and the whole project. In addition, economic and operational conditions may change unexpectedly during the life of a raw material extraction project [10,11]. The first reason is geological uncertainty. The quantity and quality of stocks are determined on the basis of samples that allow statistical estimates [12,13]. The second reason is economic uncertainty [14]. The amount and quality of the stocks to be mined in a given period depend on the costs of mining and processing the useful mineral and the selling price of the final product [15–17]. Because future sales prices cannot be determined accurately, it is difficult to decide on stocks in a deposit, even if they are selected with the high degree of accuracy allowed by new stock estimates using geostatistical methods [16–18].

3. Results and Discussion

Based on the rules for creating a matrix of unit prices and Relations (1) and (2), (Table 2), we created matrices of JC-type 8 × 8 unit prices for road transport [19].

Table 2. Matrix of unit prices for road transport.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	7.20	0.75	1.35	∞	3.30	∞	∞	∞
2	0.75	7.00	0.75	1.20	∞	∞	∞	∞
3	1.35	0.75	0	∞	1.95	∞	∞	∞
4	∞	1.20	∞	0	∞	1.20	∞	∞
5	3.30	∞	1.95	∞	0	1.35	∞	3.75
6	∞	∞	∞	1.20	1.35	0	3.75	∞
7	∞	∞	∞	∞	∞	3.75	0	0.45
8	∞	∞	∞	∞	3.75	∞	0.45	0

In our case, we propose an optimal solution of a model in which the network of mining and processing sites and customer sites, including their transport interconnection, represents the graph G = {V, H} and has the following properties [20,21]:

- G is a continuous undirected graph without multiple edges and loops;
- $V = \{v_1, v_2, \cdots, v_m\}$ is a set of graph vertices that represent mining and processing and consumption points;
- $H = \{h_1, h_2, \cdots, h_n\}$ is a set of graph edges that represent the transport network (road or rail) between individual places; the vertices of the graph, which correspond to the mining processing, are evaluated, and the evaluation of such a peak v_i is defined by [22]:

$$O(v_i) = PTN_i + NTN_i + PSN_i + NSN_i \tag{1}$$

where PTN_i is the direct extraction costs per tonne of raw material, NTN_i is the indirect extraction costs per tonne of raw material, PSN_i is the direct processing costs per tonne of material, and NSN_i is the indirect processing costs per 1 tonne ton of material; the vertices of the graph, which correspond to those customer points, are not simultaneously mining–processing points and are not evaluated, and all of the edges of the graph are evaluated. The evaluation of the edge h_i connecting the vertices v_k and v_l is defined by equation [21]:

$$O(h_i) = PN \times VZD_{kl} \tag{2}$$

The parameters of the distance of peaks (cities) and parameters of the financial costs of transportation are presented in Table 2.

It should be noted that for the value of ∞, the unit price matrices mean that the respective vertices of the graph are not adjacent. In computer processing, the value ∞ is replaced by a sufficiently large number: infinity [22–24]. We will optimize the path in the graph for road traffic (Figure 2) for the peaks corresponding to the individual mining and processing sites, i.e., for the peaks v_1 and v_2, using the described algorithm [25,26]. The search procedure and its results are clear in Table 3, in which the states of the vertices of the graph are indicated as follows: the permanent top state is in blue, permanent peaks that are also the working peaks in a given step are in green, and temporary peaks with minimum values are in red.

In step 0 (Figure 3), we set the evaluation of the source, the peak v_1, to the value of the price of the raw material after production behind the plant gates, i.e., the work area. We set the predecessor as ourselves, and marked it as permanent (green). The other vertices on the map only form customer sites (white). We marked the transport costs between the individual peaks in blue. A sufficiently significant number of reserves in the deposit is required for a long-term project [6].

Table 3. Finding the optimal path from peak 1.

