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Research Priority Trends in Coalmine Technology Efficiency

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Abstract--Considering the international scenario, knowledge is growing exponentially and scientific research is the foundation of technological innovations. Some of the major research going on health and environmental outcomes, digital technologies, artificial intelligence, blockchain, mining oil, gas, minerals, renewable energy, electric vehicles, and battery technology can be used for improving mining industry performance. Sustainable development is one of the United Nations' Global Goals that it would like to achieve by 2030. As a part of this strategy, it has developed 17 Sustainable Development Goals (SDGs). Mining is the most dangerous peace-time profession in the world and coal mining is more so because of danger of gas-dust explosions. Because of continued oil crisis, coal will continue to major role in the industries of the world, despite growth of renewables. With increase of cost of inputs, materials, wages, fringe benefits very high productive and safe technology is required for viability. Appropriate mechanization for opencast and underground mines with present trends included. Some of the latest trends worldwide and being planned by the Ministry of Coal and others are elaborated in this paper.

Keywords--Innovation, Technological Upgrades, Stakeholders, Sustainability, Digital Technologies, Viability

I. INTRODUCTION

Organizations have to integrate the SDGs into their engineering strategy more effectively to improve efficiency, productivity, and profitability whilst also promoting sustainable development and helping to solve global challenges. The domination of technology requires multidisciplinary research and a new kind of cooperation with industry that leads to a new scientific environment where engineering becomes much more important than the advancement of knowledge. Company goals help us to stay focused on our long-term plans by completing smaller tasks that improve our job performance and satisfaction. One of the most significant challenges engineers are to keep up with the current trends and acquire the necessary skills over a short period. The real challenge for the mining industry now is that the quarriable reserve of mine properties is approaching the cut-off ratio, aggravated by rising prices of inputs. Remaining reserves at greater depth and viable high productive underground mining technology need to be developed, Earlier mining areas were mostly inhabited and gradually getting populated and resettlement and rehabilitation needs stakeholder management.

High techno-economic mechanization both in opencast and underground mining possibilities are suggested.

Right planning in virgin property for new project requires detailed geological and techno-economic data. It has been observed from the study of cost-sheet for many years that because of increasing wage and material cost, social and welfare overheads; high production capacity mines are more profitable, even though investments were higher. Cost-Capacity Relationship is given by: -

$$C_A/C_B = (S_A/S_B)^x$$

Where, C- Cost of projects, S- Size of projects, Subscripts A and B for name of projects, x- Cost-capacity relationship exponent, between 0.6-0.8, as found on analysis and the researcher found it applicable in practice.

II. PROJECT MANAGEMENT

The triple constraints of the software project like time, cost, and scope are directly dependent on the requirement of the project. Agile methodology is the iterative way of developing the software project for frequent changes, fast delivery and reduce risk. Software project management also plays important role in agile based software project. Agile methodology influence software project management at 10 knowledge areas. A survey of different software companies and it shows that almost every software company uses agile development (Scrum) and has a positive impact on the software project management.

The studies also showed that project management methodologies/ models should be customized/ tailored for the different projects so as to best fit the scenario and reduce cost and time. Activities having floats in critical paths have to be crashed even with additional costs to achieve the target date of completion of the project. Finding the Critical Path, activities will affect the project's success. When deciding to crash a project, must add resources to one of the activities on the critical path.

There have been continual upgrades of project management software, around the world and numerous innovations and patents are being registered. The researcher has laid more emphasis on the long-term viability of projects by computing cost benefits as well as critical systems, rather than making just a software package of scheduling, of which many are available. Project management apps also give the project manager and any stakeholders a clear overview of each project's progress.



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Are all the tasks on track to finish on time? If one task is late, how does it affect the projected deadlines of other tasks and deliverables? Is someone available to pick up an urgent task if the assigned person is ill? Furthermore, if the project management app supports tracking finances, it can tell the people in charge whether the project is running on budget.

Some of the recent project management apps are: - Teamwork; Zoho Projects; Basecamp; GanttPro; Smartsheet; Wrike etc. Traditional project management software developed from main-frames are updating to latest versions. Only twenty mentioned here among 400 project management software developed so far.

