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Research Article

Research on Inpit Dumping Height during Tracing Mining Period between Two Adjacent Surface Coal Mines

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When two adjacent surface mines are simultaneously mined in the same direction with a certain relationship of the time and space, the mining arrangement of the former mine will greatly affect the mining plan and economic benefit of subsequent surface mine. In this paper, the optimized mathematical model is established with the mining conditions and economic benefits taken into account. The minimum cost of objective function is analyzed in the condition of considering the different transportation distance with different dumping amount and secondary stripping amount. At the end of this paper a conclusion is drawn that the reasonable dumping level is determined as 1130 based on the annual planning project location and stripping amount, which will reduce the cost of production and smooth the coal mining. Moreover, it is verified by an example to be correct that the mathematical model can be used to solve similar problems of tracing mining or adjacent districts mined in surface mines.

1. Introduction

Surface mining emerged in the mid-sixteenth century [1] and is practiced throughout the world for its enormous advantages, such as lower mining cost, higher resource recovery, safety and so on.

It will bring good economic benefits for surface mines only with scientific planning and design. At present, much theoretical analysis and practice application on surface dumping design and parameters have been studied in academia and industry, with the technology improved and economic benefits achieved. Because of the incomparable advantages and distinctive mining conditions, surface coal mining has made great progress in China, and so has the related research.

About inpit dumping of surface mines researchers have done so much and gained many achievements, especially on the dumping design [2], the safety distance between inner dump slope bottom and working slope [3], slope stability evaluation [4–7], etc., In most surface coal mines with near horizontally burial strata, inpit dumping will cover the end-wall slope of the previous mining district, causing increased secondary stripping amount when the next mining district is mined [8–12]. With dragline method the problem can be solved when the deposit's characteristics match the draglines' physical capabilities [13]. For better economic benefits and lower cost, inpit dumping with end-wall slope partially covered has been proven to be effective [14], with the disadvantage of extra costs when materials transferred from the uncovered zone [15, 16]. The overburden management [17], dumping scheduling [18–20], mining depth, bottom width and inpit dumping cover height [21, 22] will be the main research focus for a long time. Also, biological reclamation was brought out to keep the long term stability of overburden dump slope, with the numerical modeling analyzed to be feasible [23, 24].

Whether to keep the inner dump slope covered or not is the core issue, which will bring tremendous economic and research value. According to the research analysis above, the two adjacent mining districts will affect each other on mining plan, inpit dumping, and mining safety. However, few studies are carried on about the impact of the previous mined district on the subsequent adjacent district, especially when they advance in the same direction.

2. Engineering Background

Heidaigou surface coal mine and Haerwusu surface coal mine belong to the same coalfield. Also the district transition direction of the former is the same to the current advancing direction of the later, with the former advancing position behind of the latter. In order to save the stripping cost of Heidaigou surface coal mine in the subsequent mining, the dumping amount and dumping height of Haerwusu surface coal mine need to be redesigned seriously.

At present, Heidaigou surface coal mine is in the stage of district transition, while northern end-slope and the inner dump of Haerwusu surface coal mine encountering the first mining district of Heidaigou surface coal mine. After the transition is finished, the mining districts of the two mines will be adjacent with the same development direction and mining speed. And the cross region will exist for a long time, as shown in Figure 1.

The inpit dumping height near the northern end-slope of Haerwusu surface coal mine will influence the coordination mining of the two adjacent mines, which can be shown as the following aspects.

The first influence is on the northern overburden haulage distance of the Haerwusu surface coal mine. The first mining district of Haerwusu surface coal mine is divided into northern part and southern part by a gully, so the overburden has to be transported to the inner dump through the northern or southern end-slope. Then the overburden above the inpit dumping elevation should be moved down to the same elevation through temporary ramp of working slope, which extends the transportation distance.

The second affect is on the secondary stripping amount of Heidaigou surface coal mine. The first mining district of Haerwusu surface coal mine is ahead 1400 meters of the second mining district of Heidaigou surface coal mine. And the second mining district of Heidaigou surface coal mine will rehandle the overburden of inner dump which comes from the Haerwusu surface coal mine. Every dumping bench elevation increases, the stripping elevation will increase correspondingly. The relationship between the inpit dumping height and the secondary stripping amount is shown in Figure 2.