		Peak							
Step	**Parameter**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	The length of the journey	7.20	∞	∞	∞	∞	∞	∞	∞
	Condition	1	0	0	0	0	0	0	0
	Predecessor	1	−1	−1	−1	−1	−1	−1	−1
1	The length of the journey	7.20	7.95	8.55	∞	10.50	∞	∞	∞
	Condition	1	0	0	0	0	0	0	0
	Predecessor	1	1	1	−1	1	−1	−1	−1
2	The length of the journey	7.20	7.95	8.55	9.15	10.50	∞	∞	∞
	Condition	1	1	0	0	0	0	0	0
	Predecessor	1	1	1	2	1	−1	−1	−1
3	The length of the journey	7.20	7.95	8.55	9.15	10.50	∞	∞	∞
	Condition	1	1	1	0	0	0	0	0
	Predecessor	1	1	1	2	1	−1	−1	−1
4	The length of the journey	7.20	7.95	8.55	9.15	10.50	10.35	∞	∞
	Condition	1	1	1	1	0	0	0	0
	Predecessor	1	1	1	2	1	4	−1	−1
5	The length of the journey	7.20	7.95	8.55	9.15	10.50	10.35	14.10	∞
	Condition	1	1	1	1	0	1	0	0
	Predecessor	1	1	1	2	1	4	6	−1
6	The length of the journey	7.20	7.95	8.55	9.15	10.50	10.35	14.10	14.25
	Condition	1	1	1	1	1	1	0	0
	Predecessor	1	1	1	2	1	4	6	5
7	The length of the journey	7.20	7.95	8.55	9.15	10.50	10.35	14.10	14.25
	Condition	1	1	1	1	1	1	1	0
	Predecessor	1	1	1	2	1	4	6	5
8	The length of the journey	7.20	7.95	8.55	9.15	10.50	10.35	14.10	14.25
	Condition	1	1	1	1	1	1	1	1
	Predecessor	1	1	1	2	1	4	6	5

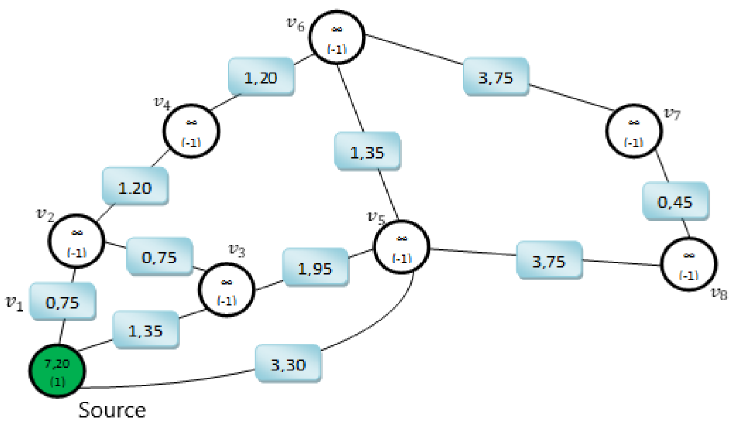

Figure 3. Finding the optimal path from peak 1—step 0.

Continuing step 1 (Figure 4), all of the peaks adjacent to v_1 were re-evaluated. The evaluation consisted of summing the price at the top of v_1 and the transport price at the top of v_1. Then, we found that out of all of the peaks that were not permanent, the peak with the minimum rating v_2 (red) was a temporary peak.

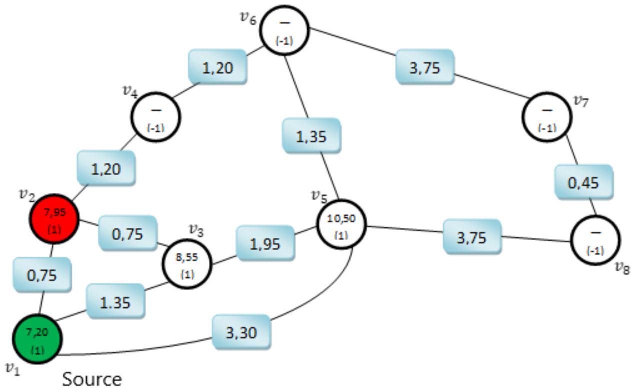

Figure 4. Finding the optimal path from peak 1—step 1.

