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Impact of In-Seam Dirt Bands on the Performance of Surface Miners in Coal Mines

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Abstract

Surface miner was introduced for coal extraction at Lakhanpur open cast project of Mahanadi Coalfields Limited in 1999 for the first time and owing to its success and benefits it offered like elimination of drilling and blasting, smooth and stable high wall, selective mining for quality control and uniform output fragment size (-100mm) etc. it was adopted in many open cast coal mines and now has become a disruptive mass production technology for coal mining in India. In terms of coal resources in the country, Odisha stands first with 88.104 BT resources but the coal seams in Odisha are characterized by its high ash content and interlaced dirt bands (10 cm to 1.5 m) often termed as rejects. For maintaining coal quality, these dirt bands predominantly of sandstone and shale are also cut by surface miners and are segregated at the time of loading and transported to reject dumps or overburden dumps. These dirt bands have a significant impact on the performance of surface miners and must be taken into account during their selection. The authors, based on the intensive field study undertaken at different open-cast coal mines in Odisha highlighted the impact of in-seam dirt bands in coal seams on the performance indicators of surface miners which are normalized production rate, diesel and pick consumption for cutting 1000te of material in this paper. Pick consumption was found to vary linearly with the quantum of abrasive material cut. Empirical relations for estimating monthly normalized production, diesel consumption, and pick consumption of surface miners operating in coal seams with intermittent dirt bands with a coefficient of determination (R2) of 0.74, 0.84, and 0.73 respectively were also developed. The developed relations were validated with the field data and the % error was found to be within +20%. This study helps the coal mining companies in the selection of suitable surface miners for achieving targeted production and also for planning inventory of picks and diesel during its operation.

Keywords: *Dirt Bands, Diesel Consumption, Picks, Production, Surface Miner*

1.0 Introduction

The coal production in India has reached a new height of 893.08 MT during financial year 22-23 of which contribution from open cast mines is 860.38 MT (96.33%)[1]. Given the advancements in the field of metallurgy particularly in pick and drum design and understanding of the rock tool interaction, extraction of coal, limestone, lignite, salt, phosphate, gypsum, bauxite, and iron ore projects around the globe with higher productivity and lower cost have become possible through mechanical cutting using surface miner[2]. In India, predominantly, surface miners are being used at Limestone and Coal mines. The recent surge in explosive prices, shortage of explosives, non-availability of land for mining, and inherent risks involved in drilling and blasting is urging the mining companies to explore the possibility of extraction of overburden like sandstone and shale through mechanical means. Already vertical rippers are deployed for blast-free extraction of overburden at Balram Open Cast Project (OCP), Hingula OCP, and Kaniha OCP belonging to Mahanadi Coalfields Ltd.

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(MCL) in Odisha. Out of 361.4 BT of coal resources in the country as of 01.04.22, 88.104 BT are in Odisha followed by 86.66 BT in Jharkhand[3]. The coal seams in Odisha are characterized by their high ash content and interlaced dirt bands (10 cm to 1.5 m) often termed rejects. Small changes in rock properties adversely affect the performance of mechanical excavators[4]. The coal and dirt bands can be characterized based on their ash content. Surface miners are proven versatile machines suitable for the extraction of soft to medium hard rock with compressive strengths up to 120 MPa[5]. Surface miners can economically cut even harder material in some circumstances like highly fractured strata[6]. The advantages it offers include working close to habitats, selective mining, simplicity and ease of operation, elimination of drilling and blasting, no secondary crushing, uniformly sized material throughput, continuous operation, reduced operating cost, requiring less supervision, maintaining smooth, clean and stable high wall, etc. Surface Miner cuts the coal seams (-100 mm) in layers and stacks the cut coal in a windrow formation. But when seams with intermittent dirt bands are cut by surface miners, both the coal and dirt bands get stacked together. The rejects are then identified, loaded, and transported to either reject dumps or overburden dumps while coal free from dirt bands/impurities is loaded and transported to coal stock or dispatch points. The proportion of coal production from surface miners vis-à-vis open cast coal production at Mahanadi Coalfields Limited (MCL) during FY 22-23 was 97.83%[7]. The trend of coal production together with dirt bands/impurities from surface miners at MCL from 2015-16 to 2022-23 is shown in Figure 1. The productivity of surface miners was found to be higher in coal than in limestone due to the ease of cutting in coal. The availability and utilization of surface miners in limestone were low, and breakdown and maintenance were high because of stickiness and hard digging conditions. The fuel consumption is the major operating cost of the surface miners[8]. The production efficiency of surface miners is defined as the ratio of actual production and targeted production, and it increases with an increase in percentage utilization. The targeted production is a function of cutting depth, cutting speed, and width of the drum. The utilization of surface miners ranged from 41.72 to 71.5 % on a daily basis in the study conducted at two mines of MCL[9]. However, it appeared that the dirt bands cut by surface miners were not taken into account while defining production efficiency.