The third is the impact on the arrangements of the benches, ramps and power supply in the crossing area of the two mines.

The production practice of the two mines is considered in this paper, and the mathematical model is established to analyze the economic impact with different dumping height, then the reasonable dumping height will be obtained. Combined with the 2014 to 2017 annual planning project locations and total amount of works, the transportation cost will be computed to verify its reliability in case of different dumping height and the secondary stripping amount.

3. Mathematical Model Analysis

The ultimate research objectives of mathematical model are the increased minimum transportation cost of the overburden above inpit dumping height in Haerwusu surface coal mine and the secondary stripping cost below inpit dumping height in Heidaigou surface coal mine. Since the secondary stripping occurs very closely, so time value is not considered in the model. The established optimization objective function is as follows:

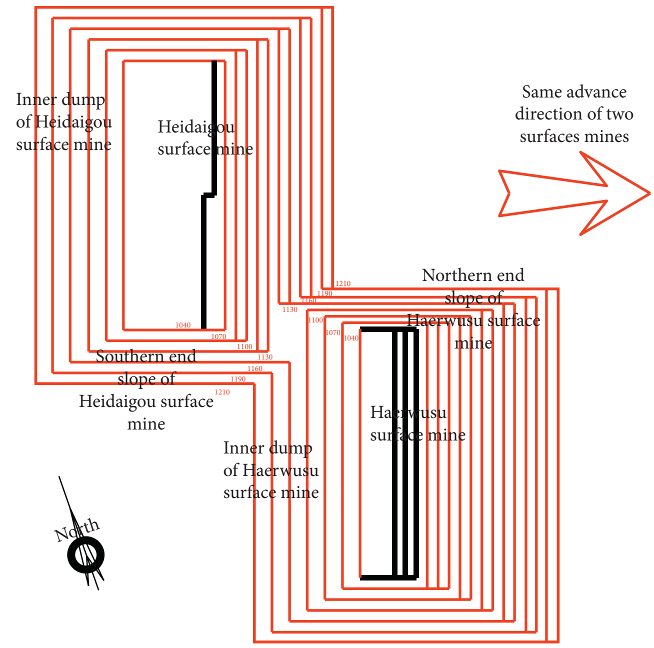

Figure 1: Schematic diagram of the crossing region between two surface mine.

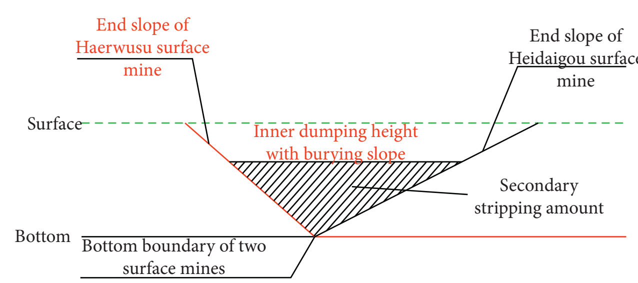

Figure 2: Relationship between the inpit dumping height and the secondary stripping amount.

$$Y_{\min} = Y_y + Y_B = \Delta S \cdot Q_y \cdot C_y + Q_B \cdot C_B, \quad (1)$$

where $Y_{\min}$ is the total cost, Y_y is the increased transportation cost above inpit dumping height in Haerwusu surface coal mine, Y_B is the increased secondary stripping cost in Heidaigou surface coal mine, ΔS is the increased transportation distance above inpit dumping height in Haerwusu surface coal mine, Q_y is the overburden amount above inpit dumping height in Haerwusu surface coal mine, C_y is the transport unit price, Q_B is the secondary stripping amount, C_B is the secondary stripping unit price.

The model structure is shown in Figure 3, and the model basic parameters are in Table 1.

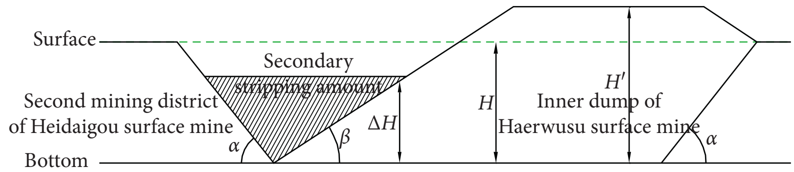

Figure 3: Inner dump schematic diagram of half dumping.