As mentioned in the methodology of the presented paper, the primary use of this algorithm is to find the shortest path in an edge-rated oriented graph. In step 2 (Figure 5), we set the vertex v_2 as permanent and working (green). Then, we repeated the procedure in step 1. Again, we found the vertex with the minimum rating in this step. It was a temporary vertex v_3 (red).

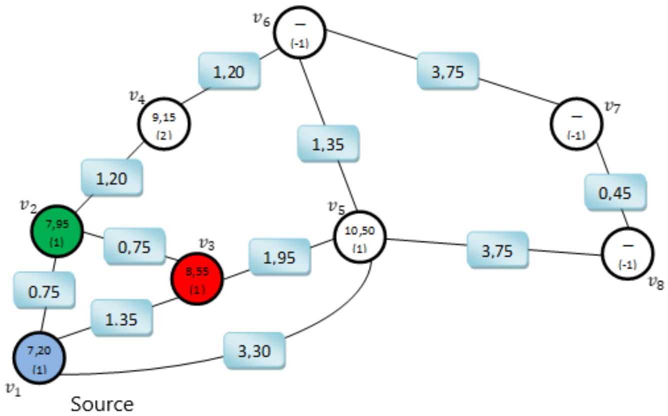

Figure 5. Finding the optimal path from peak 1—step 2.

We proceeded similarly in step 3 (Figure 6), only we chose another vertex v_3 (green) for the permanent and working peak. In this case, the peak with the minimum rating is a temporary peak v_4 (red). We can generally say that the Dijkstra algorithm is finite because exactly one node is added to the set of visited nodes in each passage of its cycle. At most, there are as many cycle transitions as there are peaks in the graph peaks.

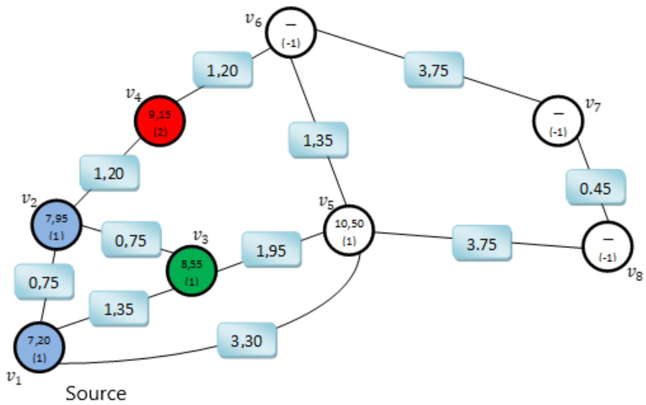

Figure 6. Finding the optimal path from peak 1—step 3.

In step 4 (Figure 7), we use v_4 as the starting point, which is permanent and working (green). After subsequent optimization, v_6 becomes a temporary peak with a minimum rating (red). Dijkstra's algorithm solves the problem of finding the shortest paths in the edge-evaluated and oriented graph. All of its edges must have non-negative weights.

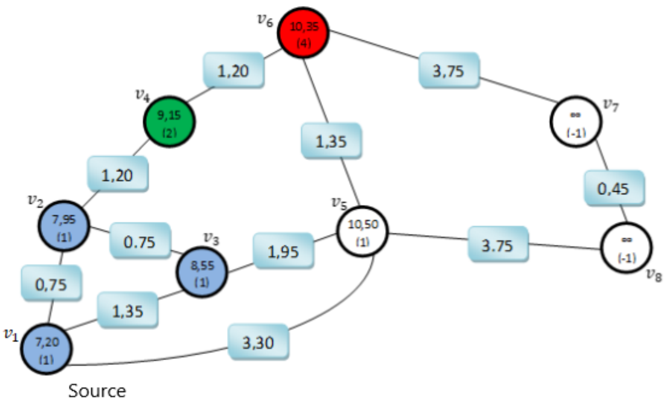

Figure 7. Finding the optimal path from peak 1—step 4.

