VIKRAM SEERVI
NAWAL KISHORE
and
AMIT KUMAR VERMA

# Selection of mode of tandem dragline operations by utilizing 3-dimensional computer graphics balancing diagram: a case study

*With the expansion of mines for higher rated outputs, the operation of a dragline in tandem has gained significance in the field. The tandem operation enhances capacity utilization of draglines which are highly capital-intensive equipment. To maximize the return on investment and improve the dragline's performance, its mode of operation and influencing parameters must be understood and carefully analysed. The balancing diagram (a graphical representation of dragline cuts and spoil geometry) for the draglines operating in tandem is the most essential tool to deploy the dragline successfully. This task manually is normally both difficult and time-consuming and requires an analytical solution. This is best suited to the application of computer graphics methods. Therefore, a balancing diagram in a 3-dimensional graphics package has been developed to assist the mine planner in planning dragline operations. The purpose of this paper is to select the most appropriate mode of dragline operation, operating in tandem, and by analysing the two indices, i.e., rate of coal exposure and percentage rehandle. The analysis will be case study-oriented with practical mining considerations and comparatives indices being formulated for better understanding. In the present study, field data pertaining to the dragline operations have been collected from one of the prestigious mines of Northern Coalfields Limited, a subsidiary of Coal India Limited, and an attempt has been made to decide the mode of operation under the existing field conditions.*

***Keywords:*** Balancing diagram, 3-dimensional balancing diagram, tandem operation, rate of coal exposure, rehandling percentage.

## 1.0 Introduction

Large walking draglines are highly capital-intensive pieces of equipment. To maximize the return on investment and to improve the dragline's performance, its operation and influencing parameters must be understood and fully analysed to optimize the process. Finding the normal working ranges for a given dragline and optimising its operation usually requires various possible mining and scenarios as well as configurations (Baafi and Mirabediny, 1997). As the selection of a dragline is a major decision for which a mine will live up to 30 years, similarly, selection of mode of operation is vital for the success of the project.

Once a mine has deployed a dragline, it cannot alter this highly capital-intensive equipment for higher rated output. Instead of replacement for higher capacity dragline, opt for another dragline with the desired capacity to fulfil the required upgraded output. Today every expenditure is being scrutinized to the fullest, mainly when this expenditure may involve an investment of millions of rupees. The major investment required by a single large dragline can be reduced by the deployment of two or more smaller draglines. Not only are these savings associated with the initial acquisition cost, but these benefits continue during ongoing operations. It may pay to operate with two smaller machines in tandem rather than one large machine (Fishler, 1987).

The operation of the dragline in tandem is advantageous from the view point of reduction in the cycle time, idle marching as well as the lesser coal dilution and increment in horizontal reach and rate of coal exposure. The coal exposure is increased, which implies an increase in the rate of advance in mining.

The mode of operation has a tremendous influence on the rate of advance in mining and the productivity of draglines. Because of the complex nature of dragline operations, many alternative digging methods are used in practice.

Where the coal seam lies at a depth that is beyond the capability of a single dragline, two draglines can be deployed in tandem in the same pit. In vertical tandem operation, the main overburden bench is divided into benches, i.e., upper bench (top) and lower bench (bottom) in synchronism. One dragline deployed on the upper bench is called leading dragline, and another dragline on lower the bench is called a lagging dragline.

As dragline operations encounter a greater depth of overburden, estimating dragline production becomes a more

Messrs. Vikram Seervi, Nawal Kishore and Amit Kumar Verma, Department of Mining Engineering, IIT-BHU Varanasi 221005, Uttar Pradesh, India. E-mail: Vikramseervi.rs.min17@itbhu.ac.in

complex task. Beyond maximum side casting depths, several stripping modes can be utilised, including chop down, extended bench, spoil side, multiple pass, and combination of these methods. In each mode, cycle time, percentage re-handle, fill factor, etc., will vary, resulting in different stripping rates of the dragline. The problem of selecting the most productive mode of operation for varying depth of overburden and pit geometries and then forecasting associated rates of production through the planned mining sequence is amplified at these greater depths (Hrebar and Cook, 1987).

Hence, considering the above, the present paper discusses the two main modes of operation in which draglines are operating in tandem. These modes of operations are based on actual operating practices at various coal mines in India. The performance of draglines and the application of these modes of operations will be examined in this text on a case study basis.

## 2.0 Balancing diagram

Balancing diagram is a basic planning tool that can be used for the effective deployment and operation of draglines. It is a graphical representation scheme for determining the suitable seating position of the dragline in order to get minimum rehandle of the dragline cuts and also provides spoil geometry which determines the rate of coal exposure, rehandle volume, and cuts volume. It decides the seating position of draglines and a balanced workload for each dragline operating in tandem operation. The ultimate purpose of the balancing diagram is to achieve the targeted coal production with minimum rehandle percentage and to decide the mode of operation. For making a decision regarding the optimum cut width, the preparation of a balancing diagram is absolutely essential (Rai, Kishore, and Nath, 1999).

## 3.0 Mode of operation

There are mainly two modes of operation practice in Indian opencast coal mines in tandem dragline operation. The two modes of tandem operations are horizontal tandem and vertical tandem. In a tandem dragline operation, one of the units is considered to be the leading (primary/independent) dragline, and the other one is the lagging (secondary/dependent) dragline. The leading dragline is the one with no hindrance against advancing. It operates at its own pace and moves freely on its allocated bench, hence called independent. The lagging dragline is deployed on the spoil side to remove some part of the overburden from the main stripping bench and rehandle some portion from earlier cast overburden to full exposure of coal seam. It is dependent on leading dragline advancement, the so-called dependent dragline. Erdem and Celebi (1999) also considered primary machine as independent and secondary machine as a dependent.

### 3.1 Horizontal tandem operation

In the horizontal tandem operation (Figs.1 and 2), both the draglines are deployed in the same bench for a fast rate of advance and coal exposure (Chironis, 1986; Chaoji and Dey, 2000). The cut width taken by the draglines will be wider depending upon the operating radius of the draglines. (Rzhevsky, 1987). Rzhevsky stated that the width of the cut should be as large as possible in order to provide a sufficiently large, opened reserve of the mineral and reduce relative time losses of standby and unproductive moves of draglines. On the other hand, it should be optimized to obtain a greater height of the stripping bench. Wider cut width will be extracted in three cuts with side-cut position (Fig.4) depending upon cut width and dragline operating radius.

The leading dragline is deployed on the highwall side and provides a key cut towards the highwall, and after completing the key cut, the dragline is moved towards the decoaled area (spoil dump side) to excavate the first cut (next to key cut). After excavating these two cuts, the leading dragline is again

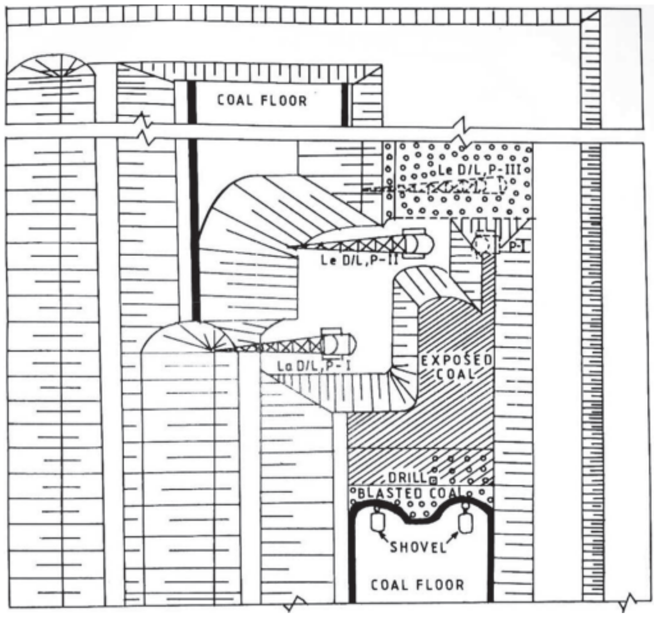


Fig.1: Plan of mining system in horizontal tandem (N. Kishore, Ph.D. Thesis, 2004)