Table 1: Basic parameters of the inpit dumping height model.

Serial number	Mining parameters	Symbol	Unit	Parameter values
1	Mining depth	H	m	180
2	Bottom working bench length	L	m	2000
3	Northern end-slope angle	α	°	32
4	Stability slope angle of inner dump	β	°	20
5	Working slope angle	γ	°	10
6	Working slope angle of inner dump	φ	°	17
7	Distance between the working bench and the bottom dumping bench	L_z	m	60
8	Transportation road gradient	i	%	8
9	Annual advancement in haerwusu surface coal mine	v	m	400
10	Annual advancement in haidaigou surface coal mine	v'	m	350
11	Transportation cost of inpit dumping	C_y	Yuan/m^4	0.0025
12	Secondary stripping cost	C_B	Yuan/m^3	12

3.1. The Transportation Distance of the Northern Overburden in Haerwusu Surface Coal Mine with Half Dumping. The transportation distance of the northern overburden consists of three parts, which are the stope transportation distance S_c, the end-slope transportation distance S_d, and the inner dump transportation distance S_p. Among them, S_c and S_p all consist of horizontal section and climbing section.

$$S = S_c + S_d + S_p. \quad (2)$$

The situation of overburden haulage in northern end-slope in Haerwusu surface coal mine with half dumping is shown as Figure 4.

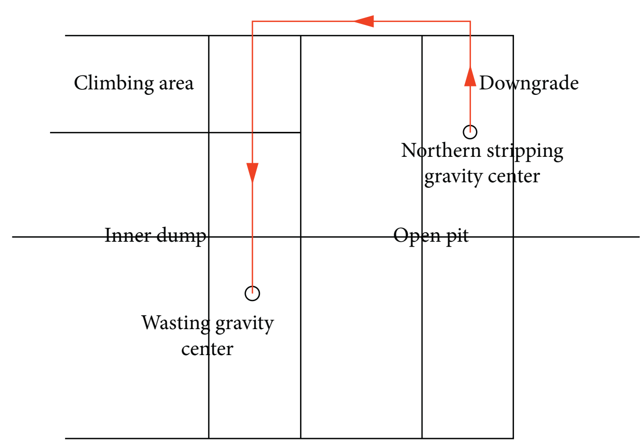

Figure 4: Overburden haulage situation of northern end-slope in Haerwusu surface coal mine with half dumping.

3.1.1. Stope Transportation Distance S_{c1}. The overburden of the northern stope above the inpit dumping elevation in Haerwusu surface coal mine should be transported to the dumping elevation through working slope road and the end-slope road in the same elevation. Therefore, the stope transportation consists of drop distance and horizontal distance.

(1) Stope Drop Transportation Distance. It is the transportation distance from the overburden gravity center to the dumping elevation. The transporting system will directly affect the drop distance in stope. The overburden gravity center is considered in this model which is half height of the overburden height over dumping elevation. also the overburden round trip transportation is considered comprehensively, which is double length of the bench. Then it can be expressed as follows.

$$S_{c1} = 2 \times \left(\frac{1}{2} \times \frac{H - \Delta H}{i}\right) = \frac{H - \Delta H}{i}, \quad (3)$$

where S_{c1} is stope drop transportation distance, H is the height from surface to bottom coal seam of north stope in Haerwusu surface coal mine, ΔH is the height from the dumping elevation to coal floor, i is the maximum ramp gradient.

The model parameters are input to the formula, then the output will be shown as follows.

$$S_{c1} = 2250 - 12.5\Delta H. \quad (4)$$

(2) Stope Horizontal Transportation Distance. It is the distance from the overburden gravity center of dumping elevation in the northern stope of Haerwusu surface coal mine to the transportation road of northern end-slope. According to the stope lineament, the position of the overburden gravity center can be calculated as 1/4 of the working bench in dumping elevation. So S_{c2} can be expressed as follows.

$$S_{c2} = \frac{1}{4}(L + 2 \cdot \Delta H \cot\alpha), \tag{5}$$

where S_{c2} is the stope horizontal transportation distance, L is the working bench length of the bottom coal seam, α is the working slope angle of end-slope.