For step 5 (Figure 8), we use a permanent and working peak v_6 (green), in which the optimal peak with a minimum rating becomes a temporary peak v_5 (red).

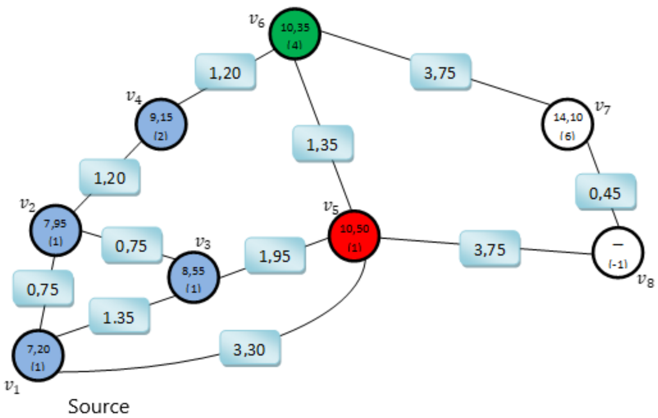

Figure 8. Finding the optimal path from peak 1—step 5.

For step 6 (Figure 9), we use a permanent and working vertex v_5 (green), in which the optimal vertex with a minimum rating becomes a temporary vertex v_7 (red).

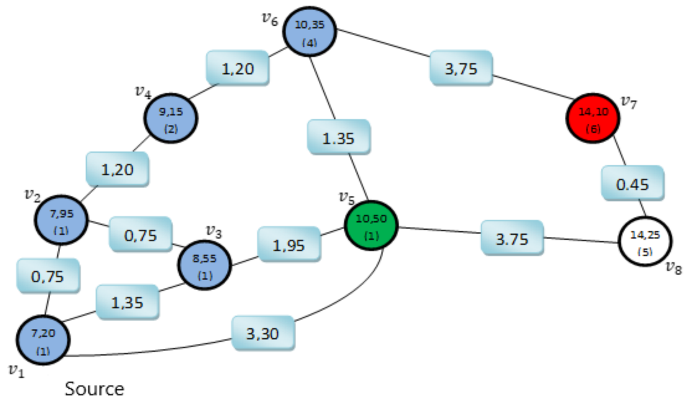

Figure 9. Finding the optimal path from peak 1—step 6.

We repeated the procedure for step 7 (Figure 10), for which we used a permanent and working peak v_7 (green), in which the optimal peak with a minimum rating became a temporary peak v_8 (red).

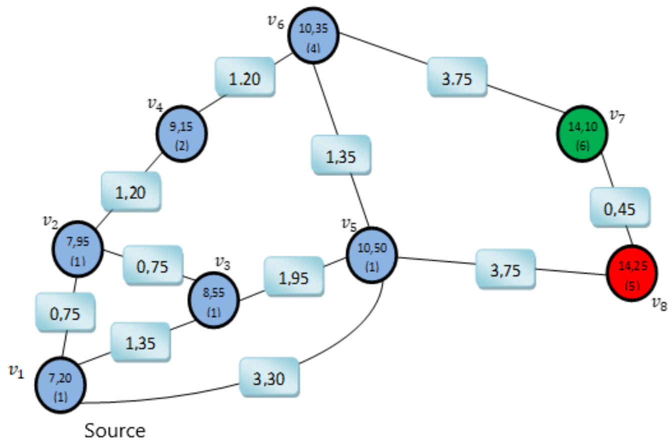

Figure 10. Finding the optimal path from peak 1—step 7.

In step 8 (Figure 11), we use a permanent and working peak, v_8 (green), in which after reassessment, all of the other peaks become optimal peaks with a minimum rating due to a smaller rating than in working peak v_8.

