Underground Mining Project Equipment Selection Model

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ABSTRACT

With global total coal production of 6.2Bt, the share of China, USA & India is about 51%, 15% and 9% (8.7%), respectively. Due to new capacity additions, coal consumption in the country remains higher than production, with a structural deficit of 187 million tonnes. With just 10 per cent share of coal production from UG mines in India, there is a need for a quantum jump in production and productivity from such mines as there are more opportunities in productivity improvement and cost benefits in underground mining. This is more relevant considering the likely exhaustion of shallow depth coal reserves and hurdles in surface land acquisition in future. The author with collection of database from one of the largest coal company of India has developed the model with all linked variables.

*Underground Face Mechanization Cost Benefit Model **'eqp'** helps mechanization by choice of method and equipment. Study of coal measure rock properties like CS (Compressive Strength), TS (Tensile Strength), SS (Shear Strength), RQD (Rock Quality Designation), ME (Modulus of Elasticity), RSR (Rock Structure Rating), CI (Cavability Index) were made. Operational cost for machinery set like SDL/LHD/CM/LWPS were collected and input of data COLLIERY, COE (Cost of Equipment), POC (Production of Coal/y), DIT (Depreciation and Interest), PMT (Power & Maintenance), SC (Store Cost), WC (Wage Cost), OC (Other Cost), to determine PC (Production Cost), CP (Cost per tonne), and then CB (Cost Benefit in Rs./t) was computed with model program run of **'eqp'** with (eqp.dat) file. Then, with analysis of results selection and scheduling of coal face equipment were done.*

KEYWORDS

COE (Cost of Equipment; POC (Production of Coal/y;DIT (Depreciation and Interest); PMT (Power & Maintenance);RQD (Rock Quality Designation); ME (Modulus of Elasticity); RSR (Rock Structure Rating); CI (Cavability Index)

1.INTRODUCTION

Underground mine performance in coal and mineral industry is declining and needs high productive systems. In fact the world scenario of underground production is dismal and many companies are facing closure even in USA. Proper selection of mechanization equipment requires many factors to be considered for long-term viability of underground mines and the researcher has exemplified such a solution. Here, specific case study with database programming has been exemplified in one of India's large coal companies. The model program run of **'eqp'** coded in Java shows many different techno-economic variables taken into computation to select proper equipment sets.As a result of exploration carried out up to the maximum depth of 1200m, a cumulative total of 301.56 Billion tonnes of Geological Resources of Coal have so far been estimated in the country as on 1.4.2014. India's coal reserve stood only 10% is in 600-1200 m depth, about 27% between 300-600 m and rest 63% occur within 300 m depth.

The present scenario of underground coal mining in India is that many underground mines are being worked with Bord and Pillar system with manual loading into tubs, which are raised by haulages or conveyors or pits to the surface. Gradual introduction of coalface loading with Side Discharge Loader (SDL) or Load Haul Dumper (LHD) is continuing for decades now and yet there is marginal improvement of underground coal productivity. Main reasons are higher input and wage costs, safety and ventilation costs. Longwall Mining is highly capital intensive and has been successful in extensive undisturbed deposits. Because of imported spare part and heavy downtime losses, Risk-Gain agreement system has been quite successful. New initiative on possibilities of full extraction with earthquake-proof special support is under research and development.

2. MECHANISATION

Improvement in underground production and profitability is essential for sustainable development.

Higher the coal produced at the faces, greater is the likely output of coal and so is chance of more revenue earned. The standard workload for piece-rated loaders is 2 tubs or tonnes roughly and even with better motivation or incentive of time-rated workmen, rarely more than 4 loader OMS is obtained. So, maximum production in a shift from such a mine could be computed from loader strength {(roll - sick - absent - diversion to time rate)* av. loader OMS}. So, even if higher capacity transport exists and ventilation and other safety provisions are in order, the production from the mine was found below Break Even Point (BEP) with losses.