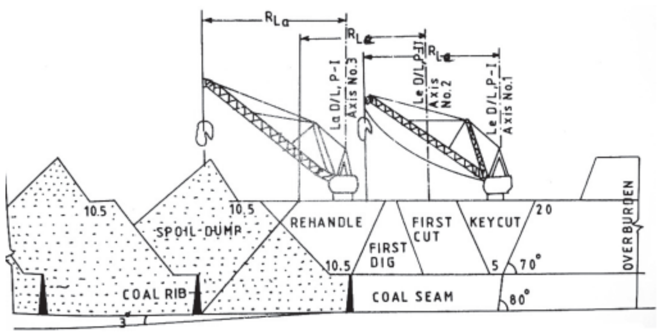


Fig.2: Cross-section showing draglines in horizontal tandem (N. Kishore, Ph.D. Thesis, 2004)

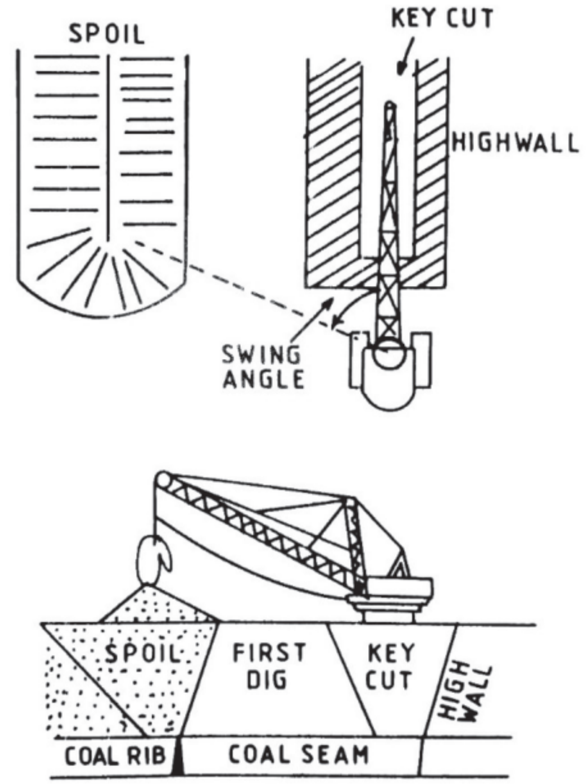


Fig.3: Excavation by dragline in end-cut position (N. Kishore, Ph.D. Thesis, 2004)

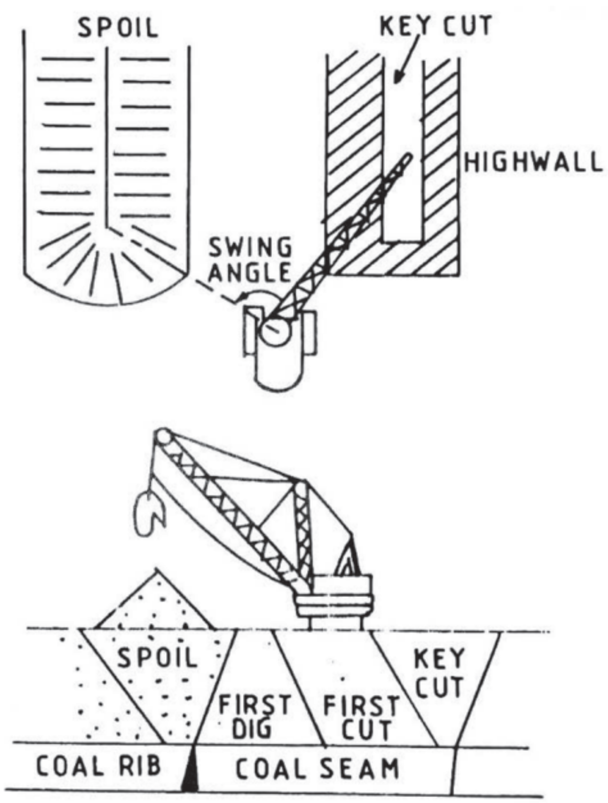


Fig.4: Excavation by dragline in side-cut position (N. Kishore, Ph.D. Thesis, 2004)

moved to a new key cut position to advance further; the dragline is ready for the next stripping cycle (the same sequence goes on). The lagging dragline is deployed on the spoil side, on the extended bench formed by the leading dragline after dumping overburden from key cut and first cut. The dragline that operates from the extended bench excavates first dig and spoil the overburden to a greater distance, and thus, extend the reach of the dragline (Chugh, 1980).

The lagging dragline first excavates the first dig (next to the first cut) in the remaining portion of the stripping bench in the side-cut position (Fig.4) and then re-handles the overburden to expose the coal seam fully.

Horizontal tandem operation is a combined method of simple side casting and extended bench. Both the draglines always operate below their own level. In this method of stripping, the draglines operate from the top of the ground surface, strip down the overburden and spoil overburden on the side into the decoaled area (space from which coal has been mined out previously) to form a level pad (extend the bench on spoil side) for deployment (seating position) of lagging dragline towards decoaled area.

Fig.1 describes the stripping sequence of the draglines deployed in horizontal tandem operation. The leading dragline sits at position I to excavate the key cut and the overburden from the key cut is dumped at the base of the spoil pile. On completing the key cut, the same dragline marches towards decoaled area to position II to excavate the first cut, and the overburden is cast on top of the key cut spoil to form a level pad. When the first cut has been completed, the leading dragline is moved to position III, the beginning of the next sequence. The leading dragline operates from the end-cut positions (Fig.3).

Now the lagging dragline is made to sit at the spoil at position P-1 (dump by leading dragline), which is levelled and graded with the help of a dozer, and excavates the first dig in side cut position (since it cannot alter its position) to expose the coal seam fully. Besides, it also rehandles the spoil dumped by the leading dragline and dumps it over the previous spoil to greater height and distance.

Fig.2 describes the dragline cuts section and the positions of the dragline travel axis (as shown in plan, Fig.1). The leading dragline excavates the key cut from position I, axis no.I. The same dragline excavates the first cut from position II, axis no.II. The lagging dragline sitting on the spoil dump cannot change its position to excavate first dig. It excavates the first dig in a side-cut position from dragline axis no. III and also rehandles the spoil in the same travel axis in end-cut position or side cut position. The spoil can be dumped further away from the side-cut position.

### 3.2 Vertical tandem operation

Where the coal seam lies at a depth that is beyond the capability of a single dragline, two draglines can be deployed in vertical tandem operation in the same pit. A detailed study has been done by Learmont (1989), who pointed out that the high investment cost of the large single dragline requires consideration of the combination of two draglines in tandem operation (vertical) for overburden depth (stripping bench height) above 30 meters. The dragline investment costs for specific applications may be reduced by modifying the proportion of overburden handled by the upper bench and lower bench dragline or by reducing the rehandling percentage by increasing cut width.