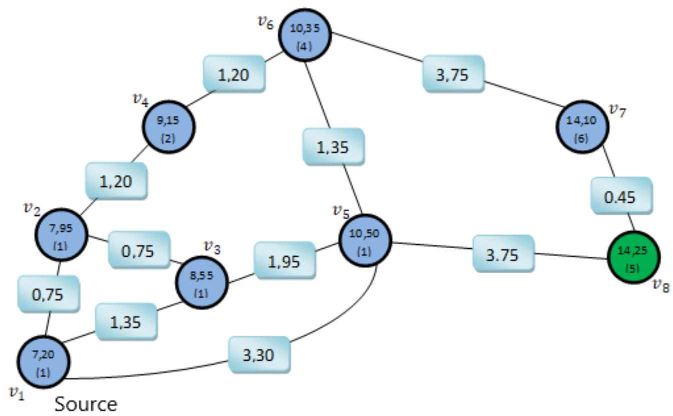

Figure 11. Finding the optimal path from peak 1—step 8.

In the following graph of vertices, we plot the final state (without colours) of route optimization from the vertex v_1 as a source of building material (Figure 12). At each peak, there is the optimal minimum purchase price as well as the predecessor on the optimal route.

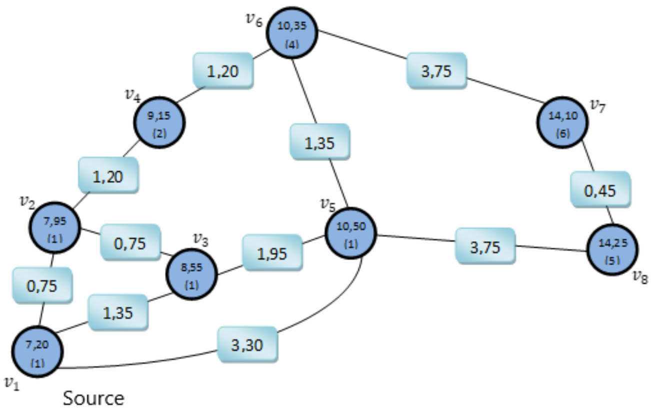

Figure 12. Finding the optimal path from peak 1—finalization.

To illustrate the creation of a model for finding the optimal path based on the data obtained using our algorithm, which we worked with to find the most financially advantageous connection along the path from the customer to the supplier location, we use the following graph showing the optimal route (Figure 13):

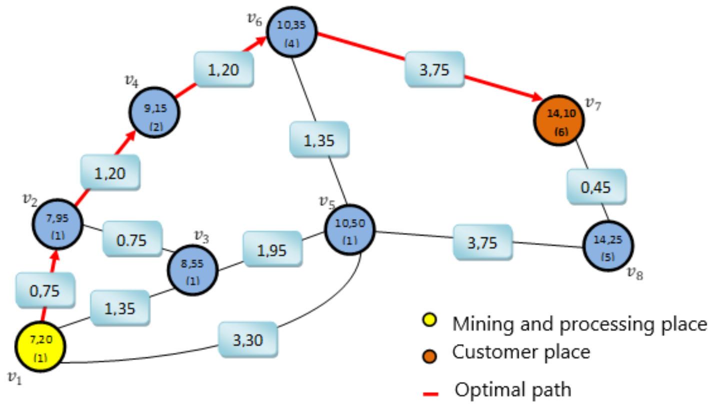

Figure 13. Optimal path from peaks 1 to 7.

The presented paper aimed to find the shortest paths from one specific vertex of the graph to all of the other vertices using the proposed method. The algorithm maintains a set of vertices whose shortest path length has been found.

Discussion and Limitation

Dijkstra's algorithm is a classic algorithms that solves the problem of finding the shortest paths from a single source point. If we are looking for the shortest point-to-point path, we stop the process when we find the distance to the point. It works by creating a steep shortest path, and during the algorithm, the nodes can acquire the states of reached, unattained, and finished [2]. A node is in the ready state when its distance from the root of the tree has been found and is therefore included in the shortest path tree [2].