The model parameters are input to the formula, then the output will be shown as follows.

$$S_{c2} = 500 + 0.8002\Delta H. \tag{6}$$

In summary, the stope transportation distance is shown as follows.

$$\begin{aligned} S_c &= S_{c1} + S_{c2} \\ &= \frac{H - \Delta H}{i} + \frac{L}{4} + \frac{\Delta H \cot\alpha}{2} \\ &= 2750 - 11.7\Delta H. \end{aligned} \tag{7}$$

3.1.2. Transportation Distance in End-Slope S_d. It is the transportation distance in the northern end-slope on the dumping elevation when the overburden of the northern stope above the dumping elevation is transported.

$$S_d = L_z + \Delta H \cot\gamma + \Delta H \cot\phi, \tag{8}$$

where L_z is the tracing distance between the working bench and the dumping working bench of Haerwusu surface coal mine, γ is the working slope angle, φ is the dumping working slope angle.

$$S_d = 60 + 8.5\Delta H. \tag{9}$$

3.1.3. Transportation Distance in Inner Dump S_p. The overburden of all levels above the dumping elevation of northern stope in Haerwusu surface coal mine should be shifted to inner dump through northern end-slope road, then be dumped on each bench of inner dump. So the inner dump transportation distance consists of climbing distance and horizontal distance.

(1) Climbing Distance in the Inner Dump. It is the transportation distance from the dumping elevation to the vertical gravity center of inner dump. The overburden gravity center and the overburden round trip transportation are considered comprehensively, then it can be expressed as follows.

$$S_{p1} = 2 \times \frac{1}{2} \times \frac{H' - \Delta H}{i} = \frac{H' - \Delta H}{i}, \tag{10}$$

where S_{p1} is the climbing distance in the inner dump, and H' is the height from the top of the inner dump to the coal seam bottom.

If the overburden is dumped in the same elevation, the inpit dumping space where transportation distance is kept reduces and the dumping gravity center rises and moves south because of half dumping. The inpit dumping space of half dumping is similar to the full dumping, then the relationship between H' and ΔH is shown as follows.

$$\begin{aligned} &\frac{1}{2}(H' - H) \cdot [2(L + 2H\cot\alpha - H\cot\alpha - H\cot\beta) \\ &\quad - 2(H' - H)\cot\beta] = \frac{1}{2}(H - DH) \cdot (H\cot\alpha + H\cot\beta \\ &\quad + \Delta H\cot\alpha - \Delta H\cot\beta). \end{aligned} \tag{11}$$

It can be arranged as follows.

$$\begin{aligned} &(H' - H)(L + H\cot\alpha - H\cot\beta) - (H' - H)^2\cot\beta \\ &\quad = \frac{1}{2}\left(H^2 - \Delta H^2\right)(\cot\alpha + \cot\beta). \end{aligned} \tag{12}$$

After the model parameters are input to the formula, the relation between H' and ΔH is as follows.

$$H' = 506.4 - 0.2\sqrt{23.9 \times \Delta H^2 + 2442617.8}. \tag{13}$$

Therefore, the climbing distance in the inner dump can be concluded as follows.

$$\begin{aligned} S_{p1} &= 6329.9 - 2.3\sqrt{23.9 \times (\Delta H + 102239.2)} - 12.5\Delta H \\ &= 6329.9 - 11.1\sqrt{\Delta H^2 + 102239.2} - 12.5\Delta H. \end{aligned} \tag{14}$$

(2) Horizontal Transportation Distance of Inner Dump. It is the horizontal distance from the transportation road of northern end-slope to the dumping gravity center of dumping elevation.

$$\begin{aligned} S_{p2} &= \frac{1}{2}[(L + 2\Delta H) - (\Delta H\cot\alpha + \Delta H\cot\beta)] \\ &\quad + (\Delta H\cot\alpha + \Delta H\cot\beta) \\ &= \frac{1}{2}[L + \Delta H(3\cot\alpha + \cot\beta)], \end{aligned} \tag{15}$$

where S_{p2} is the horizontal transportation distance of inner dump.