In vertical tandem operation (Figs.5 and 6), the main overburden bench is worked in two vertical benches, i.e., upper bench (top bench) and lower bench (main bench) in synchronism. One dragline deployed on the upper bench is called leading (primary/independent) dragline, and another dragline on the lower bench is called lagging (secondary/dependent) dragline. The upper bench is always kept ahead of the lower bench. The working of these two vertical lifts is tied up and has interference in working. The overburden material of the upper bench is cast nearer to decoaled highwall, which involves maximum rehandling. The principal advantage of vertical tandem operation is that it caters to the

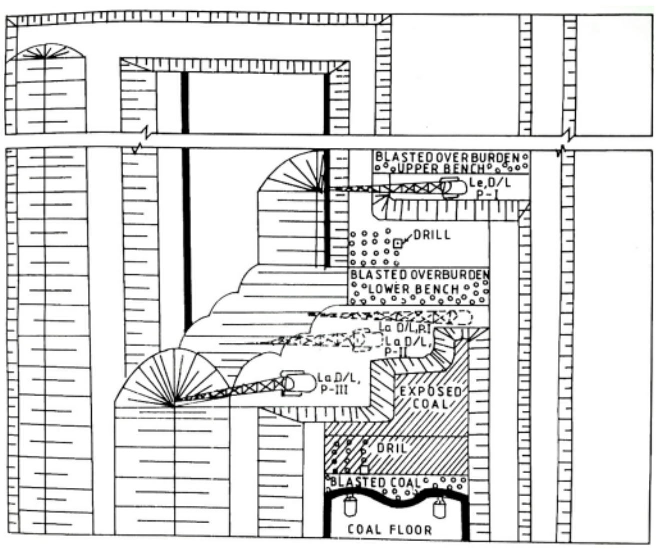


Fig.5: Plan of mining system in vertical tandem (N. Kishore, Ph.D. Thesis, 2004)

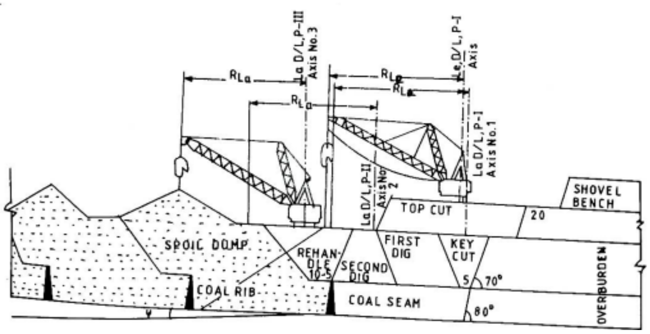


Fig.6: Cross-section showing draglines in vertical tandem (N. Kishore, Ph.D. Thesis, 2004)

higher thickness of overburden benches by draglines (Chaoji and Dey, 2000).

In vertical tandem operation, the height of stripping benches increases, and the overburden rehandle volume decreases. The use of two draglines in tandem operation raises the production capacity of the complex stripping machines, and therefore, the mineral capacity of the quarry (Rzhevsky, 1987).

Hrebar and Cook (1987) stated that as dragline operations encounter greater depths of overburden, estimating dragline production becomes a more complex task. Beyond maximum side-casting depths, a number of stripping modes can be utilized, including chop down, extended bench, spoil side, multiple pass, and combinations of these methods. In each mode, cycle time, percentage rehandle, fill factor, etc. will vary, resulting in different stripping rates for the dragline. The problem of selecting the most productive mode of operation for a varying depth of overburden and pit geometries and then forecasting associated rates of production through the planned mining sequence is amplified at these greater depths.

Vertical tandem operation is a combined method of simple side casting, advanced benching, and extended bench. Both the draglines always operate below their levels. In this method of stripping, the leading dragline operates from the top of the upper bench, strips down to the upper bench, and side casts the spoil into the decoaled area to form a level pad (extend bench) for lagging dragline. In this case, the leading dragline (on the upper bench) forms the bench for the lagging dragline on the lower bench, which first excavates the lower bench overburden with various cuts and then rehandles the dumped spoil into decoaled area to a greater height and distance sitting on spoil side.

Fig.5 describes the stripping sequence of the draglines deployed in vertical tandem operations. The leading dragline on the upper bench seat at position I (Le-D/L, P-I) excavates the upper bench overburden. It operates from the end-cut position (mid of cut width of the upper bench). Then the lagging dragline on the lower bench excavates the key cut from position I (La-D/L, P-I) and side casts the spoil into the decoaled area. After completing the key cut, the lagging dragline marches towards decoaled area to position P-II to excavate the first and second dig respectively in the end cut position in order to expose the coal seam. After this, the lagging dragline marches towards the spoil side and sits on it position P-III to rehandle the spoils for a greater height and distance to expose the coal seam fully. Upon completion of rehandling, the dragline moves again to the key cut position and repeats the basic process again.

Fig.6 describes the draglines cuts section and the positions of the dragline travel axis. The leading dragline on the upper bench excavates the upper bench overburden from position I and moves in the same dragline (Le-D/L) axis. The lagging dragline moves on the lower bench to excavate key cut from dragline (La-D/L) axis no.I, first cut and first dig from dragline (La-D/L) axis no.II, and rehandles from axis no.III (La-D/L) respectively.

In the vertical tandem mode I, the leading dragline is deployed on the upper bench for removal of the upper bench material (top cut) and come back to the lower bench to excavate the key cut in the lower bench also. The lagging dragline deployed on the lower bench to excavate first dig, second dig and rehandle parts of the material. Whereas in the vertical tandem mode-II, the leading dragline deployed on the upper bench only to excavate top cut and advances in the upper bench only. The second dragline (lagging) is deployed on the lower bench to excavate the key cut, next to key cut, i.e., first dig, second dig (as the cases prevail) and rehandle some parts of the material.

### 4.0 Interactive 3-dimensional balancing diagram using computer graphics

To alleviate the preparation of manual drawing of balancing diagrams and volumetric calculations quickly and precisely for the best alternative, an interactive computer graphics programme in language C++ has been developed to generate a 3-dimensional balancing diagram along with all possible sections and calculations. This has been achieved by developing a programme that follows the same basic steps as those taken in the manually balancing diagram. The planner will control the planning operation at every stage. All actual decision making, such as the selection of bench height and cut width along with workload distribution for each dragline working in tandem, specification of cut dimensions, coal exposure, and re-handle percentage, will be carried out interactively at the computer terminal along with the 3-dimensional view of balancing diagram. A typical 3-dimensional balancing diagrams for horizontal tandem and vertical tandem are shown in Figs.7 and 8, respectively.