China accounts for about 95% of its production from underground mines, while corresponding figures for USA and India stands at about 33% & 10%, respectively. In South Africa, production underground mines is about 50% while in Australia, it is 20%. Indian Coal Ministry has admitted that share of coal production from underground mines to total production, has fallen from 16% to 8% over the last ten years, needed to be reversed.Shallow cover opencast mines are depleting reserves fast, so underground mines are required to be highly productive in future.In underground mines funds likely to be invested for the year 2015-16, would be nearly Rs7.6bn, which is 12% of total capex of 2015-16.

TABLE NO-1: INDIAN COAL PRODUCED FROM U/G MINES YEAR WISE

Year	Total U/G Production	Percentage of Total Production	Percentage of U/GGrowth
2002-03	63.16	18.50	-2.56
2003-04	62.75	17.37	-0.64
2004-05	62.35	16.30	-0.64
2005-06	60.97	14.98	-2.20
2006-07	57.70	13.39	-5.36
2007-08	58.90	12.89	+2.08
2008-09	58.97	11.97	+0.12
2009-10	58.52	11.00	-0.76
2010-11	54.86	10.30	-6.27
2011-12	58.83	9.60	-5.51
2012-13	51.10	9.16	-1.41

In India Production of Raw Coal from Opencast and Under Ground Minesin Year 2013 – 2014was Opencast: 516.116& Under Ground: 49.649 in Mtand in Year 2014–2015 wasOpencast: 563.970 & Under Ground: 48.465 in Mt.Productivity (OMS) of underground mines for the year 2014-15 was 0.78 for CIL and 1.10 for SCCL.Import of Coking coal was 43.715 MT in 2014-15 against 36.872 MT in 2013-14 i.e. an increase of 18.56%over 2013-14. Import of Non-coking coal was 168.388 MT in 2014-15 against 129.985 MT in 2013-14 i.e. anincrease of 29.54% over 2013-14.

Total cost of production has increased,mainly because EMS (Earning per Man-Shift) including wages, perks, welfare benefits like housing, water supply, roads, schools, transport, medical services and so on. Moreover, it was computed by the researcher that share of destination price of coal, for a haul distance of 750 km, pithead price is 36%, Railway freight is 48% and Govt. cess, royalty etc. 15% in total price.

The researcher proposes appropriate coalface mechanization of underground mines for achieving profitability, as there was projected market of coal in future by various authorities. The 18th Electric Power Survey (EPS), an exercise of electricity demand forecast by Central Electricity Authority (CEA) for 12th Plan and beyond, predicted a demand of 239 GW in 2017-22. Excess cost of imported coal ranged from ₹/t 986.65 to 1916.65, which justifies increasing indigenous production of coal in India.

3. CHOICE OF METHOD

The main underground methods of working coal seams taken in this program are: -

i) Bord and Pillar,
ii) Room and Pillar,
iii) Longwall advancing,
iv) Longwall retreating,
v) Shortwall,
vi) Special methods for thick seams etc.

Major thick seam mining methods are Horizontal slicing, Inclined slicing, Transverse slicing, Sublevel caving, Jankowicz, Kazimierz, Komora, Blasting gallery etc. The choice of methods depends on: -

a) Geological conditions, thickness, quality, dip, hardness of coal, dirt bands, disturbances in the seam like faults, folds, dykes, washouts etc,
b) Nature of roof and floor cavability, heaving, slips etc.
c) Depth from surface, pillar and gallery size, type of support, presence of surface structures and so on,
d) Local practice and environment etc.

Bord and Pillar System also called Pillar and Stall method is widely practiced in India. The percentage of extraction, during development is below 30% and including depillaring by caving, it is below 70% and by stowing it is below 80%. Since, in Indian condition roof and floor are stronger, Longwall retreating method is mostly practiced and percentage of extraction could be higher than 90%. When large reserves and deep seams are there without much geological disturbances, this method is ideal.

Mechanized longwall mining with self-advancing power support, was started in India for the first time at Monidih project, BCCL in 1978. By 1989, there were 12 fully mechanized longwall faces in India, producing on an average 735 tpd. Longwall mechanization, by Shearer with self-advancing power support, is most prevalent choice today, as other Cutter-Loaders or Ploughs could not succeed in Indian hard coals.

