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# Feasibility of Synchronously Straightening Working Line of Adjacent Open-cast Mines

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**Abstract** Taking Heidaigou Open-cast Mine and Haerwusu Open-cast Mine in Zhungeer mining area as the research objects, this paper deeply analyzes the current mining status of the two mines. Based on the existing working line length, mining technology, transportation system, equipment configuration, transportation access and many other factors, it systematically discusses the feasibility of straightening the working line of adjacent open-cast mines. Through in-depth theoretical analysis, it establishes the mathematical model of impact indicators and cost calculation, and it is concluded that the work line straightening can be technically achieved. However, from the perspective of economic benefits, straightening the working line does not show obvious advantages.

**Key words** Adjacent open-cast mines, Tracing the mining, Working line straightening, Advancing direction

## 1 Introduction

In recent years, the adjacent open-cast mines or mining areas[1-2] in the same mining area have gradually started to have the same working slope advancing direction and the situation of "one after the other" tracing mining. For two adjacent open-cast mines, the reasonable working line shape will have an impact on the mining technology, development and transportation system, production management and economic benefits of the open-cast mine. However, it is necessary to study whether the ultra-long working line can be synchronously straightened when the adjacent open-cast mines tracing the mining from the working slope in production, and how the enterprise benefits will be generated after the realization[3-7].

## 2 Overview of open-cast mines

Heidaigou Open-cast Mine (hereinafter referred to as Heidaigou Mine) and Haerwusu Open-cast Mine (hereinafter referred to as Haerwusu Mine) in Zhungeer Mining Area were taken as the research objects. The stripping of Heidaigou Mine adopts the single-bucket excavator-truck mining technology and the combined mining technology of casting blasting and dragline dumping (45 m bench above the coal bed), and the coal mining adopts the single-bucket excavator-truck semi-continuous mining technology of semi-mobile crushing station; Haerwusu Mine adopts the shovel-truck mining process for stripping, and the coal mining work is the same as that of Heidaigou Mine. At present, the stripping working face of Heidaigou Mine has been transferred to the production of the second mining area, the first mining area of Haerwusu Mine is being exploited, which is adjacent to the second mining area of Heidaigou Mine, and the average working line of Heidaigou and Haerwusu mines is 2.1 km. The whole is advancing from west to east in the same direction. The working line of Heidaigou Mine lags behind Haerwusu Mine by about 1.2 km, and Haerwusu Mine moves forward in the way of "half ditch", which reduces the utilization rate of the inner dumping space, but reduces the secondary stripping of Heidaigou Mine. According to the analysis of the elevation of the ditch flat plate and the affected area, this part of the secondary stripping volume will greatly increase the stripping cost of Heidaigou Mine. In addition, the ditch part is also a transportation road running through the Heidaigou and Haerwusu mines excavation site to the waste dump. The Heidaigou and Haerwusu mines can form double-ring transportation, which reduces the transportation cost of the mine. The Heidaigou and Haerwusu mines stripping, mining and dumping works and the development and transportation system are shown in Fig. 1. The two open-cast mines are managed by Shenhua Group Zhungeer Energy Co., Ltd., and the coordinated mining work is being carried out. The production organization of the mine should break through the constraints of the Heidaigou and Haerwusu mines, optimize the mining technology, development and transportation system, equipment allocation and working line layout of open-cast mine as a whole. Firstly, taking the long working line as the breakthrough point, we focused on whether the Heidaigou and Haerwusu mines working line can achieve the horizontal consistency of the advancing direction, to avoid Heidaigou Mine's long-term tracking of the inner dumping part of Haerwusu Mine, and we analyzed whether the working line can be straightened and the impact on the transportation system after straightening.

## 3 Scheme of working line straightening

**3.1 Straightening principle of working line** (i) Heidaigou Mine should keep the total production scale of open-cast mine unchanged during the mining period. (ii) Reasonable production organization and personnel allocation plan, give full play to the capac-

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ity of equipment. (iii) The mining and stripping project is based on the existing excavation equipment of open-cast mine. The insufficient part of the equipment is solved by outsourcing. When the transportation equipment is insufficient, new equipment can be added.

