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PRODUCTIVITY IMPROVEMENT IN UNDERGROUND COAL MINES – A CASE STUDY

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Abstract
Improvement of productivity has become an important goal for today's coal industry in the race to increase price competitiveness. The challenge now lying ahead for the coal industry is to identify areas of waste, meet the market price and maintain a healthy profit. The only way to achieve this is to reduce production costs by improving productivity, efficiency and the effectiveness of the equipment. This paper aims to identify the various factors and problems affecting the productivity of underground coal mines adopting the bord and pillar method of mining and to propose suitable measures for improving them. The various key factors affecting productivity, namely the cycle of operations, manpower deployment, machine efficiency, material handling and management of manpower are discussed. In addition, the problem of side discharge loader (SDL) cable handling resulting in the wastage of precious manpower resources and SDL breakdown have also been identified and resolved in this paper.

Keywords
productivity improvement; lean manufacturing; underground coal mine; bord and pillar mining method; side discharge loader (SDL); lead distance

1. INTRODUCTION

India has emerged as the third largest coal producer in the world after China and USA with a 9% share of the total global coal production. While the coal production from underground mining in countries like China, USA and Australia are about 95, 33 and 20% respectively, India produces only about 15% of coal from underground mines (Prasad 2009). Of the total output of coal from underground mines, more than 90% of coal is obtained by the bord and pillar method, the predominant method of mining followed in India, and the rest is mined by the longwall mining method. The Indian coal mining industry has witnessed a persistent decline in underground coal production over the years with more emphasis on opencast mining. The trend of coal production from mines (both surface as well as underground) of Coal India Ltd. (CIL), the single largest coal producer of India, from 1974–75 to 2011–12 shown in Figure 1 (Source: www.ibkmedia.com) clearly shows the decline of coal production from underground mines. Since the near-surface coal deposits are becoming exhausted at an alarming rate, augmenting production from underground coal mines has now become the priority of the coal industry in view of the increasing coal demand and growing awareness towards sustainable development. The coal mining industry in India aims to reach at a total coal production of 30 percent from the current share of 15 percent from underground mines by 2030 (Prasad 2009). In order to meet the coal demand, a number of actions are being taken by mining companies to increase production from the existing mines and through the introduction of new technologies.

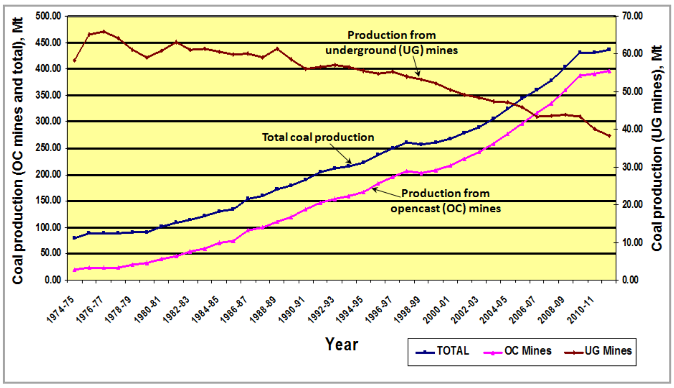

Fig. 1. Trend of coal production in million tonnes (Mt) from CIL mines from 1974–75 to 2011–12

The gloomy scenario of coal production along with the likely exhaustion of shallow depth coal reserves and problems faced regarding surface land acquisition for opencast mining have warranted a quantum jump in coal production and productivity from underground mines in India. Moreover, while opencast mining has seen major advancements, underground mining has remained sluggish for the past five years with an output per manshift (OMS) hovering in the range of 0.70–0.77 tonne. Such a low OMS compared to other countries indicates that the norms of equipment productivity adapted and attained in India are themselves low (Kulshreshtha, Parikh 2001). Technology is a critical and long-run factor which influences the productivity of mines (Topp et al. 2008). While technical progress seems to have been the major driving factor behind productivity growth in opencast mining, efficiency growth has been the most important factor in the growth of underground mine productivity (Kulshreshtha, Parikh, 2002). This suggests that underground mining must make use of technological advancements and utilize innovative mining techniques that suit the country's specific geo-mining conditions.

