Full Paper Proceedings

The Institution of Engineers (India)

A Century of Service to the Nation

All India Seminar on

RECENT ADVANCES IN SMART MINING TECHNOLOGIES AND RESOURCES

Organised by :
West Bengal State Centre, IE(I)

Under the aegis of :
Mining Engineering Division Board, IE(I)

Jointly with :
Department of Mining Engineering, IIEST Shibpur

DATE

JULY 19-20 2024

Venue : Sir R N Mookerjee Hall, 8,Gokhale Road, Kolkata-700020

All India Seminar
on
Recent Advances in Smart Mining Technologies and Resources

19th - 20th July, 2024

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West Bengal State Centre

&

Department of Mining Engineering

IIEST Shibpur

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About IEI

- The Institution of Engineers (India) or IEI is the largest multidisciplinary professional body that encompasses 15 engineering disciplines and gives engineers a global platform from which to share professional interest. IEI has membership strength of above 0.7 million. Established in 1920, with it's headquarter at 8 Gokhale Road, Kolkata-700020 IEI has served the engineering fraternity for over nine decades. In this period of time it has been inextricably linked with the history of modern-day engineering.
- In 1935, IEI was incorporated by Royal Charter and remains the only professional body in India to be accorded this honor. Today, its quest for professional excellence has given it a place of pride in almost every prestigious and relevant organization across the globe. IEI functions amongst professional engineers, academicians and research workers. It provides a vast array of technical, professional and supporting services to the Government, Industries, Academia and the Engineering fraternity, operating from over 105 Centre located across the country. The Institution has established R&D Centre at various locations in the country and also provides grant-in-aid to its members to conduct research and development on engineering subjects.

  For details, please see: www.ieindia.org.

About Indian Institute of Engineering Science and Technology, IIEST, Shibpur

Indian Institute of Engineering Science and Technology(IIEST), Shibpur owes its origin to the erstwhile Bengal Engineering College, the history of which goes to the nineteenth century when industries in the sense we understand today, were practically absent. Prompted by the idea of meeting the requirement of trained engineering personnel for the Public Works Department, the then council of Education, Bengal, decided to open Civil Engineering classes and a Professorship in Civil Engineering was created at Hindu College, Calcutta, in the year 1843-44. A college of engineering was started by the name of Civil Engineering College on 24th November, 1856, in the premises of the Writers Building, Calcutta.

With the establishment of Calcutta University on January 24, 1857, the college was affiliated to this University in May 1857. The first-degree examination in Bachelors of Civil Engineering was held in 1864 in which only two students graduated. In 1865, the college merged with The Presidency College, Calcutta and from 1865 to 1869 the college functioned as the Civil Engineering Department of Presidency College. In 1880, the college was shifted to its present campus at Shibpur, Howrah, and was christened the 'Government College, Howrah,' in the premises of Bishop's College. It started imparting training in Civil Engineering as well as Mechanical Engineering. The college became wholly residential from the year 1889.

In 1921, the name of the college space was changed to 'Bengal Engineering College' (popularly known as B. E. College). During 1921-43, the various departments of the college were reorganized on the recommendation of the 'Mukherjee Committee' under the Chairmanship of Sir R. N. Mukherjee, one of the most distinguished ex-students of the college. The degree course in Mining Engineering was introduced in the year 1906 and the first batch of Mechanical and The first batch of students in Mechanical Engineering appeared in the degree examination in 1932. The degree course in Electrical Engineering was introduced during 1935-36 and that in Metallurgical Engineering in 1939. The Department of Humanities started in 1945, Applied Mechanics in 1947, and Architecture, Town and Regional Planning Department in 1949.

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR
Department of Mining Engineering, Howrah 711 103

Editorial

The National Seminar on "Recent Advances in Smart Mining Technologies and Resources" has illuminated a path forward that merges technological innovation with sustainable practices in the mining industry. As we navigate the complexities of resource extraction in the 21st century, it is clear that smart technologies are pivotal in optimizing efficiency, ensuring safety, and minimizing environmental impact. The most prestigious national seminar for enhancing smart mining technology all over India is being organized by the Department of Mining Engineering of IIEST Shibpur jointly with the West Bengal State Centre, IE (India) under the aegis of Mining Engineering Division Board of IE (India) during19 -20th July, 2024.

Central to discussions at the seminar are advancements in automation and artificial intelligence (AI) that are revolutionizing mining operations. From autonomous drilling rigs to predictive maintenance systems powered by machine learning, these technologies are enhancing productivity while reducing the risks associated with human intervention. The integration of AI-driven analytics is enabling real-time decision-making, thereby optimizing resource utilization and operational efficiency. Remote monitoring systems, wearable sensors, and advanced communication networks are transforming safety protocols, ensuring rapid response to emergencies and proactive risk mitigation strategies.

This seminar has received tremendous interests and enthusiasm from authors, as huge number of papers is submitted on different fields. The Technical Committee of the national Seminar has done a great job in reviewing the articles submitted and suggesting possible modifications. Finally 27 paper abstracts have been selected and accepted for oral presentation under various themes comprising five technical sessions spread over two days of July 19-20, 2024. Full length paper proceedings will be published and it will include all the abstracts of accepted contributory articles, four special lectures, two keynote speakers, and it will be distributed to the participants. The editorial board has taken great care of covering all important aspects of smart mining technologies and to compile these proceedings in the best possible form.

The proceedings are an outcome of the relentless team efforts by the technical committee members and other technical staff members of the organizing committee of the conference. The organizing committee expresses thanks to all the authors for their contributions to this volume. The mining industry has contributed in a big way in the form of sponsorships for the grand success of this National Seminar.

We are confident that the proceedings of the National Seminar on "Recent Advances in Smart Mining Technologies and Resources" would be of immense help to mining researchers, academicians, planners, governmental agencies, industry professionals and technology providers who are directly or indirectly involved, in the adoption of sustainable practices in mining operations globally. As we look ahead, it is imperative to maintain momentum by embracing innovation, prioritizing safety and sustainability, fostering collaboration, and empowering the next generation of mining professionals. We extend a warm welcome to all the delegates and special invitees on behalf of the organizing committee of the conference.

Prof. Ashis Bhattacherjee
Chairman

Dr. Shreedevi Moharana
Convener

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The Institution of Engineers (India)

AN ISO 9001 : 2015 CERTIFIED ORGANISATION
(ESTABLISHED 1920, INCORPORATED BY ROYAL CHARTER 1935)

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A Century of Service to the Nation

FROM THE DESK OF PRESIDENT, IEI

It gives me great pleasure to know that the West Bengal State Centre of The Institution of Engineers (India) is organizing the All India Seminar on the topic "Recent Advances in Smart Mining Technologies and Resources," in collaboration with the Department of Mining Engineering, IIEST Shibpur on 19-20 July 2024. It promises to be a pivotal event in exploring innovative advancements and sustainable practices in the field of mining.

The seminar aims to delve into advancements such as automation, IoT, and AI-driven solutions that optimize operations and enhance safety in mining. With the good number of papers spanning five technical sessions, experts will discuss sustainable practices, environmental stewardship, and the future implications of smart mining technologies. The diversity of topics and the depth of expertise represented in these papers reflect the dynamism and dedication of our engineering community towards shaping the future of mining. I am sure that this gathering serves as a platform for engineers and researchers to exchange ideas and chart the course for a more efficient and sustainable mining sector.

I extend my sincere greetings to the organizers for their diligent efforts in putting together this insightful seminar. Such initiatives sanguinely play a crucial role in fostering knowledge exchange and collaboration within our engineering community. I encourage all participants to engage actively in discussions and networking opportunities during the seminar, thereby enriching our shared knowledge base and forging new pathways for advancement.

I wish the Seminar a grand success.

Dr G Ranganath

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निदेशक

Prof. V.M.S.R.Murthy
Director

IIEST, Shibpur

भारतीय अभियान्त्रिकी विज्ञान एवं प्रौद्योगिकी संस्थान, शिबपुर
(शिक्षा मंत्रालय, भारत सरकार के अधीन एक राष्ट्रीय महत्वपूर्ण संस्थान)

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR
(An Institute of National Importance under MoE, Govt. of India)

MESSAGE

I am pleased to learn that a Seminar on "Recent Advances in Smart Mining Technologies and Resources" is being organized by the Department of Mining Engineering of IIEST Shibpur jointly with the West Bengal State Centre, IE (India) under the aegis of Mining Engineering Division Board of IE (India) during19 -20th July, 2024. The topic chosen by organisers is apt and timely in the context of growing complexities in the mining operations.

Traditional mining practises are less productive, hazard prone, costly and complex geological conditions make this much more challenging. Smart mining integrates traditional mining practices with information and communication technology (ICT), representing the fourth industrial revolution (Mining 4.0). It focuses on leveraging digital transformation to optimize operations and enhance safety, efficiency, and sustainability. Some of the technological innovations are, advanced sensors and data analytics to improve process parameters, detect anomalies, and prevent equipment failures, smart helmets and wearable proximity warning systems to help prevent collisions between equipment and pedestrians, machine learning and robotics applications in predictive maintenance, anomaly detection, and optimization of mineral processing operations, machine-vision-based systems in smart hoppers to detect and remove obstructive rocks, path-planning methods using high-precision digital maps for open-pit mining to optimize transportation costs by considering terrain factors and immersive learning environments using Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) to simulate complex mining equipment and their operational planning. The key benefits foreseen are improved safety, reduced downtime and maintenance costs, increased efficiency, and more sustainable mining practices.

I am glad that the proposed seminar will be attended by a good number of researchers and experts from various quarters of academia and industry and trust it will certainly provide a platform to deliberate on the themes covering the mining value chain and share views on varied topics of contemporary interests. The discussions, I am sure would benefit all the stakeholders for realising safe, smart and sustainable mining concepts and practises.

I wish the two-day All India Seminar a grand success and complement the praiseworthy efforts of the organizers.

Date : July 09, 2024

(V. M. S. R. Murthy)

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A Century of service to the nation

FROM THE DESK OF CHAIRMAN, WBSC, IEI

It is my great pleasure to know that the Mining Engineering Divisional Sub Committee is going to organize All India Seminar on “Recent Advances in smart Mining Technologies and Resources” . The Seminar is scheduled to be held on July 19-20, 2024 at Sir R N Mookerjee Hall, WBSC, IEI, Kolkata. I believe that the Seminar will provide an open platform to all Technical fraternity from the country for felicitating exchange of ideas and concept aiming to emphasize India’s emergent role for ‘Make in India’ as a Global leader in Engineering and Technology. In fact, today’s Stand of India is as an inherent and indispensable player in the Global arena of Science, Engineering and Technology. Truly speaking, India’s recognition in the field of Mining in the World today is largely secured by its one of the pillars of Mineral Sector. I hope this Seminar would come out with valuable suggestions and Recommendation for more purposeful use of the ever-emerging new Technologies for better sustainable future. I congratulate the Mining Engineering Divisional Sub Committee and extend my best wishes for the grand success of the Seminar.

Prof. (Dr.) Raju Basak

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR
Department of Mining Engineering, Howrah 711 103

FROM THE DESK OF ORGANISING SECRETARY AND CO-CHAIRMAN OF THE SEMINAR

I am delighted to learn that the Institute of Engineers (India), West Bengal State Centre under the aegis of Mining Engineering Division Board, IEI jointly with Department of Mining Engineering, IIEST Shibpur is organizing an all India seminar on “Recent Advances in Smart Mining Technologies and Resources” be held during July 19-20, 2024 at Sri R N Mukharjee Hall, 8 Gokhale Road Kolkata-700020. The seminar aims at giving open platform to renowned personalities in the field of Mining Engineering to deliver lectures, so as to prepare guidelines on various aspects of advancements in Mining Sector. It is also learnt that a diverse group of distinguished guests, industry leaders, experts from academia and research have shown their keen interest in attending this event.

It’s well-known that engineering is all about the transformation of fundamental science into an acceptable solution that answers to the challenges faced by the human civilization as a whole. In this rapidly changing world, the engineering methods and techniques for a given system do not remain the same. Engineers face significant challenges to cope up with the increasing demand of energy, work efficiency and adequate safety, health and environment (SHE). In this context, outcome from the “Smart Mining Technologies and Resources” can be very good solutions to the asset management especially for the managers and all stake holders, to have sustainable and continuous operation with high reliability and availability.

I wish the two-day All India Seminar a grand success and applaud the praiseworthy efforts of the organizers to take up such a good and appropriate theme for discussion. I strongly believe that the outcome of this seminar would help in giving a new dimension in the field of Mining Sector in India and abroad.

Prof. (Dr) Netai Chandra Dey
HOD (Mining), IIEST Shibpur

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A Century of service to the nation

FROM THE DESK OF HONORARY SECRETARY,WBSC,IEI

I am delighted to be part of the Organizing Team to host the **All India Seminar on RECENT ADVANCES IN SMART MINING TECHNOLOGIES AND RESOURCES,** being organized by West Bengal State Centre under the aegis of Mining Engineering Division Board (MNDB), of The Institution of Engineers (India), jointly with Department of Mining Engineering, Indian Institute of Engineering, Science and Technology, Shibpur, scheduled to be held during **July19 – 20, 2024** at Sir R N Mookerjee Hall of the institution.

In the dynamic landscape of mining engineering & technology, a strategic focus on productivity enhancement initiatives is driving transformative changes. This concerted effort aims to optimize workforce efficiency and operational processes by implementing advanced strategies and technologies. Efforts are also directed towards planning and time management, leveraging advanced systems to plan mining operations with precision.

Pursuant with the above mission, vision & objective, the present All India Seminar is all set to create a platform where distinguished experts in the field from academy, research and industry from across the country will discuss and deliberate on the fittingly devised theme of the event to draw up consequential recommendations.

I extend my sincere thanks and gratitude to all the participants, guests, experts, sponsors, advertisers and all who have directly and indirectly extended their support and co-operation to make this event a grand success.

Sd/-
Anirban Datta
Honorary Secretary
West Bengal State Centre
The Institution of Engineers (India)

INDIAN INSTITUTE OF ENGINEERING SCIENCE AND TECHNOLOGY, SHIBPUR
Department of Mining Engineering, Howrah 711 103

FROM THE DESK OF CONVENER OF THIS SEMINAR

It is with great pleasure and anticipation that I extend my warmest welcome to each of you to the National Seminar on "Recent Advances in Smart Mining Technologies and Resources" is being organized by the Department of Mining Engineering of IIEST Shibpur jointly with the West Bengal State Centre, IE (India) under the aegis of Mining Engineering Division Board of IE (India) during19 -20th July, 2024. This gathering promises to be an enlightening and pivotal event in the realm of mining technology.

In today's rapidly evolving landscape, the mining industry stands on the precipice of transformational change driven by advancements in smart technologies. This seminar serves as a crucial platform for experts, researchers, industry leaders, and policymakers to converge and explore the frontier of innovation and their profound implications for mining practices globally. The main purpose is to foster an environment of knowledge exchange and good collaboration with industry leaders, researchers, academia that will explore cutting-edge technologies such as artificial intelligence (AI), machine learning (ML), advanced data analytics, IoT, automation, and their applications in enhancing operational efficiency, safety standards, and environmental sustainability in mining operations. Throughout the seminar, you can expect thought-provoking keynote addresses, insightful technical sessions, and special lectures that will highlight real-world case studies and success stories. These sessions are designed not only to showcase technological breakthroughs but also to facilitate discussions on overcoming challenges and harnessing opportunities in the smart mining era.

I extend my heartfelt gratitude to our distinguished speakers, session chairs, co-chairs, sponsors, participants, and organizing committee members for their invaluable contributions in shaping this event. Your dedication and expertise are instrumental in ensuring the success of this seminar. I invite all of you, to actively participate, share your insights, and forge connections that will drive innovation and sustainability in mining. I look forward to fruitful discussions and to make this seminar a grand success and a memorable experience for all involved.