Restricted road planning takes into account all of the constraints or certain types of constraints that occur in the road network and seeks to address this problem or parts of it [2,14]. There are different ways to deal with this problem, but other methodsoften only solve it using a certain set of constraints, such as dual graph representation, and are focused on allowed tapping and disabled tapping [15,21]. This approach creates a dual graph over the original graph that addresses the constraints. Another approach is to extend the Dijkstra algorithm so that attributes are added to work with the constraints. All of the approaches to constrained route planning can be grouped into two main groups [27]:

- Methods that deal with editing a graph, representing a graph, or creating auxiliary graphs. This group includes, for example, dual graph representations.
- Methods that modify the crawling algorithm without changing the original graph.

The different groups of approaches have different problems. The main problems with the graph editing group are the memory requirements and the time required to transform the chart. Memory and time requirements increase with the size of the graph. In the group dealing with the adjustment of the algorithm, these memory and time requirements vary considerably, and they can be larger but also smaller than when editing the graph and mainly depend on the adjustment transferred to the algorithm.

4. Conclusions

The created algorithm generally searches for the shortest possible-optimal path between the start vertex and the target vertex. The method requires knowledge of the relative distance between the vertices and the definition of the Euclidean distance of the vertices from the target vertex (so-called distance as the crow flies) [27]. The algorithm scans all of the paths and chooses the one with the minimum distance. Using the previously described algorithm, we found our shortest (optimal) route from the top of v_1 (source of the raw material). Our optimal path is shown in Figure 13 in red. Dijkstra's algorithm can also be modified so that it can be used to find distances and the optimally shortest oriented routes from any given vertex to other vertices and not only ones on evaluated (applies to our case) oriented graphs but also to other vertices of unrated oriented graphs. The locations of the vertices were verified. The geological conditions of their origin determine the exploited mineral deposits. In contrast to regions that are poor in minerals, there are regions that are relatively rich in mineral deposits, and the regional infrastructure and employment have been adapted accordingly. However, from the current trend of using the domestic raw material base and not opening new deposits, especially those of non-metallic minerals, it is not possible to expect a substantial increase in employment in this sector soon.

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References

1. Mula, J.; Poler, R.; García-Sabater, J.; Lario, F. Models for production planning under uncertainty: A review. *Int. J. Prod. Econ.* **2006**, *103*, 271–285. [CrossRef]
2. Maravelias, C.T.; Sung, C. Integration of production planning and scheduling: Overview, challenges and opportunities. *Comput. Chem. Eng.* **2009**, *33*, 1919–1930. [CrossRef]
3. Straka, M.; Khouri, S.; Rosova, A.; Caganova, D.; Culkova, K. Utilization of Computer Simulation for Waste Separation Design as a Logistics System. *Int. J. Simul. Model.* **2018**, *17*, 583–596. [CrossRef]
4. Kuo, Y.-H.; Kusiak, A. From data to big data in production research: The past and future trends. *Int. J. Prod. Res.* **2019**, *57*, 4828–4853. [CrossRef]
5. Rosova, A. Indices system design of distribution logistics, transport logistics and materials flow as parts of controlling in enterprise's logistics. *Acta Montan. Slovaca* **2010**, *15*, 67–72.
6. Wang, F.; Lai, X.; Shi, N. A multi-objective optimization for green supply chain network design. *Decis. Support Syst.* **2011**, *51*, 262–269. [CrossRef]
7. Erol, I.; Sencer, S.; Sari, R. A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain. *Ecol. Econ.* **2011**, *70*, 1088–1100. [CrossRef]