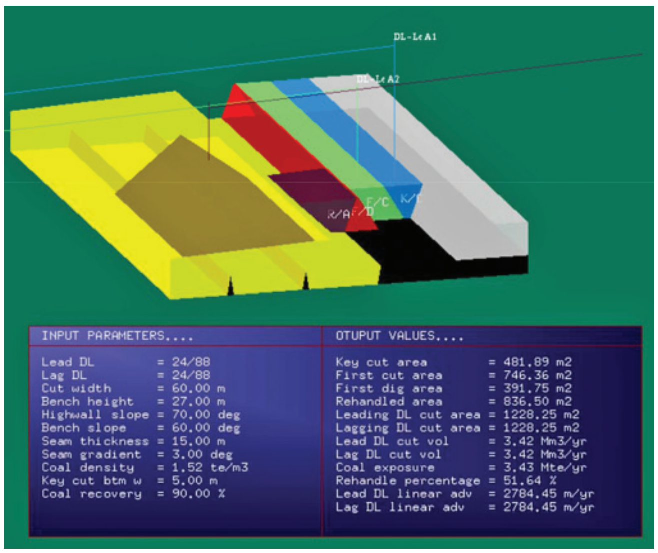


Fig.7: A typical 3-dimensional balancing diagram of horizontal tandem

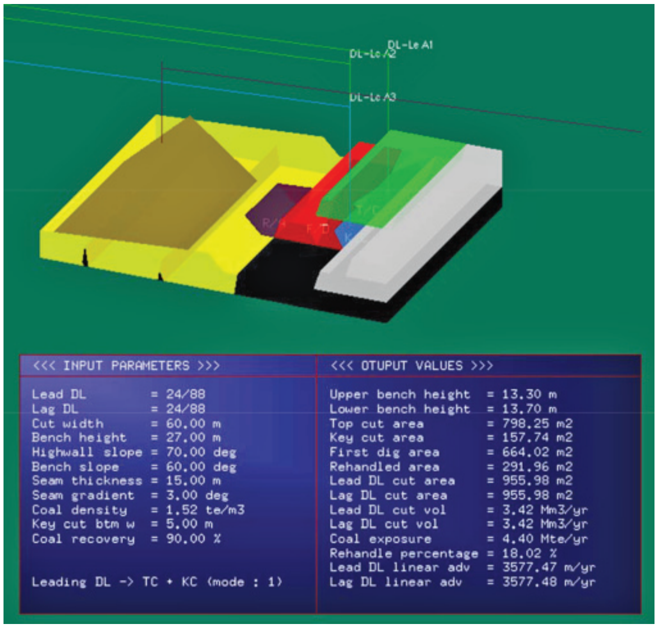


Fig.8: A typical 3-dimensional balancing diagram of vertical tandem

The computer is used as a tool to speed up the time-consuming aspect of the dragline balancing diagram for planning operations. A computer graphics system is used as an interactive tool to draw the balancing diagram with all cut sections by varying all influencing parameters like geological, mechanical (machine specifications), and operational (pit design). The programme provides the capability for the rapid calculation, tabulation, and display of coal exposure, re-handle percentage, draglines advancement per annum, and also area of cut sections taking into account workload distribution principal.

The inputs to the programme are factors associated with geology (i.e., seam thickness, seam gradient, and density of coal), dragline specifications (i.e., annual productivity and reach of draglines), and pit design operational parameters (i.e., cut width, bench height, and percentage of coal recovery). The output is a 3-dimensional balancing diagram plotted on the screen with all calculations like coal exposure, rehandle percentage, volume of top cut in vertical tandem, volume of key cut, volume of first dig, volume of re- handing part, and the bench division in case of vertical tandem (lower bench and upper bench) according to the capacity of the draglines. The philosophy is to automate the preparation of 3-dimensional balancing diagram and provide specific calculation of volume excavated by leading and lagging draglines with coal exposure and re-handle percentage.

The programme lists all possible mine designs that meet the prerequisite criteria. Various rules of thumb based on operating experience have been used to assist in selecting various parameters. Thus, it helps select the most appropriate mode of operation for the targeted coal exposure by varying the input parameters.

TABLE 1: INPUT DESIGN PARAMETERS USED IN THE PROGRAMME

| | Main parameters | Sub-parameters | Particulars | Acquired from the field for case study |
|---|---|---|---|---|
| 1. | Geology | Seam thickness, m | Variable | 15 |
| | | Seam gradient, degree | Variable | 3 |
| | | Density of coal, t/m$^3$ | Variable | 1.52 |
| 2. | Dragline specification | Annual productivity of leading dragline, Mm$^3$ | Variable | 3.4 |
| | | Reach of leading dragline, m | Variable | 88 |
| | | Annual productivity of lagging dragline, Mm$^3$ | Variable | 3.4 |
| | | Reach of lagging dragline, m | Variable | 81 |
| 3. | Pit Design (operational) | Bench height, m | Variable | 42 |
| | | Cut width, m | Variable | 90 |
| | | Bench slope angle for intactground, degree | Fixed (60) | 60 |
| | | High wall angle, degree | Fixed (70) | 70 |
| | | Bench slope angle for looseground, degree | Fixed (40) | 40 |
| | | Angle of repose, degree | Fixed (38) | 38 |
| | | Key cut bottom width, m | Fixed (5) | 5 |
| | | Berm (Rehandling area), m | Fixed (10.5) | 10.5 |
| | | Berm (lower bench in verticaltandem), m | Fixed (20.0) | 20.0 |
| | | Coal rib, m | Left for full height | 15 |
| | | Dragline availability cum utilization, % | Variable | 100 |
| | | Coal recovery, % | Variable | 90 |
| | | Angle of coal extraction, degree | Fixed (80) | 80 |

## 5.0 Case Study

After the development of this programme, the application of these alternative modes of operation was examined in this text on a case study basis. The study has been conducted in one of the major opencast coal mines of Singrauli coalfields. The area has been chosen because it is the only coalfield in India, where the entire coal production is mined by opencast mining. Another unique feature of this region is that the large volume of excavation is carried out by deploying large walking draglines operating in tandem to meet the desired rate of coal exposure and coal extraction. This coalfield has the highest number of draglines in India, mostly working in tandem. The various sizes of dragline ranging from 10 to 24 cubic meter bucket size with boom length of 72 to 96 m are being deployed in this region. At present, 23 draglines are in operation in this region. The parameters like geo-mining, dragline specifications, and operational have been acquired from the field and appended in Table 2.

TABLE 2: DATA ACQUIRED FROM THE FIELD

| Parameters | Items | Particulars |
|---|---|---|
| Geo-mining | Nature of overburden | 90% Sandstone (fine to medium grained) |
| | Thickness of coal seam, m | 15-18 |
| | Seam gradient, degree | 3-6 |
| | Density of coal, t/m$^3$ | 1.5 |
| Dragline specification | Annual productivity of leading dragline 24/96, Mm$^3$ | 3.4 |
| | Annual productivity of lagging dragline 24/96, Mm$^3$ | 3.4 |
| Operating | Bench height, m | 27-42 |
| | Cut width, m | 60-90 |
| | Utilization, % | 100% |
| | High wall angle, degree | 70 |
| | Bench slope angle, degree | 60 |
| | Angle of repose for loose, degree | 38 |
| | Berm clearance, m | 10.5 |

### SEQUENCE OF MINING OPERATIONS

Mining will be done from rise to dip with individual benches moving along strike in certain cut width of 60-90m with bench height varies from 27-45m for dragline working and a width of 57m-63m for shovel-dumper working in the overburden and 45m-60m in coal. The width of the non-working bench will be 37m-43m for the shovel-dumper bench in the overburden and 25m in coal. Topsoil will be removed by shovel-dumper combinations and followed by overburden excavation by deploying two draglines above the bottom-most coal seam for final coal exposure and its extraction. Presently, the mine is operating with a combined system of opencast mining with the use of draglines and shovel-dumper combination in two sections (east and west section) with central haul road.