Artificial Intelligence, (AI) has been successfully used for years in advanced applications. Fuzzy logic computations are for dealing with uncertain and complex problems. Profitability Index (PI), Return On Investment (ROI), or Discounted Cash Flow (DCF) rate of return are some of the indicators of profits. All the packages are further divided into sub-packages and the sum is made head-wise, applicable for all types of mining, in conformity with budget heads. Table No-1 shows some 20 mostly used project management software for networking in the industry.

Table No-1: Computer Project Software And Networking

1. Microsoft Project
2. Best Software TimeSheet Professional
3. KLH project systems CRESTA and PREMIS
4. ARTEMIS has PC, mini and even mainframe versions.
5. TRIRIGA(R) Web-based facilities and solutions.
6. CMiC Enterprise and Project Management..
7. MEDIACHASE collaboration project management.
8. SAP in oracle projects Costing and Project Management.
9. (EPM). PLM application is for project and data management.
10. JTECH for PMX is a utility designed for project management.
11. Project InVision 6.0 complex project management.
12. XML (PMXML) is project management application.
13. VERTIS RealTimeProof is online Visionbank TDW
14. COMPUWARE is for Value Analysis, Schedule as per PMI.
15. VERTABASE Pro Software crafts faster and better project
16. Deltek Vision integrates planning, and automation.
17. BORLAND adds project-management features to CaliberRM.
18. TENROX financial and project management
19. Method123 suite of project management, Sweden
20. Gemcom Software - Mine Phase and Development

III. OPENCAST MINING

Stripping activity provision (Ratio Variance): Stripping activity provision recognized earlier is based on the policy followed consistently by CIL since its inception. Stripping activity provision (net) was recognized or reversed based on the current ratio of OB to Coal as compared to the average Stripping ratio (Standard ratio) of the mine. This accounting method has been substantiated and validated by a multitude of authoritative bodies and forums, including income tax authorities.

It has been estimated that more than two-thirds of the world's yearly mineral production is extracted by surface mining.

There are several types of surface mining, but the three most common are open-pit mining, strip mining, and quarrying. Sanskrit texts mention the use of bitumen, rock salt, yellow orpiment, chalk, alum, bismuth, calamine, realgar, stibnite, saltpeter, cinnabar, arsenic, Sulphur, yellow and red ochre, black sand, and red clay in prescriptions. With stricter environmental norms, challenges in obtaining surface rights for opencast mining heavily dependent on use of technology. More and more mining lands are getting inhabited by people in the hope that they will get employment and compensation.

The operating cost of mechanized opencast mines has escalated more so with increase in prices of essential inputs, spiraling prices and improved welfare facilities to employees. We should plan for minimizing diesel guzzling HEMM (Heavy Earth Moving Machinery) as thousands of Crores of ₹. is spent annually towards import of petroleum products, as there is deficit of indigenous crude petroleum production.

Figure No-1 shows the largest Battery Electric Dumper. The eDumper dump truck (Komatsu HB 605-7) is the largest electric vehicle in the world. The e-Dumper, made by Kuhn Schweiz, it's based on a Komatsu HB 605-7, it's 30 feet long, 14 feet wide, and 14 feet tall. The tires are six feet high, and the dump bed reaches over 28 feet when it's fully raised. With a 600-kilowatt-hour battery pack, all of the truck's energy is stored in its lithium electric battery which weighs around 5 tons.



Figure No-1: Battery Electric Dumper

CIL has introduced State-of-the-Art technology to improve work efficiency. High capacity HEMMs like 42 cum Shovel with 240T Rear Dumper are running in Gevra Expansion, Dipka & Kusmunda opencast mines. 20 cum Shovel with 190T/200T Rear Dumpers are running in Amlohri, Dudhichua, Jayant, Khadia & Nigahi of NCL, and in Rajmahal of ECL. Population of these high capacity HEMMs in CIL as on 30.11.2025 is 42 cum shovel - 8 numbers, 20 cum shovel - 26 numbers, 240T dumpers - 72 numbers and 190T/200T dumpers - 163 numbers.

Surface Miners have been introduced in opencast mines in a big way to improve operational efficiency, customer satisfaction & to cater environmental needs.

54.84% of total coal production of CIL during 2023-24 was achieved through using Surface Miners and it has increased to 57.85% during 2024-25. As on 30.11.2025, 47 numbers of departmental Surface Miners in addition to the Surface Miners deployed through hiring mode are in operation in several opencast mines of CIL.