The success of coal face equipment is primarily upon coal productioncapacity and then ventilation, transport, lighting, dust control, quick erecting supports, condition of roof and floor etc. For example, crawler mounted machines are preferable compared to tire mounted ones, because of harder floor in Indian coalmines. Various models and designs with different loading capacity are available, but the models found quite successful in Indian conditions have been taken into consideration with actual costing data.

Since, Longwall Power Support with Shearer is much cost intensive, all pros and cons have to be examined. Cavability Index of overlying roof depends upon thickness, massiveness, and strength parameters. Typical Cavability Index of easily cavable roof is 2000, moderately cavable-4000, cavable with difficulty-6000 and above. Typical coarse-grained coal-measure sandstone has RQD-86%, Comp.Strength-480, Tensile strength-44, Shear Strength- 80 kg/sq. cm and it is observed that RQD is very close to Shear Strength value.

Cutting action of L/W Shearer or Continuous Miner picks is mostly by shearing force generated in the coalface. SDL/LHD tires mounted in soft floors and crawler mounted machines in hard floors should be deployed. There are several rock properties and shear and tensile strength is roughly 6-10 times less than the compressive strength of coal-measure rocks. A sample of coal-measure rock properties, tested at ISM Rock Mechanics Laboratory, from samples provided by CMPDIL are as given below in Table No: -2, where Strength and Modulus is in kg/sq.cm.

TABLE NO- 2: INDIAN COAL MEASURE ROCK PROPERTIES

Sl.No.	Type of Rock	Sp.Gr	Comp. Str.	Ten. Str.	Shear Str.	Mod.of Elasticity
1	Sandstone	2.69	1335	89	118	74700
2	Sandstone	2.58	829	67	76	22300
3	Sandstone	2.54	595	48	59	28300
4	Shale	2.55	771	81	74	30700
5	Siltstone	2.42	858	45	117	50500
6	Siltstone	2.53	551	32	66	26700
7	Sandstone	2.69	648	65	84	34500
8	Coal	1.45	85	20	32	28410
9	Coal	1.42	109	26	14	41000
10	Shale	2.70	482	116	111	35720
11	Coal	1.40	107	31	26	34750
12	Coal	1.38	115	28	12	37930

Various researchers have used different rock properties like RQD% (Rock Quality Designation) developed by Decre, Protodeakonov Index (1-7), Moduli of Elasticity (2-7*10000 kg/sq.cm), Creep properties etc. Rock classification by Tergazhi or Lauffer is mostly based on structural defects like spacing, condition and orientation of joints. RQD ranges from less than 25% for poor rocks and more than 80% for excellent rocks. Rock Structure Rating (RSR) range from 6 for soft rocks to 30 for very hard rocks and for Indian coal-measure rocks RSR is 20-25. Rock Mass Rating (RMR) ranges from 15 for very poor rock to 80 for very good rock.

4. MODEL FOR SELECTION OF MACHINERY

Initial program development was done with the Mainframe Computer, Prime 2450 installed at Indian School of Mines, Dhanbad. Significant specifications were: - Microprocessor-32 bit ICC, IC Memory-4 MB, Cache memory 16 KB, CPU Speed-1.3 MIPS, Dual Winchester disk-512 MB. The PRIME computer was manufactured in Natwick, Massachusetts, and Revision 19.4with PRIMOS operating system and FORTRAN.

However, Mainframe computers are gradually getting out of vogue, except for old data storage for faster computers. Mini computers and Pentium class microprocessor based PCs can perform what earlier Mainframe versions could do. Therefore, Pentium based PC was used to run the Java program converted from Fortran, as Java program could be operated with any type of Operating System and is also web-centric.

Equipment cost includes cables, switchgears and other ancillaries for installing and operation at the coal faces. The program computes then, depreciation and interest, Production cost and Cost-Benefit per tonne expected. The model program **'eqp'** along with the subroutine, selects equipment type with inputs of Shear Strength of roof stone, coal, floor stone, thickness of coal seam, size of largest faultless panel. The eqp.java is the source file, and eqp.cls is the compiled file. The program has considered 4 types of equipment packages, most commonly used in Indian coalmines, namely Equipment set of Side Discharge Loader (ESDL), Load Haul Dumper (ELHD), Continuous Miner (ECHMN) and Longwall Shearer with Power Support (ELWPS).