In a study undertaken at eastern coalfields by Prakash, it was found that the cutting speed of surface miners while cutting hard bands was maintained at 12 to 14m/min and while cutting coal it was maintained at 12 to 22 m/min. This is to prevent overloading of machine[10]. Conical picks are normally used in surface miners as these are efficient in cutting soft and brittle rocks. Increased pick consumption has an impact on the production of surface miners and also the operating cost. During cutting, the magnitude of cutting forces changes continuously due to chipping and the brittle nature of the rock. High cutting force damages the carbide tip of the cutting pick[11]. Rock abrasiveness directly influences the cutting pick maintenance cost[12]. The abrasive of each seam differs due to variations in coal quality. The magnitude of pick wear depends on chemical composition, petrology, grade, UCS and hardness of coal, machine handling by operators, maintenance practices

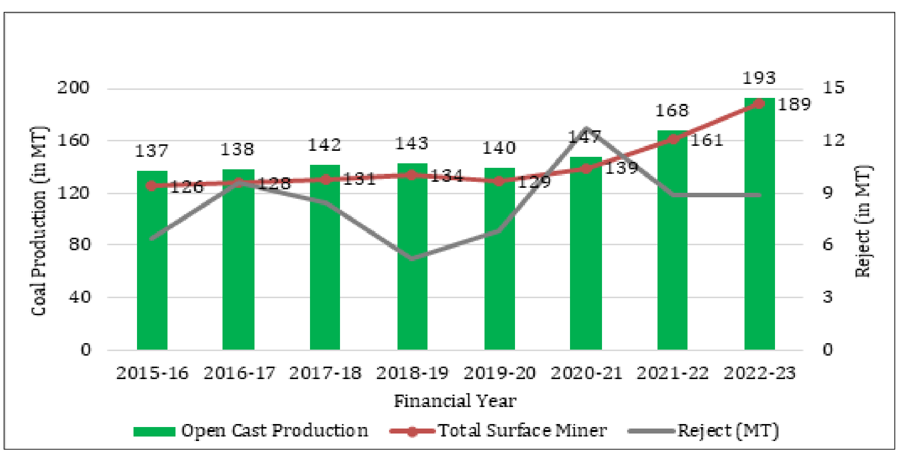


Figure 1. Opencast coal production vis-à-vis production from surface miners.

utilization of surface miners, etc. It was found that the coal quality, particularly the silica content directly impacts the rate of abrasion of cutting picks. The average life of pick ranged from 275 hours to 681 hours in the Gevra and Kusmunda open-cast coal mines of South Eastern Coalfields Limited[13]. Mammen, J reported that with an increase in moisture content of a sandstone sample, the cutting force, the normal force, specific energy, and pick wear were found to be decreased[14].

Bandopadhyay defined the Abrasion Index (AI), expressed in (mg/kg), as the average loss in mass of four standard metal blades of medium carbon steel when rotated at 1450 rpm for 12,000 revolutions in a known mass of coal (2 ± 0.001 kg) of specified size. The coefficient of correlation (R^2) between Abrasion Index (AI) and % ash in coal was found to be 0.79[15]. Mathematically, it is written as

$$AI = 1.35 \times \%Ash \quad (1)$$

Cutting the material with a higher % ash content results in higher pick wear. Pick wear is a continuous process and it increases proportionately with the quantum of abrasive material cut. Abrasive material cut can be defined as the product of the quantum of material cut (te) with its % ash content.

The Cuttability Index (CI) for the selection of surface miners was developed for the first time by Dey and Ghose which is as follows:

$$CI = I_s + J_v + A_w + J_s + M \quad (2)$$

Where I_s is point load strength index, J_v is volumetric joint count, A_w is rock abrasivity, J_s is the direction of cutting with respect to major joint orientation and M is machine power, and when CI > 80, surface miners should not be deployed[16,17].