Dr. Shreedevi Moharana
Convener
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KEY NOTE SPEACH

Smart Mining Techniques adopted in Malanjkhand Copper Project of Hindustan Copper Ltd

Vivek Narayan Mishra[1], Arindam Ghosh[2], Nagesh Gopalkrishna Shenoy[3], Sanjiv Kumar Singh[4]

Abstract:

Malanjkhand Copper Mine (MCP) having India's single largest copper deposit of M/s. Hindustan Copper Limited (HCL), under the administrative control of Ministry of Mines, GoI, established in 1979 over an area of 479.90 ha. The underground mine is developed below the existing open pit with "Large Dia Blast Hole with Post Paste filling" mining method. Presently, the mine is producing to the tune of 2 MTPA of copper ore with a plan to enhance the production capacity to the tune of 5 MTPA. As the production is scheduled for augmentation, some of the smart and advanced operational techniques have been introduced/proposed for cost effecting mining with highest safety standards. As the mining and developmental activities are getting deeper and deeper with the passage of time, it is inevitable to prove the depth extensions of ore body for sustainable life of the mine and as such exploratory drilling through directional drilling method is being adopted in the mine for the first time. For better voice communication amongst the underground work persons & mine officials and to control the heavy traffic through decline, leaky feeder with Wi-Fi facility is introduced in the underground mine. Cavity Monitoring System (CMS) is being introduced for determination of exact volume of excavation in each stope. Mill tailings will be used to make paste and to be used for filling the underground mine voids. For this purpose, "Paste Fill Plant" having a production capacity of 3 MTPA is under commissioning stage and will be in operation shortly. Energy saving initiatives have been undertaken in Malanjkhand by installing roof top solar units on all the public buildings and also in the premises with a cumulative capacity of 4,886.5 kWp and saves approx. 3.24 MT of carbon dioxide emissions in each year. This flagship unit of HCL is maintaining Zero Liquid Discharge (ZLD) System as per the study and recommendation suggested by CSIR-NEERI, Nagpur. HCL strictly follows the Standard Operating Procedures (SoP) for each mining related activity in the mines in order to attain the high standard of safety. As a result, this mine has been awarded 5-star rating (highest possible rating for any mine in India) by Indian Bureau of Mines in the year 2021-22 for its excellence in the category of mining, environment, safety, health & eco-friendly aspects.

Key words: Malanjkhand Copper Mine, Multi Directional Drilling, Mining Method, Leaky feeder, Energy Saving techniques, ZLD.

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3. Executive Director (Mines), Hindustan Copper Limited

4. Director (Mining), Hindustan Copper Limited

धरती का करें रक्षण, स्वच्छ रखें पर्यावरण।

हर प्रयास,
हरित प्रयास

CONTENTS

Theme 1: Innovation in surface mining operations

NO : 1.1

Application and approach designing of terrestrial laser scanner in concurrent excavation-backfill model operation mine and its impact on ease of operation of mine of M/S. Hindalco industries limited

Sabhyasachi Biswas[1] and Pradyumna Das[2]
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[2]AGM (Geology), Hindalco Industries Ltd.

Abstract:

Innovations in Digitalization of Surveying methods revolutionized the industry by enhancing accuracy, efficiency, speed and safety. In Baphlimali Bauxite Mine, the largest Bauxite Mine of Hindalco Industries Ltd, where an annual bauxite production of 7 milliontonnes of Bauxite requires a total excavation of around 12 Million tonnes, the high material handling rate of 32,600 tonnes per day require very frequent and intensive surveys for plan and volume reconciliation, which cannot be catered by use of conventional survey instruments like Total Station and DGPS. Hence, the necessity of Laser Scanner was initiated in the mine, which has the capability of scanning around 10lakhs datapoints within 5mins of survey ranging over 1 km radius. The usual benefits of using a Laser Scanner are as follows:

Higher point-cloud data density, owing to higher resolution of digital surface

- Lower TAT of Survey jobs
- Reduced use of Manpower
- Data collection from inaccessible terrains
- Reduced chances of human error during survey

However, in a mine like Baphlimali, where backfill operations are concurrent alongside excavation, development planning, quality control, scheduling and ore exhaustion assurance become a huge challenge. In fact, while month-end survey scans cannot cover the month's active areas which have been backfilled before month-end survey, holding backfill operations for such surveys can greatly impact other interlinked operations and massively hamper mine's production. Hence after procurement of the TLS, it was very necessary to establish an approach design for TLS surveys in concurrent backfill-operated mines, which even OEM experts did not have an experience of. Other than the usual benefits, the add-on benefits that were obtained are as follows:

- Accurate month-end volume calculations
- Better service provision to mining operations team
- Better model reconciliation for quality control as well as ore exhaustion
- Mine's Volume balance experiments (which can be later implemented for small-scale mines where establishing FMS is not economic)

The paper would cover aspects of TLS applications in mines with the purpose of educating how it is highly functional in mine surveying, but would also greatly focus on the approach design to the challenges faced during its survey in concurrent-backfilling mines, and also focus on how Baphlimali team is creating dynamic use-cases using the TLS application and its data.

1. Introduction

1.1 Background

Topographic surveys have always been the source of truth for reconciliations in developments inventory managements. In the mining industry, these surveys are done periodically for multiple purposes, namely topographic updates, aerial progress tracking, compliance tracking, contractor evaluation-based estimations, stockpile management and production tracking. Presently across the mining business, a wide range of survey instruments are deployed to carry out the above-mentioned activities, ranging from the traditional Total Station and DGPS to newer automated or semi-automated instruments like LiDAR scanners and drone-based Photogrammetric scanners, all four of which are presently deployed in Baphlimali Bauxite Mine.

1.2 Research Scope

The scope of the case study is limited to the operations, process flow design and output utilization of the Terrestrial Laser Scanner for excavation-backfilling volume estimations and its integration with geological modelling software for accurate excess bottom bauxite recovery estimations.

1.3 Research Problem

Baphlimali Bauxite Mine is a concurrent backfilling modelled mine that runs without a grade-controlled stockpile management system. It operates at 7.5 Mtpa of bauxite production and handles over 12.75 Mtpa of material, thereby handling over 34,500 tonnes of material every day. Small deviation percentages in such his high amount of material handling and area degradation can lead to heavy quantities of deviations. Hence the Terrestrial Laser Scanner has been deployed for faster and more accurate determination of excavation volume. However, since Baphlimali Mine undergoes concurrent backfilling, there are two major concerns/problems faced:

A. Even though pre-backfill surveys are conducted at frequencies of 3-4 days, the usual method of volume calculation using standard softwares yield inaccurate estimations due to possible filling data from later surveys.

B. Currently in Baphlimali Mine, even though survey PV are done for total material excavation, bifurcation of handling of ore and waste is done through weighment of some parameters and subsequent calculations of other parameters. Hence, topographic survey PV is yet fully self-sufficient.

C. Since Bauxite deposits in the Eastern Ghats Mobile Belt are mostly blanket-type deposits, the high spatial undulations of the ore bottom surface can never be accurately mapped using borehole interpolations. This is because variations are as close as 10m which is a highly uneconomic spacing for exploration in bauxite deposits. In such situation, the bottom ore surface interpolated in geological model cannot capture the deeper bauxite presence in between the boreholes.

2 Methodology

For all three issues, the first few common steps are to filter the data collected from survey scans. In *Figure 1*, the registered data cloud is shown. A Digital Terrain Model (DTM) is generated from the registered and filtered data cloud.

A. For issue stated in section 1.3 (A), all survey DTM's are collated and *Lowest Z combination surface* (M1 DTM) is generated (shown in *Figure 2*), and volume is calculated against previous month's DTM (M0 DTM) using software's command to yield existing month's excavation volume (*Figure 3*)

B. Similarly for issue stated in section 1.3 (B), the processed and filtered DTM of existing month (M1 DTM) (shown in *Figure 4*) and previous month's DTM (M0 DTM) (shown in Figure 4) are combined for *highest Z combination surface* (shown in *Figure 5*) and its subsequent fill volume is estimated. The estimated value is then compared with calculated volumes to validate for *Fill Factor* (shown in *Table 1*) and Tons per Trip (TPT)

C. For issue stated in section 1.3 (C), the *lowest Z combination surface (*shown in *Figure 2)* generated for any month is used to split the native geological model (shown in *Figure 6*), which has been generated with an extra footwall bottom zone, and extract the mined-out portion of the model (shown in *Figure 7*). The model is then evaluated for the footwall zone (with an assumption that more than 95% of the unplanned bottom excavation is for ore) yielding the cumulative extra bottom bauxite recovery till date. Every month, this process is repeated, and value estimated for current month is then deducted by the same of previous month to yield single month recovery.

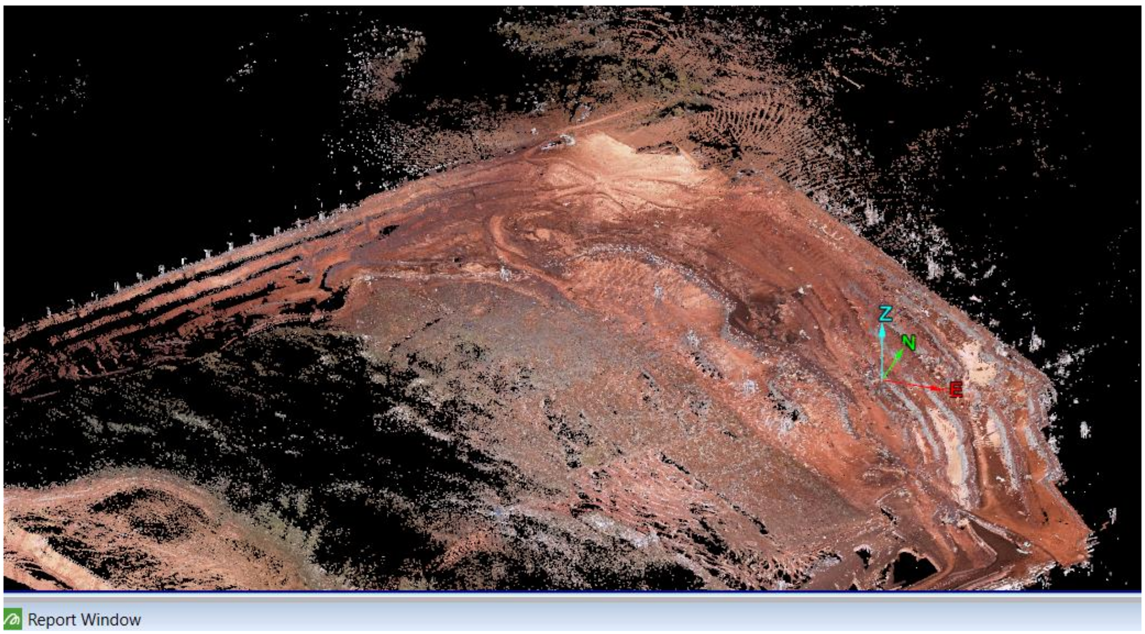


Figure 1: Registered Data Cloud

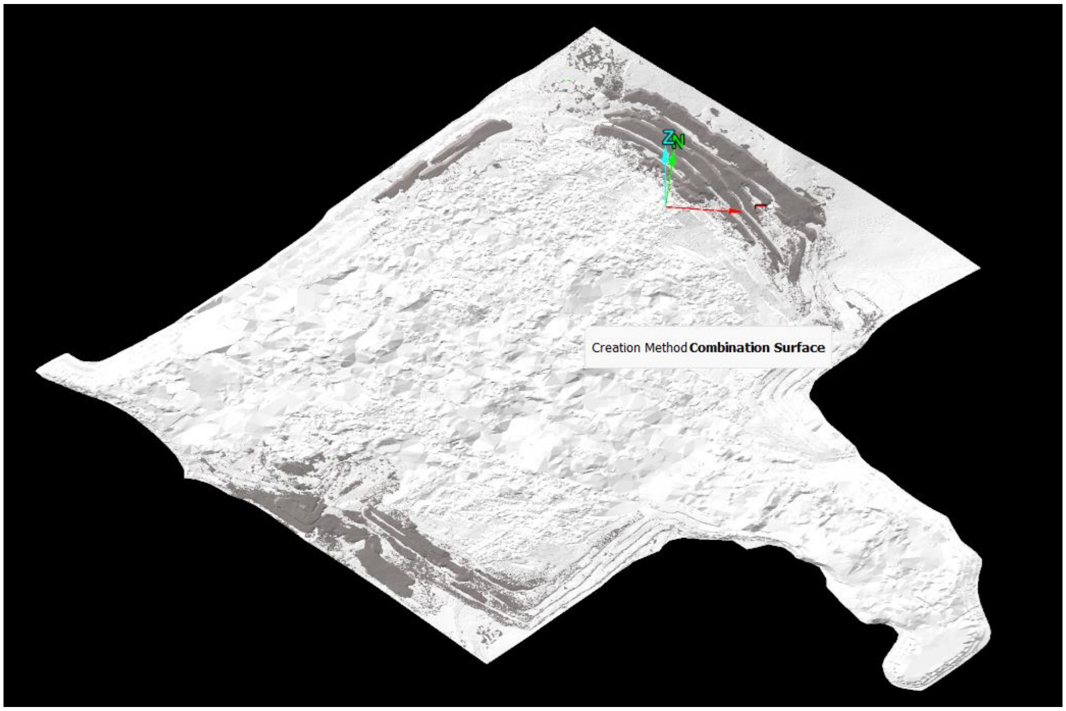
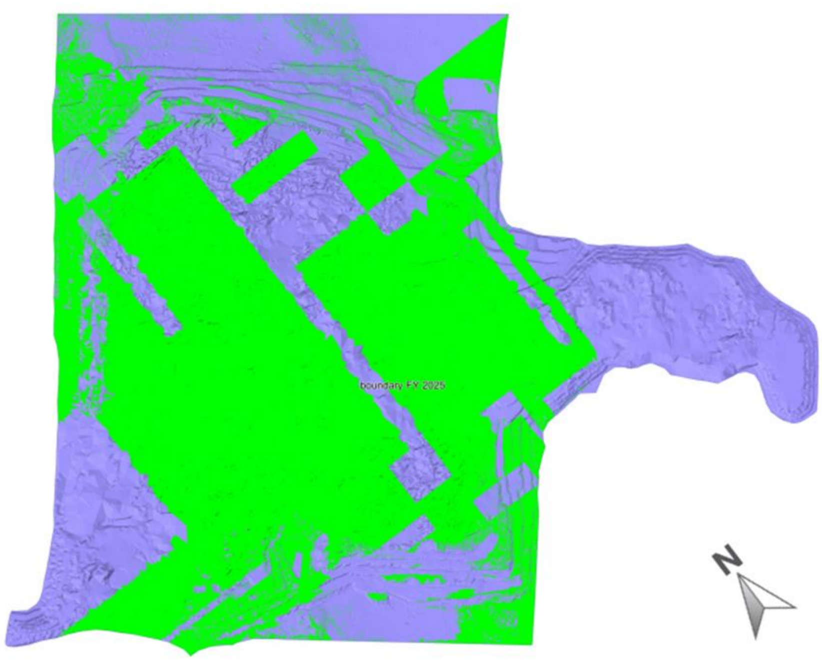


Figure 2: Lowest Z Combination Surface

Plan View



Summary

Region	Cut	Legend
boundary FY 2025	776,127.662m³	

Volume calculated using base surface: [redacted]
Stockpile surface: [redacted]