The variable names have been declared with codes and data types-namely SLNO, COLLIERY, COE (Cost of Equipment). The cost of equipment have been shown with switchgears and declared in DATA statement, in Rs. Millions – ACNV (Armored Conveyor), BCNV (Belt Conveyor), CCNV (Chain Conveyor), The input data file has been named eqp.dat and its header is formatted, as per statement 5.The Run file is named eqp.txt and the header is formatted as per statement 10. Input of data has been according to actual cost figures and so there is great variance but the names of the collieries are deliberately coded. The result of choice of EQTYP by the subroutine is fed to the main program, which then calculates cost of equipment on the choice of equipment.

Figure No-1 shows Flowchart of model program 'eqp' for Selection of Underground Equipment.

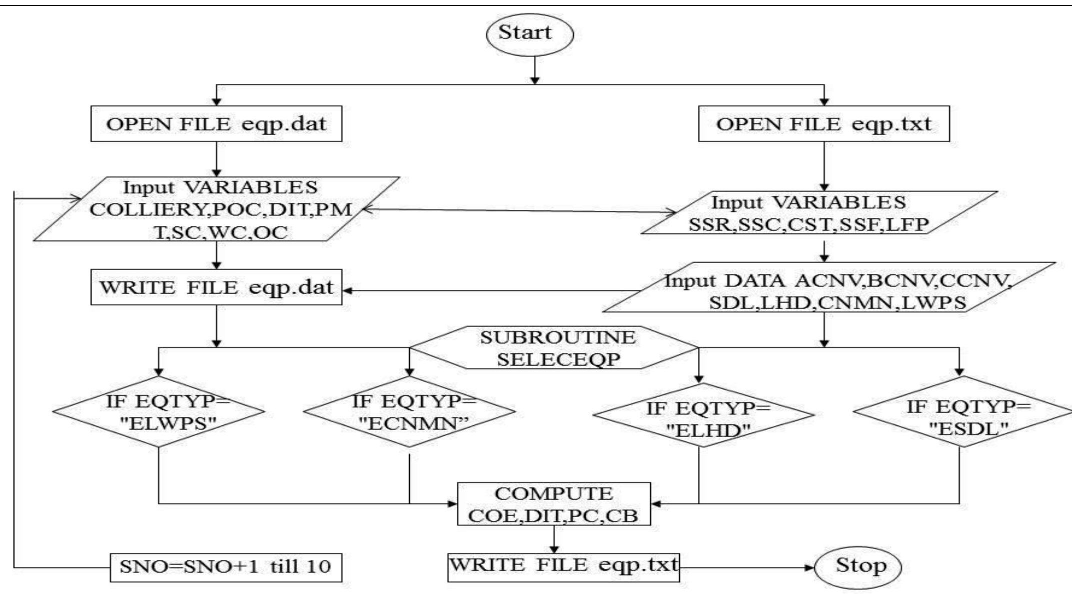

FIGURE NO- 1: SELECTION OF UNDERGROUND EQUIPMENT

Algorithm of eqp/* for Appropriate Choice of Equipment for planning and scheduling

Step 1: Open new File"eqp.dat", for read-write; for input data for program

Step 2: Open new File “eqp.txt", for read-write; for Economic Equipment Package and write headers

Step 3: |SLNO|COLLIERY|EQUIPMENT TYPE|COST OFEQPT.|PRODUCTION OF COAL,LTPY|DEP&INT YLY,Rs/T|POWERSTORE+MNT,RSPT|COSTWAGERSPT|COSTOTHCSTRSPT|OTHCSTRSPT|PROD.COSTRSPT|COALPRICERSPT|COSTBENEFITRSPT,YLY|

Step 4: Up to SNO<=10;Input COLLIERY;COLLIERY
Step 5: Input COAL PRICE;CP
Step 6: Input PRODUCTION OF COAL;POC
Step 7: Input POWER + MAINT;PMT
Step 8: InputSTORE COST, WAGE COST;SC, WC
Step 9: Input OTHER COST;OC