Moreover, the cutting performance can be expressed as

$$L^* = (1- CI/100)\, k.\, M_c \quad (3)$$

where L^* is cutting performance (m^3/hr), M_c is the rated capacity of the machine (m^3/hr), CI is a cuttability index, k varies between 0.5 to 1 and depends on pick lacing, pick shape, specific cutting conditions, etc.

Prakash *et al.*, developed a Rock Cuttability Index for surface miners (RCI_{SM}) for estimating key performance indicators of surface miners mainly productivity, diesel, and pick consumption using a total of 10 different parameters categorized under intact rock parameters, rock mass parameters, machine parameters and operational parameters. This was based on the study undertaken in coal mines and limestone mines[18].

In all the previous research, very little study has been made on the performance evaluation of surface miners in coal seams interlaced with dirt bands/impurities leaving a scope for research. The coal and dirt bands both differ in terms of ash content (%) and so the pick wear is also different. The dirt bands of varying thickness which are very often encountered within the coal seams are of sandstone and shale and so evaluation of the performance of surface miners in these coal seams will help the contractors and mining companies in better understanding the costs involved. This study acts as a hand guide for the deployment of surface miners in coal seams with interlaced dirt bands/impurities. The main objective of this study is to develop empirical relationships for estimating normalized production, pick, and diesel consumption of a surface miner while cutting coal seams with intermittent dirt bands and also to quantify the impact of inseam dirt bands on normalized production rate, pick and diesel consumption for cutting 1000te of material. Coal and dirt bands cut by surface miners are shown in Figure 2.

Figure 2. Coal and dirt bands/impurities cut by surface miners at Garjanbahal OCP.

2.0 Materials and Methods

The study was performed in 7 open cast mines of MCL where 18 nos. of surface miners owned by MCL comprising of 3 different models (KSM 303 and KSM

403 of L and T make, PMM-2205 of Puzzolana make) are in operation. The authors have studied the operation and maintenance practices of surface miners in these mines and have collected their machine configurations. The open cast mines of Mahanadi Coalfields Limited are spread over two Coalfields i.e., IB coal fields (Jharsuguda and Sundergarh districts) and Talcher Coalfields (Angul district) of Odisha. The geology of the coal deposits in IB fields and Talcher fields varied widely. The workable coal seams in IB Coalfields are Parkhani, Lajkura, Rampur of Barakar formation and IB seam of Karharbari formation whereas in Talcher coal fields are Seam IX, VIII, VII, VI, V, IV, III, and II of Barakar formation[19,20]. The coal seams of Talcher coalfields are dominated by vitrinite followed by inertinite and liptinite[21]. The coal seams in Odisha are characterized by their high ash content, low gross calorific value, and presence of inseam dirt bands of varied thickness ranging from 10 cm to 1.5 m. Due to this small and varying thickness, blasting is not performed and is cut through the surface miners only. The average ash content and coal grade of all mines of MCL during the financial year 2021-22 were found to be 42.23% and G-13 respectively. In all the previous works undertaken by researchers, the performance of surface miners was analyzed considering only the coal production and neglected the dirt bands often termed as rejects cut by surface miners. The dirt bands cut by all surface miners in MCL during FY 20-21 and 21-22 were 12.7 MT and 8.9 MT respectively. The proportion of dirt bands/impurities in the coal seams as inferred from borehole lithology/ seam cross section at Garjanbahal open cast mine of MCL is about 25%. The presence of dirt bands within the coal seam affects the performance of surface miners to a great extent and very little research was reported considering the effect of dirt bands on the performance of surface miners. Hence the authors chose to study the operation of surface miners in MCL mines so that the true representation of rock characteristics from varied geology and the presence of dirt bands are taken into account while evaluating the performance indicators of surface miners.

The Turnback method is the predominant method of surface miners' operation at MCL. However, in circumstances like the availability of a small working face area due to the non-availability of land required for mining or when the mine has reached its boundary, the continuous mining method is adopted. The movement of surface miners at Samaleswari OCP of MCL was tracked through a highly accurate GPS/Galileo/GLONASS system. Figure 3 shows the turn-back method of operation where the length and width of the working face available for surface miners are 468 m and 69 m respectively while Figure 4 shows the continuous mining method of operation where the length and width of the working face available for surface miners are 122 m and 73 m respectively. The picks of surface miners are examined by a competent person on the first shift of every day during the maintenance time and the picks which are worn out are replaced with new picks. The weight of the new tungsten carbide cutting pick of the KSM 403 model surface miners was found to be 1335 gm and the average weight of fully worn-out picks was found to be 1087.5 gm. The surface miner is operated at a reduced speed while cutting the dirt bands to avoid overloading on picks and the machine. The amount of heat adversely affects the tool material properties which