8. Kumar, S.; Putnam, V. Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors. *Int. J. Prod. Econ.* **2008**, *115*, 305–315. [CrossRef]
9. Abdallah, T.; Farhat, A.; Diabat, A.; Kennedy, S. Green supply chains with carbon trading and environmental sourcing: Formulation and life cycle assessment. *Appl. Math. Model.* **2011**, *36*, 4271–4285. [CrossRef]
10. Straka, M.; Rosová, A. Principles of computer simulation design for the needs of improvement of the raw materials combined transport system. *Acta Montan. Slovaca* **2018**, *23*, 163–174.
11. Bai, C.; Sarkis, J. Integrating sustainability into supplier selection with grey system and rough set methodologies. *Int. J. Prod. Econ.* **2010**, *124*, 252–264. [CrossRef]
12. Chen, R.J.; Gotman, C. Efficient fastest-path computations for road maps. *Comput. Vis. Media* **2021**, *7*, 267–281. [CrossRef]
13. Žic, J.; Zic, S. Multi-criteria decision making in supply chain management based on inventory levels, environmental impact and costs. *Adv. Prod. Eng. Manag.* **2020**, *15*, 151–163. [CrossRef]
14. Delling, D.; Goldberg, A.V.; Pajor, T.; Werneck, R.F. Customizable Route Planning in Road Networks. *Transp. Sci.* **2017**, *51*, 566–591. [CrossRef]
15. Nagyová, A.; Pačaiová, H.; Markulik, Š.; Turisová, R.; Kozel, R.; Džugan, J. Design of a Model for Risk Reduction in Project Management in Small and Medium-Sized Enterprises. *Symmetry* **2021**, *13*, 763. [CrossRef]
16. Ahluwalia, P.K.; Nema, A.K. Multi-objective reverse logistics model for integrated computer waste management. *Waste Manag. Res. J. Sustain. Circ. Econ.* **2006**, *24*, 514–527. [CrossRef]
17. Yanjun, L.; Xiaobo, L.; Osamu, Y. Traffic engineering framework with machine learning based meta-layer un software-defined networks. In Proceedings of the 2014 4th IEEE International Conference on Network Infrastructure and Digital Content, Beijing, China, 19–21 September 2014; pp. 121–125.
18. Malindzakova, M.; Straka, M.; Rosova, A.; Kanuchova, M.; Trebuna, P. Modeling the process for incineration of municipal waste. *Przem. Chem.* **2015**, *94*, 1260–1264. [CrossRef]
19. Wicher, P.; Staš, D.; Karkula, M.; Lenort, R.; Besta, P. A computer simulation-based analysis of supply chains resilience in industrial environment. *Metalurgija* **2015**, *54*, 703–706.
20. Sinay, J.; Balážiková, M.; Dulebová, M.; Markulik, Š.; Kotianová, Z. Measurement of low-frequency noise during CNC machining and its assessment. *Measurement* **2018**, *119*, 190–195. [CrossRef]
21. Sobrino, D.R.D.; Košťál, P.; Cagáňová, D.; Čambál, M. On the Possibilities of Intelligence Implementation in Manufacturing: The Role of Simulation. *Appl. Mech. Mater.* **2013**, *309*, 96–104. [CrossRef]
22. Kleijnen, J. Supply chain simulation tools and techniques: A survey. *Int. J. Simul. Process Model.* **2005**, *1*, 82. [CrossRef]
23. Pačaiová, H.; Sinay, J.; Turisová, R.; Hajduová, Z.; Markulik, Š. Measuring the qualitative factors on copper wire surface. *Measurement* **2017**, *109*, 359–365. [CrossRef]
24. Wielki, J.; Grabara, J. The Impact of Ad-Blocking on the Sustainable Development of the Digital Advertising Ecosystem. *Sustainability* **2018**, *10*, 4039. [CrossRef]
25. Drastich, A. Optimization of material flow by simulation methods. *Acta Logist.* **2017**, *4*, 23–26. [CrossRef]
26. Hadi, M.A.; Brillinger, M.; Wuwer, M.; Schmid, J.; Trabesinger, S.; Jäger, M.; Haas, F. Sustainable peak power smoothing and energy-efficient machining process thorough analysis of high-frequency data. *J. Clean. Prod.* **2021**, *318*, 128548. [CrossRef]
27. Cvitić, I.; Peraković, D.; Perisa, M.; Gupta, B.B. Ensemble machine learning approach for classification of IoT devices in smart home. *Int. J. Mach. Learn. Cybern.* **2021**, *12*, 3179–3202. [CrossRef]