Step 10: EQTYP=SELECEQP; COE=(BCNV+4*CCNV+3*SDL) for SDL set

Step 11: COE= (BCNV+5*CCNV+4*LHD) for LHD set

Step 12: COE=(3*BCNV+CNMN) for Continuous Miner Set

Step 13: COE=(BCNV+ACNV+LWPS) for Longwall Power Support set

Step 14: DIT= (0.22*COE/POC);PC=DIT+PMT+SC+WC+OC; CB=CP-PC

Step 15: Compute COE,DIT,PC,CB

Step 16: InputSHEAR STRENGTH OF ROOFSTONE;SSR

Step 17: Input SHEAR STRENGTH OF COAL; SSC

Step 18: Input COAL SEAM THICKNESS;CST

Step 19: Input SHEAR STRENGTH OF FLOOR STONE ;SSF

Step 20: Input LARGEST FAULTLESS PANEL;LFP

Step 21: if ((LFP>1000) && (SSR<100)); EQTYP = "ELWPS";

Step 22: if ((SSC < 20) && (LFP>500)); EQTYP = "ECNMN";

Step 23: if ((CST>5) && (SSF>80)); EQTYP = "ELHD";

Step 24: if ((CST<4) && (SSF>100)); EQTYP = "ESDL";

Step 25: Write EQTYP;SNO=SNO+1;

Step 26: Print eqp.txt and close files

5. RUN OF THE MODEL

According to assignment statements and formula the output data are computed and automatically stored in the appropriate format and location in the output file. Rock properties like Shear strength etc. have been taken from CMRI data, on Indian Coal Measure rocks. After study of the outputs, if further modifications are desired, the program has to be accordingly edited, recompiled, re-linked and rerun, according to the above procedure, till expected results are obtained. The printout of the files could then be taken again for final record and the files may be deleted from memory of the computer. But, on the whole, data input of 10 collieries has been on realistic basis, apportioning the costs, on different heads, as can be observed from input data file, shown in Table No-3.

Cost data of mines operating on similar technology have been taken with permission of the company. Data went into the computer run and recorded as eqp.txt file. This indicates that on the basis field cost data input, the projects could be scheduled, or prioritized on the basis of projected cost benefit accruable per tonne.

6. ANALYSIS OF RESULTS

If target standard productions of the machines are achieved, it is found that there could be considerable saving in cost benefit in each case. The input data is fuzzy in the sense that colliery cost sheets do not prepare separate cost sheets for SDL/LHD mines, but includes the figures of the manual district also and so data had to be interpolated.

In cost of equipment, incidentals like cost of switchgears, cables etc. are included but indirect costs like improving ventilation, lighting, support, increase in skilled manpower for operation and maintenance and reduction of unskilled manpower etc. are difficult to compute, unless specific case is analyzed and the overall effect would be on the plus side. But, where due to adverse geological or water seepage problem, in the dip development, excessive power failure etc. rated production is not achieved, losses mount.

Regarding selection criteria of equipment, Continuous Miner performance in past Indian experience has not been satisfactory, because of harder Indian coals and so it should be selected for only coal seams with very low shear strength of friable nature or tool-pick designs like that of rock tunneling Moles have to be fitted.

TABLE NO- 3: COMPUTER MODEL RUN IN JAVA
ECONOMIC SCHEDULING OF EQUIPMENT PACKAGE

SLNO	COLLIERY	EQUIP	COST	PRODN	DEP&INT	POWER	STORECOST	WAGECST	OTHCST	PRDCOST	PRICE	BENEFIT
	TYPE EQPT COALLTPY YLYRSPT +MNTRSPT RSPT RSPTRSPTRSPTRSPT RSPT,YLY											
1	BKL/BKL	ESDL	45	1	9	61	75	152	73	370	437	67
2	CHR/KND	ELHD	70	2	7	60	68	178	98	411	480	69
3	CHN/SOD	ECNMN	49	1	10	97	81	165	87	440	475	35
4	DHM/STP	ELWPS	175	7	5	94	82	130	115	426	450	24
5	JRA/JHR	ELWPS	175	9	4	65	76	125	124	394	411	17
6	NSR/KNT	ESDL	45	1	9	83	91	138	74	395	464	69
7	PRS/KNT	ESDL	45	1	9	75	84	154	79	401	472	71
8	BHL/KND	ESDL	45	1	9	81	95	157	92	434	490	56
9	DBS/SDP	ESDL	45	1	9	93	82	149	91	424	485	61
10	KLD/SAT	ESDL	45	1	9	60	51	148	105	373	436	63