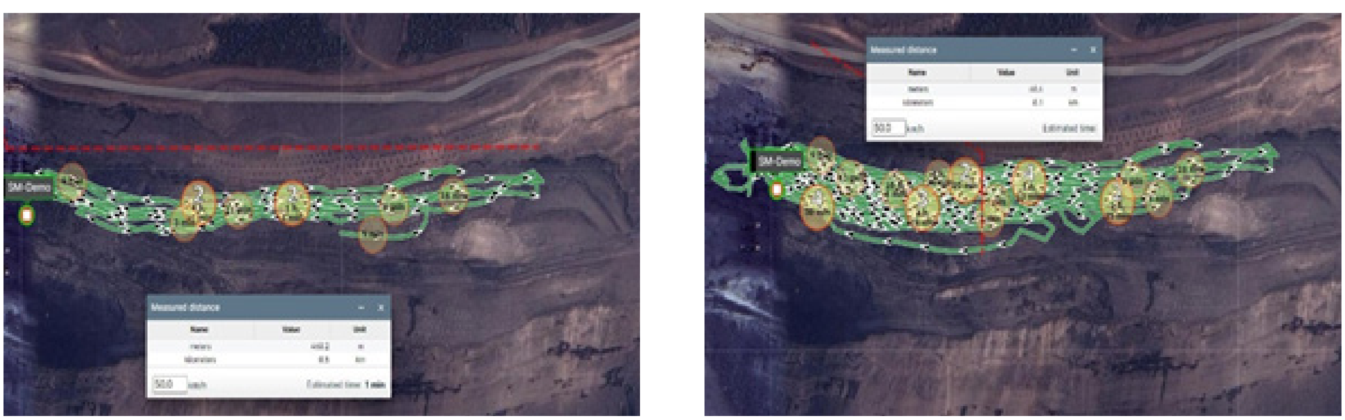


Figure 3. Turn back method of surface miner operation at Samaleswari OCP.

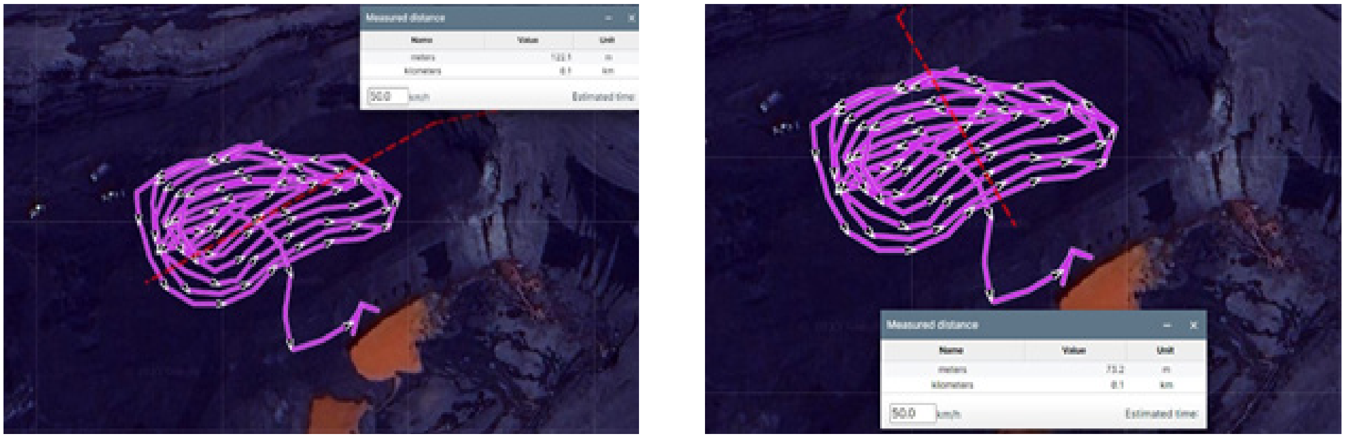


Figure 4. Continuous mining method of surface miner operation at Samaleswari OCP.