Figure 3: Single month Excavation Output

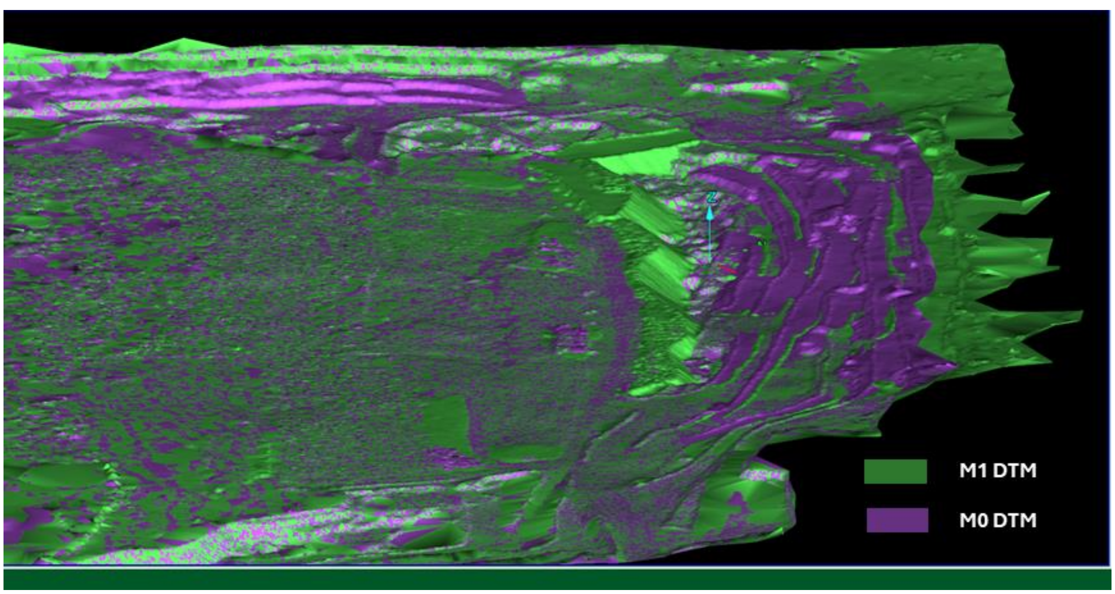


Figure 4: Comparison of M1 DTM and M0 DTM

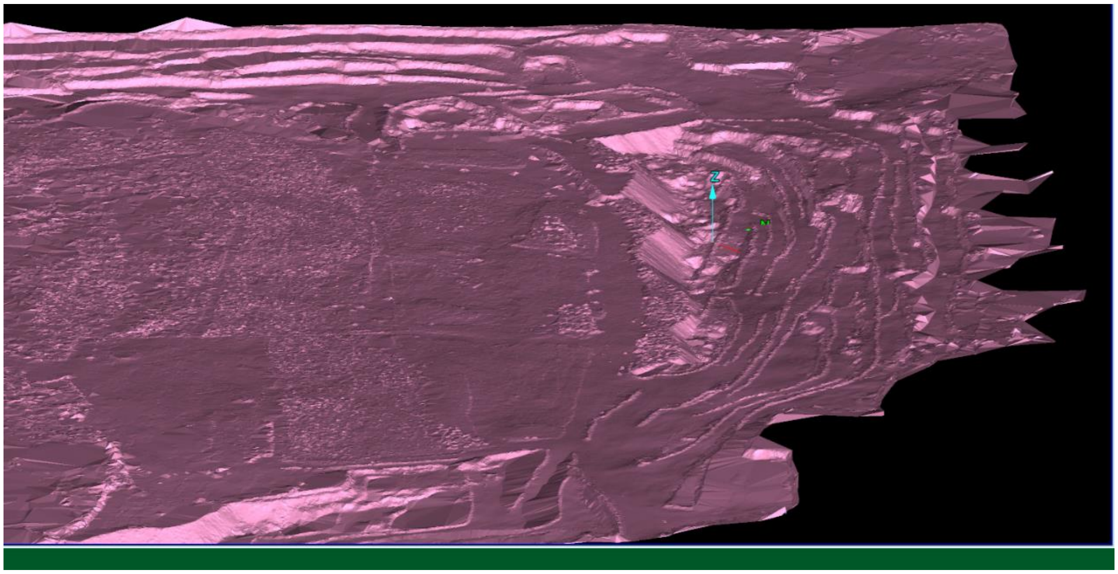


Figure 5: Highest Z Combination Surface from 2 separate month's DTM

Month	Topsoil Handled		OB Handled		Bauxite Handled		Total Volume	OB Backfilled	Fill Factor
	Tonnage	Volume	Tonnage	Volume	Tonnage	Volume	Calculated	Volume	%
M1	22,253	13,090	4,89,386	2,53,568	7,40,163	3,97,937	6,64,595	3,56,773	0.71
M2	51,855	30,503	6,96,480	3,60,870	7,01,199	3,76,989	7,68,362	4,59,514	0.79
M3	11,127	6,545	6,04,472	3,13,198	6,64,246	3,57,122	6,76,865	3,65,509	0.82

Table 1: Overburden (OB) Waste Reconciliation Table

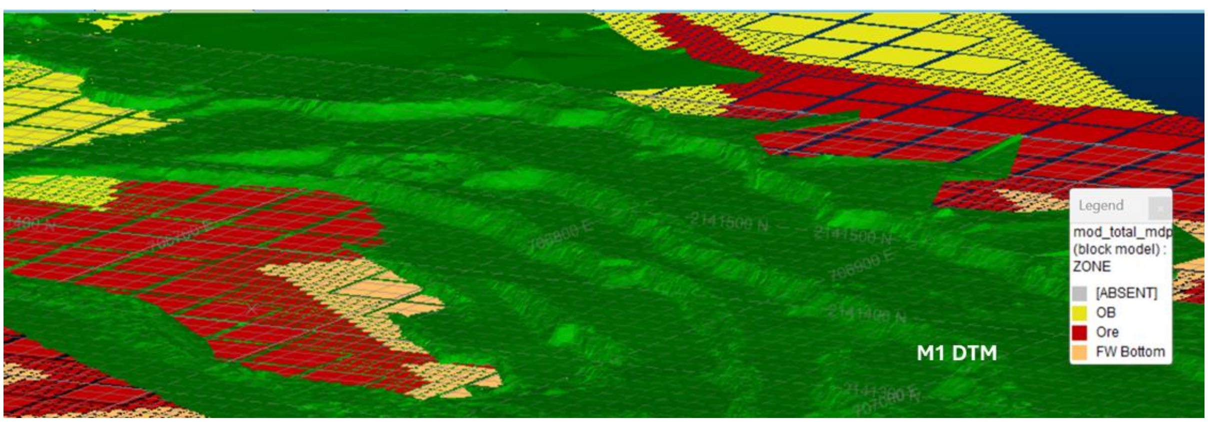


Figure 6: Model Split using Lowest Z Combination Surface

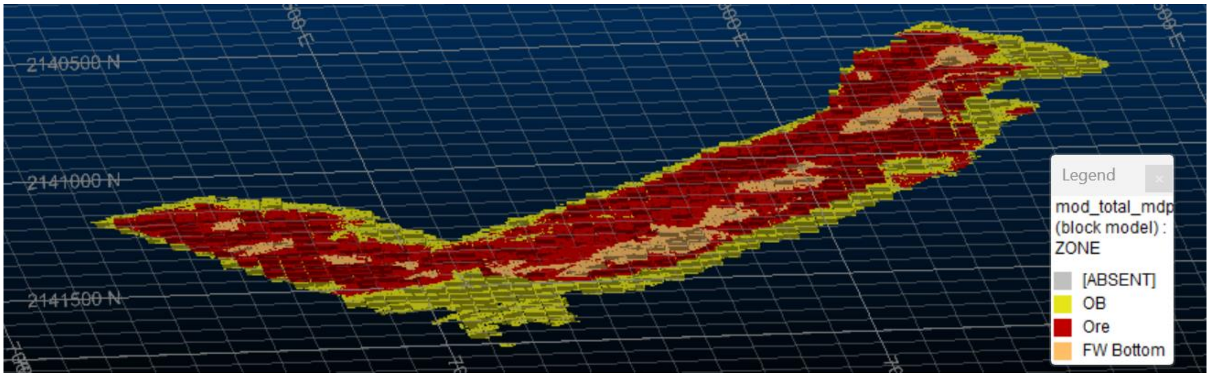


Figure 7: Bottom-up view of Mined-out Model

The summarized approach design has been displayed in *Figure 8* below:

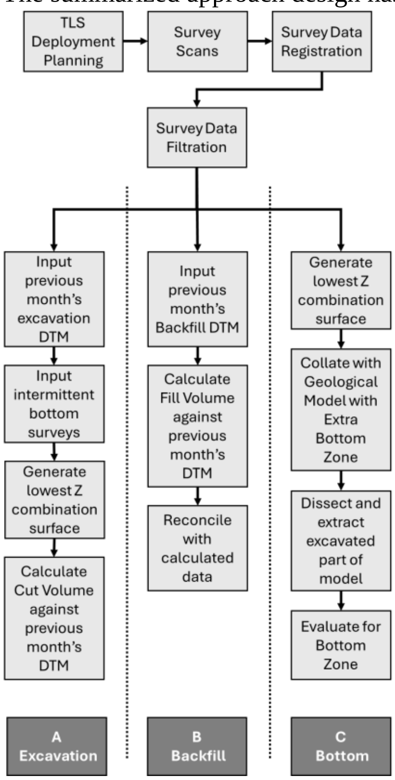


Figure 8: Workflow chart

3 Conclusions

Value addition and some critical insights was brought in from the three cases under discussion. In general, there has been a much increased degree of safety, speed and accuracy due to the deployment of Terrestrial Laser Scanner. Higher frequencies of surveys are being able to be conducted which promotes closer vigilance of mining progress and compliance. The case-specific findings are as follows:

A. As per OEM's SOP for excavation volume calculation, there were a lot of regions which went unaccounted due to subsequent backfilling. The use of the lowest Z combination surface allowed estimation of the lowest surface ensuring maximum excavation calculation, and the volume estimations turned out to be 10%-15% more accurate than the generic method.

B. As per past internal studies, the Fill Factor of waste materials ranged from 0.75 to 0.9 depending on the composition of material being dumped and the time gap between dumping and survey (higher time gap meaning higher compaction over time). The Fill Factor in month M1 was below this acceptable range. Hence, it was discussed with Operations team to monitor the TPT calculation more closely. Consequently, the next two months' Fill Factors were more in range.

C. Adding an extra lithology for Footwall Bottom Zone, quantitative estimations were possible for more accurate Bottom Bauxite Recovery, which accounted to almost 10.5% of total planned production in a year. This quantity is then realized along with analysed quality of samples drawn from these bottom regions, and the same set is being considered during next-stage plans and schedules.

4 Acknowledgements

We would like to extend my deepest gratitude to the entire mining team for their coordination for their active participation to the experiments that were conducted without any hindrance in production and development. We would like to convey a special vote of thanks to our surveyor. Mr. Chandan Swain, whose vigilant activism towards survey data collection was exceptional; to our Head of Department of Geology, Mr. Krishna Jyotishi for providing all possible administrative support during the studies; and to Ms. Suvitha K., Geologist, who assisted during bottom bauxite recovery calculations.

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Smart mining: Techniques, Practices and Future prospects of Highwall mining in India

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***Abstract*:**

Smart mining technology should offersolutions to thechallenges of mining. Underground extraction of coal is one of the most challenging mining scenarios due to the hazardous and complex nature of mining operations havingproblems in achieving desired production, productivity and safety.One of the best examples of smart miningtechnologies for underground mining is the Highwall mining technology.

Highwall mining is implemented when opencast coal mines can no longer expand due to constraints such as reaching the pit limits,the presence of surface properties or unfavourable stripping ratios. This technology involves remotely controlled extraction of coal through successive parallel entries made into the coal seam from the highwall face. These entries are unmanned and unsupported, and the operation is fully automated from outside. The success of highwall mining depends on the meticulous design of web pillars between adjacent web cuts to minimize failure or interaction of different adjoining workings or strata formation thereby protectingoverlying workings or strata formation, surface structures, etc.The stability of the highwall is largely determined by the stability of these web pillars and the overall slope stability. This becomes even more critical in multi-seam conditions, where the stability of the web pillars and surrounding rock mass is vital. The efficient design of the highwall mining method can be done using numerical modelling and empirical formations by taking into account various geological and geotechnical factors of the strata formation leading to improved production, productivity and safety.

The first highwall mining operation in India was launched at the Ramagundam Opencast Project-II (OCP-II) by M/s Singareni Collieries Company Limited (SCCL). Since then, this technology has been deployed at several sites across India, with a number of additional sites identified for future highwallmining operations. This paper presents the design practices of highwall mining methods in India with case studies and future prospects for maximizing coal recovery through paste fill in highwall mining.

Keywords: Highwall mining, Opencast coal mines, Multi-seam mining, Web pillars, Web cut, Pastefill

1. Introduction

India's burgeoning energy needs are predominantly met by coal, making it an essential component of the country's energy sector. The Indian mining industry is poised for further expansion with increased production and productivity. Therefore, companies are adopting smart technologies to improve mining operations with enhanced safety. The synergy of mechatronics and artificial intelligence has transformed system control and automation, leading to better decision-making, improved safety and techno-economics without compromising productivity. With surface mining reaching its operational limits, smart technology like highwall mining has emerged as a pivotal method to access residual coal seams that would otherwise remain untapped. In contemporary global mining operations, three paramount considerations are safety, productivity, and environmental responsibility. Highwall mining excels in these areas by operating remotely, reducing risk, being cost-effective, productive and minimizing environmental impact. It has a low impact on overburden rock and ground surface compared with conventional opencast and underground mining methods. Typically, after an opencast mine is excavated, a highwall remains along the edge is often abandoned or covered up with overburden dumps. This prompted engineers to explore ways to extract coal from these highwalls, giving rise to highwall mining. The method involves extracting coal from a series of parallel openings made into the coal seam from the highwall face, leaving coal pillars between these entries. The operation is conducted remotely from the highwall pad outside, with an operator in a cabin of highwall miner using onboard cameras, sensors and computers to oversee and manage the machine's advancement. Originated from auger mining, it is a cutting-edge technology that extends the lifespan of opencast mines without disrupting surface structures, ensuring both economic efficiency and productivity. Even thinner coal seams of less than 1.0 m can now be extracted with this technology, which would not have been possible with other existing methods (Newman and Zipf, 2005). Effective highwall mining requires careful design of left-out coal pillars called web pillars and stability analysis of surrounding rock mass (Porathur et al. 2013, 2017). Stability analysis aims to avert catastrophic failure even if a few isolated pillars do not perform according to their projected capacity. A slight increase in the excavated area or localized failures could lead to minor instability within a mine (Adhikary et al., 2002). Increased percentage of extraction, however, might cause instability on a global scale (Huang et al., 2021). The conditions of multi-seam mining aggravate the instability even more (Newman, 2009; Das et al., 2023).

Highwall mining is originated in the USA in 1970 and has been widely used since 1980. In Australia, highwall mining was introduced in 1990 and since then has been applied in several coal mines. It has also been used in a few mines in Indonesia and Thailand. India's first highwall mining operation began in December 2010 at Ramagundam Opencast Project-II (OCP-II) by M/s Singareni Collieries Company Limited (SCCL). This technology has been deployed at some other sites with more locations planned for future operations.

Safety issues in highwall mining mainly involve rock falls from highwalls or slope failure, roof and rib falls at the portal, and web cuts leading to equipment entrapment. These are often linked to highwall instability due to inadequate mine design or operational complexities and geological structures (Zipf, et al. 2005). The stability of highwall structures is significantly affected by the stability of web and barrier pillars, excessive spans caused by cross holes, the stability of the final pit slope, parting stability in multi-seam mining, floor failure in multiple lift mining, entry mouth stability, and the sequence of multiple seam extraction. This paper delves into the various techniques and the design practices of highwall mining methods in India with field implementation and provides insights into the future prospects for maximizing coal recovery through paste fill in highwall mining.

2. Highwall mining systems and methods

The different variants of highwall mining systems are Auger highwall mining system, Archveyor system, Addcar highwall mining system and Continuous Highwall Miner (CHM). Common methods used with highwall miners include Contour Mining, Trench Mining and Highwall mining in opencast highwalls.

3. Design aspects

Geo-mining conditions in highwall mining situations can often be quite complex. The design elements critical for ensuring safe highwall mining operations include:

3.1 *Strength of Web pillar*

For Indian coalfields, the strength of the web or barrier pillars is calculated by the CSIR-CIMFR pillar strength formula (Sheorey et al. 1987; Sheorey, 1992), which reads as:

$$S = 0.27\sigma_c h^{-0.36} + (H/250 + 1)(W_e/h - 1) \quad (1)$$

Where, S = Strength of coal pillar, MPa; σ_c = uniaxial compressive strength of 25 mm cube coal sample, MPa; h = working height, m; H = depth of cover, m; W_e = equivalent width of pillar, m = $2W$ for long pillar; W = width of the web pillar, m. The widely used formula for the effective width of a rectangular pillar is $W_e = 4\,(WL)/\,2\,(W+L)$ where L is the length of the web pillar in m (Wagner, 1974). When L>> W for a web pillar, $W_e = 2W$. Based on a numerical modelling study Das et al. (2023), suggested an effective width for a rectangular pillar as given below:

$$W_e = W + (4A/O - W)\, 0.66 \quad (2)$$

Where W is the width of a rectangular pillar (m), A is the area of the rectangular pillar (m^2) and O is the perimeter of the rectangular pillar (m). For long web pillars, the effective width will be 1.66W as obtained from equation (2).

3.2 *Load on Web pillar*

The load on web pillars is estimated using the tributary area method, which is given as:

$$P = [\gamma H(W + W_C)]/W \quad (3)$$

Where P = Load on web pillar, MPa; γ = Unit rock pressure (0.025 MPa/m); H = Depth of cover, m; W = Width of the web pillar, m; W_c = Web cut width in m.