Subsequently, with the help of these acquired input data, a balancing diagram for both modes of operation under existing field conditions is performed, and results are shown in Tables 3, 4, and 5 respectively. Finally, a comparative

Table 3: Horizontal mode of operation for leading and lagging draglines of same capacity 3.4 $Mm^3$ in various cut width and bench height

| | Cut Width (m) | Bench height (m) | Excavation area taken by Leading D/L ($m^2$) | Area ($m^2$) | Excavation area taken by lagging D/L ($m^2$) | Area ($m^2$) | Coal exposure (Mte/yr) | % Re-handle |
|---|---|---|---|---|---|---|---|---|
| 1. | 60 | 27 | Key cut | 481.89 | First dig | 391.75 | 3.43 | 51.64 |
| | | | First cut | 746.36 | Rehandle | 836.50 | | |
| 2 | 70 | 27 | Key cut | 481.89 | First dig | 526.75 | 3.62 | 44.26 |
| | | | First cut | 881.36 | Rehandle | 836.50 | | |
| 3 | 80 | 27 | Key cut | 481.89 | First dig | 661.75 | 3.75 | 38.73 |
| | | | First cut | 1016.36 | Rehandle | 836.50 | | |
| 4 | 90 | 27 | Key cut | 481.89 | First dig | 796.75 | 3.87 | 34.42 |
| | | | First cut | 1151.36 | Rehandle | 836.50 | | |
| 5 | 60 | 35 | Key cut | 757.91 | First dig | 404.43 | 2.48 | 61.48 |
| | | | First cut | 937.67 | Rehandle | 1291.15 | | |
| 6 | 70 | 35 | Key cut | 757.91 | First dig | 579.43 | 2.63 | 52.70 |
| | | | First cut | 1112.67 | Rehandle | 1291.15 | | |
| 7 | 80 | 35 | Key cut | 757.91 | First dig | 754.43 | 2.74 | 46.19 |
| | | | First cut | 1287.67 | Rehandle | 1291.15 | | |
| 8 | 90 | 35 | Key cut | 757.91 | First dig | 929.43 | 2.84 | 40.99 |
| | | | First cut | 1462.67 | Rehandle | 1291.15 | | |
| 9 | 60 | 42 | Key cut | 1049.39 | First dig | 376.92 | 1.96 | 70.09 |
| | | | First cut | 1093.69 | Rehandle | 1766.17 | | |
| 10 | 70 | 42 | Key cut | 1049.39 | First dig | 586.92 | 2.09 | 60.07 |
| | | | First cut | 1303.69 | Rehandle | 1766.17 | | |
| 11 | 80 | 42 | Key cut | 1049.39 | First dig | 796.92 | 2.19 | 52.56 |
| | | | First cut | 1513.69 | Rehandle | 1766.17 | | |
| 12 | 90 | 42 | Key cut | 1049.39 | First dig | 1006.92 | 2.28 | 46.72 |
| | | | First cut | 1723.69 | Rehandle | 1766.17 | | |
| 13 | 60 | 45 | Key cut | 1188.58 | First dig | 354.10 | 1.79 | 73.77 |
| | | | First cut | 1157.32 | Rehandle | 1991.80 | | |
| 14 | 70 | 45 | Key cut | 1188.58 | First dig | 579.10 | 1.91 | 63.23 |
| | | | First cut | 1382.32 | Rehandle | 1991.80 | | |
| 15 | 80 | 45 | Key cut | 1188.58 | First dig | 804.10 | 2.01 | 55.33 |
| | | | First cut | 1607.32 | Rehandle | 1991.80 | | |
| 16 | 90 | 45 | Key cut | 1188.58 | First dig | 1029.10 | 2.09 | 49.18 |
| | | | First cut | 1832.32 | Rehandle | 1991.80 | | |

performance index for the case under study is tabulated in Tables 6 and 7. For the evolution of the performance of operating draglines, two indices, namely, the rate of coal exposure and the percentage re-handle, were computed from the 3-dimensional balancing diagram.

In Table 3, the results in terms of excavation of the cut area, coal exposure, and percentage rehandle are tabulated for horizontal tandem operation, and a typical balancing diagram is shown in Fig.9.

In Table 4, the results in terms of excavation of the cut area, coal exposure, and percentage rehandle with proper bench divisions are tabulated for vertical tandem mode-I operation, and a typical balancing diagram is shown in Fig.10. With respect to Fig.6, first dig area and second dig area are jointly considered as first dig area in Tables 4, 5 and in 3-dimensional diagram for vertical modes-II,III for ease of understanding and calculation.

In Table 5, the results in terms of excavation of the cut area, coal exposure, and percentage rehandle with proper bench divisions are tabulated for vertical mode-II operation, and a typical balancing diagram is shown in Fig.11.

The rate of coal exposure and percentage of rehandling in all three modes have been appended in Table 6 for clear understanding and summarisation.

Based on the Tables 3 to 5, Table 7 is appended for cut width varying from 60 to 90m in which the rate of coal

Table 4: Vertical tandem mode-1 operation for leading and lagging draglines of same capacity 3.4 Mm³ in various cut width and bench height

| | Cut width (m) | Bench height (m) | Excavation area taken by leading D/L ($m^2$) | Area ($m^2$) | Excavation area taken by lagging D/L ($m^2$) | Area (m2) | Coal exposure (Mte/yr) | % Re-handle | Upper bench | Lower bench |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 60 | 27 | Top cut | 798.25 | First dig | 664.02 | 4.40 | 18.02 | 13.30 | 13.70 |
| | | | Key cut | 157.74 | Rehandle | 291.96 | | | | |
| 2 | 70 | 27 | Top cut | 933.31 | First dig | 799.47 | 4.50 | 15.40 | 13.33 | 13.67 |
| | | | Key cut | 157.22 | Rehandle | 291.06 | | | | |
| 3 | 80 | 27 | Top cut | 1068.37 | First dig | 934.81 | 4.58 | 13.44 | 13.35 | 13.65 |
| | | | Key cut | 156.83 | Rehandle | 290.38 | | | | |
| 4 | 90 | 27 | Top cut | 1203.41 | First dig | 1070.06 | 4.64 | 11.93 | 13.37 | 13.63 |
| | | | Key cut | 156.53 | Rehandle | 289.86 | | | | |
| 5 | 60 | 35 | Top cut | 1026.52 | First dig | 831.70 | 3.32 | 20.79 | 17.11 | 17.89 |
| | | | Key cut | 241.77 | Rehandle | 436.59 | | | | |
| 6 | 70 | 35 | Top cut | 1201.71 | First dig | 1007.80 | 3.41 | 17.73 | 17.77 | 17.83 |
| | | | Key cut | 240.48 | Rehandle | 434.39 | | | | |
| 7 | 80 | 35 | Top cut | 1376.85 | First dig | 1183.61 | 3.47 | 15.46 | 17.21 | 17.79 |
| | | | Key cut | 239.53 | Rehandle | 432.76 | | | | |
| 8 | 90 | 35 | Top cut | 1551.96 | First dig | 1359.24 | 3.53 | 13.70 | 17.24 | 17.76 |
| | | | Key cut | 238.80 | Rehandle | 431.52 | | | | |
| 9 | 60 | 42 | Top cut | 1222.91 | First dig | 966.62 | 2.71 | 23.28 | 20.38 | 21.62 |
| | | | Key cut | 330.47 | Rehandle | 586.76 | | | | |
| 10 | 70 | 42 | Top cut | 1433.29 | First dig | 328.08 | 2.79 | 19.82 | 20.48 | 21.52 |
| | | | Key cut | 328.08 | Rehandle | 1178.63 | | | | |
| 11 | 80 | 42 | Top cut | 1643.57 | First dig | 1390.11 | 2.85 | 17.26 | 20.54 | 21.46 |
| | | | Key cut | 326.32 | Rehandle | 579.78 | | | | |
| 12 | 90 | 42 | Top cut | 1853.78 | First dig | 1601.24 | 2.90 | 15.28 | 20.60 | 21.40 |
| | | | Key cut | 324.98 | Rehandle | 577.51 | | | | |
| 13 | 60 | 45 | Top cut | 1306.09 | First dig | 1020.93 | 2.51 | 24.38 | 21.77 | 23.23 |
| | | | Key cut | 372.98 | Rehandle | 658.13 | | | | |
| 14 | 70 | 45 | Top cut | 1531.58 | First dig | 1248.46 | 2.58 | 20.73 | 21.88 | 23.12 |
| | | | Key cut | 369.96 | Rehandle | 653.07 | | | | |
| 15 | 80 | 45 | Top cut | 1756.94 | First dig | 1475.31 | 2.64 | 18.04 | 21.96 | 23.04 |
| | | | Key cut | 367.75 | Rehandle | 649.36 | | | | |
| 16 | 90 | 45 | Top cut | 1982.21 | First dig | 1701.73 | 2.69 | 15.96 | 22.02 | 22.98 |
| | | | Key cut | 366.06 | Rehandle | 646.53 | | | | |

exposure with the percentage of rehandling and bench height division for horizontal and vertical tandem modes as a comparative performance index.