The measurement of productivity relies on concepts of production theory and may be expressed as the ratio of output(s) to the input(s) used for the related production. More output with minimum input results in an increase in productivity. Therefore, this measure is used as an indicator of the performance of an economic unit as compared to its past performance or compared to other economic units (Hannah 1981). Generally, three major parameters affect the productivity of a mine, viz. cycle of operations, machine efficiency and manpower management. The different mining operations in an underground coal mine include, dewatering, dressing and supporting of face, drilling of blast holes at the coal face, charging, stemming and blasting explosives at face, fume clearance after blasting, loading of coal at the face using loaders and conveying coal to the bunker by conveyor belts etc. Productivity improvement through lean manufacturing approach is recently being adopted by many industries, which is based on the optimization and co-ordination of input resources to minimize the wastes and produce products that meet customer expectations (Womack, Jones 1996). The productivity of a mine can be improved by increasing the level of mechanization, the introduction of state-of-the-art machines and ensuring their optimal utilization as per international standards, proper inventory management, reduction in cost due to accidents through improved health and safety standards, improved work culture and discipline through efficient management.

This paper mainly focuses on improving the efficiency of various operations carried out during the coal extraction process for improving productivity of underground coal mines. Three innovative methods for side discharge loader (SDL) cable handling which will lead to a significant increase in the productivity have also been proposed in this paper.

2. THE CASE STUDY MINE

This study has been carried out in Digwadih Colliery, an underground coal mine belonging to the Jamadoba Section of the Jharia division of M/s Tata Steel Ltd and located in the Dhanbad district of Jharkhand, India. The mine produces washed prime coking coal. The colliery is currently being operated in Seam 9 and Seam 11 employing the bord and pillar method. It should be mentioned here that the bord and pillar mining method comprises two phases, i.e. development and depillaring. In the development phase, a series of narrow headings known as "bords" or "galleries" are driven into the coal seam parallel to each other along the dip direction which are cut across at right angles by another series of headings driven along the strike and thus forms the pillars simultaneously for subsequent extraction during depillaring. Coal extraction in Digwadih Colliery is done by drilling and blasting, and SDL is used as the main work horse for coal production. SDL dumps the coal on the chain conveyors which bring the coal to the main belt conveyor for transportation to the Jamadoba Coal Preparation Plant (JCPP). The schematic layout of a typical bord and pillar mine deployed with SDL and a conveyor system is presented in Figure 2.

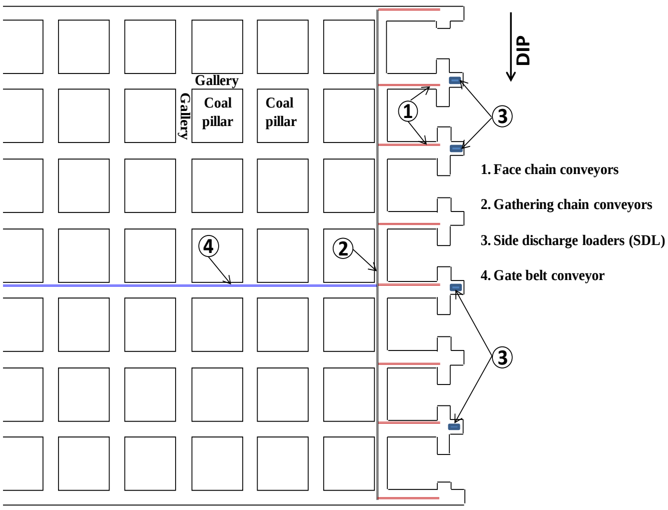

Fig. 2. Schematic layout of a bord and pillar mine development with SDL and conveyor system

3. PROBLEMS AFFECTING PRODUCTIVITY OF THE MINE

In search of a critical problem affecting the productivity of an underground coal mine, the problems identified are listed below:

- More travelling time of the transportation equipment: time needed to be optimized in order to save both time and production cost.
- Poor pull
  - Improper blast round design
    - Inaccurate wedge cut formation
    - Improper direction of holes
    - Improper length of shot holes
    - Improper spacing between the holes
  - Improper charging
    - Inadequate stemming
    - Excessive stemming
    - Improper delay mechanism
    - Improper connection
  - Presence of shale bands or other deformities on the face
- Improper fragmentation
- Breakdown of SDL
- Breakdown of chain conveyor (Skat)
- Breakdown of belt conveyor
- Breakdown of drill machine
- Improper lead distance
- Poor performance of SDL

- Improper ventilation
- Improper maintenance
- Electric faults and power tripping
- Roof problems
- Availability of water

Out of these, the major problems affecting productivity are: poor pull, improper lead distance, machine breakdown and roof bolting time.