**3.2 Allocation of bucket excavator mining process** At present, the working line of Heidaigou Mine advances 360 m, and the bucket excavator process is matched with the single bucket-excavator-truck mining process. When the working line length of the bucket excavator mining process does not exceed 2.0 km, the applicable advance shall be less than 300 m. If Heidaigou Mine is to achieve the same working line level as Haerwusu Mine, the existing propulsion strength still needs to be increased. At this time, the bucket excavator mining process is not suitable, and it can continue to be used after resuming normal production.

**3.3 Statistics of production capacity of existing mining equipment** In order to straighten the advancing direction of the working line between Heidaigou Mine and Haerwusu Mine, it is necessary to increase the advancing intensity. The "half-ditch" passage between Heidaigou and Haerwusu mines is gradually exploited, the double-ring transportation of Heidaigou and Haerwusu mines is cut off, and the transportation distance of open-cast mine stripping is increased. During the coordinated exploitation of Heidaigou and Haerwusu mines, equipment and resources can be adjusted for a short time. The equipment of Haerwusu Mine can be adjusted to Heidaigou Mine, and the coal from open-cast mine is mainly from Heidaigou Mine. The raw coal will be separately transported to the crushing system of the Heidaigou and Haerwusu mines, and the transportation distance will be increased for Haerwusu Mine, so the number of trucks for stripping and coal mining will be increased. In this study, according to the length of the working line of Heidaigou Mine, the self-owned excavation equipment is arranged to the maximum extent, and the insufficient parts should be outsourced to achieve the maximum propulsion strength. The truck shall be calculated according to the excavation quantities and transportation distance. The existing mining equipment of the Heidaigou and Haerwusu mines is listed in Table 1 and Table 2.

**Table 1 Production capacity statistics of mining equipment for stripping works of Heidaigou and Haerwusu mines**

| No. | Registered equipment model | Specification $m^3$ | Q'ty // set | Equipment production capacity // $10^4$ $m^3$/set · year | Total production capacity $10^4$ $m^3$/set · year | Remarks |
|---|---|---|---|---|---|---|
| Excavation equipment for Heidaigou Mine stripping work | | | | | | |
| 1 | Electric shovel WK55 | 58 | 1 | | | Auxiliary bucket excavator |
| 2 | Hydraulic shovel EX3600 | 22 | 1 | | | |
| 3 | Single-bucket excavator 395B | 32 | 6 | 590 | 3 550 | |
| 4 | Single-bucket excavator PH2800XP | 25/23 | 2 | 600 | 1 200 | |
| 5 | Single-bucket excavator WK-35 | 35 | 1 | 680 | 680 | |
| 6 | Single-bucket excavator WK-55 | 58 | 3 | 780 | 2 340 | |
| Total | | | 14 | | 7 770 | |
| Excavation equipment for Haerwusu Mine stripping work | | | | | | |
| 1 | Single-bucket excavator 495HR | 60.4/52.8/58 | 6 | 910 | 5 460 | |
| 2 | Single-bucket excavator WK55 | 58 | 3 | 860 | 2 580 | |
| 3 | Single-bucket excavator 395BI | 32 | 1 | 380 | 380 | |
| 4 | Loader L950 | 13.76 | 2 | 270 | 540 | |
| Total | | | 12 | | 8 690 | |