### 6.0 Results and discussions

1. It is evident from Table 3 that the key cut area and re-handle area are constant for the same bench height from cut width of 60m to 90m in horizontal tandem operation. It is due to bench geometry such as highwall angle, bench slope angle, angle of repose for loose, berm clearance on rehandle area, the bottom of key cut geometry considered as constant in balancing diagram. At the same time, the variation was observed in the first cut and final dig to maintain the workload on each dragline.
2. It is also observed from Table 4 that a marginal variation occurred in the key cut area and re-handle area in vertical tandem mode-I due to proper bench division considered in balancing diagram and varies according to variation of the height of lower bench marginal for the same bench height. At the same time, a significant variation was observed in the top cut and first dig to maintain the workload on each dragline. Moreover, movement of leading dragline from the upper bench after excavating top cut to the lower bench to excavate key cut and vice versa in mode-I operation is uneconomical due to continuous engagement of dozers in both benches for levelling work and preparation of sitting pad of leading dragline.

Table 5 Vertical tandem mode-2 operation for leading and lagging dragline of same capacity 3.4 $Mm^3$ in various cut width and bench height

| | Cut width (m) | Bench height (m) | Excavation area taken by leading D/L ($m^2$) | Area ($m^2$) | Excavation area taken by lagging D/L ($m^2$) | Area ($m^2$) | Coal exposure (Mte/yr) | % Re-handle | Upper bench (m) | Lower bench (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 60 | 27 | Top cut | 924.57 | Key cut | 121.88 | | | | |
| | | | | | First dig | 573.55 | | | | |
| | | | | | Rehandle | 229.14 | 4.55 | 14.14 | 15.41 | 11.59 |
| 2 | 70 | 27 | Top cut | 1062.80 | Key cut | 125.53 | | | | |
| | | | | | First dig | 701.66 | | | | |
| | | | | | Rehandle | 235.59 | 4.62 | 12.47 | 15.18 | 11.82 |
| 3 | 80 | 27 | Top cut | 1200.36 | Key cut | 128.45 | | | | |
| | | | | | First dig | 831.19 | | | | |
| | | | | | Rehandle | 240.72 | 4.68 | 11.14 | 15.00 | 12.00 |
| 4 | 90 | 27 | Top cut | 1337.45 | Key cut | 130.82 | | | | |
| | | | | | First dig | 961.73 | | | | |
| | | | | | Rehandle | 244.89 | 4.72 | 10.08 | 14.86 | 12.14 |
| 5 | 60 | 35 | Top cut | 1213.38 | Key cut | 177.79 | | | | |
| | | | | | First dig | 708.83 | | | | |
| | | | | | Rehandle | 326.76 | 3.47 | 15.56 | 20.22 | 14.78 |
| 6 | 70 | 35 | Top cut | 1393.61 | Key cut | 183.83 | | | | |
| | | | | | First dig | 872.56 | | | | |
| | | | | | Rehandle | 337.19 | 3.53 | 13.76 | 19.91 | 15.09 |
| 7 | 80 | 35 | Top cut | 1572.79 | Key cut | 188.68 | | | | |
| | | | | | First dig | 1038.54 | | | | |
| | | | | | Rehandle | 345.56 | 3.57 | 12.34 | 19.66 | 15.34 |
| 8 | 90 | 35 | Top cut | 1751.22 | Key cut | 192.65 | | | | |
| | | | | | First dig | 1206.13 | | | | |
| | | | | | Rehandle | 352.42 | 3.61 | 11.19 | 19.46 | 15.54 |
| 9 | 60 | 42 | Top cut | 1470.77 | Key cut | 232.95 | | | | |
| | | | | | First dig | 816.28 | | | | |
| | | | | | Rehandle | 421.53 | 2.86 | 16.73 | 24.51 | 17.49 |
| 10 | 70 | 42 | Top cut | 1688.15 | Key cut | 241.60 | | | | |
| | | | | | First dig | 1010.25 | | | | |
| | | | | | Rehandle | 436.30 | 2.91 | 14.84 | 24.12 | 17.88 |
| 11 | 80 | 42 | Top cut | 1904.11 | Key cut | 248.59 | | | | |
| | | | | | First dig | 1207.30 | | | | |
| | | | | | Rehandle | 448.20 | 2.95 | 13.34 | 23.80 | 18.20 |
| 12 | 90 | 42 | Top cut | 2119.01 | Key cut | 254.35 | | | | |
| | | | | | First dig | 1406.64 | | | | |
| | | | | | Rehandle | 458.01 | 2.98 | 12.12 | 23.54 | 18.46 |
| 13 | 60 | 45 | Top cut | 1582.33 | Key cut | 258.26 | | | | |
| | | | | | First dig | 859.42 | | | | |
| | | | | | Rehandle | 464.65 | 2.66 | 17.21 | 26.37 | 18.63 |
| 14 | 70 | 45 | Top cut | 1815.76 | Key cut | 268.18 | | | | |
| | | | | | First dig | 1066.06 | | | | |
| | | | | | Rehandle | 481.51 | 2.71 | 15.29 | 25.94 | 19.06 |
| 15 | 80 | 45 | Top cut | 2047.57 | Key cut | 276.21 | | | | |
| | | | | | First dig | 1276.21 | | | | |
| | | | | | Rehandle | 495.13 | 2.74 | 13.75 | 25.59 | 19.41 |
| 16 | 90 | 45 | Top cut | 2278.19 | Key cut | 282.86 | | | | |
| | | | | | First dig | 1488.95 | | | | |
| | | | | | Rehandle | 506.39 | 2.77 | 12.50 | 25.31 | 19.69 |