Keeping this in mind, a cycle time study of various operations at the coal face was performed during a study at Digwadih Colliery, in order to assess and interpret the issues relevant to productivity. Thereafter, the average time taken for each operation was calculated. The analysis of time study results revealed that the travelling time of SDL, which is directly related with productivity is quite high and as a result impedes the productivity of the mine. The monthly productivity losses in Digwadih Colliery due to different reasons presented in Figure 3 indicate that the highest production loss occurs in SDL, followed by due to bad roof conditions and in belt conveyors.

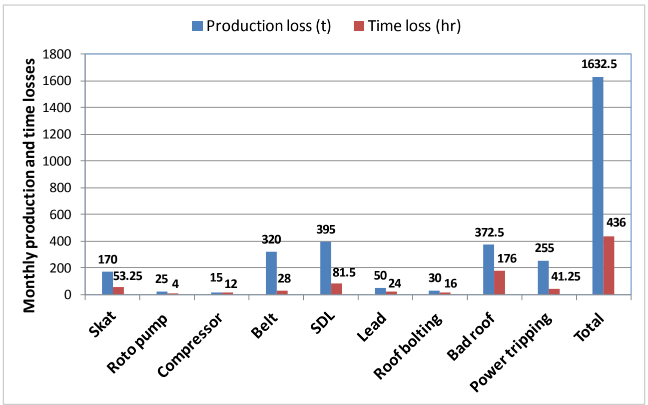

Fig. 3. Bar chart showing the monthly production and time losses in Digwadih Colliery

4. PROBLEM ANALYSIS AND PRODUCTIVITY IMPROVEMENT MEASURES

The various important parameters adversely affecting the productivity of the mine and their improvement measures are discussed in the following sections.

4.1. Pull per blast

Pull per blast plays a major role in the productivity of a mine. It decides the production and loading time of the blasted coal. It is prescribed that the optimum pull per blast should be 1.5 m, but the average pull distance actually achieved in the mine is 1.3 m. This difference in the pull affects the productivity of the mine quite a lot. For instance, in a working face of 4.2 m width and 2.4 m height, the volume of coal blasted for 1.3 m pull is 13.104 m^3 in place of the required volume of 15.12 m^3 for a pull of 1.5 m. It may be mentioned here that a drastic improvement in the productivity of SDL can be achieved by maintaining an optimum pull. In order to get an optimum pull of 1.5 m, the following suggested measures should be adopted:

- Proper training about the blast round design and the method of drilling shot holes.
- Miners should see to it that there are no sockets remaining in the face after blasting. For this, the capping should be well done so that the shock waves penetrate inside and blasting is done effectively and the required pull is achieved.
- Regular inspection by the respective assistant managers or mining engineer of a particular panel on a regular basis, to provide guidance and supervise men working in the panel.
- Proper guidelines should be issued to the mining foreman and overmen to keep a vigil on the various operations going on at the face such as:
  - Proper charging of the holes
  - Adequate stemming of the holes
  - Proper delay between the holes
  - Proper connection of the wires
  - Proper direction of drilling of shot holes
  - Regular inspection of the pattern being followed

4.2. Lead distance

Lead distance, which is nothing but the haul distance of SDL between the working face and chain conveyor (Skat), plays a very important role in deciding the cycle time and hence has a direct impact on the performance and productivity of the SDL. The productivity of SDL can be improved to a large extent by optimizing the lead distance. The best way to improve SDL productivity is to keep the lead distance in the range of 6 to 9 m and at any time it should not exceed 18m during any shift. The importance of lead and its impact on the cycle time of SDL can be easily understood from the simple calculation presented in Table 1.