**Table 2 Statistics of production capacity of equipment of Heidaigo and Haerwusu mines**

| No. | Registered equipment model | Specification $m^3$ | Q'ty set | Equipment production capacity $10^4$ $m^3$/set · year | Total production capacity $10^4$ $m^3$/set · year | Registered equipment model | Specification $m^3$ | Q'ty set | Equipment production capacity $10^4$ $m^3$/set · year | Total production capacity $10^4$ $m^3$/set · year |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Single-bucket excavatorWK-35 | 49 | 2 | 770 | 1 540 | Single-bucket excavator 495HD | 49.2 | 1 | 540 | 540 |
| 2 | Wheel loader L1350 | 30 | 1 | 520 | 520 | Single-bucket excavator WK35 | 49.2 | 1 | 730 | 730 |
| 3 | Wheel loader 992G | 14 | 2 | 220 | 440 | Single-bucket excavator WK35 | 35 | 1 | 680 | 680 |
| 4 | | | | | | Loader L2350 | 38 | 2 | 580 | 1 160 |
| 5 | Subtotal | 5 | | 2 599 | | Subtotal | | 5 | | 3 110 |
| 6 | Total | 5 610 | | | | | | | | |

**3.4 Equipment arrangement of Heidaigou Mine working face** During the mining period, Heidaigou Mine is the main advancing pit, and Haerwusu Mine is the auxiliary one. Excavation equipment shall be arranged on the working face as much as possible in combination with the length of the working line of Heidaigou Mine, mining parameters and the type of excavation equipment.

**3.4.1** Calculation of length of excavator working line. The working line length of excavator operation area generally includes drilling area, blasting area (except surface soil) and mining and loading area. The working line length shall be able to meet the normal operation of various operations, so as to ensure that the excavator has 5 – 10 d of mining and loading blasting, and the excavator op-

eration volume is calculated as 7 d. As indicated in Table 1, there are many types of mining equipment in Heidaigou and Haerwusu mines, which are classified according to 50 t and above, 30 t, and 20 t and below. In combination with the production capacity of excavation equipment, the daily production capacity of different levels of excavation equipment is counted. According to the Equation (1) for calculating the working line length, the working line length for 7 d of excavator operation is calculated, as shown in Table 2.

$$L = \frac{Q}{h \times A} \times (N_1 + N_2 + N_3) \quad (1)$$

where $L$ denotes working line length (m) of excavator operation; $Q$ denotes the daily production capacity of excavator ($m^3$); $h$ denotes the bench height, which is taken as 15 m; $A$ refers to the width of the cutting zone, which is taken as 40 m; $N_1$ refers to the number of mining and loading days in the drilling area; $N_2$ refers to the number of mining and loading days in the blasting area; $N_3$ refers to the number of days in mining and loading area.

According to Table 3, different types of excavators have different working line lengths in the operation area. The working line length of excavators of 50 t grade and above is 1 070 m, that of excavators of 30 t grade is 648 m, and that of excavators of 20 t grade and below is 414 m. Self-operated equipment is used to mine rock benches, with an average working line length of 710 m.

**3.4.2** Arrangement of working face excavation equipment. In combination with Heidaigou Mine bench distribution map 2, there are rock benches from level 1 070 to level 1 165. There are 9 benches with working line length of 2.2 km and 2 benches with working line length less than 2.2 km, as shown in Table 4. The average working line length of the rock bench excavator is 710 m, and it is calculated that 30 sets of excavation equipment can be arranged at most for the rock bench. Blasting is not required for the topsoil bench, which is completed in the form of outsourcing, and the working line of outsourcing equipment is only considered to be 200 m. Above the level 1 180, there are topsoil benches, one with a working line length of 2.2 km and five benches with a working line length of 0.7 km. A maximum of 28 sets of excavation equipment can be arranged for the calculation of the soil bench. Similarly, a maximum of 9 sets of excavation equipment can be arranged on the Heidaigou Mine coal bench.