There is quite a number of software available for Mining like Surpacby Gemcom Software International; Carlson Mining 2009 by Carlson Software; iGanttby Minemax; Minecare; by Modular Mining Systems; Mineographby Core General Systems; MinePoint ERP by UXC Eclipse; Promine by Promine; Vulcan by Maptek; Xerasby RungePincockMinarco etc. Some leading project management software are shown in Table No-4.

TABLE NO-4: COMPUTER PROJECT SOFTWARE AND NETWORKING

1. Microsoft Office Project 2013 for project management.
2.Best Software TimeSheet Professional 9.0, a widely recognized leader.
3.KLH project systems CRESTA and PREMIS have both AOA and AON outputs.
4.ARTEMIS for project management has PC, mini and even mainframe versions.

5. TRIRIGA(R) has Web-based facilities and project management solutions.
6. Computer Methods International Corp.'s CMiC Enterprise and Project Management..
7. MEDIACHASE has collaboration capabilities with project management.
8. Oracle Apps, Siebel, J2EE, SAP in oracle projects Costing and Project Management.
9. (EPM). SAP's PLM application is for project management, and data management.
10. JTECH Update for PMX is a utility designed for project management.
11. Project InVision 6.0 is with enhancements to simplify complex project management.
12. The Project Management XML (PMXML) is project management application.
13.VERTIS RealTimeProof is online Visionbank TDW/Project Management solution.
14.COMPUWARE is for Reliability, Value Analysis, Schedule as per PMI.
15. VERTABASE Pro Software crafts faster and better project
16.Deltek Vision integrates project management, resource planning, and automation.
17. BORLAND adds project-management features to CaliberRM.
18. TENROX 8.3 featuring integration, of major financial and project management
19. Method123 suite of project management templates, at Malmo, Sweden
20. Gemcom Software - Mine Phase and Development

6.CONCLUSIONS

Since the wage rates have gone very high, and manual loading mines are losing at much higher rate because of poor productivity. There is hardly any other option but to make a success of coalface mechanization. Some of the critical points observed by the researcher need be mentioned for applications: -

(1) The indigenous manufacture of the successful models is recommended for easy availability of spares and so likelihood of better availability, utilization.
(2) Indian ambient conditions, like high temperature and humidity need better oil-seals or even microprocessor control for less downtime and efficient operation. Even the latest Shearer designs are with microprocessor control with no chance of hydraulic oil leakage or downtime.
(3) For capital intensive LWPS, favorable geological conditions should be ensured before introduction, at least 1 km^2, i.e.100 hectares should be without any major fault. The roof should be cavable and shear strength of roof-stone should be preferably less than 100 kg/cm^2.
(4) Load Haul Dumper is much sturdier but costly, compared to SDL and is most suited for deployment with Blasting Gallery Method of mining thick seams, for loading and hauling from a distance of long hole blasted coal to the conveyor.
(5) Any face mechanization program, has to be backed up with properly equipped underground workshop, sufficiently trained manpower for maintenance and operation, proper ventilation and lighting and support systems, like roof-bolts, wherever required, for ease of movement of the machine, motivated crew with attractively designed incentive scheme etc.
(6) Scheduling for introduction of proper face mechanization has to depend upon the amount of likely cost benefit to be achieved, budget position, fund reallocation according to the company’s priorities, infrastructure, power, manpower availability, marketability of coal and so on.
(7) The model developed by the researcher could be adapted for all OS and could be easily utilized by a mine planner, with knowledge of programming. But the researcher’s effort has been to make the program realistic based on operational cost data in present coal mining industry for use by a mine planner.
(8) For high production and profitability, where Longwall is not applicable, CM technology has to be introduced with comparatively less investment and record performance achieved was by a Joy Continuous Miner of 229, 214 t in a month.

Program run of model **‘eqp’** with realistic data, can help make right choice of equipment-sets for underground mine mechanization planning and then project scheduling and monitoring.

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