If the model parameters are input the formula, the output will be reached as follows.

$$S_{p2} = 1000 + 3.7742\Delta H. \tag{16}$$

In summary, the transportation distance can be expressed as follows.

$$\begin{aligned} S_p &= S_{p1} + S_{p2} \\ &= \frac{H' - DH}{i} + \frac{L}{2} + \frac{\Delta H(3\cot\alpha + \cot\beta)}{2} \\ &= 7329.9 - 11.12\sqrt{\Delta H^2 + 102239.2} - 8.7\Delta H. \end{aligned} \tag{17}$$

According to the stope transportation distance, the end-slope transportation distance and the dumping transportation distance calculated as above, the overburden transportation distance of Haerwusu surface coal mine can be obtained.

$$S = S_c + S_d + S_p = 10139.9 - 11.12\sqrt{\Delta H^2 + 102239.2} - 11.5\Delta H. \quad (18)$$

3.2. Overburden Transportation Distance of Northern Stope in Haerwusu Surface Coal Mine with Full Dumping. The overburden transportation distance of northern stope in Haerwusu surface coal mine with full dumping can be described as Figure 5.

The overburden above the dumping elevation in the north of Haerwusu surface coal mine can be shifted from every working bench to different dumping bench of the inner dump.

$$S' = S'_c + S'_d + S'_p = 2 \times \frac{1}{4}\left(L + 2 \times \frac{H + \Delta H}{2} \times \cot\alpha\right) + L_z + \frac{H + \Delta H}{2}(\cot\gamma + \cot\phi), \quad (19)$$

where S' is the overburden transportation distance above corresponding height (ΔH) with full dumping, S'_c is the overburden transportation distance in the stope, S'_d is the overburden transportation distance in the inner dump, S'_p is the overburden transportation distance in the end-slope.

If the model parameters are input the formula, the output will be obtained.

$$S' = 2008.8 + 5.3\Delta H. \quad (20)$$

3.3. Overburden Transportation Increment of Northern Stope in Haerwusu Surface Coal Mine. It is the overburden transportation difference between half dumping and full dumping above the dumping elevation.

$$\Delta S = S - S' = 8131 - 11.1\sqrt{\Delta H^2 + 102239.2} - 16.8\Delta H. \quad (21)$$

3.4. Overburden Amount above the Dumping Elevation of Northern Haerwusu Surface Coal Mine. With the complex terrain and the effect from gully throughout the first mining district considered, the influence coefficient of gully should be considered. Then the overburden above the dumping elevation can be expressed as follows:

$$Q_y = \frac{1}{2}\left[\frac{1}{2}(L + 2H\cot\alpha + L + 2\Delta H\cot\alpha)\cdot(H - \Delta H)\cdot v\right]\cdot K_G = \frac{1}{2}(L + H\cot\alpha + \Delta H\cot\alpha)\cdot(H - \Delta H)\cdot v\cdot K_G, \quad (22)$$

Where v is the annual advancing distance of Haerwusu surface coal mine, K_G is the influence coefficient of gully to stope overburden.

If the model parameters are input the formula, the output will be got.

$$Q_y = 49422100.6 - 24000\Delta H - 192\Delta H^2 \quad (23)$$

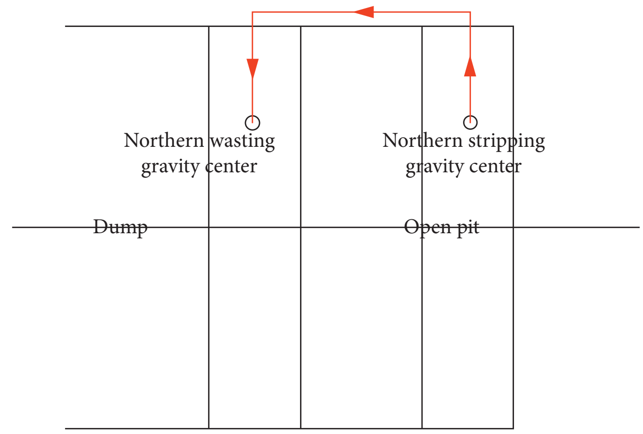

Figure 5: Overburden transportation distance of northern stope in Haerwusu surface coal mine with full dumping.

3.5. Secondary Overburden of Heidaigou Surface Coal Mine. Without the loss of coal pillar between the two mines considered, the secondary overburden of Heidaigou surface coal mine can be got as follows.

$$Q_B = \frac{1}{2}\Delta H(\cot\alpha + \cot\beta)\cdot\Delta H \times v' = \frac{1}{2}(\cot\alpha + \cot\beta)\cdot\Delta H^2\cdot v', \quad (24)$$

Where v' is the annual advancing distance of Heidaigou surface coal mine. If the model parameters are input the formula, the output will be obtained.

$$Q_B = 760.867\Delta H^2. \quad (25)$$

3.6. Relationship between the Dumping Height and the Total Cost. According to the model and optimization objective function above, the relationship between the dumping height and the total cost can be got. The relationship between the dumping height and the total cost is shown in Figure 6, and the total cost with 15 m bench height is calculated in Table 2.