Table 1. Empirical equations for Theoretical Production of surface miner

Sl. No.	Method of Working	Theoretical Production (Pe) in Windrowing Mode	
1	Empty Travel Back Method	P_e = DW×L×d [WH×60/(L/v + t_e)]	P_e = Theoretical Production (Cum) DW = Drum Width (m) L = Length of face (m) d = pre-determined depth of cut (m) v = Cutting speed of machine (m/min) t_t = machine turning time (min) t_e = empty travel back time (min) WH= working hours (hr)
2	Turn Back Method	P_e = DW×L×d [WH×60/(L/v + t_t)]	
3	Continuous Mining Method	P_e = DW×v×d×WH ×60	

reduces the tool life, particularly in hard rocks[22]. The temperature of cutting picks increases with increased cutting depth and speed. Enhanced wear rate at high temperatures reduces the life of pick[23].

Empirical equations for estimating the theoretical production of surface miners in different working methods are given in Table 1.

Prakash *et al.*, have normalized the production of a surface miner with respect to drum contact area (t/h/m²) for a better comparison of production capacities between different make/models.

$$NTPH = TPH/CA \quad (4)$$

$$CA = L_a DW \quad (5)$$

$$L_a = \frac{2\pi R\left[\frac{(R-D)}{R}\right]}{360} \quad (6)$$

Where NTPH = Normalized Production (t/h/m²), TPH is actual production (t/h), CA is the contact area of the drum with rock (m²), DW is drum width, L_a is the length of arc in contact with rock (m), R is the drum radius (m), and D is the depth of cut (m)[24].

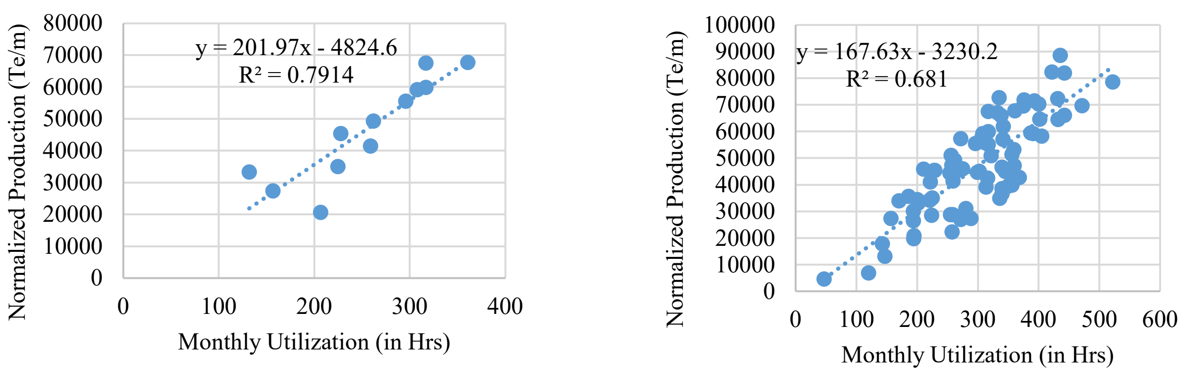
From the above equations, it is evident that the drum width, depth of cut, cutting speed of the machine, and availability of working face length directly influence the production capacity of a surface miner. Different make/model has different drum widths and drum radii and thus has different production capacities. So, for better comparison of production capacities of different surface miner models, production was normalized with respect to drum width. Normalized production (in te/m) is defined as the tonnage of material (coal and dirt bands) cut per unit width of the cutting drum.

$$NP = P_a/DW \quad (7)$$

Where NP is normalized production (in te/m), DW is drum width (in m) and P_a is actual production (in te). This normalized production parameter helps in the performance assessment of surface miners of different make/models.