Table 1. Saving in SDL cycle time due to the reduction of lead distance from 30 to 15 m

Parameters	Time (s)	
	For lead distance of 30 m	For lead distance of 15 m
Movement of empty SDL to the face	50	25
Loading of the bucket	45	45
Movement of loaded SDL to the Skat	60	30
Discharge of single bucket of coal on the Skat	30	30
Total cycle time for one cycle of operation	185	130
Assuming a17 cycles of operation, total time taken for loading of coal	3145	2210
Thus the amount of time saved by decreasing the lead distance from 30 to 15 m = 3145 – 2210 = 935s ≈ 16 min		

This 935 s (≈ 16 min) time saving due to the reduction of lead distance from 30 to 15 m would give rise to the discharging of an additional 935 s ÷ 130 s (cycle time at 15 m lead distance) ≈ 7 buckets of coal by the SDL. In other words, at a lead distance of 15 m there will be an increase of 7 cycles of operation from the original 17 cycles of operation at a lead distance of 30 m, or the productivity of SDL will increase by 41%.

4.3. Roof bolting time

Roof bolting time also affects cycle time. A reduction in roof bolting time will result in a reduction in the cycle time and increased productivity. The impact of reduced roof bolting time on the cycle time and productivity of SDL is presented in Table 2 in the form of a simple calculation. In order to optimize this roof bolting time, the deployment of another roof bolting machine with higher RPM will be needed.

Table 2. Impact of reduced roof bolting time on the cycle time and the productivity of SDL

Parameters	When bolting time for 1 roof bolt is 7 min	When bolting time for 1 roof bolt is 5 min
Bolting time for 8 roof bolts (min)	56	40
SDL cycle time (min)	197.13	189.63
No. of blasts	2.03	2.11
Per SDL production (tpd)	130.3	135.45

4.4. Assessment of breakdown of mining machineries

Machines play an important role in the smooth running of a mine, and each and every machine is important from the production point of view. The proper functioning of various equipment engaged in production should be managed and maintained regularly to achieve better mine productivity. Regular maintenance enhances the efficiency of machines or in other words, helps in minimizing the breakdown and/or increasing the availability of machines (Taylor 1973). The machines used in the mine include SDL, belt conveyor, chain conveyor (Skat), compressor, roof bolting machine, drill machine, etc. The breakdown of any one machine may affect productivity by delaying the cycle of operations as well as affecting the operation of other machines. The main reasons of a machine breakdown are human errors and machine failure. Therefore, to lessen the chances of this occurring, regular scheduled maintenance is necessary so that the chances of breakdown of equipment are minimized. The various measures for minimizing the breakdown of important machines used in the mine are outlined in the following sections.

4.4.1. Measures for minimizing the chances of SDL breakdown

The major problems which can lead to the breakdown of an SDL are outlined as follows:

a. Trailing cable damage by coming under the crawler, which can be prevented by carefully handling the cables as explained later in methods 1 to 3 of this section.
b. Bearing breakage due to water infusion in the gear box, which can be prevented by checking the gearbox and filling it with lubricant once a fortnight.
c. Hose pipe leakage, which can be prevented by periodic maintenance of an SDL.

These entail proper and regular maintenance of the SDL and hence inspection of the following parts should be carried out regularly:

- Daily maintenance
  - checking the hose pipe for leakage
  - bucket chain for wear and tear
  - checking all the cylinders like lifting cylinder, roll back cylinder, etc.
  - cleaning of the machine by water sprinkling in order to facilitate identifying any damage.
- Weekly maintenance (on Sundays)
  - gear box checking
  - control block checking
- Half yearly maintenance
  - triple gear hydraulic pump replacement
- Complete overhauling of the machine after a maximum of 5 years.

In addition, the electricity supply to the SDL gate end box (GEB) should be regularly inspected in order to prevent any chances of tripping and stoppage of production. Moreover, the trailing cable should be properly handled to ensure efficient operation and to prevent further breakdown of the SDLs. The three proposed methods below can be employed for the efficient handling of an SDL trailing cable.

Method 1: In this method the trailing cable is tensioned using weights as shown in Figure 4. Hangers which can also act like a roof bolt in drives are installed at regular intervals of 1–1.5 m to support the cable. The weights would help in hoisting the cable back and forth thus preventing the trailing cable to come under the crawler. The arrangement is done by keeping in mind the type of cable used. The cable strength is the deciding factor for the weights that are to be used for loading.