Despite technological advances, load haul circuits remain wasteful and highly variable. McKinsey and Company estimate that 45-52% of emissions are associated with loading and hauling in a typical open pit mine. Titan reduces payload variability, tightens spreads, and increases average truck payloads without increasing overloads - meaning you get more tonnes for your equivalent emission footprint.

Projects can be designed with all stages in a single step and design changes can be updated with the NETPRO Mine. Open Pit Planning module can automatically generate and edit interior ramps along with the pit lines, and automatically report all solid and block model creation operations and volume results according to the needs. This module offers practical solutions for our Open-pit design, waste/stock design, tailings dam design, surface road design, and blasting pattern design projects. Ability to design using different bench angles in specified areas ramps and control ramp slopes. Switchback design in ramp turns.

Simplifying design lines and softening them according to different methods.

Highwall mining is generally adopted where open-pit reaches its pit limit and further expansion is not viable – multiple and multi-pass highwall mining is possible and has been demonstrated at the end user mine site. Where the roof conditions are good, moderately flat seams, competent coal seam, stable highwall and strata is free from geological disturbances and presence of stone bands in the seam. Figure No-2 shows a Highwall Miner being used in many abandoned shallow quarries in India.



Figure No-2: Highwall Miner From Quarry

Highwall miner produces high volumes of coal at very low costs. More importantly, it is safer than traditional underground mining, as it sends no one underground, and it works economically with a small crew and very little support equipment. It's versatile in its mobility and application, and it produces large quantities of coal at inherent ash levels.

When you need to improve the recovery of your coal reserves, consider the Highwall Miner – consider the HW300. Specifications- Highwall Mining System; Maximum Penetration Capability: 300m



The main features of Plasma Blasting are many. Blasting may be performed at any sensitive locations. Easy to handle and transport as it is a non-explosives material. Very less ground vibration and noise. Negligible fly rocks has no blasting fumes and Environmentally friendly and many more advantages.

Implementation of Integrated Command Control Centre (ICCC) is to augment overall e-security and surveillance. At the field level, the system is equipped with Artificial Intelligence (AI) enabled cameras and Video Analytics which generate alerts on different parameters such as movement of man and machinery, moving object detentions, crowd detection, intrusion detection, camera tampering, vehicle count, Automatic Number Plate recognition etc.

ASX battery hopeful improves solid state storage of hydrogen Australian Mines getting closer to a hydrogen storage solution that can be used for light duty vehicles and mining trucks. Despite technological advances, load haul circuits remain wasteful and highly variable. McKinsey and Company estimate that 45-52% of emissions are associated with loading and hauling in a typical open pit mine.

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IV. UNDERGROUND MINING

Underground mine performance in coal industry is declining and needs high productive systems. Proper selection of coalface mechanization equipment requires many factors to be considered for long-term viability of underground mines and the researcher has exemplified such a program. 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.

Underground mining sustainability is on the wane, because of environmental, ventilation, and support legislation resulting in poor productivity. Longwall mining is a highly productive underground coal mining technique, provided a very large area with an undisturbed roof is available.

Being a highly capital-intensive Longwall Power Supports System (LWPS), as well as Continuous Miner System, require project and operation management to be interlinked.

CIL has prepared a UG Vision Plan and according to it, CIL has planned to produce 100 Mt by the year end 2034-35. The major thrust area to augment UG production is by introducing Continuous Miner (CM) in a big way as well as by implementing large number of Highwall mines to improve percentage of extraction. At present, 42 nos. of Continuous Miners (CM) have been deployed in 23 UG mines of CIL with total production capacity of about 20.671 Mty and 2 longwall faces with production capacity of about 2.4 Mty.

As per UG Vision Plan, CIL has envisaged a plan for commissioning of another 37 Nos. of CMs in pipeline and balanced 61 are going to be projected by 2034-35. At present, 5 Highwall miners are running with a capacity of 2.5 Mt and additional 5 nos. of Highwall miners will be commissioned by 2034-35. Further, 46 man-riding system has been introduced in a number of underground mines with the objective of reducing unproductive travelling time of mine workers. Also, trackless transport system (five free-steered vehicles and seven multi-utility vehicles) have been introduced for men and material transportation.