The load P is usually not uniform throughout the length of the web pillars due to depth variation, end effect, multi-seam interaction, and induced abutment stresses caused by pit or trench excavation. Thus, it is prudent to obtain the maximum vertical stress acting on a web pillar using numerical modelling.

3.3 *Safety factor*

Safety factor (SF) of the pillar is calculated using the following equation:

S.F. = Strength of web pillar/Load on web pillar = *S/P* (4)

For the Indian mining scenario, the web pillar is designed with a minimum *S.F.* of 1.5 for multi-seam conditions to take care of the interaction effect and a minimum *S.F.* of 2.0 to prevent surface subsidence.

3.4 Entry span stability

Weak clay or shale roofs can cause frequent falls during extraction, damaging the cutters and conveyors and causing stoppages for repairs and debris removal. Severe roof falls can increase the effective pillar height, reduce pillar strength, and lead to panel failure. Therefore, assessing roof span stability is essential.

3.5 Multi-seam working

When contiguous seams are present, the interaction between proposed extractions in both seams should be assessed. If the web cuts in contiguous seams are found to influence each other, it is advisable to superimpose the workings in contiguous multi-seams. For seams with a parting of weak strata less than 3 m thick, it is recommended to design web pillars considering the combined height of both seams, including the parting. Stability assessments for multi-seam extractions should be done through numerical modelling.

3.6 Highwall stability

Highwall stability is primarily influenced by the stability of web pillars and in general by slope stability. In India, final highwall slopes are kept relatively flat at around 40-45°, whereas in trench highwall mining, slopes are typically steeper, ranging from 70-80°.

3.7 Entry mouth stability

When highwall slopes are typically very steep, this results in increased cover pressure on the web pillars right at the entry, leading to vulnerability to spalling and crushing. Therefore, it is crucial to ensure that the highwall slope angle at the pit is adjusted to reduce cover pressure on web pillars near entry points.

3.8 Identification of geological and structural features

Detailed geotechnical mapping of the designated highwall mining area is essential to identify water bodies, underground structures, hard rock bands, existing faults, etc. Geological conditions significantly impact the performance and efficiency of highwall mining machines.

3.9 Sequence of multiple seam extraction

When extracting exposed seams in an opencast mine at the final highwall, it's advisable to follow an ascending extraction sequence. In trench mining, both ascending and descending sequences of extraction can be chosen based on operational convenience.

4. Indian case studies

India's first highwall mining operation began in December 2010 at OCP-II in Ramagundam, SCCL using the ADDCAR highwall mining system. After this, mining began at the nearby Medapalli Opencast Project. In 2011, South Eastern Coalfields Limited (SECL) started highwall mining at Sharda Opencast mine for thin seams, 1.0-1.4 m thick using trench mining concept. Highwall mining has been in operation at West Bokaro mine of Tata Steel Limited since May 2016. Recently, Eastern Coalfields Limited (ECL) introduced highwall mining at Nimcha and Narayankuri mines and Bharat Coking Coal Limited (BCCL) in Block-II mine. This technology is in various stages of implementation in few other mines like Dhori (CCL), Gare Palma (Jindal Power Limited), etc. The recent designs of highwall mining in West Bokaro and Narayankuri mines are presented below.

4.1 Highwall mining at West Bokaro

West Bokaro Mines of Tata Steel Limited successfully extracted several panels using this technology. One of the multi-seam highwall area contains three coal seams, VII, VI, and V in descending order, given in Figure 1 whose thicknesses vary between 6.0-8.1 m, 3.0-6.0 m, and 2.4-3.3 m, respectively. The seams are separated by partings of 12.3-20 m between VII and VI and 5.7-10.6 m between VI and V. These seams are located at depths of 15-80 m, 27.3-98 m, and 33-108 m from the surface. The strata of the area primarily consist of sandstones, shales, and coal seams from the Barakar formation of the lower Gondwana subgroup. The area is divided into three sub-areas, Area-1, Area-2, and Area-3 due to faults. Surface structures are present in Areas 1 and 2, while those in Area-3 are to be relocated. Web pillars have been designed for stability in all three sub-areas using empirical and numerical simulations, considering lithology, physical properties, and geomining conditions. Highwall mining proceeds from the bottom seam V to the top seam VII. Web pillars in each area are designed by considering the interaction effects among the coal seams during their extractions. The widths of web pillars for the extraction of VII, VI and V seams obtained from numerical modelling exercises and stability assessment are given in Table 1 for different areas. For the web cut of 3.5 m width, these web pillars and intervening parting among the seams are found to be stable. For seams with less than 6 m parting between VI and V, only one seam should be extracted to avoid parting failure. The height of pillar is 8 m for VII Seam, 5 m for VI Seam and 3.8 m for V Seam, with a penetration depth of 300 m. A photograph showing the web cut and web pillars at West Bokaro Mine is given in Figure 2.

Table 1: Web pillar thickness determined by numerical modelling method for VII, VI and V Seam

	Area-1	Area-2	Area-3
VII Seam	8m	9.5m	12m
VI Seam	7m	8m	9.5m
V seam	7m	7.5m	8.5m

Figure 1: Highwall mining site under multi-seams conditions at West Bokaro mine.

Figure 2: Photograph showing web cut and web pillars in highwall mining at West Bokaro Mine.

For extraction under multi-seam conditions in ascending order, the web pillars should be stable throughout and after the mining operation to ensure the safety of upper seams workings as well as surface structure, if any. As the water treatment plant and New CHP are located in Area-1 and Area-2, respectively, web pillars have been designed keeping a minimum safety factor of 2.0 for long-term stability and to avoid the occurrence of surface and sub-surface subsidence. For Area-3, a web pillar with a safety factor of around 1.5 to 1.8 has been designed for medium-term stability purposes so that developed web pillars in lower seams should remain stable during extraction through Highwall mining in upper seams. Seam VII, being 8 m thick, is extracted in two lifts to accommodate the maximum cutting height of the Continuous Highwall Mining equipment. The vertical stress on web pillars is depicted in Figures 3 and 4.

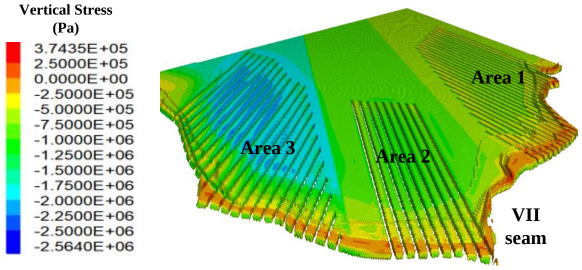

Figure 3: Vertical stress developed on web pillars of the three areas in VII seam.

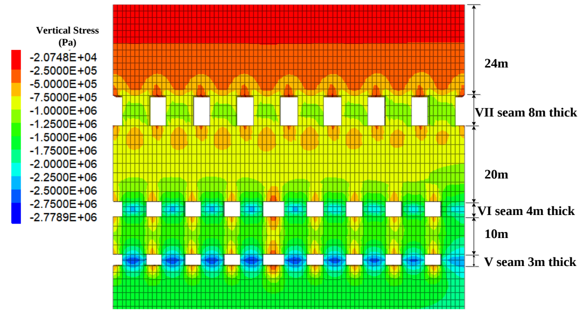

Figure 4: Vertical stress contours during extraction of coal seams in Area-1.

4.2 Highwall mining at Narayankuri

At Narayankuri opencast patch (OCP) of Mahabir (R) Colliery of ECL, highwall mining using continuous highwall miner has been introduced in R-VIII B2 (also called R-VIII Bottom) seam and R-VII Top seam. The R-VIII B2 seam, averaging 4.6 m thick, is at a depth of 36 m, while the underlying R-VII Top seam is around 3.07 m with a depth of cover varying from 65 m to 91.6 m. The average parting between these seams is 51 m. Overburden rocks and parting comprised of alluvium, fireclay, shale, medium-grained to coarse-grained sandstone, intercalation, shaly sandstone and shaly coal of variable thicknesses. The demarcated area is divided into three blocks marked as Block-1, Block-2 (2a, 2b & 2c), Block-3 and the east and west sides of the trench for the implementation of Highwall technology. Web pillars are designed for different blocks considering surface structures, thickness, depth of cover and physico-mechanical properties of the individual seam. In Block-1, Block-2b, east and west sides of the trench, important surface properties exist. Other blocks are devoid of surface properties. The numerical modelling has been carried out for the design of web pillars, to understand stress regimes and failure characteristics of the web pillars and surrounding rock mass for highwall mining. Due to the presence of surface structures in Block-1, Block-2c, overlapping part of Block-3 (beyond OCP) and east and west sides of the trench, the web pillars are designed for a minimum safety factor of 2.0 for the protection of surface structures on a long-term basis. Wherever surface structures do not exist like Block- 2a, 2b and Block-3 within the OCP, the web pillars are designed for a safety factor around 1.8 which is medium-term stable, i.e., stable for a few years. The thickness of solid web pillars to be left in R-VIII B2 and R-VII Top seams in different blocks of the demarcated area as obtained from numerical modelling exercises and stability assessment are given in Table 2.

Table 2: Web pillar thickness determined by numerical modelling for R-VIII B2 Seam and R-VII Top Seam

R-VIII B2 Seam	R-VII Top Seam						
Block-1 5m	Block-2a 4.2m	Block-2b 4.6m	Block-2c 4.0m	Block-3 within OCP	Block-3 beyond OCP	East of Trench 4.5m	West of Trench 3.5m

				3.3m	10.1m		

The grid of highwall drivages in different blocks is given in Figure 5. The height of pillar is 4.6 m for R-VIII B2 Seam and 3.07m for R-VII Top Seam. In Block-3, there should be alternate long and short cuts of web drivage. The shortcut should be up to the opencast edge. In Block-2c, web pillars are designed after the removal of the overburden (OB) dump. Similarly, in Block-3, web pillars are designed after the removal of backfilled OB up to the quarry floor of the R-VIII B2 seam. After exposing the floor of the R-VIII B2 seam, a trench of 40 m width along the northern side of the quarry will be made for positioning of Highwall Miner (Figure 5). From this trench, coal of R-VIII B2 seam will be extracted by drivage of 3.5 m wide and 300 m long web in Block-1. An access ramp of 20 m wide and gradient 1 in 16 will be cut from the floor of the R-VIII B2 seam to reach R-VII Top seam. Thereafter, a trench at a convenient place along East-West in the R-VII Top seam will be cut and will be kept ready for extraction of this seam.

The trench dimension will be 80 m wide × 600 m long + 40 m wide × 80 m long on the east side near dyke. After extraction of the R-VIII B2 seam is completed, the Highwall miner will be shifted to the trench in the R-VII Top seam from where the seam will be extracted all around. Web drivage in the south and north will be 300 m long whereas in the west and east will be 220m and 100m respectively. Access trench/ramp above the highwall mining workings should have a minimum hardcover parting of 15 m for the safe movement of HEMM as found from the numerical modelling exercise. The access trench from the floor of R-VIII B2 seam to R-VII Top seam and the trench made along East-West in R-VII Top seam will be formed by the formation of benches. The slope angle of the benches from crest to toe of the access trench/ramp is planned to be kept at 45°. The slope angle of the benches of the trench made in the floor of R-VII Top seam is planned for 60° all around. The vertical stress contours in and around web pillars during extraction of R-VIII B2 seam are given in Figure 6 and the scheme of extraction is shown in Figure 7.

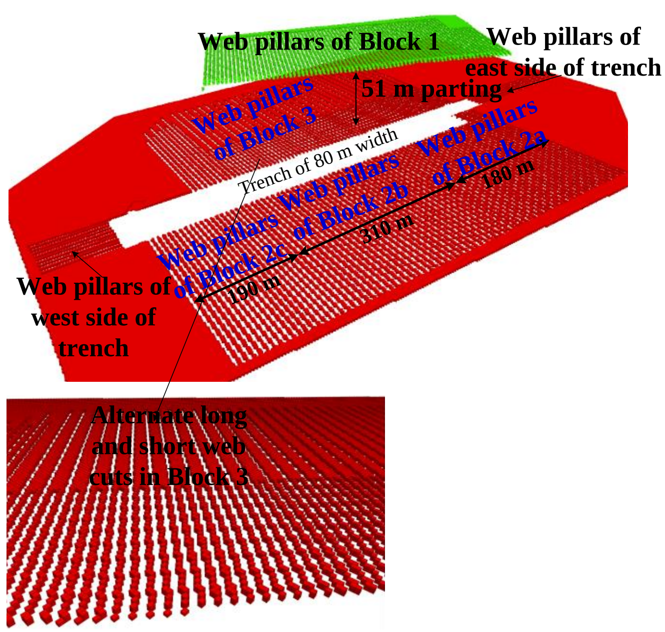

Figure 5: Highwall drivages in different blocks in the proposed zone of work.

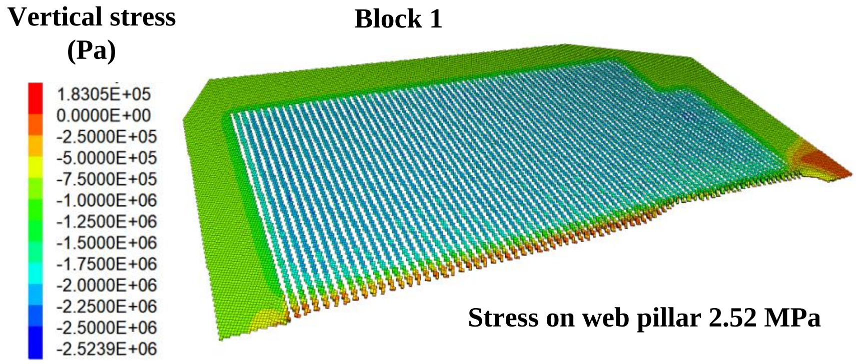

Figure 6: Vertical stress contours in and around web pillars during extraction of R-VIII B2 seam.

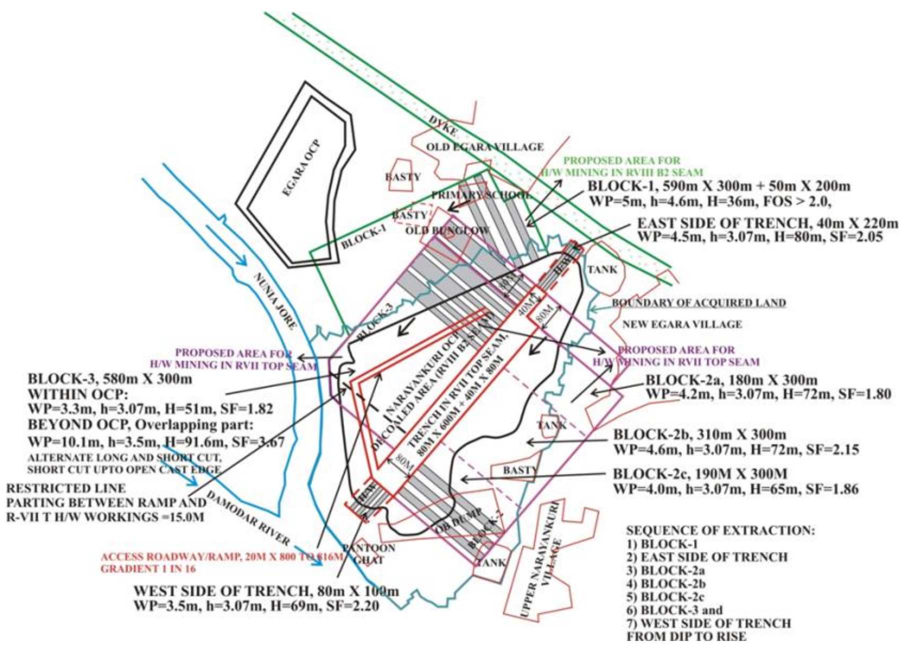

Figure 7: Scheme of extraction by highwall mining at Narayankuri OCP.

5. Future prospects

In conventional highwall mining, leaving web pillars results in the loss of coal resources. A method to minimize this loss is backfilling in highwall mining operations. Backfilling these entries supports roofs and remnant pillars after mining, enhancing immediate pillar strength and reducing degradation from pillar spalling and roof instability. Backfilling significantly reduces the pillar size required for long-term stability and increases the recovery. Additionally, it facilitates underground disposal of solid mine waste, reducing surface environmental impacts. Methods such as paste backfill and slurry backfill are applicable, with paste backfill involving injecting a mix of fly ash, crushed overburden, cement, and water in paste form into web cuts to form a supportive solid once set. West Bokaro Mine of Tata Steel Limited, in collaboration with CSIR-CIMFR, conducted a feasibility study on highwall mining with paste backfill. Numerical modelling using paste fill properties indicated a substantial reduction in web pillar thickness while enhancing recovery without compromising safety. However, field implementation of this initiative is pending.