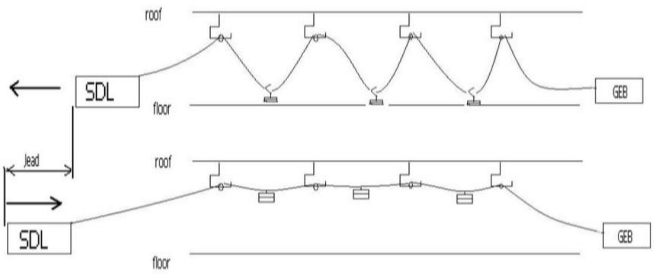

Fig. 4. SDL cable handling using hangers and weights

Method 2: The arrangements for cable handling in the second method shown in Figure 5 utilizes springs attached to the side walls of the gallery. These springs are attached to the cable at sufficient intervals. As the SDL moves towards and away from the face, the springs are coiled and uncoiled. Thus the cable doesn't hinder the free movement of SDL and the chances of cable damage due to riding over by the crawler are eliminated.

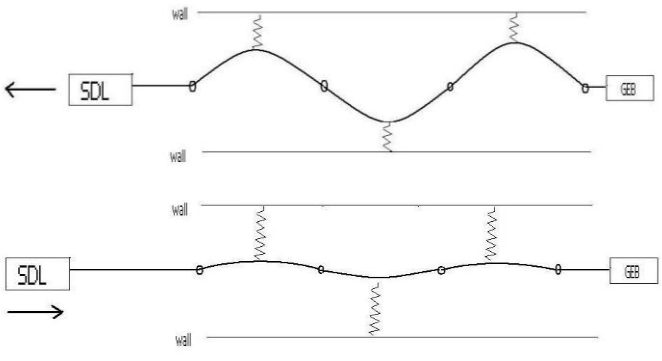

Fig. 5. SDL Cable handling using springs attached to the side walls of the gallery

Method 3: The method shown in Figure 6 utilizes a wire hanging near the roof of the drive for cable handling. Sufficient numbers of hooks are attached to the wire, which are mobile and free to slide over the wire. These hooks bear the load of the SDL cable and thus the cable handling solely depends on the movement of the SDL. In this arrangement, there is no external force being acted upon the SDL cable. As the SDL cable hangs, there is no chance of damaging the trailing cable during SDL movement.

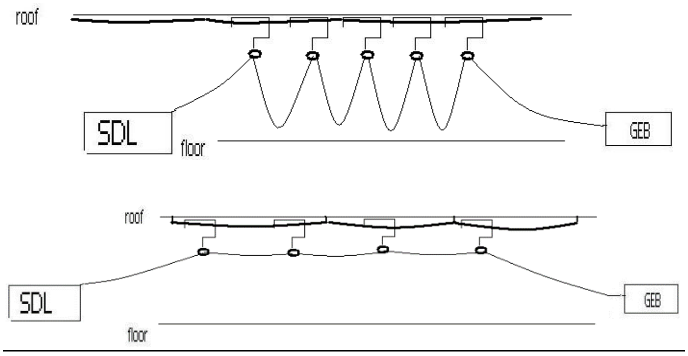

Fig. 6. SDL cable handling using hooks hung from the wire near the roof of the drive

4.4.2. Measures for minimizing chances of breakdown of belt conveyor

Proper and regular maintenance of the belt conveyor should be done. There are almost 700 to 800 idlers in one trunk belt circuit, of which 1 or 2 idlers are replaced daily. Return idlers are replaced from time to time and gear box oil monitoring is carried out. Belt trailing (from drive head to tail end) is done daily. Large-sized boulders should be adequately crushed before loading on to the belt to prevent unnecessary wear and tear of the belt, idler, etc. A proper coordination should be maintained between the various belt conveyors running in the circuit to ensure continuous production without any breakdown. The power supply to the drive head motor should be properly checked to prevent any chances of tripping and stoppage of production.

4.4.3. Measures for minimizing chances of breakdown of drill machine

Proper and regular maintenance of the drill machine should be done in the following respects:

- Trigger (telescopic switch) should be checked regularly.
- Gear box greasing should be done on a weekly basis.
- IR (insulation resistance) value of the cable (optimum 1 mega ohms) should be checked daily.

The drill bit and drill rod should be properly selected. The drill bit should be changed at regular intervals. The power supply to the drill panel gate end box should be checked regularly to prevent any chances of tripping and single phasing. The transformer should be thoroughly checked so that tripping or failure of the transformer doesn't occur. The plug socket assembly should be checked in the maintenance time so that no breakdown takes place.