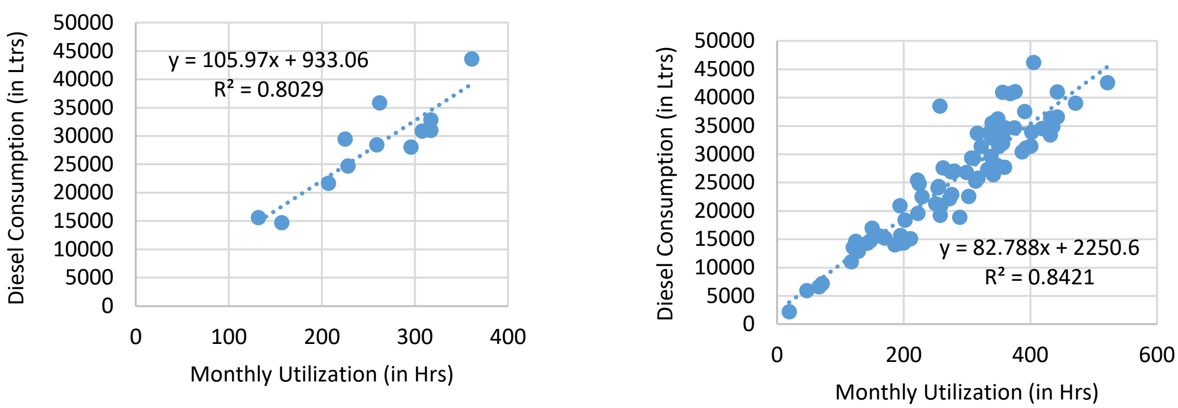
3.0 Results and Discussion

A total of 93 data sets of 18 surface miners (3 models) operating in 7 open cast mines in different seams that include utilization (Hrs), coal production (te), dirt bands cut and segregated (te), ash% in coal and dirt bands, diesel consumption (ltrs) and pick consumption (Nos) were generated. It was found that only 12 data sets out of 93 data sets have no cutting of dirt bands i.e., rejects. This indicates that most of the coal seams in Odisha are characterized by the presence of in-seam dirt bands. To quantify the impact of dirt bands on the machine performance, graphs for normalized production vis-à-vis monthly utilization, diesel consumption vis-à-vis monthly utilization, and pick consumption vis-à-vis abrasive material cut were plotted separately for coal without dirt bands and coal with dirt bands and have been presented in Figures 5(a), 6(a), 7(a) and Figures 5(b), 6(b), 7(b) respectively. Monthly utilization (hrs) of surface miner includes the time spent in production activities i.e., cutting and traveling, and doesn't include



(a) (b)

Figure 5. Normalized production vs Monthly utilization **(a)** coal without dirt bands **(b)** coal with dirt bands.



(a) (b)

Figure 6. Diesel consumption vs Monthly utilization **(a)** coal without dirt bands **(b)** coal with dirt bands.

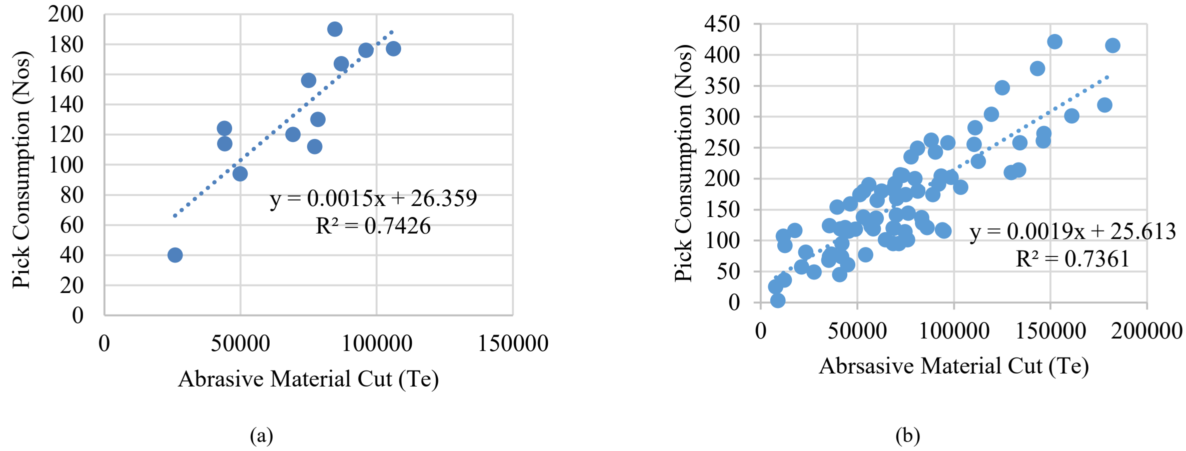


Figure 7. Pick consumption vs Abrasive Material Cut **(a)** coal without dirt bands **(b)** coal with dirt bands.