6. Conclusion

Highwall mining, as a smart mining technology, efficiently recovers coal locked-up in the highwalls of open pit mines. Success depends on optimizing the size and stability of web pillars during and after the mining operation. Pillars with lower slenderness ratios (w/h) are more susceptible to failure unless carefully designed. Major design considerations include multiple seams in close proximity, parting stability, the strength of coal, seam thinning, weak roof layers, dip angle, highwall and entry mouth stability, seam undulations, the presence of geological disturbances, etc. Three-dimensional numerical modelling is crucial for highwall mining design. In Indian mining, web pillars are designed with a minimum safety factor (S.F.) of 1.5 for multi-seam conditions to account for interaction effects and a minimum S.F. of 2.0 to prevent surface subsidence. Pillars with w/h ratios < 1.0 or S.F. < 1.5 are typically avoided unless barrier pillars are left after a set number of web cuts to prevent catastrophic failure. India's first highwall mining operation began in 2010 at OCP-II in the Ramagundam area of SCCL, expanding fast to other sites with plans for future expansions. Case studies are discussed, introducing backfilling as a strategy to minimize coal loss, although its practical implementation in highwall mining entries remains pending.

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Establishing a relationship between penetration rate of drill rod and specific energy during drilling operation by a Jumbo Drill Machine in an underground hard rock mine

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Abstract:

Specific Energy obtained during drilling is a useful predictor of physico-mechanical properties of rock. But, direct quantification of specific energy is not easy work. It requires lots of calculations and field experimentations. Again researchers found that the penetration rate of drill rod determined during drilling operation has distinct relation with specific energy. In this paper we have tried to establish a relationship between penetration rate of drill rod and Specific Energy during drilling operation by a Jumbo drill machine in an underground metalliferous mine, which can help in understanding rock characteristics, thereby enabling mine management to determine the efficiency of drilling operation by proper selection of drill bit. The study involved formation of an empirical model between penetration rate of drill rod and specific energy, in which it was found that the specific energy is inversely proportional to the penetration rate of drill rod. The model was further verified by MAPE. The model so determined with the help of MATLAB software showed a linear correlation with R2 value of 0.99 and thus the model seemed highly viable, which can be further used for determination of Specific Energy from penetration rate of drill rod. It is expected that the established relationship between specific energy and penetration rate will help in on-site determination physico-mechanical properties of rock mass without laboratory investigation.

Keywords: MAPE (Mean Absolute Percentage Error), Penetration Rate, Specific Energy, Jumbo Drill Machine

1.0 Introduction

Drilling is an inevitable part of mining unit operations. In underground trackless mining, drilling is carried out by Jumbo Drill Machine, in which the machine is being utilized for numerous operations such as drilling blast holes, rock bolts and clamp holes etc. The drilling efficiency is very much dependent on the penetration rate of drill rod,
i.e. how long a drill rod takes to complete a drill hole [1]. Penetration rate is also considered as a useful predictor of the physico- mechanical characteristics of rock mass as well as to deduce rock strength [2-5]. Again, in rock drilling, specific

energy is the minimum amount of energy required for removing the unit volume of rock [4]. Specific Energy is used as a mode of evaluation of efficiency in relation to different excavation methods [6]. Researchers observed that, there exists a relation of increasing specific energy with rock strength [7]. Thus the Specific Energy of drilling can be considered as a useful rock parameter. Many researchers have tried to establish relations between specific energy and other rock parameters, but with limited success [8-10, 11,13].

A number of factors influence rock drilling specific energy in relation to the rock type and the drilling apparatus [11]. The efficiency of a drill depends on Power and thrust, Physical size, Mode of breakage (rotary or percussive or both), Bit geometry and Bit sharpness etc. [6,7,12]. Researchers found that the bit sharpness and available power have most influence on rock drill performance [13]. Besides these, a rock's drilling penetration rate and specific energy is also influenced by a number of parameters, such as rock strength, rock stiffness, presence of structural discontinuities, abrasiveness and hardness of the mineral constituents, nature of the rock matrix and nature of the mineral grain etc. [12-14].

Above discussion showcases that there exists few common influencing factors which governs the penetration rate as well as specific energy quantitatively. In this study, the authors have tried to establish a relationship between penetration rate and specific energy quantified during drilling by a Jumbo drill machine. An empirical model between penetration rate of drill rod and specific energy has been developed by analyzing penetration rate and specific energy data acquired during the operation of drill jumbo machine at a specified rock zone located in an underground hard rock mine. The study is expected to help in understanding rock mass characteristics and therebyenables mine management to enhance the efficiency of drilling operation by proper selection of different drilling tools comprising appropriate drill bit geometry for different rock mass.

2.0 Experimental Method, Materials and Case Study

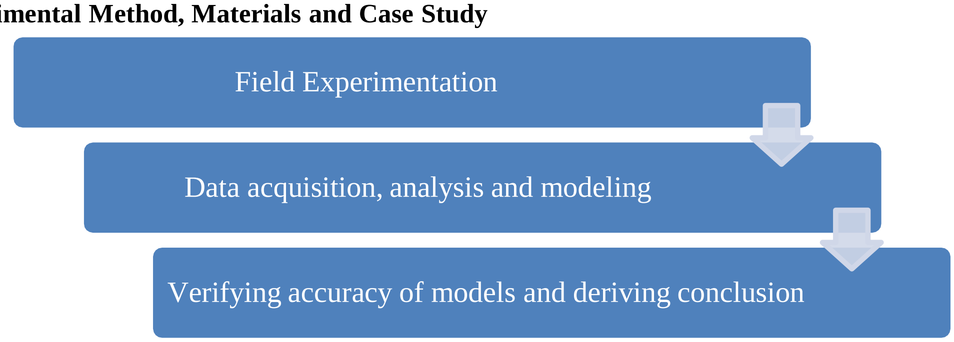


Figure 1: Outline of Methodology

Figure 1 demonstrates various steps of the research works inform of field experimentation, data acquisition and analysis. The study was conducted at an underground metalliferous mine in Seraikela-Kharsawan District of Jharkhand state in eastern India. The mine under study follows a 'cut and fill' with post pillar method of mining alliedwith split boundary ventilation system. An eight degree decline serves as main entrance to the mine, through which men and machines can travel to reach the work places. A vertical shaft with drum winding system has also been sunk for material hoisting from the deeper levels. The mine is a mechanized mine in which Scoop Tram (ST), Mine Truck (MT), Jumbo Drill machine and Passenger Carrier (PC) etc. are deployed for production purposes. The host rocks for mineralization are tourmaline bearing quartz sericite schist for Hangwall Lode and magnetite bearing quartzite / quartz schist for Footwall Lode. The range of RMR varies between 65-70. **Figure 02** depicts the longitudinal section of the mine under study.

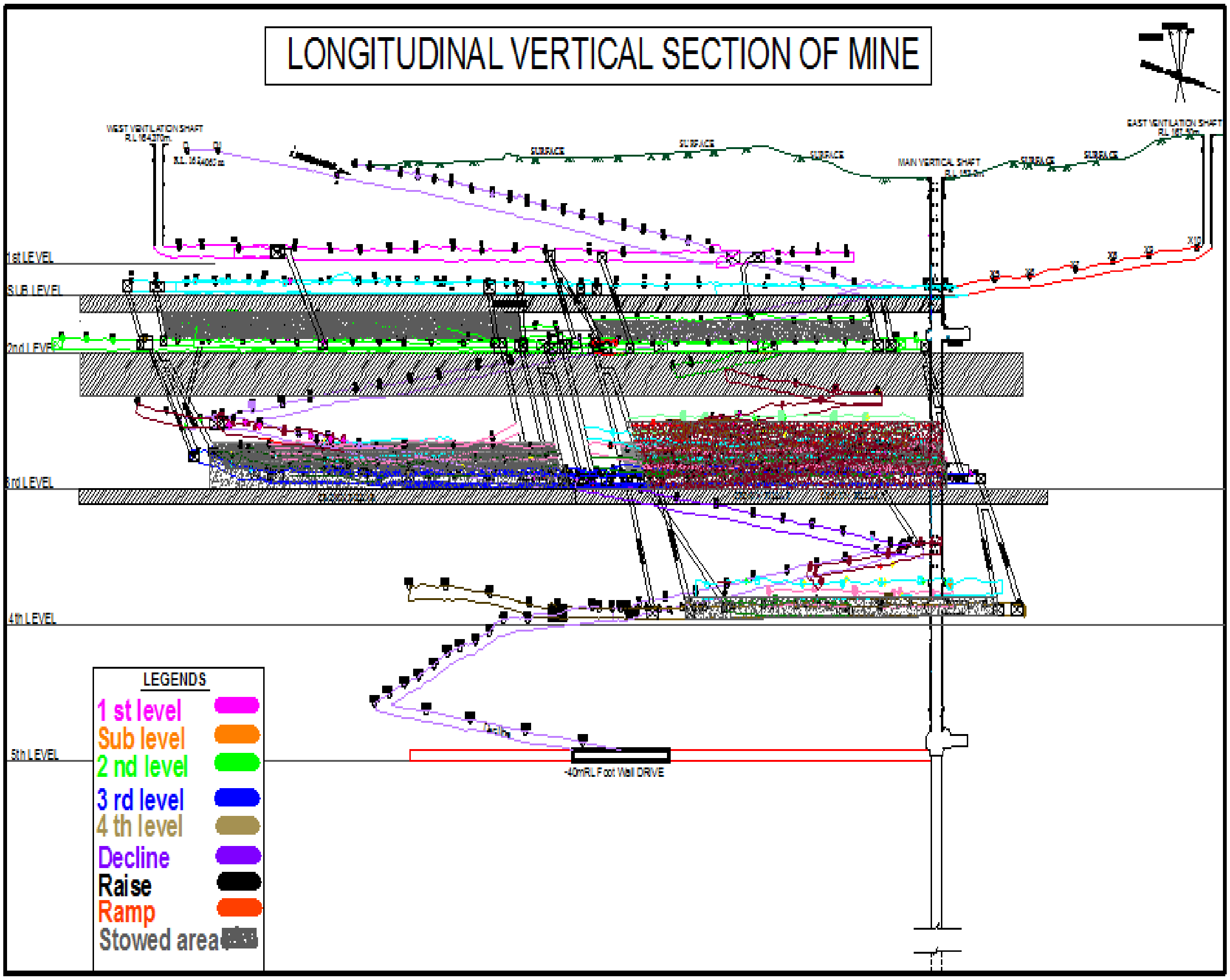


Figure 02: Longitudinal Vertical Section of the mine

Drilling for experimentation purpose was carried out by Jumbo Drill Machine Boomer 281**(Figure 03)**, which is an electro hydraulically operated mining face drilling rig with one BUT 28 heavy-duty boom anddouble tripod suspension for accurate hydraulic parallel holding during drilling operation. It also has a telescopic feed for left/right handed booms. The main Motor is of 55 KW and is operated at 440 V connected by coupler through Gate End Box in underground mine. The length of the drill rod used is 3.4 m and diameter of drill bit is 45 mm.

Figure 03: Boomer 281 Drill Jumbo Equipment

Jumbo Drill machine was utilized for drilling blast holes in hanging wall of a Stope of the mine under study, comprising of tourmaline bearing quartz sericite schist as the host rock. During drilling of blast holes in the face, penetration rate of drill rod in each hole was measured in m/min. In totality 50 holes having 03 m length were drilled in the slice of the stope. Along with penetration rate, drill rod speed in rotation per minute (r.p.m) was noted and was found to be constant for most of the holes (180-190 rpmfor 50 holes). Further the drill bit diameter was 45 mm, for all the 50 holes drilled and hence the area removed during drilling of holes remains same. The rock type being tourmaline bearing quartz sericite schist, hence the thrust provided during drilling has been noted for all the holes and was observed to be around 180-200 bar. The torque of Rotation Motors, which is developed at the bit rock interface corresponding to the applied thrust, remains constant with a value of 640 Nm throughout the drilling of 50 holes at the face. Thus the Specific Energy during drilling was measured using the data as obtained from the **Equation No. 01** as mentioned below:

$$\textbf{Specific Energy} = \frac{E}{V}\ \textbf{Nm/m}^3 \quad \textbf{(01)}\ [14]$$

Where E = Energy Consumed (Nm) and V= Volume of the rock broken (m^3)

In the next phase, regression analysis was performed using MATLAB software keeping Penetration rate(m/min) of drill rod as the independent variable and Specific Energy (J/m^2) as the dependent variable and the regression analysis of polynomial fit of 2^{nd} degree so obtained is depicted in **Figure No. 04**, which is further verified by Mean Absolute

Percentage Error (MAPE).

Finally in the last phase, validation of the derived model was carried out. For validation of the derived model, the jumbo drill machine was first deployed at a new location in a recently developed Footwall drive of the mine having magnetite bearing quartzite as the host rock at 5th level [at 200m depth from surface] of the mine with a strike length of 500 m and dip of 35^{0}. Again corresponding measurementswere taken as aforementioned during drilling operation (which is illustrated below in Table No. 02) in the face and fed in the model so derived as the **Equation No. 02**. Furthermore, correlation analysis was performed to depict the strength of the relationship between the derived and the calculated values of Specific Energy.

3. Outcomes of Experimentation

The data acquired through infield experimentation during drilling by Jumbo Drill machine is depicted below in **Table No. 01.**

Table No. 01: Data acquired through infield experimentation

Sl. No.	Penetration rate (m/min)	Thrust (N)	Specific Energy (E) (J/m2)
1	1.2	180	28290.55
2	1.22	183	28762.05
3	1.55	198	31119.59
4	1.21	182	28604.88
5	1.25	182	28604.88
6	1.53	190	29862.24
7	1.56	200	31433.93
8	1.2	182	28604.88
9	1.18	175	27504.69
10	1.2	181	28447.71
11	1.3	190	29862.24
12	1.29	188	29547.90
13	1.55	197	30962.42
14	1.2	180	28290.54
15	1.1	170	26718.84
16	1.1	170	26718.84
17	1.16	174	27347.52
18	1.58	199	31276.76
19	1.16	175	27504.69
20	1.16	176	27661.86
21	1.14	175	27504.69
22	1.25	188	29547.90

Table No. 01: Data acquired through infield experimentation continued….

Sl. No.	Penetration rate (m/min)	Thrust (N)	Specific Energy (E) (J/m2)
23	1.17	178	27976.20
24	1.15	172	27033.18
25	1.34	192	30176.58
26	1.48	196	30805.2589
27	1.51	200	31433.93
28	1.5	199	31276.76
29	1.46	185	29076.39233
30	1.14	178	27976.20
31	1.14	178	27976.20
32	1.23	180	28290.54
33	1.25	185	29076.39
34	1.36	188	29547.90
35	1.39	189	29705.07
36	1.35	187	29390.73
37	1.33	187	29390.73
38	1.32	186	29233.56
39	1.55	195	30648.08
40	1.55	196	30805.25
41	1.54	197	30962.42
42	1.23	183	28762.05
43	1.21	183	28762.05
44	1.23	181	28447.71
45	1.2	182	28604.88
46	1.48	195	30648.08
47	1.1	172	27033.18
48	1.12	174	27347.52
49	1.15	178	27976.20
50	1.26	186	29233.56

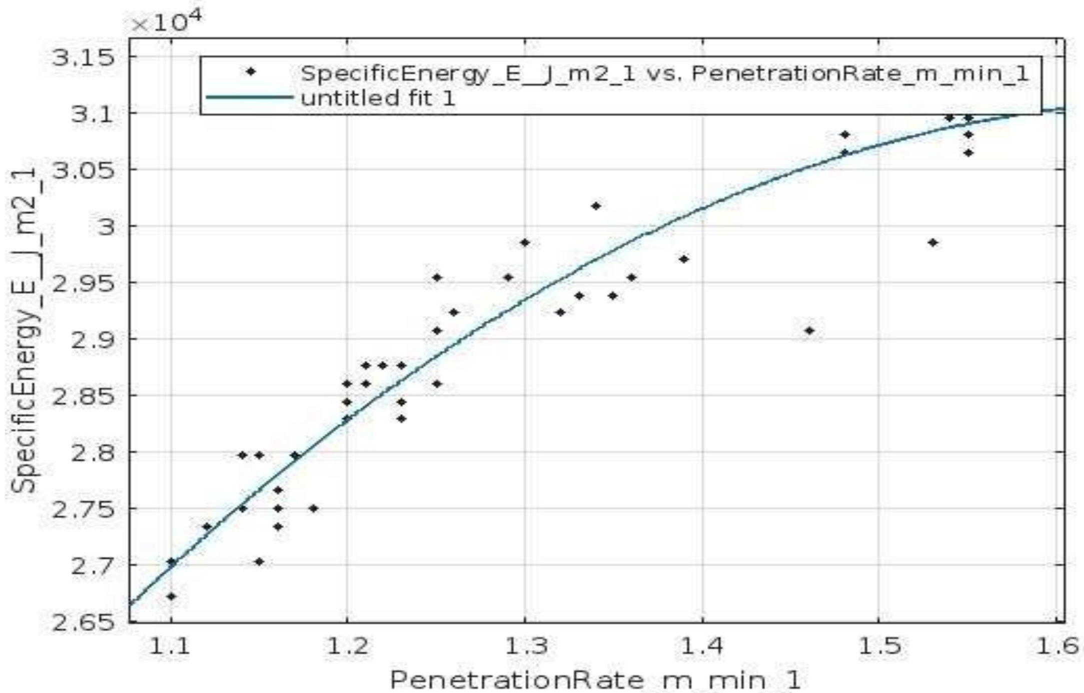
3.2 Linear Regression Analysis in MATLAB software

In this study, Penetration Rate (m/min) has been taken as independent variable and Specific Energy (J/m^2) was considered as dependent variable. The data set illustrated in **Table No. 01** has been used for linear regression analysis of Polynomial Fit of 2nd degree. The outcome of linear regression analysis is depicted in **Figure 04**. The relationship between Penetration Rate (m/min) and Specific Energy (J/m^2) can be described from the obtained **Equation No. 02**.