**Table 3 Length of working line in excavator operation area**

| Excavator model | Daily production capacity of excavator //$10^4$ $m^3$ | Bench height//m | Cutting zone width //m | Working length line//m |
|---|---|---|---|---|
| 50 t grade and above | 2.84 | 15 | 40 | 1 069.97 |
| 30 t above | 1.85 | 15 | 40 | 648.55 |
| 20 t grade and below | 1.18 | 15 | 40 | 414.29 |

**Table 4 Working line length and quantity of mining equipment**

| Item | Working line length//km | Number of benches | Average working line length of excavator//m | Quantity of equipment that can be arranged on each bench//set | Total equipment //set |
|---|---|---|---|---|---|
| Rock bench | 2.2 | 9 | 710 | 3 | 27 |
| | 1.8 | 1 | 710 | 2 | 2 |
| | 0.7 | 1 | 710 | 1 | 1 |
| | | | Total | | 30 |
| Soil bench | 2.2 | 1 | 200 | 11 | 11 |
| | 0.7 | 5 | 200 | 3.5 | 17.5 |
| | | | Total | | 28 |
| Coal bench | 2.3 | 3 | 710 | 3 | 9 |
| | | | Total | | 9 |

The total number of excavators for rock works in the Heidaigou and Haerwusu mines is 26 sets. According to Table 4, 30 excavators can be arranged at most on the rock working face. Therefore, the rock working face of Heidaigou Mine meets the requirements of the arrangement of the existing excavation equipment in the Heidaigou and Haerwusu mines. The total number of excavators for coal mining works is 10, which meets the equipment arrangement of the working face and does not require additional investment in excavation equipment.

**3.4.3** Increase of trucks. The middle ditch transportation road of open-cast mine is exploited, the double-ring transportation road of inner dumping is cut off, the transportation distance is increased, the annual operation volume of transport equipment is reduced, the large-scale transport equipment is not suitable for outsourcing, so it is necessary to increase the input of transport equipment. The transportation distance of raw coal from the coal transportation project to the Haerwusu Mine crushing system is also increased, and coal trucks need to be increased. The transportation distance of stripping and coal mining works is increased by 2.0 and 2.5 km, respectively, which affects the round-trip running time of trucks. The transportation time increase coefficient is 1.2. The number of new trucks is calculated according to the number of existing transportation equipment, as shown in Table 5. A total of 39 trucks of different types are added.

**3.4.4** Traffic density. According to Table 4, there are 50 sets of transportation equipment for coal mining works and 183 sets of transportation equipment for stripping works. The truck-shovel ratio of outsourcing equipment for open-cast mine topsoil work is calculated as 1∶6, and 28 sets of excavation equipment are arranged on the working face, so 168 sets of transportation equipment for

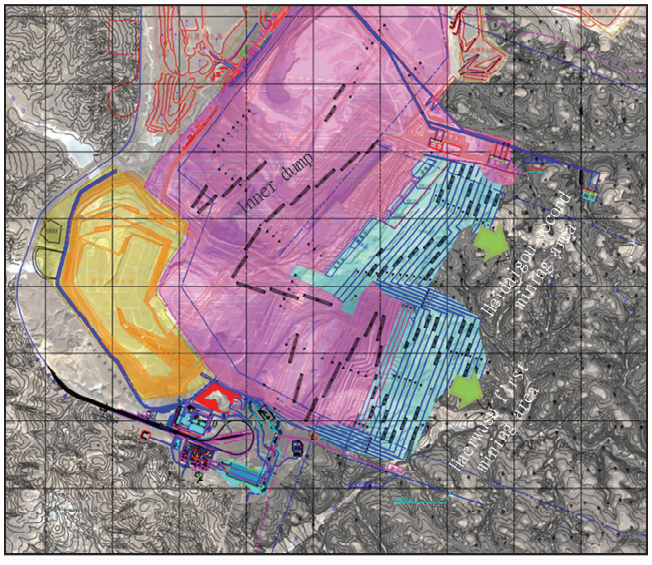


**Fig. 1 Stripping, mining and dumping works and the development and transportation system of Heidaigou and Haerwusu mines**

topsoil works are arranged. The maximum traffic flow density of the transportation road shall meet the requirements of vehicle traffic. The passing capacity of the intersection of the main entrance and exit ditch of vehicle transportation and the road with high traffic density can be calculated according to Equation (2)[8]:

$$N_D = 1\,000\,Vnf/S \quad (2)$$

where $N_D$ denotes road traffic capacity (vehicle/h); $V$ denotes average driving speed of vehicles in the calculation section (km/h); $n$ refers to the number of driving lines, $n = 0.5$ for single lane, $n = 1$ for two lanes; $f$ denotes imbalance coefficient of vehicle driving, $f = (0.5 - 0.7)$; $S$ denotes the minimum safe following distance, $S = (50 - 60)$ m. Based on the average driving speed of 40 km/h, two lanes, vehicle driving imbalance coefficient of 0.5 and minimum safe following distance of 60 m, the average maximum traffic capacity of each lane is 333 vehicles/h. The total number of open-cast mine stripping dump trucks is 349. Since the stripping and dumping method is inner dumping, the open-cast mine is transported to the end slope transport platform through the working face transport road and finally to the inner dumping site. There are many transport roads, so the driving density of 349 transport equipment meets the requirements. The total number of coal mining equipment is 50, which are transported separately to the Heidaigou and Haerwusu mines crushing system. There are at least 4 coal transport outlets, and the traffic density of coal mining equipment also meets the requirements. Heidaigou and Haerwusu mines, from the technical point of view, the straightening of working lines can be realized in the next 2 to 3 years, but the feasibility of straightening should be further analyzed from the economic point of view.

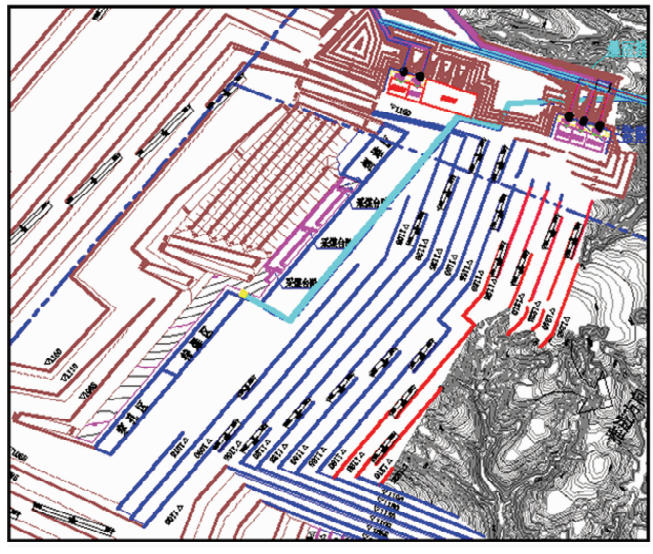

**Fig. 2 Distribution of mining benches in Heidaigou Mine**

**Table 5 Calculation of quantity of newly added trucks**

| Project | Registered equipment model | Specification // t | Registered quantity // set | Coefficient of increase | Equipment increase // set |
|---|---|---|---|---|---|
| Haerwusu Mine stripping | MT5500 | 326 | 37 | 1.2 | 7 |
| | 930E | 290 | 23 | 1.2 | 5 |
| | SF33900 | 220 | 12 | 1.2 | 2 |
| Subtotal | | | 72 | | 14 |
| Haerwusu Mine mining | MT4400 | 236 | 18 | 1.2 | 4 |
| Subtotal | | | 18 | | 4 |
| Heidaigou Mine stripping | 630E | 154 | 31 | 1.2 | 6 |
| | SF32601 | 154 | 1 | 1.2 | 1 |
| | 730E | 185 | 5 | 1.2 | 1 |
| | 830E | 220 | 10 | 1.2 | 2 |
| | SF33900 | 220 | 13 | 1.2 | 3 |
| | 930E | 290 | 21 | 1.2 | 3 |
| Subtotal | | | 81 | | 16 |
| Heidaigou Mine mining | 630E | 154 | 23 | 1.2 | 5 |
| Subtotal | | | 23 | | 5 |
| Total | | | | | 39 |

## 4 Economic benefit analysis

After the working line of the Heidaigou and Haerwusu mines is straightened, the middle transportation passage no longer exists, and the double-ring transportation of the stripped materials will be cut off. Although Heidaigou Mine no longer strips the secondary works of Haerwusu Mine, However, the stripping and transportation distance of Heidaigou and Haerwusu mines increases. The main indicators affected by working slope straightening are listed in Table 6.

