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ANALYSIS EFFECTS OF OPERATING VARIABLES AND REGRESSION ANALYSIS OF OUTPUT VARIABLES IN A SDL BASED MINING OPERATING SYSTEM IN INDIA MINES

ROZBOR VLIVŮ PROVOZNÍCH PROMĚNNÝCH A REGRESNÍ ANALÝZA VÝSTUPNÍCH PROMĚNNÝCH V SYSTÉMU HLUBINNÉHO DOBYVÁNÍ VYBAVENÝCH ZAŘÍZENÍM SDL POUŽÍVANÝCH V INDICKÝCH DOLECH

Abstract

V Indické republice je asi 90 % uhlí těženo hlubiným způsobem a to metodou pilířování. Z toho je 60 % dobýváno pomocí důlní mechanizace. Hlavní mechanizací v hlubiných dolech a to především 78 % tvoří dobývání pomocí nakládačů s bočním vyklápěním. (SDL) Hlbinné dobývání je zde závislé na poloze uhelných slojí a jejich poruchách, které se během dobývání poměrně často mění. Jak těžba tak i doprava těženého uhlí je ovlivněna celou řadou proměnných, které se mění stochasticky a nelze je popsat žádnou standardní statistickou metodou. Způsob výpočtu se nachází při použití analýzy stochastického řešení, které je dosti složité na to, aby byl celý cyklus popsán pomocí matematických vzorců. Pro řešení dané problematiky se nám nabízí metoda počítačové simulace. V tomto příspěvku byla použita pro stanovení vzájemných vztahů regresní analýza. Příslušné sledování vlivů odchylky variace několika vstupních proměnných na výkon dobývání a hodnot tří výstupních proměnných, kterými jsou průměrná produkce na směnu s SDL, porubný výkon na hlavu a směnu (OMS) a procentově využití SDL (indikátory produktivity práce a stroje) jsme došli k dále uvedeným výsledkům.

Abstract

In India about 90% of underground coal is produced by bord & pillar mining method and 60% of total underground coal production comes from mechanized mining operation. 78% of total mechanized coal production is from SDL based system only. Underground mining operations and the resources deployed therein are subjected to random failures and have to face various types of operational irregularities at different points of time during working. Both coal winning and handling operations are influenced considerably by a number of random variables, the trend of variation of which does not generally follow any standard statistical distribution. This finds a widespread application in the analysis of stochastic system that is complex enough to be represented by the mathematical formulae. Therefore, it is the problem domains that can be conveniently and appropriately solved by computer simulation. In this paper the effect of variation of some input variables on the system performance as well as the values of three output variables such as average shift production per SDL, output per manshift (OMS) and percentage utilization of SDL (labour and machine productivity indices) have been used to establish their inter-relationships through regression analysis.

Introduction

In bord and pillar mining in India application of SDLs for the purpose of loading, tramming, and dumping of material on chain or belt conveyor has gained much popularity. Johnson [(1992)] analyzed that introduction of semi-mechanized bord and pillar system using SDL is well advanced and proving moderately successful while longwall one has not attained the expected level of productivity required to justify the huge capital investment. Present total number of SDL machine in India is about 950 as revealed by the census report. The percentage of mechanized coal production by SDL -

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based mine operating system is about 78%. The number of mines where this SDL-based mine operating system has been already adopted is around 152 (48.25%) out of total 315 underground coal mines. There will be about 35% increase in the of SDL by the end of X^{th} five year plan. The capital blocked through investment that has already been made towards purchasing this large fleet of machines is in the tune of more than 3780 millions of rupees. It is obvious that even a marginal increase in the utilization of this large population of SDL machines will result in substantial economic benefit to the both to mines and the whole India. To augment the production and productivity, face loading was identified as one of the most important factors. Kurnar (1995), suggested that due attention has to be given for improvement in the transport layout of the districts so that higher level of productivity can be achieved. Bhandari and Muralidhar (1995), acknowledged that though SDL has proved its worth as a loading machine in bord and pillar method of working, there is scope for further improvement by enhancing the availability of SDL and its productivity by the application of a timely and economically viable maintenance schedule. Investigation into the factors, influencing the performance of coal preparation and handling system, could help in arriving at rationalized system design. Appropriate selection of equipment and other resource deployment pattern would help in achieving the reliably planned system output. Rao and Subramanyam (1990) proposed that the reliability of the machine depend on the maintenance schedule of it. This is the main reason for which the machine is experiencing increasing failure rate (IFR). In the district itself the layout of the working faces vis-a-vis SDL deployment is has a great influence on system productivity as the availability and the utilization of the underground transport system depends on the effective working time. As a matter of fact the performance of SDL's in Indian mines are far from expectation due to poor availability of the machines. In this paper a comprehensive simulated study on the effect of variation of sensitive input variables on the system performance (sensitivity analysis) has been done on the Indian mining context to establish relationships amongst a few performance indices through regression analysis.