$E = -1.2313 * 10^4 PR^2 + 4.1329 * 10^4 PR - 3.5658 * 10^3$, Where E = Specific Energy (J/m^2) & PR = Penetration Rate (m/min) ……… (02)

It is found that the Specific Energy and Penetration Rate (m/min) are strongly correlated with R^2 value of 0.907 and adjusted R^2 value of 0.903 and RMSE value 421.62. Therefore, it may be concluded that the Penetration Rate (m/min) obtained from drill feedback is a suitable predictor of Specific Energy (J/m^2) and with the increase of penetration rate the specific energy during drilling also increases as is evident from the curve obtained in **Figure 04.**

7.1 Figure 04: Regression Analysis of Polynomial Fit of 2nd Degree



4.0 Determination of MAPE for the derived model

The Mean Absolute Percentage Error (MAPE) was derived for the above model. On determining MAPE, it was found that the MAPE is 1.088%, which means that the derived model from **Equation No. 02** as aforementioned is 98.912% accurate and can be used for prediction of Specific energy (J/m^2) from Penetration Rate (m/min) of drill rod during Jumbo drilling operation in underground metalliferous mines.

5.0 Validation of the derived model

For validation of the derived model, the jumbo drill machine was first deployed at a new location in a recently developed Footwall drive of the mine having magnetite bearing quartzite as the host rock at 5th level [-40 mRL] [at 200m depth from surface] of the mine with a strike length of 500 m and dip of 35^0.

Again corresponding measurements were taken as aforementioned during drilling operation for 06 numbers of holes and fed in the model so derived in the equation no – 02, which are illustrated below in **Table No. 02**. Also a graphical representation as depicted in **Figure 05** wherein the relationship between derived Specific Energy obtained from **Equation No. 02** and calculated Specific Energy from **Equation No. 01** is revealed. After deriving correlation between these two variables, we obtain a **correlation coefficient** of **0.867**, which indicates a strong positive linear relationship between the two variables.

7.2 Table No. 02

Sl. No.	Penetration Rate (m/min)	Thrust (N)	Derived Specific Energy (J/m^2) from Equation No. 02	Calculated Specific Energy (J/m^2) from Equation No. 01
1	1.35	190	29787.90	29862.24
2	1.12	180	27277.25	28290.54
3	1.16	185	27807.46	29076.39
4	1.05	181	26254.56	28447.71
5	1.04	178	26098.61	27976.20
6	1.08	175	26707.63	27504.69

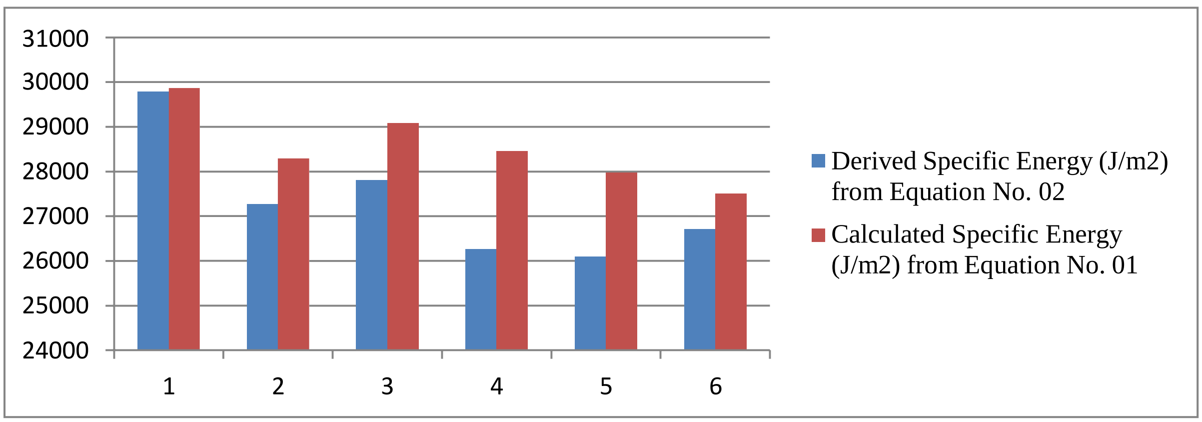


Figure 05: Graph depicting the relationship between derived Specific Energy and CalculatedSpecific Energy

6.0 Conclusion

On site determination of Specific Energy from penetration rate of drill rod during drilling is expected tobe very useful in deducing the rock parameters and its characteristics. It can be utilized to estimate the rock hardness, thereby helping in deciding the bit utilization, drilling factor, the nature of bit to be used for drilling, the sharpness of bit and apposite bit geometry etc. Henceforth, it will help the mine management in reducing production cost by proper selection of drill bit according to the specific rock mass condition. This procedure of indirect in-situ determinations of physico-mechanical properties ofrock mass can save a considerable amount of time which is required for numerous laboratory testing. It will also indirectly help mine management to ensure the better safety during mine face operation by providing contemporary rock mass information during mine working.

7.3 7.0 References

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NO : 1.4

Planning and Management of Safety Issues of industrial set up in new normal life post pandemic

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Abstract:

Integrating the Internet of Things into mining operations solves significant issues in air quality monitoring and supervision, essential for personnel safety and regulatory compliance. An advanced real-time remote air quality monitoring system designed for mining sites is presented in this research study. The primary goal of this system is to evaluate how emissions of gases and particulates will affect the environment. The system uses various sensors and GPS-enabled devices to detect temperature, relative humidity, SO_2, NO_x, $PM_{2.5}$, and PM_{10}. It then uses these sensors to collect and send large amounts of data about air quality to a central server on its own. It is then possible to continuously monitor and visualize data online, which may be accessed remotely via login credentials. Moreover, the system reduces potentially hazardous situations with an automated sprinkler mechanism activated when it senses increased pollution levels. The project uses regression machine learning and mathematical modelling to build a real-time forecast and estimation model for environmental scores in underground mines. The historical data gathered from IoT sensors deployed at India's Munsar Manganese Mines and Kandri Manganese Mines (MOIL) is used to develop this model. By offering early warnings and automated solutions, this state-of-the-art technology increases safety while satisfying the need for practical, continuous air quality monitoring in mines.

Keywords:Air Quality Monitoring; Sensors; Internet of Things; Mine Environment

Contents

INTRODUCTION

A Pandemic mainly tells us about infectious diseases where we see a chain of person suffering from a disease and it gets transferred from one person to another person spreading in huge number of countries around the whole world at same time.

After 1.5 years of Lockdown, all Factories, Stores and Industries are opening one by one. So it's the duty of the Individual Corporation to look at the Safety of all their workers from this invisible Virus as well as the Safety of their products which will reach to the customers.

It's the companies way on how they will train their working employees to fight with this Covid-19 and find the safest ways to cope up with it and do well in their job during and after the pandemic. Masks need to be mandatory for all industries be it a small or big [1].

Coronavirus disease (COVID-19) is an infectious disease caused by a newly discovered Coronavirus or SARS-CoV-2 virus. Most people infected with the Corona virus experience mild to moderate respiratory illness and recover without requiring special treatment. Elder people, and those with underlying medical problems like cardiovascular disease, diabetes, chronic respiratory disease, and cancer are more likely to develop serious illness often leading to death. The best way to prevent and slow down the transmission of the COVID-19 virus is to be well informed about it, the disease it causes and how it spreads. Protect yourself and others from infection by washing your hands regularly for 45 seconds or using an alcohol based rub frequently and not touching your face, wearing a N-95 mask and preferably hand gloves [2,3].

The COVID-19 pandemic is an immediate health emergency. Measures to cope up with the pandemic also have a direct impact on markets, production of goods and other services, needless to say the world of work too.

How is the world of work affected?

Lockdowns and related business disruptions, travel restrictions, school closures and other containment measures have had sudden and drastic impacts on workers and industries. Often the first to lose jobs are who were already in precarious condition – such as, for example mine workers, factory workers, waiters, kitchen staff, baggage handlers and cleaners, IT workers etc[7]. In a world where only one in five people are eligible for unemployment benefits, layoffs become a catastrophe for millions of families.Informal workers, accounting around 61% of the global workforce, are particularly vulnerable during the pandemic as they already face higher occupational safety and health (OSH) risks and lack sufficient protections[8]. Working in the absence of the basic necessary protections such as sick leave or unemployment benefits, these workers may need to make a choice between health and income, which comes at a risk of both their health and the health of others including their economic wellbeing [10].

Since its a cycle connected to one another, the workplace experiences the below events leading to one another: -

- **Absenteeism** . Workers can be absent because they are sick and they are the caregivers for their family members or have at-risk people at home, such as elder family members or easily diseased prone members; or are afraid to come to work because of fear of possible exposure.

- **Change in patterns of business**. Consumer demand for items related to infection prevention (e.g., respirators) has likely increased significantly, while consumer interest in other goods may have declined. Consumers may try to shop at off-peak hours to reduce contact with other people, show increased interest in home delivery services to reduce person-to-person contact.

- **Interrupted delivery**. Shipments of items from geographic areas are getting severely affected by COVID-19 which are causing delay or cancellation with or without notification.On the demand side, restrictions on people's movements and the closure of non-essential economic activities have significantly reduced consumption. These factors are causing massive capital outflows from emerging markets as investor confidence plummets. This, combined with declining exports, reduced revenues, and collapsing commodity prices, is creating a perfect storm for a looming deflationary economic crisis [14].

Guidelines to Develop, Implement, and Communicate about the Workplace Flexibilities and Protections for the Employees

- Actively encourage sick employees to stay home.
- Ensure that sick leave policies are flexible and consistent.
- Do not go for pay cut of the employees if they are out on sick leave.
- Maintain flexible policies that permit employees to stay home to care for a sick family member.
- Be aware of workers' concerns about pay, leave, safety, health, and other issues. Provide adequate, usable, and appropriate training, education, and informational material about business-essential job functions and worker health and safety, including proper hygiene practices and the use of any workplace controls (including PPE) [10].

WHO given guidelines for Covid-19

In the context of the COVID-19 pandemic, there is no "zero risk". If you don't feel well or show any symptoms of COVID-19, stay home [15].
If you choose to attend a gathering, practice prevention measures, regardless of your COVID-19 vaccination status:

- Get vaccinated as soon as it's your turn
- Keep a distance of at least 1 metre from others
- Open windows when possible for ventilation
- Wear a mask
- Clean hands regularly
- Cover your face when coughs and sneezes by bending your elbow
- Stay home when sick

Source: WHO

OBJECTIVE OF THE STUDY

Through this work, we intend to study: -

- The mental health and current condition of unorganized labours.
- The post pandemic adaptation on workplace safety which is taken by different private and government organisation.
- The guidelines on post pandemic adaptation given by WHO.
- The precautions given by the ministry of home affairs of India.
- To sort out some extraordinary ways to help unskilled and unorganized labours
- How industries manage their requirement for skilled labour which is vacant due to migration.

PROPOSED METHODOLOGY

First of all we analyse the impact of COVID 19 by conducting a survey to find out the mental and economic condition of workers, thereafter some workplace will be visited to analyse the workplace condition and the present condition of workers after lockdown, then we study the post pandemic adaption on workplace safety provided by different organisations. We will go through the guidelines provided by WHO to study the precautions for organised workers and try to make a working checklist for unorganized workers to increase their mental stability and physical safety compared to others.

EXPECTED OUTCOME

We are trying to reach out to these pillars of expectations-

- A hygienic workplace for workers.
- Elimination of spreading of the disease at workplace
- Eliminating the health hazard.
- To produce a secured workplace for unorganized workers.
- To boost the moral of the worker.
- To erase the financial crisis of poor worker.

SURVEY OF LITERATURE

[4][5] The COVID-19 crisis is substantially impacting all aspects of our lives. The immediate and ongoing priority is, understandably and rightly, focused on public health, a focus that is likely to persist in the coming weeks and months. In the realm of statistics, there is an equally strong emphasis on timely information regarding the virus's spread and impact. Initially, this pertains to statistics on the number of cases and their outcomes. However, there is also significant interest in the broader impacts of COVID-19, including its profound economic and labor market effects, which have been immediate and substantial, with potential to continue in the near future and beyond. Millions of workers across many countries have been directly affected by lockdowns[9]. While some can continue their work through teleworking or remote arrangements, many others have experienced a reduction or complete loss of their livelihood. Additionally, workers in health and public security sectors face a different type of change: a significant increase in workload due to the crisis in the trained workers.

Tracking and describing all these changes is a considerable challenge for official statistics worldwide. The restrictions necessary to combat COVID-19 create significant obstacles to normal data collection approaches and operations, precisely when there is a massive increase in demand for information. Furthermore, the rapidly evolving situation makes normal planning impossible.

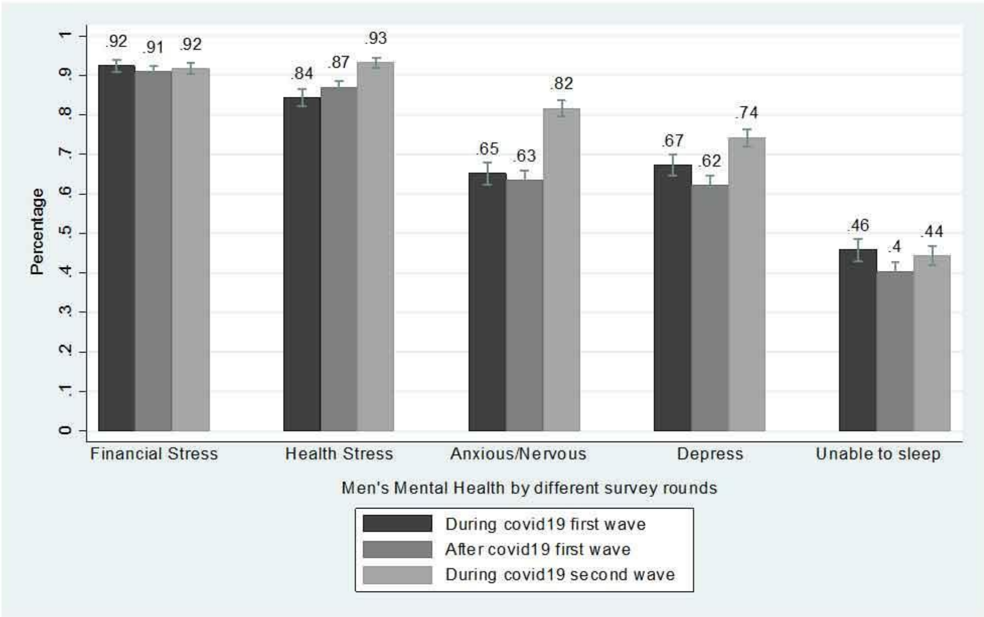
Impact on labour and employment

a. Mental Well Being

The community of internal migrant workers is vulnerable and prone to psychological effects due to a double impact: the COVID-19 crisis and the adverse employment environment [12].Migrant workers often face a unique set of challenges that predispose them to psychological distress and peri-traumatic symptoms.Possible stressors include susceptibility to respiratory infections and the possibility of acting as vectors, pre-existing physical problems, such as pneumonia, tuberculosis, HIV infections, or pre-existing psychosocial factors, such as the absence of family support during the crisis, difficulty following personal safety regulations, isolation, and inability to receive psychiatric support promptly. This professional group is particularly vulnerable to psychological distress due to factors such as financial constraints related to job loss, the absence or suspension of workplace safety measures, and the lack of enforcement of basic occupational risk laws [4,12]. Since the first wave of the pandemic in April 2020, high levels of psychological stress among our respondents have been documented.
Financial insecurity was the most important source of stress for both men and women workers at the beginning of the pandemic which continued to dominate over the 2021, 2022 (Figure 1 and 2). However, health concerns are now almost equal to the financial concerns in the second wave – about 93% of respondents reported health concerns, which is an increase from the 84% reported during the first wave [12].·Hence, while financial concerns remain, health

worries have heightened with the pandemic's progress. This attributes to the devastating second wave that saw India record consistently high daily figures of Covid-19 infections and deaths for weeks, due to the highly infectious Delta variant of the Virus, accompanied by the collapse of the healthcare system. Not surprisingly, we also observe a significant increase in depression and anxiety, while reported sleep disorders remain more or less the same.