Recent investigations in Rock Mechanics and technological development of earthquake proof designing, the method suggested could be promising. The author is associated with development of earthquake-quake proof support for full extraction in underground mining through Central Institute of Mining & Fuel Research. The success of the S&T project will have far reaching advantages in the coal industry for underground coal extraction, not only in India, but across the world.

Underground mechanization in India have been mostly with Longwall Power Support system with caving method with danger of subsidence to upper seams or surface. Moreover, hard sandstone roof difficult to cave and collapse of support system have occurred eg Khottadih in ECL and others. New coal exploration show that most coalfields have multiple seams and Continuous Miners of high capacity are being planned. Figure No-3 shows a Continuous Miner for high production from underground coalmine.



FIGURE NO-3: CONTINUOUS MINER FOR UNDERGROUND

For precision of highest level, Total Station & 3D TLS survey instruments have already been introduced for survey & measurement work. High end survey grade Drone Technology equipped with Optical Sensor, LIDAR and Thermal Sensors have been procured by CMPDI which are being used for different survey purposes such as, Volumetric measurement, Topographical survey, thermal mapping of mine fire zones, change detection, Soil Moisture Conservation (SMC) Studies and generation of digital terrain models & Fly-through videos. DGPS equipment is being used for Boundary surveys. Side Discharge Loaders, Load Haul Dumpers can be used in conjunction with local spillage.

V. SAFETY FIRST

Legislation related to mines in India are many and safety of mines are mainly controlled by internal safety organizations of the mining company. Directorate General of Mines Safety not only ensure safety by inspections, but also issue Circulars for safety. Main legislations followed are 1) Mines Act; 2) Occupational Safety and Health Code, 2022; 3) Coal Mines Regulations, 2017; 4) Metalliferous Mines Regulations, 1961; 5) Oil Mines Regulations, 2017; 6) Mines Rules, 1955; 7) Mines VT Rules, 1966; 8) Mines

Creche Rules, 1986; 9) Indian Electricity Rules, 1956; 10) Mines Rescue Rules, 1985; 11) DGMS Circulars; 12) Notifications; 13) Mines and Minerals (Development and Regulation Act, 1957 (as amended upto 27 March 2015); Mineral Conservation and Development Rules, 2017; 14) Minerals (Evidence of Mineral Contents) Rules, 2015.

VI. ENVIRONMENT MANAGEMENT

The main problem in mining areas is urban growth facing the grave challenges of cost and safety. Tree-felling for mining purposes should be solved by compensatory plantation, as per Forest Department. Many mining areas have been already declared as earthquake-prone zones and constructions should be approved on this basis.

Indian coal PSUs have also undertaken initiatives in bio-reclamation and afforestation as per the approved Mining and Environmental Management Plans. Mined-out areas, overburden (OB) dumps and other disturbed lands in and around mining areas are being progressively reclaimed and afforested. These PSUs are implementing scientific reclamation methods, including multi-tiered plantations and the use of innovative techniques like seed ball plantations and drones for seed casting.



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The adoption of advanced sustainable technologies in coal companies is an ongoing process.

In coal mining, an effective EMS addresses critical issues such as: Air and water quality monitoring; Waste management; Land rehabilitation and biodiversity conservation; Energy use and greenhouse gas emissions reduction Compliance with environmental regulations For the Mine Environmental Scientist, EMS is not simply about complying with rules; it involves a strategic management approach t towards efficiency, sustainability, and long-term profitability.

VII. FUTURE PROSPECTS

Systems engineering has an emerging set of digital tools, a similar pathway for all engineering disciplines. For 2026, Coal India have set a capital expenditure target of 16,000 Crore. To meet the demand of coal in the country and become 'Atmanirbhar' and simultaneously eliminating non-essential import of coal in the country, CIL has envisaged to enhance its production to 1 BT by the year 2028-29 from current level production of 781 MT achieved in 2025. CIL has already identified all resources required, including major projects that will contribute to its 1 BT production plan and its related issues/enablers like requirement of EC/FC, land, evacuation constraints etc.