**Factors Influencing the System Production & Productivity**

On SDL-based system study some sensitive factors are identified which have substantial influence on the overall production and productivity.

- Pillar dimension
- Number of headings in the district
- Face dimensions
- Gradient
- Transport equipment lay-out and its periodical shifting
- Equipment fleet and deployment pattern
- Operational interference
- Available shift hours
- Machine speed
- Lead distance
- Some other important factors are work culture, operating skills/training of the operators, standard of maintenance - back up, telecommunications, discipline and supervision.

Out of these sensitive factors: pillar size, face dimension and district size (i.e. number of headings in the working district) have significant influence on the system productivity. Therefore, the effect of variation of pillar sizes, face dimensions and district sizes (lay-out 1 to 3) on the system performance have been critically observed and discussed in this paper.
A Study on the Influences of Operating Variables on System Productivity – Sensitivity Analysis

A number of operating variables having direkt have been indentifid / indirect impact on the system productivity. A series of experiments have been conducted to know the effects of change of operating variables like number of headings, pillar dimensions and face dimensions on the overall system performance through the simulated study for a period of 120 shifts. Out of a lot of variables there are some which are independent, some of them are dependent but few variables are interdependent. Relationships between variables are thus important to understand their influence on mine production system. The different notations, patterns, arrays that have been used in these experiments are shown below:

- **Notations used in the model for experiment**
  6(1) - stands for 6 of headings for pattern 1.
  5(3) - stands for 5 of headings for pattern 3.
  5(1) - stands for 5 of headings for pattern 1.
  4(1) - stands for 4 of headings for pattern 1.
  4(2) - stands for 4 of headings for pattern 2.

  This is an input variable.

- **SDL deployment pattern (shown in the layouts)**

  **Pattern 1** - One SDL is supposed to handle a pair of headings located side by side and this is applicable for 6, 4, 3 heading respectively. In a 5-heading district the third SDL is allotted to one heading only. In a 3-heading district, one SDL is available for a pair of successive headings while the second SDL is allotted to one heading only.

  **Pattern 2** - Two SDLs are supposed to cater to three consecutive headings with one heading common for both SDLs. This pattern is applicable for 2, 3, 4-heading district. In a 4 heading district, the third SDL is allotted to one heading only.

  **Pattern 3** - This is applicable for 5 headings only, where two SDLs are to lift coal from three consecutive headings and the third SDL is deployed for other two headings.

- **Deployment of set of equipment and operating crew**

  The set of equipment only includes the face machine like SDL, drill, CCM and the operating crew involving manpower for blasting, dressing & supporting gang.

  30333 'combination array' indicates:

  - number of drill machines: 3
  - number of coal cutting machines: 0
  - number of dressing supporting gang groups: 3
  - number of blasting gang groups: 3
  - number of SDL machines: 3

  This is an input variable.

**Effect of Variation of Number of Headings on System Productivity**

A series of experiments have been conducted through simulation model (SIMSDL) to analyze the effect of change of number of headings on the overall system productivity. On examining the results it has been found that average shift production and machine utilization varies substantially with the change in number of headings in the district. Machine deployment pattern is a variable, which is dependent on number of headings in the district, where the number of headings and pillar dimensions
are independent variables. It has also been observed that 5 headings with SDL deployment pattern 3 i.e. 5(3) is the best choice for the given set of inputs because of the following reasons:

(a) The average shift production is maximum for 5(3), as three consecutive headings are getting the benefit of service of two SDLs simultaneously enabling quicker rate of extraction and thereby ensuring maximum utilization offaces by SDLs, as evident from Figure 1.1. For a the same reason the change in pattern of machine deployment from (1) to (3) for a five-heading district improves the average shift production about 10%. These findings also appear to be true for a district having 4 headings if the machine deployment pattern is changed from (1) to (2). It is further interesting to note that a 5-heading district may produce better result than a 6-heading district if the machine deployment pattern is changed from (1) to (3)

(b) The percentage utilization of SDL machines is maximum in this case as evident from Figure 1.2, and thereby the overall productivity is also more than that of other headings (patterns). It has been observed from these figures that the percentage utilization of face equipment has increased to an extent of about 10% due to change in number of headings and machine deployment pattern from 5(1) to 5(3)

Effect of Variation of Pillar Sizes on System Productivity
A series of experiments have been conducted through simulation model to identify the effect of variation of pillar sizes on system productivity. Face dimension is a variable dependent on pillar dimension where pillar dimension is an independent variable. Figure 1.3 represents curves to highlight variations of shift production with change in pillar size for a given set of inputs which reveals the following information:

(i) The difference in production from 20 m x 20 m and 25 m x 25 m 30 m pillar size gives significantly lesser production per shift.