5. MANPOWER OPTIMIZATION

Manpower plays an important role in deciding the productivity or OMS and therefore should be optimized to improve the productivity of a mine. Mathematically, the OMS is given by the ratio of production to the number of miners working in a mine. Therefore, for a given production, if the manpower is decreased, the OMS will be increased. For example, the OMS of the mine could be improved from the existing value of 1.6 to 1.94 tonne by optimizing the manpower from the present value of 57 to 47. Manpower can be optimized from the positions such as trailing cable and roof bolting machine. Also, the two explosive carriers can be deployed for operating the Skat and sectional belt after delivering the explosive to the coal face. Moreover, the operators of the explosive carriers should be trained to serve as fitters. Adoption of the above recommendations can optimize two workers from each SDL.

6. PRODUCTIVITY BENEFIT ANALYSIS

Lastly, the productivity benefit analysis for the mine has been done and Table 3 gives the output results by considering different variants for improving SDL productivity of the mine. The details of the variants are given as follows:

Variant 1: Retaining the present values of **pull, lead and roof bolting time**

Variant 2: Changing the present **pull** (1.3 m) to **optimum pull** (1.5m)

Variant 3: Changing the present **lead** i.e. from 30 to 15 m

Variant 4: Changing the present **roof bolting** time i.e. from 7 to 5 min

Variant 5: A combination of both **Variant 2 and Variant 3**

Variant 6: A combination of both **Variant 2 and Variant 4**

Variant 7: A combination of both **Variant 3 and Variant 4**

Variant 8: A combination of **Variant 2, Variant 3 and Variant 4**

Table 3. Productivity improvement of SDL of the mine considering several variants

Parameters	Variants							
	1 (actual)	2	3	4	5	6	7	8
Cycle time (min)	253.08	262.91	239.37	245.58	246.96	255.41	231.87	239.46
No. of blasting	1.58	1.52	1.67	1.63	1.62	1.57	1.73	1.67
Per SDL production (tpd)	101.49	113.6	107.3	104.6	120.94	116.94	110.77	124.72
Coal per blast (m^3)	17.84	20.74	17.84	17.84	20.74	20.74	17.84	20.74
Total SDL (5 nos.) production (tpd)	507.45	568.00	536.50	523.00	604.70	584.70	553.85	623.60

Figure 7 shows the total SDL production, per SDL production and cycle time of the operation under different variants. It can be inferred that Variant 8, which is a combination of variants 2, 3 and 4, not only gives rise to decreasing the cycle time from 253.08 min to 239.46 min, but also increases the productivity of SDLs by 22.9% from its original value and hence should be considered for the mine.

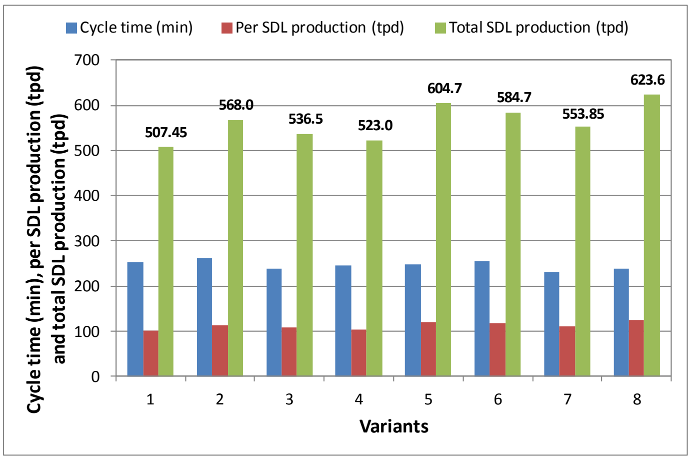

Fig. 7. SDL production and cycle time for various variants

7. CONCLUSIONS

The productivity of an underground coal mine is affected by several factors. There is always scope for improvement regarding productivity and overall effective use of resources. This paper throws lights on the parameters affecting the productivity of a mine; the cycle of operations, machine efficiency and manpower management. Also, measures for preventing the breakdown of machines used in underground coal mines are highlighted. This paper also demonstrates productivity improvement of the case study mine through the enhancement of SDL productivity in terms of several variants. Many of the changes suggested in this paper can be implemented with minimal effort and could have a profound effect on improving productivity at a minimal cost.

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