There are about 25 coalfields extracting coal from various underground and open cast mines. All such coalfields have multiple extractable seams. In many instances, to 10 Highwall mining the tune of about 20%, of these seams occur contiguous to another seam or section (within 9m of vertical parting). There also exist thick seams in almost all coalfields, which may require multiple-pass or sections to extract by highwall mining. Some coalfields even have over 30 workable seams. A cursory glance at the scope of highwall mining indicates that almost every coal mining area, with existing opencast extractions, provides opportunity for highwall mining.

A total of approximately 117.36 KM of railway track need to be laid down for creating around 630.74 MTY evacuation capacity from the connected projects in order to serve the requirements of power plants and other industries. This entails well-orchestrated co-ordination and investment with Indian Railways for building the requisite evacuation capacity. In addition to this, approximately 440 KM of road connectivity need to be added to the new, ongoing and completed projects in order to achieve an additional evacuation capacity of about 381.62 MTY.

VIII. CONCLUSIONS

The knowledge and technical awareness of geotechnical parameters are necessary at every stage from planning, excavation methodology, and equipment selection to the actual process of excavation, transportation, damage prediction, assessment & control, design of supports, and instrumentation. With the advent of modern technologies of investigation, sensor networks, and intelligent applications. The application of mining-specific and generic optimization techniques in the mining industry is deeply rooted in the discipline of operations research (OR). There are various models of Operations Research, namely 1. Optimization model; 2. Simulation model; 3. Network model; 4. Multi-criteria decision-making (MCDM) model; 5. Global optimization model.

AI and the use of robotic advances make work easier for project management. Global trends include the impact of disruptive digital technologies, including ground-breaking current advanced technology applications for the future. Computing power has increased drastically; "Big Data" gathering and storage of digital transactions through "the Internet of Things". Large machines may autonomously maneuver themselves. The mining industry in Australia already uses remotely controlled trucks.

The year 2025 marks a milestone year for Coal India Limited (CIL) — completion of a glorious five decades of ensuring India's energy security and contributing to national progress. CIL has evolved in step with changing times, fueling the nation's growth story since 1975. India's coal production targets are set at 1.3 billion tonnes by FY 2027 and 1.5 billion tonnes by FY 2030. Ten rounds of commercial mining auctions have invited private participation. Policies now place greater emphasis on mechanised loading and rail logistics through First Mile Connectivity (FMC) initiative.

India possesses 389.421 billion tonnes of geological coal resources, including 212 billion tonnes of proven reserves. However, most of this is non-coking coal (around 89%), with limited availability of high-quality coking coal, resulting in continued dependence on imports for the steel industry. New subsidiaries of Coal India are: Bharat Coal Gasification and Chemicals Limited, Coal Gas India Ltd. Coal to Synthetic Natural Gas Project, Bharat Coal Gasification and Chemicals Limited (BCGCL) was incorporated for the coal gasification business. A subsidiary Company was incorporated on 25th March, 2025 for Coal to SNG plant business. CIL is having 51% equity stake and GAIL is having 49%.

Coal exploration presents a realistic picture of mineable reserves and project profitability. CIL requires drilling of around 6123.07 thousand meters over the period from 18 19 to 29-30. Over 113 Project Reports are to be prepared for mining projects for a projected capacity of 825.20 MTY with mineable reserves of 15096.58 MT for achieving the desired set targets.

External Stakeholders especially District Administration, State Government and Ministries of Central Government play a pivotal role in successful implementation of critical activities of a project. The thrust areas are obtaining necessary compliances and Environment and Forest Clearances, Land Acquisition and compensation, taking physical possession of land, rehabilitation and resettlement, creation of necessary infrastructure and coal evacuation.

ARIS is the only BPM software on the market that supports our transformation from strategy down to operations, and throughout the six BPM phases—from understand, process design, implement & automate, rollout, execute & run, to measure and control. ARIS acts like a “one stop shop” for your one way of working. It’s the only solution on the market that combines modeling and mining into a single tool, unlocking advantages you’re unlikely to achieve in a standalone scenario.

Keeping these objectives in view, Joint Working Group on coal had been set up with France, Germany, Russia, Canada, Australia and China. Department of Coal is also the nodal Department for the Joint Commission with Poland. The priority areas, inter-alia, include acquisition of modern underground mining technology, introduction of high productive opencast mining technology, working underground in difficult geological conditions, fire control and mines safety. With the liberalization of the economy, greater thrust is being given to get the foreign investments /assistance on the basis of cost competitiveness.

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