(ii) Though 25 m x 25 m pillar size gives the highest average shift production for entire ra pillar sizes is insignificant.

The above observations may be justified by the following reasons:

(a) In case of 30m pillar size, the lead distance has significant impact on the cycle time of SDL. Considerable time is lost to lift one round of blasted coal due to increased lead distance, whereas on the other hand, the shiftings of conveyors are not so frequent compared to that of 20 m x 20 m and 25 m x 25 m pillar sizes. Loss of time for shifting of conveyors is only 8 hours, which is required after 30m progress of the faces and headings, whereas loss of time for increased lead distance affects every trip of each SDL. The cumulative losses of time for this increased lead distance are much heavier than that of shifting of conveyors. Therefore, this significantly lowers the SDL productivity, percentage utilization of SDLs and drills.

(b) A verage shift production for 20 m x 20 m. and 25 m x 25 m pillar sizes are almost identical because the lead distance for 25m x 25m pillar is more than that of 20 m x 20 m. pillar size but frequency of shifting conveyors (as coal is transported from the face to surface by scraper chain conveyors and belt conveyors) is less than that of 20m x 20 m pillar size. The resultant effect of both these factors together gives rise to almost the same production.

Percentage utilization of SDLs are maximum for 25 m x 25 m pillar size (Figure 1.4). Therefore, 25 m x 25 m pillar size appears to be the best option for the given set of inputs.

Effect of Variation of Face Dimensions on System Productivity
Face dimension is a critical parameter in SDL performance. A series of experiments have been conducted to know the effect of variation of face dimensions for a given set of inputs on the overall system productivity. Though the number of mines with SDL having face dimensions 6 sq.m to 7.5 sq.m is negligible they have been included in the simulated study so as to observe the effect of lower face dimension on the system performance. In the earlier experiments it was found that 25 m x 25 m pillar size and 5 heading district with SDL deployment pattern 3 i.e. 5(3), have given the best results for the definite set of inputs. Therefore, a few experiments are conducted here for 25 m x 25 m pillar size and 5 headings with deployment pattern 3. While assessing the impact of face dimension on average
shift production, the SDL numbers were changed in number of headings (30332 combination) and identical nature in variation was observed. In these experiments the total average loss of time (as percentage loss of time) have been calculated based on 120 shifts simulation results separately for SDL and drill machines and for different face dimensions.

In this study the maximum width and height of faces have been assumed to be 4.8 m and 3 m respectively. The face width varies from 3 m to 4.8 m and height varies from 2 m to 3 m.

In these experiments the face width, height along with the cross section (within the brackets) of faces that have been considered are shown below.

<table>
<thead>
<tr>
<th>Face width (m)</th>
<th>Face Height (m)</th>
<th>Cross-section (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>2,5</td>
<td>7,5</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
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<td>2</td>
<td>7,2</td>
</tr>
<tr>
<td>3,6</td>
<td>2,5</td>
<td>9</td>
</tr>
<tr>
<td>3,6</td>
<td>3</td>
<td>10,8</td>
</tr>
<tr>
<td>4,2</td>
<td>2</td>
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<tr>
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<td>2</td>
<td>9,6</td>
</tr>
<tr>
<td>4,8</td>
<td>2,5</td>
<td>12,6</td>
</tr>
<tr>
<td>4,8</td>
<td>3</td>
<td>14,4</td>
</tr>
</tbody>
</table>

a) Figures 1.5 and 1.6 indicate the following facts

I. For any district size and pillar sizes, 12.6 sq.m. face dimension shows the best average shift production.

II. The Average shift production increases with increase in face dimensions till 12.6 sq.m area, beyond which production starts dropping.

III. The 10.8 sq.m face dimension gives higher production in comparison with 14.4 sq.m face dimension.

IV. The 14.4 sq.m face dimension though produce adequate quantity of coal but comparative time loss for drilling as well as for dressing and supporting the faces diminishes that benefit. Therefore 12.6 sq.m is the optimum face dimension in all aspects because it gives the highest production as well as the least percentage loss of time for SDL.

The above results are caused due to the fact that inadequate quantity of coal is produced per round of blasting for SDL's in faces having smaller x-section, necessitating repetitive blasting to achieve the required productivity. but in turn it increases the loss of operating time for SDLs significantly.

b) Figure 1.7 shows the functional relationship between % utilisation of SDL (considered as y-axis) and face dimension (considered as x-axis). The figure also indicates that percentage utilization of SDL machine gives better results for 12.6 sq.m face dimension. Minimum loss of time is the main cause for these improved results. This rlay be concluded that the face dimension has a significant impact on the system productivity for a SDL based bord & pillar development working.