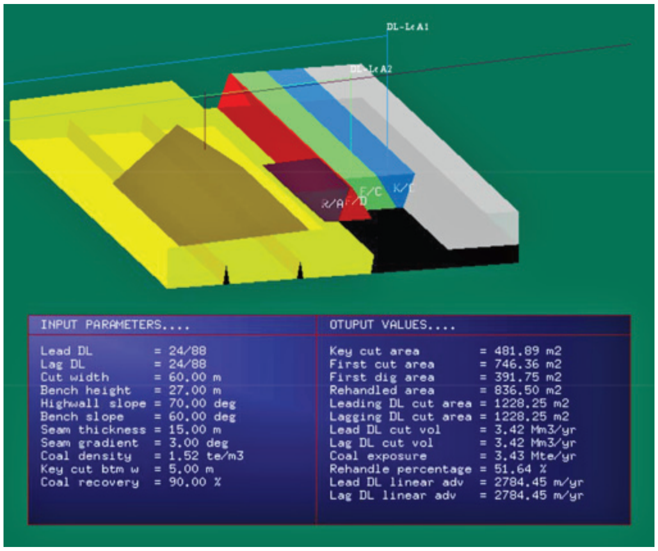


Fig.9: A typical 3-dimensional balancing diagram of horizontal tandem

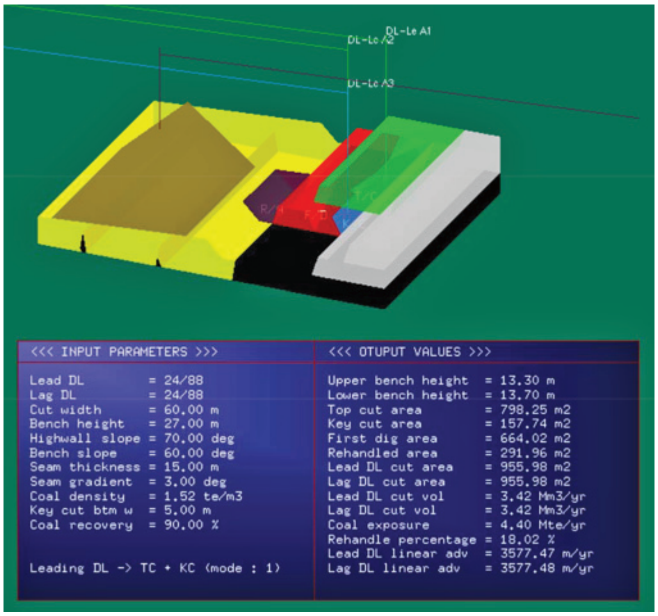


Fig.10: A typical 3-dimensional balancing diagram of vertical tandem mode-I

3. It is obvious from Table 5; an adequate variation occurred in key cut and re-handle area in vertical tandem mode-II due to proportionate bench division considered in balancing diagram and varies according to lower bench height variation. Again, a significant variation was observed in the top cut and first dig to maintain the workload on each dragline. The rate of coal exposure in mode-II operation increases considerably due to leading dragline working in upper bench only, excavating more area in top cut than mode-I operation, hence increase in upper bench height and decrease in lower bench height.
4. From Table 6, it is revealed that the rate of coal exposure increases by varying cut width in all three modes of tandem operations by keeping all other parameters constant. For cut width 60m, coal exposure in horizontal tandem is 3.43 Mte/year; in vertical tandem mode-I, it is 4.40 Mte/year, and in vertical madam tandem mode-II, it is 4.55 Mte/year whereas overburden bench height is 27 m, and coal seam thickness is 15m. The rate of coal exposure is 3.87,4.64, and 4.72 Mte/year for cut width of 90 m having same bench height of 27m and coal seam thickness is 15m respectively.

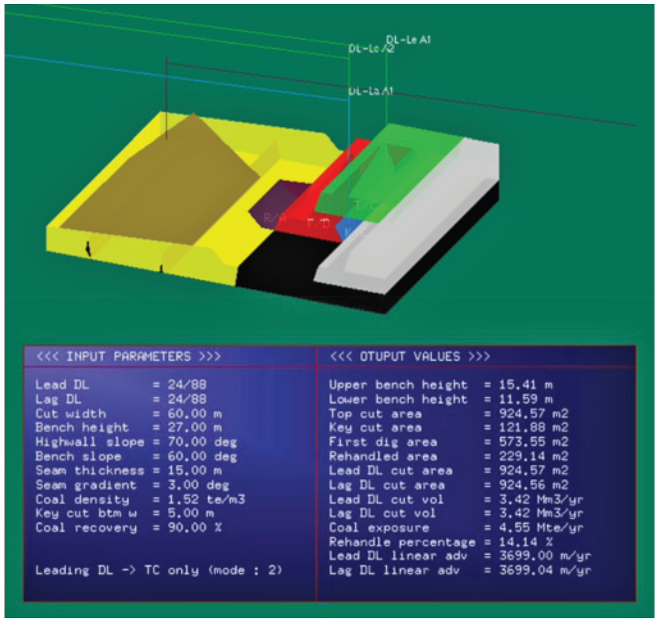


Fig.11: A typical 3-dimensional balancing diagram of vertical tandem mode-II

5. From Table 6, it is also revealed that when bench height increases from 27m to 45m, the rate of coal exposure decreases from 3.43 to 1.79 Mte/year for cut width of 60 m and seam thickness of 15 m, along with the percentage of re-handle increases from 51.64 to 73.77 in horizontal tandem. Whereas the rate of coal exposure also decreases from 4.40 to 2.51 Mte/year along with the percentage of rehandle increases from 18.02 to 24.38 in vertical tandem mode-I and rate of coal exposure 4.55 to 2.66 Mte/year along with the percentage of re-handle increases from 14.14 to 17.21 in vertical tandem mode II.
6. Based on Table 7, a comparative performance index indicated that vertical tandem mode-II operation is the preferable mode as it gives the highest rate of coal exposure as well as the lowest percentage of re-handle by increasing cut width by keeping bench height and coal seam thickness constant, respectively. Area re-handle decreased in vertical tandem mode-II operation due to reduction in lower bench height, as the upper bench height increased in this mode of operation, i.e., upper bench and lower bench is constant.

TABLE 6: RATE OF COAL EXPOSURE AND RE-HANDLE PERCENTAGE IN VARIOUS MODE OF TANDEM OPERATION

| Leading DL | Lagging DL | Cut width (m) | Bench height(m) | Seam thickness(m) | Coal exposurein horizontal tandem (Mte/Yr) | % re-handle in horizontal tandem | Coal exposure in vertical tandem mode-I (Mte/Yr) | % Re-handle in vertical tandem mode-I | Coal exposure in vertical tandem mode-II (Mte/Yr) | % Re-handle in vertical tandem mode-II |
|---|---|---|---|---|---|---|---|---|---|---|
| 24/88 | 24/88 | 60 | 27 | 15 | 3.43 | 51.64 | 4.40 | 18.02 | 4.55 | 14.14 |
| 24/88 | 24/88 | 70 | 27 | 15 | 3.62 | 44.26 | 4.50 | 15.40 | 4.62 | 12.47 |
| 24/88 | 24/88 | 80 | 27 | 15 | 3.75 | 38.73 | 4.58 | 13.44 | 4.68 | 11.14 |
| 24/88 | 24/88 | 90 | 27 | 15 | 3.87 | 34.42 | 4.64 | 11.93 | 4.72 | 10.08 |
| 24/88 | 24/88 | 60 | 35 | 15 | 2.48 | 61.48 | 3.32 | 20.79 | 3.47 | 15.56 |
| 24/88 | 24/88 | 70 | 35 | 15 | 2.63 | 52.70 | 3.41 | 17.33 | 3.53 | 13.76 |
| 24/88 | 24/88 | 80 | 35 | 15 | 2.74 | 46.19 | 3.47 | 15.46 | 3.57 | 12.34 |
| 24/88 | 24/88 | 90 | 35 | 15 | 2.84 | 40.99 | 3.53 | 13.70 | 3.61 | 11.19 |
| 24/88 | 24/88 | 60 | 42 | 15 | 1.96 | 70.09 | 2.71 | 23.28 | 2.86 | 16.73 |
| 24/88 | 24/88 | 70 | 42 | 15 | 2.09 | 60.07 | 2.79 | 19.82 | 2.91 | 14.84 |
| 24/88 | 24/88 | 80 | 42 | 15 | 2.19 | 52.56 | 2.85 | 17.26 | 2.95 | 13.34 |
| 24/88 | 24/88 | 90 | 42 | 15 | 2.28 | 46.72 | 2.90 | 15.28 | 2.98 | 12.12 |
| 24/88 | 24/88 | 60 | 45 | 15 | 1.79 | 73.77 | 2.51 | 24.38 | 2.66 | 17.21 |
| 24/88 | 24/88 | 70 | 45 | 15 | 1.91 | 63.23 | 2.58 | 20.73 | 2.71 | 15.29 |
| 24/88 | 24/88 | 80 | 45 | 15 | 2.01 | 55.33 | 2.64 | 18.04 | 2.74 | 13.75 |
| 24/88 | 24/88 | 90 | 45 | 15 | 2.09 | 49.18 | 2.69 | 15.96 | 2.77 | 12.50 |