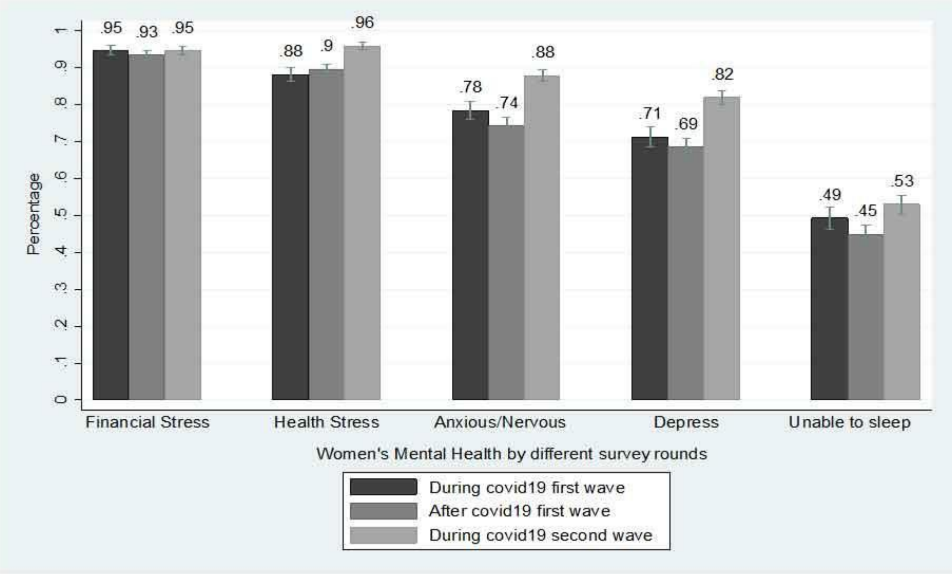
Figure 1. Men's mental health, by survey rounds



Note: The survey periods are: During Covid-19 first wave (April-May 2020), After Covid-19 first wave (August-October 2020), During Covid-19 second wave (April-June 2021).

We observe similar responses by women too (see Figure 2 below) where high financial stress accompanied by an increase in health stress, anxiety, and depression is noticed. Unlike men, women also report an increase in sleep disorders from 49% during the first wave, to 53% during the second wave.

Figure 2. Women's mental health, by survey rounds



Note: The survey periods are: During Covid-19 first wave (April-May 2020), After Covid-19 first wave (August-October 2020), During Covid-19 second wave (April-June 2021).

In each survey wave, women's mental well-being is significantly worse than men's, with more women reporting emotional concerns than men.

b. Job loss

With high levels of adverse mental health, the COVID-19 pandemic affected economic security through increased job loss.

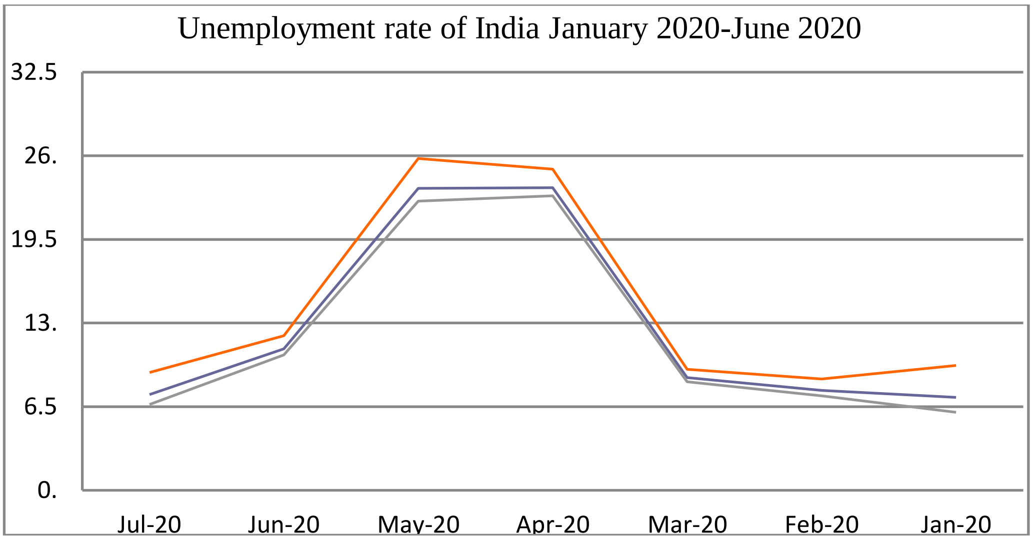
In India, unemployment rose to a high of 24% in April 2020, the highest rate in the past 30 years, and remained between 6.5 and 9% since the end of the first nationwide lockdown, which took place from March to May 2020[11].

This led the International Labor Organization (ILO) to estimate that more than 25 million jobs worldwide had been threatened due to the spread of the coronavirus. It is estimated that four out of five people in the global workforce of 3.3 billion are currently affected by full or partial workplace closure. Most of the European and Asian countries (UK, US, India etc) have begun to register huge job losses leading to significant rise in unemployment rate.There are significant concerns for low-paid and low-skilled informal workers in low and middle-income countries, where industries and services employ a high proportion of such workers who lack any social protection. This sudden loss of livelihood is devastating for them [4][6].

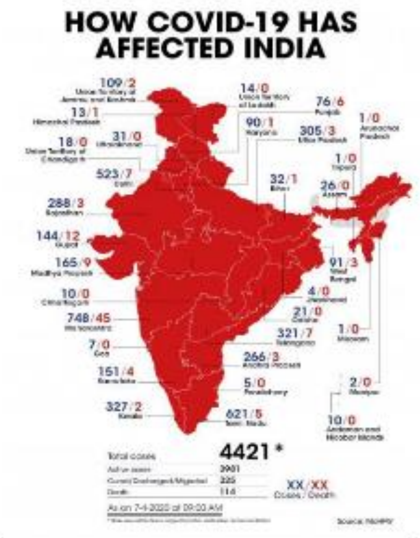
Understandably, this indicates that the current nationwide lockdown has been the biggest job-destroyer in history. However, these estimates only reflect the impact on jobs during the lockdown period and should not be considered as a permanent loss of livelihood. Many may be able to return to employment after the lockdown ends. Nonetheless, it is true that many workers, particularly informal workers involved in casual or contractual work and those who returned to their villages, may not be able to regain their jobs.Additional precautions such as social distancing, contact tracing, and strict health controls over entry at the workplace and market will also impact the employer-worker relationship, marking a significant departure from the usual business practices.

In conclusion, the worst-affected informal workers—approximately 40 million casual or daily wage workers involved in vulnerable urban occupations—may not regain their employment or livelihood status for an extended period and are likely to be trapped in deeper poverty. While the CMIE survey results may have some estimations errors, but it is true that there are huge job losses(Figure3) where the worst affected are the informal workers, who are facing livelihood crisis.In light of the data on migrant laborers, the poor, and the destitute (as part of the informal workforce), the government, NGOs, and even the Supreme Court intervened to address their plight. Consequently, 26,000 shelters (for 1.5 million people) and over 38,000 food camps were set up across the country in the initial weeks of the lockdown, collectively supporting around 10 million people [9].

Figure 3. Unemployment Rate of India January 2020- June 2020



Source: Centre for Monitoring Indian Economy Pvt. Ltd.



Source: downtoearth.org.in /coronavirus-update-India-unemployment-rate-spikes

Experimental Case Study :-

NAME OF THE COMPANY	COMPANY'S OBJECTIVE	NUMBER OF WORKERS
JAI TUBE MANUFACTURING COMPANY	MANUFACTURE OF BASIC PRECIOUS AND NON-FERROUS METALS	250Approx
SPIN CAN PVT LTD	MAKING SILVER CANS BY USE OF SPINNING MILLS	300-350Approx
EASTERN COPPER MANUFACTURING COMPANY	PRODUCTION OF UNINSULATED COPPER WIRE, COPPER ROD	150-200Approx

B. PRE AND POST PANDEMINC PLANNING DETAILS

<table>
<tr><th>SL NO.</th><th></th><th>JOB DONE BY A WORKER</th><th>PLANNING OF INDUSTRIAL SET UP BEFORE PANDEMIC</th><th>PLANNING OF INDUSTRIAL SET UP AFTER PANDEMIC</th></tr>
<tr><td>1</td><td rowspan="3">JAI TUBE COMPANY</td><td>production of brass curtain rods</td><td rowspan="3">no work gap,no gloves and no sanitisation required</td><td rowspan="3">50 rotational days they are called back,use of gloves,proper sanitisation every parts</td></tr>
<tr><td>2</td><td>oval profile with bracket</td></tr>
<tr><td>3</td><td>wooden drapery hardware</td></tr>
<tr><td>4</td><td>SPIN CAN COMPANY</td><td>manufacture of wearing apparel</td><td>cloths were made,packed and distributed</td><td>goes through high temperature and sanitisation before packing</td></tr>
</table>

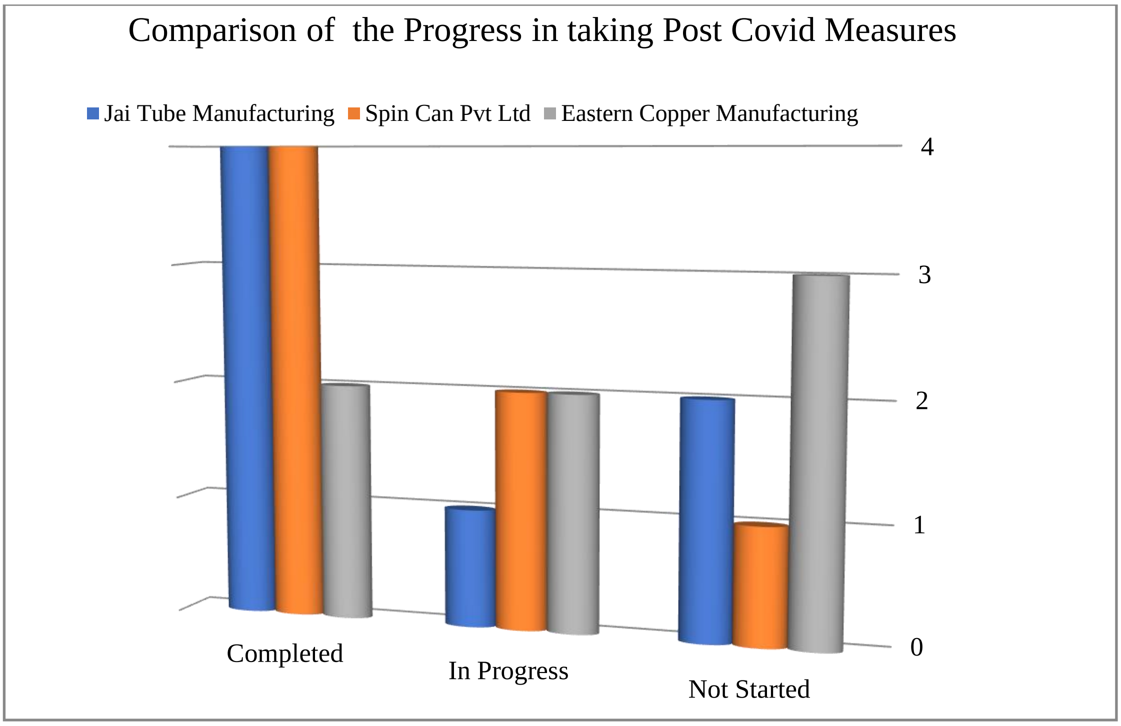
5		incorporation of single and double ball race construction	deeply groove ball bearing	no change
6	EASTERN COPPER COMPANY	handling copper rod casting machine	air pollutant machine	oxygen free copper rod casting in use,the oxygen released undergoes a process in separate tank to get purifird and is kept ready as part of emergency use during scarcity of oxygen fore corona affected people
7		processing scrap wire granulator machine	more labour were required to run it	reduced human workforce and got more dependent on machines and automated process

C.SAFETY/INFECTION CONTROL ACTIVITIES CHECKLIST

ACTIVITIES	COMPLETED			IN PROGRESS			NOT STARTED		
	JAITUBECOMPANY	SPINCANCOMPANY	EASTERNCOPPERCOMPANY	JAITUBECOMPANY	SPINCANCOMPANY	EASTERNCOPPERCOMPANY	JAITUBECOMPANY	SPINCANCOMPANY	EASTERNCOPPERCOMPANY

SAFETY PLAN AND APPOINT A SAFETY OFFICER TO	✓	✓	✓						
DEVELOP AN AGENCY/FACILTY FOR SAFETY PLAN	✓				✓				✓
SUPPORT N95 RESPIRATOR FIT-TESTING	✓	✓				✓			
RETURN TO WORK POST ILLNESS POLICY					✓	✓	✓		
EVALUATION OF NEED FOR FAMILY SUPPORT							✓	✓	✓
STAFF MONITORING FOR SIGN OF ILLNESS	✓	✓	✓			.			
PRE IDENTIFICATION STRATEGIES AND RESOURCES TO ENSURE BEHAVIORAL HEALTH SUPPORT		✓		✓					✓

Figure 3: Graphical representation of the Progress made in taking safety Measures by the company.