**Regression Analysis amongst Output Variables**

The values of 3 output variables, average shift production per SDL, output per manshift (OMS) and percentage utilization of SDL (labour and machine productivity indices), have been used to establish their inter-relationships through regression analysis. The relationships of average production per SDL per shift with OMS and percentage utilization of SDL have been graphically represented for districts having 5 & 6 headings.
Mathematical Regression for a district (5 & 6 he hheadings)

i) Relation between average production (t) per SDL per shift & % utilization of SDL

The mathematical relation between average production per SDL per shift and % utilization of SDL is represented in Figure 1.8 where the nature of the graph is found to be linear, which is the best fitting curve and the mathematical equation that can satisfy their relationship has been shown below:

\[ y = a + bx \]

coefficient values are: 
\[ a = 0.10409 \quad b = 2.5719 \]
standard error : 2.154

The relationship between average production per SDL per shift and % utilization of SDL shows that they are directly proportional. The % utilization of SDL predominantly varies from 23.5% to 26.2% for production variation from 60 -70 ton per shift per SDL. Percentage utilization depends on actual working time of a SDL. This machine utilization percentage increases when machine completes more number of cycles in a shift and as a result machine production increases. There are a few parameters that directly influences the % utilization of SDL such as machine downtime, variation in lead distance, effect offailure of outbye transport system and inadequate availability of coal etc.

ii) Relation between average production (t) per SDL per shift & OMS (t)

The Mathematical relation between average production per SDL per shift and OMS (t) is represented in the figure 1.9 where the nature of the graph is found to be of exponential association which is the best fitting curve and the mathematical equation that can satisfy their relationship has been shown below :

\[ y = a \left( 1 - e^{-bx} \right) \]

coefficient values are :
\[ a = 5.644 \quad b = 0.0215 \]
standard error : 0,135

In this case the output per manshift (OMS) increases with the increase in average machine production per shift upto 67 tons but beyond that the change becomes not so significant. This is because of the fact that within the given set of input (i.e. face dimension, district size, face availability, delay and interferences of other system operation), the increase in operating crew will have less or no significant impact on the increase in average shift production. This shows pooroms and or underused operating crew, which lead to stagnation of OMS. Consequently, the loss of time due to tilting, shifting, extension and maintenance of machines is heavier in this district size. This reduces the available productive hours of shift, which approximately neutralizes the benefit of having more number offaces in the district.

Conclusions:

The simulated study advocates that the production per shift increases with the correct deployment of face equipment with respect to district size. The experimental analysis shows that the shift production, OMS, machine utilization (output variables) improves significantly with the judicious selection of SDL deployment pattern, number of headings in the district, face dimension and number of operating crews provided. The gainful deployment of face equipment and operating crews with respect to district size will not only ensure maximum average shift production but also reduces idle time significantly. The model helps to understand the effect of different delays, wait times, interference time etc. on the overall system performance. Beside machine downtime and recurring delays associated with each sub-system operation, the effect of some hidden parameters such as seasonal
absenteeism of workmen, lack of work culture, delay in attending the machine under breakdown are also significant.

Effect of Variation of Number of Headings on Average Shift Production
(pillar size - 25 m.; face dimension - 12.6 sq. m., combination 30333)

![Bar Chart](image)

**Figure 1.1**

Effect of Variation of Headings on % SDL - Utilisation
(Corresponding to 20, 25, 30 m. pillar size; Combination: 30333)

![Line Graph](image)

**Figure 1.2**

Effect of Variation of Pillar Sizes on Average Shift Production for Different Face Dimensions [Number of headings (SDL deployment pattern) - 5 (3); combination: 30333]

![Line Graph](image)

**Figure 1.3**

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Effect of Variation of Pillar Sizes on % Utilisation of SDL
[Face dimension - 12.6 sq. m.; number of headings (SDL deployment pattern) - 5(3); combination: 30333]

Figure 1.4

Effect of Variation of Face Dimensions on Average Shift Production for Different Number of Headings (25 m. pillar size; combination: 30333)

Figure 1.5

Loss of Time for SDL Due to Change in Face Dimensions

Figure 1.6
Effect of Variation of Face Dimensions on % Utilisation of SDL
[for 25 m. pillar size; number of headings (SDL deployment pattern) -5 (3); combination: 30333]

Figure 1.7
Average Shift Production vs % Utilisation of SDL for Large District (5 or 6 headings)

Figure 1.8
Output per Manshift vs Average Shift Production for Large District (5 or 6 headings)

Figure 1.9
References:


Recenzent: doc. Dr. Ing. Miloš Němček