Table 2. Descriptive statistics of input and output parameters

Sl. No	Parameter	Minimum	Maximum	Mean	Range	Median	Standard Deviation
1	Drum Width	3	4	3.568	1	4	0.496
2	Monthly Utilization (Hrs)	19	522	287.815	503	310	106.424
3	Picks consumption (Nos)	3	421	165.63	418	144	86.322
4	Diesel Consumption (Ltrs)	2199	46163	26078.16	43964	27029	9600.921
5	Coal Cut (Te)	18075	308040	140261	289966	132684	67394
6	Dirt Band Cut (Te)	15	54704	14887	54690	12054	13839
7	Normalized production (Te/m)	4580.55	88528.48	43444.99	83947.92	42713.03	19822.68
8	% Ash in Coal	38.18	50.77	44.86	12.58	43.54	3.74
9	% Ash in Dirt bands	60	80	70.161	20	72	5.291
10	Abrasive Material Cut (Te)	7793.12	182218.7	74274.96	174425.6	70276.4	39285.59

Table 3. Performance indicators of surface miners

Sl. No.	Description	Average Normalized Production rate (te/m/hr)	Average Diesel Consumption (Ltr) per 1000 te of material cut	Average Pick Consumption (Nos) per 1000 te of material cut
1	Surface mine cutting only coal (No Dirt Bands)	183.10	177	0.79
2	Surface miners cutting coal and dirt bands	152.09	189.10	1.15

idle time and maintenance time. The wear of the pick is directly proportional to its interaction with the abrasive material. The dirt bands often termed as rejects have higher ash content than that of coal. Abrasive material cut (te) is defined as the sum of coal cut (in te) × wt% of ash in coal/100 and dirt bands cut (in te) x wt% of ash in dirt bands.

The descriptive statistics of 81 data sets of input and output parameters for surface miners cutting both coal and dirt bands are given in Table 2.

The key performance indicators of surface miners while cutting only coal i.e., without dirt bands, and while cutting both coal and dirt bands are summarized in Table 3.

The average cost of one pick is Rs. 1500 and the average diesel price is Rs. 96 per liter. This translates to an increase in unit operational cost by Rs. 1.70/te of material cut by surface miners in coal seams interlaced with dirt bands. Thus, not considering the impact of dirt bands on the performance of surface miners will have a significant impact on project economics. It was assumed that except for diesel and pick consumption other running costs remain the same. The monthly production capacity (in te) can arrive from the product of the average normalized production rate (te/m/hr) and width of a drum (m) and monthly utilization (hrs).

The data shows that the empirical equations and coefficient of determination (R^2) in estimating normalized production, diesel and pick consumption of surface miners cutting only coal and coal with dirt bands are different. Very limited work was reported on the performance of surface miners cutting both coal and dirt bands, and so the empirical relationships for estimating normalized production, diesel and pick consumption of surface miners working in coal with dirt bands were developed as given below. This helps the coal mining companies in planning for the inventory (picks and diesel) and selection of surface miners for achieving targeted production.

$$NP\ (te/m) = 160.83 * MU\ (Hrs) - 2845.1\ (R^2 = 0.75) \quad (8)$$

$$DC\ (ltrs) = 82.788 * MU\ (Hrs) + 2250.6\ (R^2 = 0.84) \quad (9)$$

$$PC\ (Nos) = 0.0019 * AMC\ (te) + 25.613\ (R^2 = 0.74) \quad (10)$$

$$AMC\ (te) = CC\ (te) * \%Ash\ in\ Coal/100 + DBC\ (te) * \%\ Ash\ in\ Dirt\ bands \quad (11)$$

Where NP is normalized production (te/m), MU is monthly utilization (hrs), DC is diesel consumption (ltrs), PC is picking consumption (Nos), AMC is abrasive material cut (te), CC is coal cut (te) % Ash in coal is wt% of ash in coal, DBC is dirt band cut (te), % Ash in dirt bands is wt% of ash in dirt bands.

The normalized production and diesel consumption varied linearly with monthly utilization (hrs) of surface miners with a coefficient of determination of 0.745 and 0.84 respectively whereas the pick consumption increased linearly with an increase in abrasive material cut with a coefficient of determination of 0.736. The relationships defined above are simple and easy to use. Factors like depth of cut, operator's skill, intact rock properties, rock mass properties, machine parameters, pick replacement strategy being followed in each mine, rainfall, method of working of a surface miner, etc. were not considered.