Therefore, the reasonable dumping height is 135 m in the first mining district of Haerwusu surface coal mine without the time value of finance considered, which is the lowest total cost point on the curve combined the transportation cost and secondary stripping cost. At present the coal seam bottom elevation is 1000 m to 990 m, so the reasonable dumping elevation is 1130, with the current height of northern end-slope in Haerwusu coal mine considered.

4. Method Reliability Verification

Based on the annual planning projects and locations from 2014 to 2017, the cost of secondary stripping amount in Haidaigou surface coal mine and the overburden cost of Haerwusu surface coal mine can be calculated according to

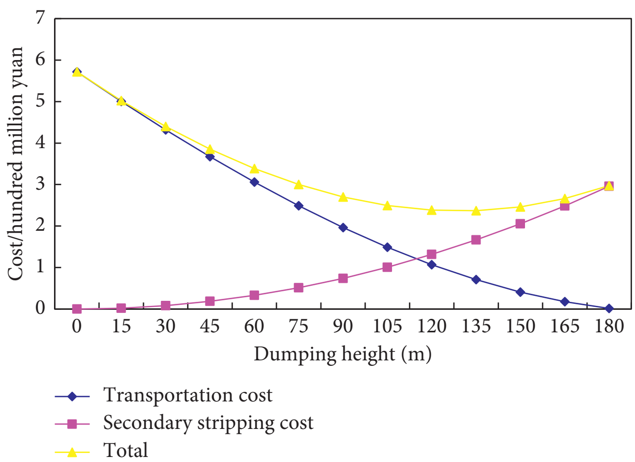

Figure 6: Relationship between the dumping height and the total cost.

Table 2: Relationship between the dumping height and the total cost.

Dumping height (m)	Transportation cost (million yuan)	Secondary stripping cost (million yuan)	Total cost (million yuan)
0	571.50	0	571.50
15	500.27	2.05	502.32
30	431.98	8.22	440.20
45	367.03	18.49	385.52
60	305.83	32.87	338.70
75	248.78	51.36	300.14
90	196.31	73.96	270.27
105	148.86	100.66	249.52
120	106.83	131.48	238.31
135	70.65	166.40	237.05
150	40.74	205.43	246.17
165	17.53	248.57	266.10
180	0	301.59	301.59

the corresponding different dumping elevation. Then the reasonable dumping height of end-wall slope can be compared and certificated.

4.1. The Dumping Elevation Is 1100. When the dumping elevation is 1100, the secondary stripping amount and cost in Heidaigou surface coal mine can be listed as Table 3.

The transportation cost of stripping spoil over elevation 1100 in Haerwusu coal mine is listed in Table 4 as follows with elevation 1100 covered.

The total cost is 1477.65 million yuan calculated from the two tables above when the elevation 1100 is covered, which includes secondary striping cost in Heidaigou surface coal mine and overburden transportation cost of northern Haerwusu surface coal mine.

4.2. The Dumping Elevation Is 1130. When the dumping elevation is 1130, the secondary stripping amount and cost in Heidaigou surface coal mine can be listed as Table 5.

Table 3: Secondary stripping amount and the cost with 1100 elevation dumped of Heidaigou surface coal mine.

Year	Secondary stripping tonnage ($m^3 \times 10^6$)	Stripping unit price (yuan)	Secondary striping cost (million yuan)
2015	3.78.	12	4.54
2016	30.72	12	36.87
2017	33.68	12	40.42
Total	68.19	12	81.83

Table 4: Transportation cost of stripping spoil over elevation 1100 in Haerwusu coal mine with elevation 1100 covered.