**Table 6 Main indicators affected by working slope straightening**

| Time | During straightening the working line | | After straightening the working line | | |
|---|---|---|---|---|---|
| Parameters | $Q_M$ // $10^4$ $m^3$ | $k_M$ // km | $Q$ // $10^4$ $m^3$ | $Q_B$ // $10^4$ $m^3$ | $k_B$ // km |
| | 2 365 | 2.5 | 386 | 15 197 | 2 |

**NOTE** The symbols in the table have the same meanings as those in equations (3) and (4).

According to Table 6, we calculated the reduced cost of Heidaigou Mine without secondary stripping works, and compared and analyzed the increased transportation cost after the double-ring transportation road is cut off (this calculation is based on the fact that the central transportation road is not added at other work locations).

(i) Cost reductions in the secondary stripping works at Heidaigou Mine:

$$N = Q \times j \times k \tag{3}$$

where $N$ denotes the cost of secondary stripping, 10 000 yuan; $Q$ denotes the reduced secondary stripping works, 10 000 $m^3$/year; $j$ denotes the unit price of secondary stripping, 2.0 yuan/$m^3$ · km; $k$ denotes the transportation distance, 2.0 km. According to Equation (3), the cost of secondary stripping after the work line of Heidaigou Mine is straightened is 15.44 million yuan per year.

(ii) Total transportation cost increased by straightening the working line.

$$M = (Q_M \times k_M + Q_B \times k_B) \times y \tag{4}$$

where $M$ denotes the total transportation cost increased by straightening the working line, 10 000 yuan; $Q_M$ refers to the work quantity of the increased transportation distance of the coal transportation project during straightening the working line, 10 000 $m^3$; $k_B$ denotes the added value of stripping transportation distance, 2.0 km; $k_M$ refers to the added value of coal transportation distance, km; $Q_B$ denotes the work quantity of the increased part of stripping transportation distance after the working line is straightened, 10 000 $m^3$; $y$ represents the unit transportation cost of the truck, which is taken as 2.2 yuan/$m^3$ · km.

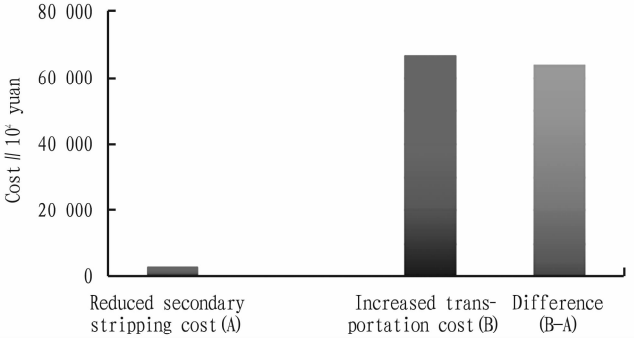


**Fig. 3 Comparison of economic benefits**

According to Equation (4), it is calculated that the total transportation cost increased by straightening the working line is 798 735 600 yuan, of which the annual stripping transportation cost increased by straightening is 668 668 000 yuan. Only considering the transportation cost of open-cast mine after straightening and the reduced secondary stripping cost of Heidaigou Mine, the straightening of Heidaigou and Haerwusu mines working slope has no economic advantage, and the economic effect analysis is shown in Fig. 3.

## 4 Conclusions

During the tracking mining period, the mine operation is mainly concentrated in Heidaigou Mine, and the transportation distance of coal transportation and stripping works is increased, so additional transportation equipment is required. In summary, it is technically feasible to straighten the advancing direction of the working lines of Heidaigou and Haerwusu mines. However, it is not economically reasonable, so it is recommended that the central transportation road should be kept in the production of the two open-cast mines, the average length of the working line of the Heidaigou and Haerwusu mines should be maintained at 2.1 km, and the method of tracing mining of "one after the other" working slope should be applied.

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