4.0 Model Validation

Initially, twelve data sets were taken out from the collected field data such that they cover different models of surface miners operating in different mines for the purpose of

Table 4. Input data for validating the developed empirical relations

Sl. No.	Utilization (Hrs) (a)	Pick Consum-ption (Nos.) (b)	Diesel Consum-ption (ltrs.) (c)	Drum Width (m) (d)	Coal Prod-uction (in Te) (e)	Dirt band Cut (Te) (f)	Ash% in Coal (g)	Ash% in Dirt Bands (h)	Abrasive Material Cut (i) = (e*g + f*h)/100	Normalized Production (te/m) (j) = (e+f)/d
1	252	130	24532	3	120418.3	2280	40.67	68	50527.11	40899.4
2	309	118	28642	3	140268.9	2416	42.18	68	60814.32	47561.6
3	306.0	135	28339	3	130917.1	2702	41.07	80	55926.45	44539.7
4	345.0	138	33691.9	3	147030.9	7902	41.91	80	67943.14	51644.3
5	222.5	185	18725	4	144178.7	8281.44	48.52	72	75922.12	38115.0
6	402	276	33925	4	241034.3	17562.4	46.66	72	125107.8	64649.2
7	371	286	31585	4	238351.4	18391.14	48.52	72	128896.3	64185.6
8	477	315	41445	4	305288.1	21633.14	46.66	72	158018.5	81730.3
9	435	332	38040	4	266358.9	26445.6	49.05	72	149678.8	73201.1
10	358.0	253	35500.65	4	220650.2	27924	42.03	80	115078.7	62143.6
11	389.5	280	34188	4	256429.3	28052.52	49.05	72	145965.7	71120.4
12	436.5	346	36534	4	246825.4	34770.56	49.66	72	147604.4	70399.0

Table 5. Validation of normalized production, diesel, and pick consumption

Sl. No.	Predicted Normalized Production (te/m)	% Error	Predicted Diesel Consumption (Ltrs.)	% Error	Predicted Pick Consumption (Nos.)	% Error
1	37684.06	7.86	23113.18	5.78	122	6.16
2	46851.37	1.49	27832.09	2.83	142	-20.34
3	46368.88	-4.11	27583.73	2.67	132	2.23
4	52641.25	-1.93	30812.46	8.55	155	-12.32
5	32939.575	13.58	20670.93	-10.39	170	8.11
6	61808.56	4.39	35531.38	-4.74	264	4.35
7	56822.83	11.47	32964.95	-4.37	271	5.25
8	73870.81	9.62	41740.48	-0.71	326	-3.5
9	67115.95	8.31	38263.38	-0.59	311	6.33
10	54732.04	11.93	31888.70	10.17	245	3.17
11	59798.185	15.92	34496.53	-0.90	303	-8.22
12	67357.195	4.32	38387.56	-5.07	307	11.28

validating the model. The remaining 81 data sets were used for the development of empirical equations for estimating normalized production, diesel, and pick consumption while working in coal seams with intermittent dirt bands. The data used for validating the empirical equations is given in Table 4 and the results of validation are given in Table 5.

The % error of predicted normalized production from actual normalized production varied between -4.11% to 13.58%. The % error of predicted diesel consumption from actual diesel consumption varied between -10.39% to 10.17%. The % error of predicted pick consumption from actual pick consumption varied between -20.34% to 11.28%. Mining activity is dynamic in nature and has many elements that cannot be factored in and thus the results seem to be in agreement with the actual measurement in all three output parameters i.e., normalized production, diesel, and pick consumption.

5.0 Conclusions

Coal production from surface miners is increasing trend owing to the benefits it offers like elimination of drilling and blasting, uniform size throughput, selective mining for grade control, smooth and stable highwall, etc. The coal seams in Odisha are characterized by high ash content in coal and are interlaced with dirt bands often termed rejects. The conclusions drawn from this study are:

- The presence of inseam dirt bands/impurities had a significant impact on the performance indicators of surface miners where the normalized production rate of surface miners was decreased by 16.9%, diesel and pick consumption increased by 6.8% and 45.5% respectively in comparison with its operation in only coal.
- The main reason for the decrease in the productivity of surface miners is that the machine is operated at reduced speed while cutting dirt bands to avoid overloading, vibration, and overheating of the machine.
- The normalized production and diesel consumption varied linearly with utilization of the machine whereas pick consumption varied linearly with abrasive material cut by the machine.
- The empirical relations developed for estimating the normalized production, diesel, and pick consumption to give first-hand information for the management in the selection of surface miners to achieve targeted production and also in planning for an inventory of picks and diesel.

6.0 Acknowledgements

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