Elevation	Engineering quantity ($m^3 \times 10^6$)	Distance (m)	Transportation unit price (yuan/m^4)	Transportation cost (million yuan)
1205	0.74	6455	0.0025	11.88
1190	2.01	6360	0.0025	32.03
1175	3.82	6445	0.0025	61.50
1160	8.72	6520	0.0025	142.19
1145	16.08	6545	0.0025	263.11
1130	22.94	5630	0.0025	322.82
1115	24.06	4520	0.0025	271.82
1100	29.41	3950	0.0025	290.46
Total				1395.82

Table 5: Secondary stripping amount and the cost with 1130 elevation dumped of Heidaigou surface coal mine.

Year	Secondary stripping tonnage ($m^3 \times 10^6$)	Stripping unit price (yuan)	Secondary striping cost (million yuan)
2015	2.23	12	26.71
2016	6.98	12	83.73
2017	6.53	12	78.31
Total	15.73	12	188.76

The transportation cost of stripping spoil over elevation 1130 in Haerwusu coal mine is listed in Table 6 as follows with elevation 1130 covered.

Then the total cost is 1427.88 million yuan calculated from the two tables above when the elevation 1130 is covered, which includes secondary striping cost in Heidaigou surface coal mine and overburden transportation cost of northern Haerwusu surface coal mine.

4.3. The Dumping Elevation Is 1160. When the dumping elevation is 1160, the secondary stripping amount and cost in Heidaigou surface coal mine can be listed as Table 7.

The transportation cost of stripping spoil over elevation 1160 in Haerwusu coal mine is listed in Table 8 as follows with elevation 1160 covered.

Then the total cost is 1616.46 million yuan calculated from the two tables above when the elevation 1160 is covered, which includes secondary striping cost in Heidaigou surface coal mine and overburden transportation cost of northern Haerwusu surface coal mine.

The reasonable dumping height can be certificated as Table 9, which is consistent with the previous analysis.

Table 6: Transportation cost of stripping spoil over elevation 1130 in Haerwusu coal mine with elevation 1130 covered.

Elevation	Engineering quantity ($m^3 \times 10^6$)	Distance (m)	Transportation unit price (yuan/m^4)	Transportation cost (million yuan)
1205	0.74	5115	0.0025	9.41
1190	2.01	4970	0.0025	25.03
1175	3.82	5124	0.0025	48.90
1160	8.72	5170	0.0025	112.75
1145	16.08	5255	0.0025	211.25
1130	22.94	4700	0.0025	269.50
1115	24.06	4520	0.0025	271.82
1100	29.41	3950	0.0025	290.46
Total				1239.12

Table 7: Secondary stripping amount and the cost with 1160 elevation dumped of Heidaigou surface coal mine.

Year	Secondary stripping tonnage ($m^3 \times 10^6$)	Stripping unit price (yuan)	Secondary striping cost (million yuan)
2015	8.86	12	106.31
2016	12.88	12	154.51
2017	12.13	12	145.54
Total	33.86	12	406.36

Table 8: Transportation cost of stripping spoil over elevation 1160 in Haerwusu coal mine with elevation 1160 covered.

Elevation	Engineering quantity ($m^3 \times 10^6$)	Distance (m)	Transportation unit price (yuan/m^4)	Transportation cost (million yuan)
1205	73.6	4401	0.0025	8.10
1190	201.45	4280	0.0025	21.56
1175	381.70	4310	0.0025	41.13
1160	872.35	4415	0.0025	96.29
1145	1608.0	5255	0.0025	211.25
1130	2293.6	4700	0.0025	269.50
1115	2405.5	4520	0.0025	271.82
1100	2941.4	3950	0.0025	290.46
Total				1210.10

Table 9: Contrast between dumping height and the total cost.

Dumping height	Total cost (thousand yuan)
1100	147.77
1130	142.79
1160	161.65

5. Conclusions

(1) Two adjacent surface mines mined simultaneously in the same direction have a great impact on both sides, especially the inpit dumping. The proper covered height of end-slope will reduce mining cost and transportation cost greatly. According to the present situation and the engineering characteristics of the adjacent surface mines, a mathematical model is established, and the minimum cost of objective function is analyzed.

(2) Inpit dumping transporting system will be affected by different covered height in end-slope. The relationship between the transportation distance and the total cost with different dumping height is analyzed in the condition of economic cost considered, with the reasonable dumping elevation determined as 1130.

(3) With dumping height and the total cost in three different dumping height of end-slope compared, the correctness of the above theory is verified by an example, which can be used to solve the similar problems when adjacent districts mined in surface mines.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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