TABLE 7: COMPARATIVE PERFORMANCE INDICES FOR ALL MODES OF OPERATION UNDER CASE STUDY (H.T., V.T. M-1, V.T. M-2 STANDS FOR HORIZONTAL TANDEM, VERTICAL TANDEM MODE-I AND VERTICAL TANDEM MODE II, RESPECTIVELY)

| Cases | Cut width in m | Coal exposure (Mte/Yr) | % Re-handle | Bench height (upper + lower) in m |
|---|---|---|---|---|
| H.T. | 60 | 3.43 | 51.64 | 27 |
| V.T. M-1 | 60 | 4.40 | 18.02 | 13.30 + 13.70 =27 |
| V.T. M-2 | 60 | 4.55 | 14.14 | 15.41+ 11.59 =27 |
| H.T. | 70 | 3.62 | 44.26 | 27 |
| V.T. M-1 | 70 | 4.50 | 15.40 | 13.33 + 13.67 =27 |
| V.T. M-2 | 70 | 4.62 | 12.47 | 15.18+11.82 |
| H.T. | 80 | 3.75 | 38.73 | 27 |
| V.T. M-1 | 80 | 4.58 | 13.44 | 13.35 +13.65=27 |
| V.T.M-2 | 80 | 4.68 | 11.14 | 15.0 +12.0 =27 |
| H.T. | 90 | 3.87 | 34.42 | 27 |
| V.T. M-1 | 90 | 4.64 | 11.93 | 13.37+13.63=27 |
| V.T. M-2 | 90 | 4.72 | 10.08 | 14.86 +12.14=27 |
| H.T. | 60 | 2.48 | 61.48 | 35 |
| V.T. M-1 | 60 | 3.32 | 20.79 | 17.11 +17.89=35 |
| V.T. M-2 | 60 | 3.47 | 15.56 | 20.22 +14.78=35 |
| H.T. | 70 | 2.63 | 52.70 | 35 |
| V.T. M-1 | 70 | 3.41 | 17.73 | 17.17+17.83=35 |
| V.T. M-2 | 70 | 3.53 | 13.76 | 19.91+15.09=35 |
| H.T. | 80 | 2.74 | 46.19 | 35 |
| V.T. M-1 | 80 | 3.47 | 15.46 | 17.21+17.79=35 |
| V.T. M-2 | 80 | 3.57 | 12.34 | 19.66+15.09=35 |
| H.T. | 90 | 2.84 | 40.99 | 35 |
| V.T. M-1 | 90 | 3.53 | 13.70 | 17.24+17.76=35 |
| V.T. M-2 | 90 | 3.61 | 11.19 | 19.46+15.54=35 |

*Contd...*

| Cases | Cut width in m | Coal exposure (Mte/Yr) | % Re-handle | Bench height (upper + lower) in m |
|---|---|---|---|---|
| H.T. | 60 | 1.96 | 70.09 | 42 |
| V.T. M-1 | 60 | 2.71 | 23.28 | 20.38+21.62=42 |
| V.T. M-2 | 60 | 2.86 | 16.73 | 24.51+17.49=42 |
| H.T. | 70 | 2.09 | 60.07 | 42 |
| V.T. M-1 | 70 | 2.79 | 19.82 | 20.48+21.52=42 |
| V.T. M-2 | 70 | 2.91 | 14.84 | 24.12+17.88=42 |
| H.T. | 80 | 2.19 | 52.56 | 42 |
| V.T. M-1 | 80 | 2.85 | 17.26 | 20.54+21.46=42 |
| V.T. M-2 | 80 | 2.95 | 13.34 | 23.80+18.20=42 |
| H.T. | 90 | 2.28 | 46.72 | 42 |
| V.T. M-1 | 90 | 2.90 | 15.28 | 20.60+21.40=42 |
| V.T. M-2 | 90 | 2.98 | 12.12 | 23.54+18.46=42 |
| H.T. | 60 | 1.79 | 73.77 | 45 |
| V.T. M-1 | 60 | 2.51 | 24.38 | 21.77+23.23=45 |
| V.T. M-2 | 60 | 2.66 | 17.21 | 26.37+18.63=45 |
| H.T. | 70 | 1.91 | 63.23 | 45 |
| V.T. M-1 | 70 | 2.58 | 20.73 | 21.88+23.12=45 |
| V.T. M-2 | 70 | 2.71 | 15.29 | 25.94+19.06=45 |
| H.T. | 80 | 2.01 | 55.33 | 45 |
| V.T. M-1 | 80 | 2.64 | 18.04 | 21.96+23.04=45 |
| V.T. M-2 | 80 | 2.74 | 13.75 | 25.59+19.41=45 |
| H.T. | 90 | 2.09 | 49.18 | 45 |
| V.T. M-1 | 90 | 2.69 | 15.96 | 22.02+22.98=45 |
| V.T. M-2 | 90 | 2.77 | 12.50 | 25.31+19.96=45 |

## 7.0 Conclusions

Following main conclusions have been drawn from the present field-based study:

1. Vertical tandem mode-II operation is the most preferable method of tandem dragline operation as it gives the highest rate of coal exposure with the least percentage rehandle. It is beneficial for higher overburden bench height where the digging depth exceeds the digging ability of draglines.
2. Vertical tandem mode-II operation is the cumbersome method of tandem dragline operation due to frequent movement of the leading dragline in the upper bench to excavate top cut as well as the lower bench to excavate key cut. The levelling work for both benches and preparation of sitting pad for leading dragline is cyclic in nature, and it is uneconomical due to continuous engagement of machinery and monitoring during such work.
3. Whereas the horizontal tandem operation is the preferable mode of operation due to its ease of applicability and monitoring in the same bench though it has the lowest rate of coal exposure with a maximum percentage of rehandling. This mode of operation is desirable for wider cut width where coal rib must be left to minimize the coal losses.
4. Graphics-based 3-dimensional balancing diagram generated precise results in terms of area of cuts, coal exposure, and percentage rehandle, which helps the planner to achieve the targeted rate of coal exposure.

## References


1. Baafi, E.Y.; Mirabediny, H. and Whitchurch, K. (1997): Computer simulation of complex dragline operations, *International Journal of Surface Mining, Reclamation, and Environment*, Vol.11, No.1 p.7-13.
2. Chaoji, S.V., and Dey, B.C. (2000): Dragline operation in mines - an overview, *Journal of Mines, Metals & Fuels*, Vol. XLVIII, No.5, p.84-93.
3. Chironis, N.P. (1986): Smaller, Versatile Dragline Operating in Tandem, Reach Deep Seams Efficiently, Coal Age, December, p.48-51.
4. Chugh, Y.P. (1980): Surface mining of minerals by dragline in the U.S.A., *Trans. Instn Min. Metall. Sec.* A, Vol. 89, October, p. A198-A204.
5. Erdem, B. and Celebi, N. (1999): A method to synchronize the tandem dragline systems, CIM Bulletin, Vol.92, No.1029, p.55-61.
6. Fishler, S.V. (1987): Selection of the most cost-effective dragline system, *International Journal of Surface Mining,* Vol.1, p.91-95.


*(Continued on page 135)*