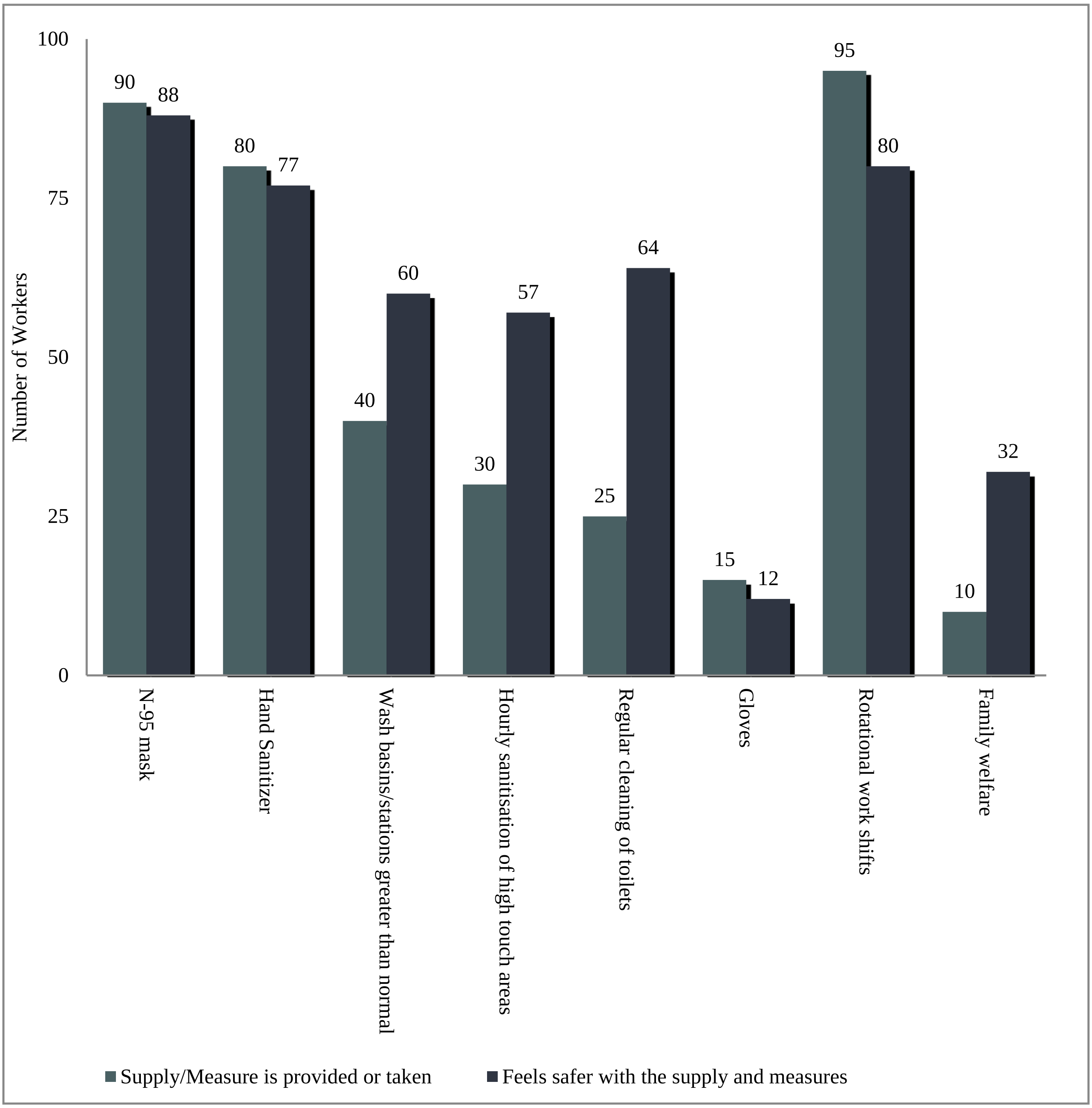


	Jai Tube Manufacturing	Spin Can Pvt Ltd	Eastern Copper Manufacturing
Completed	4	4	2
In Progress	1	2	2
Not Started	2	1	3

OBSERVATION OR EMPLOYEE SATISFACTION:-

About 200 study participants were asked if additional self-cleaning tools such as handwash, hand sanitizer were provided to them or not, if hand washing areas were having wash stations greater than normal size. They were asked if access to sanitization materials and PPE (e.g., latex gloves, face shields, respiratory N95, and others) were provided by their employers on sites during the COVID-19 pandemic and whether such suppliers or designated washing areas made them feel somehow safer (i.e., protected from or less exposed to the virus). Fig. 4 presents the response results on the availability of the cleaning solutions on sites and whether the participants felt safer with such cleaning solutions available on site. Only participants who used this preventive measure were asked if it made them feel safer.

Figure 4: Graphical Representation of responses by the employees's satisfaction on covid measures



EXPERIMENTAL RESULTS: -

Summary of Implications, Issues for Future Research, and Insights for Action regarding COVID-19 and the Workplace

Domain of Work	Implications	Issues for Future Research	Insight-Driven Actions
Emergent Changes in Work Practices			
Work From Home (WFH)	The massive, abrupt, and mandatory (for many employees) switch to work from home (WFH) has required employees to adapt while employers have become more open to adopting the practice post-pandemic.	How will WFH policies affect employee attitudes and behaviors to their employers as well as their co-workers? How will employee attitudes to privacy and monitoring shift for work that is done outside of an office setting?	Employees should create rituals that allow transitions (in the absence of commuting) in order to manage the boundaries between work and home. Organizations should adopt and encourage routines that enhance trust while being attentive to the costs of increase monitoring.
Virtual Teams	Employees who are forced to work virtually for team projects have needed to navigate the indirect and direct conflicts that can result in performance losses.	How will emotion expression and communication in teams with either low or high virtuality affect out comes? What factors will lead to helping and prosocial behaviors in teams with either low or high virtuality – and how will these impact outcomes?	Team members need to pay attention to the structure and nature of communication flows in order to manage them effectively. Organizations should provide opportunities for non-task interactions among employees to allow emotional connections and bonding to continue among team members.
Virtual Leadership and Management	Leaders are tested when presented with systemic shocks and must continue to project vision. Managers are faced with new challenges to supervise and cultivate the	How will leaders adapt their styles in response to shocks such as the current pandemic? How can organizations create superior leader communication to	Leaders need to balance optimism and realism in their communications with employees while demonstrating skills such as charisma.

	development of their subordinates from much greater distance than usual.	Allow feedback and mentoring to happen effectively?	Organizations need to (continue to) invest in the development of current and potential leaders to build new skills to function effectively in new work settings.
Economic and Social-Psychological Impacts			
Unemployment and Layoffs	The costs of unemployment are both economic and latent due to the loss of social structure, status, and socialites. There are also direct and indirect costs experienced by those who remain working in organizations that have laid off workers.	What is the impact of unemployment beyond mental health outcomes and can the unemployed recover? What HR practices, policies, programs, and/or forms of support can alleviate the negative consequences of mass layoffs on those who remain employed?	Job searching requires resilience and persistence and job seekers should seek support and information from others. Job seekers should also prepare for a longer job search than would be the case with lower unemployment rates.
Absenteeism/ Presenteeism	Among people serving "essential" jobs, there is likely to be an increase in people going to work when ill.	How can employer pay and benefit plans best be structured to discourage people going to work when ill?	Employers should not incentivize employees to work through illness. Leaders should model appropriate Behavior and not attend work when ill.
Economi c Inequalit y	Increases in inequality expected from the shock of COVID-19 is likely to lead to burnout, deviant behaviors, and withdrawals.	How can organizations best minimize the individual and organizational costs of broader social inequality?	Organizations need to reduce inequalities, by reducing selection biases in favor of the demographically privileged and taking action to prevent further negative pirating of pay and benefits.
Social Distancing and Loneliness	WFH– and there-organization of workspaces to ensure distance among people	How can organizations foster high-quality social interactions among co-	HR communications should Acknowledge the risk of workplace loneliness and the value of social

	– is likely to hamper social connections and, in turn, negatively affect employee mental and physical health.	workers when WFH or working in-densified workplaces? What innovations are most effective for mitigating an increase in loneliness?	connections as part of broader employee wellness programming. Organizations should identify and implement policies and interventions to support social connections among employees.
Stress and Burnout	Increased job demands and reduced resources are likely To lead to greater stress among employees.	Does rumination about a major crisis like COVID-19 exacerbate the stress And preclude effective use of the available job resources?	Leaders should be trained to facilitate job crafting to that employee can Better cope with new and uncertain job demands.
Addiction	Increase in substance misuses possible during the pandemic and any subsequent economic downturn.	What is the efficacy of internet-based, brief interventions in preventing the onset and/or exacerbation of alcohol misuse among employees? What is the impact of the relaxation of COVID restrictions/return to work on alcohol misuse and addictions more generally?	With appropriate consent and attention to privacy issues, organizations should invest in machine learning and wearable technologies designed to virtually and rapidly identify the onset or exacerbation of risky behaviors such as alcohol misuse.
Moderating Factors			
Age	Older employees face disparate health and economic risks related to COVID-19 with impacts on retirement planning.	How will organizations respond to age-specific concerns involving the risks associated with COVID-19?	Organizations should intervene to simultaneously (a)optimize employee human capital across the lifespan and (b)strengthen internal labor markets (e.g., through cross-age mentoring).
Race and Ethnicit y	Members of racial and ethnic minority groups face disparate health and economic risks related to COVID-19.	How do organization as foster inclusion and a sense of belonging among racial and ethnic minorities when the economy is uncertain and the threat of job loss is	Employers need to create an environment where all employees, including racial and ethnic minorities, realize how they can contribute to the organization's goals.

		high?	

Gender	Men are more likely to face direct health threats of COVID-19. Women are more likely to be affected by the adverse economic and social costs.	What is the value of feminine leadership styles in extreme crisis management, despite the documented preference for masculine leaders under crisis?	Greater value should be placed on alternatives to more masculine leadership styles that seem to be effective in relation to COVID-19.
Family Status	Working parents with school-age children faced is pirate WFH challenges, especially when schools are closed.	Will mandatory WFH and "School from Home" disadvantage working mothers more than working fathers?	Working couples should communicate openly about how they divide household labor and child care.
Personality	Differential impact of social distancing and work from home for those high on Extraversion and Conscientiousness compared to those who are lower. Other individual differences will also be important such as segments and integrators struggling with WFH.	How do personality traits – in particular, Extraversion and Conscientiousness – function in response to the"strong situation" represented by COVID-19? How will the pandemic diminish –or even reverse–the advantageous work relations typically associated with Extraversion and Conscientiousness?	Organizations should strive to reduce unpredictability (i.e., providing clarity to job roles and work goals) to help restore the benefits of traits such as Conscientiousness. "Segmentary" will need to tolerate non-work interruptions when working while "Integrators" will benefit from some segmenting of time and space.

Cultural Differences	Norms will tend to be stronger and less flexible, leading to a greater tightness of organizational cultures, when the threat of infection is high. As the perceived threat of infection lowers, there will be a corresponding loosening of norms.	How do organizations effectively tighten and loosen (or "close" and "open") in response to systemic shocks?	Leaders need to understand how to be ambidextrous regarding social norms, knowing when to deploy tightness and looseness as needed since the former offers protection and the latter facilitates creativity and innovation.

CONCLUSION: -

The present study provides an investigation of the implementation of safety and health measures to mitigate COVID-19 risk in the manufacturing industries. This study contributes to help improving the knowledge base of the industries on the usage and perceived effectiveness of COVID-19 counter measures and identifying opportunities for improvement in approaches used to mitigate the spread of the virus among the workers. The study extends current knowledge by highlighting the need for continued advocacy aimed at smaller companies that have limited resources for occupational health and safety management. The findings indicate that the workers are slightly satisfied with the safety and health measures implemented by their companies to control, prevent, and mitigate the spread of COVID-19 on job sites. However, the study highlighted some issues with their organizations' preparedness to deal with the pandemic. The present study offers recommendations for mitigating these issues in the future and ensuring that all small companies implement a rigorous health and safety management plan. This plan should prioritize employee health and safety and minimize potential exposure to deadly viruses. The findings of this investigation are expected to provide valuable insights for practitioners seeking to incorporate effective COVID-19 safety and health measures into their regular management plans. Adopting health and safety measures would help employees for their participation in and adherence to the safety plan.

FUTURE SCOPE: -

This research focuses primarily on the safety and precautions of Industrial migrant workers and labourers after the Covid-19 pandemic. The Future research can expand to look on to the safety and precautions of other workers such as- the Frontline Health workers, doctors, IT Employees, children and office goers Post Covid.

Also, this research is about the well beings “post” covid, but for future work, this research can be spread on the 3 phases – Pre Covid, During Covid and Post Covid.

The research and survey conducted was limited to India only, it can be expanded to other regions also to get a diversified view of what all safety measures have been taken to cope up with this pandemic.

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Theme 2: U/G Mine Operation

NO : 2.1

An over view on smart mining technology in winding system of metalliferous mines

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Abstract:

Winding is a very important aspect of underground mines with shafts which consist of a loading station for ore, service station for workers, shaft conveyances like skips and cages, ropes that suspends the conveyances, system to guide the conveyance, head gear, winding engine and room. Smart mining in winding system aims to enhance operational efficiency, improve safety standards and reduce environmental impact through the integration of advanced technologies and automation solutions in winding system. The implementation of smart mining involves several key aspects such as automation which plays a crucial role by enabling remote operation and monitoring of hoisting equipment. This reduces the need for workers to be physically present near hazardous shaft areas, thereby improving safety outcomes. Predictive maintenance is another component which predicts when the maintenance is required by utilising sensors and data analytics and it also helps the operators to predict equipment failure before they actually occur. This predictive maintenance minimizes downtime and extends the lifespan of critical components enhancing operational reliability. Energy efficiency measures is also a core objective of smart mining which optimize energy usage in the winding system by adjusting the speed of hoist based on load requirements or by using regenerative braking system that can capture and reuse energy during descent. Data-driven-decision making is also an important aspect in optimising the performance of winding system by integrating data from various sensors and systems. Smart mining in winding systems represents a transformative approach to underground mining operation. By embracing smart mining technologies in winding, mining operations can be safer, more efficient and environmentally sustainable.

Keywords- conveyances, automation, data analytics, regenerative braking system, data driven decision making

Introduction

Mining is a crucial industry for our modern society, providing valuable resources that fuel our economies and drive technological progress. However, traditional mining practices can be dangerous, environmentally damaging, and costly, and they often face challenges such as declining ore grades, increasing depths of mineral deposits, and complex geological conditions. The concept of smart mining, which combines traditional mining technology with information and communication technology, constitutes the fourth industrial revolution of the mineral industry in the age of digital transformation. Smart mining technology offers a promising solution to these challenges, leveraging the latest advances in sensing, automation, and data analytics to optimize mining operations and improve safety, efficiency, and sustainability. In the winding system of metalliferous mines involves integrating advanced automation, data analytics, and digital connectivity to enhance the efficiency, safety, and reliability of the mine's hoisting operations. Smart Mining Technology in the winding system of metalliferous mines aims to transform traditional hoisting operations into highly efficient, safe, and sustainable processes through the integration of advanced automation, connectivity, and data-driven decision-making.

The rest of the paper is organised as follows: Section 2 describes Necessity for Introduction of Smart Mining Technology in Winding System. Section 3 describes Applications of Smart Mining Technology in Winding System of Metalliferous Mines. Section 4 describes Advancement of Technology in Safety Devices used in Winding System. Section 5 describes Application of AI in Braking System of Winder. Section 6 describes Proposed Measures for Reduction of Rope Snapping Accidents in the Winding System. Section 7 describes Other Advantages of Smart Mining and finally Section 8 describes Conclusion and Future Scope.

1. Necessity for introduction of smart mining technologies in winding system

Human error, equipment failure, or unsafe conditions are major causes of mine accidents. To give an instance the incident at Kolihan Copper mine of Khetri Copper Complex, Khetrinagar, Rajasthan on May 14, 2024 where an accident caused due to snapping of rope and collision of cage at the pit bottom buffer resulting in one fatal and fourteen severe bodily injury can be taken into account [1].

The introduction of smart mining technology in the winding system of metal mines [2] is driven by similar critical needs and challenges faced by the mining industry. These needs justify the adoption of advanced technologies to optimize hoisting operations and improve overall mine efficiency and safety. Key necessities for introduction of Smart Mining Technologies can be listed as:

1.1. Enhanced Safety

Safety is paramount in mining operations, especially during hoisting activities where risks of accidents and injuries are higher. Smart mining technologies such as automated systems, collision avoidance sensors, and real-time monitoring can significantly reduce these risks by enhancing control and oversight of hoisting operations [9].

1.2. Operational Efficiency

Traditional hoisting systems may operate at suboptimal efficiency levels due to manual control and limited real-time data availability. Smart mining technologies enable automated operations, predictive maintenance, and optimized scheduling based on real-time data analytics [5]. This improves overall operational efficiency, reduces downtime, and increases ore throughput.

1.3. Cost Reduction

Mining companies are under pressure to reduce operational costs while maintaining productivity. Smart mining technologies contribute to cost reduction through improved energy efficiency, optimized resource allocation, reduced maintenance costs through predictive analytics, and enhanced equipment lifespan [3].

1.4. Environmental Sustainability

Modern mining operations are increasingly focused on minimizing environmental impact. Smart mining technologies support sustainability goals by reducing energy consumption, optimizing water usage, and minimizing waste through better operational management and resource utilization [3].

1.5. Regulatory Compliance

Compliance with stringent safety and environmental regulations is a significant challenge for mining companies. Smart mining technologies help ensure compliance by providing accurate data monitoring and reporting capabilities, thereby facilitating regulatory adherence and minimizing potential liabilities.

1.6. Workforce Skills and Retention

As mining operations become more technologically advanced, there is a growing need for skilled workers capable of operating and maintaining smart mining systems. Investing in smart technologies can attract a new generation of workers interested in technology-driven industries, while also upskilling existing workforce to manage and operate advanced equipment [7].

1.7. Competitive Advantage

Adopting smart mining technologies can provide a competitive edge in the industry. Companies that embrace innovation and efficiency enhancements are better positioned to navigate market fluctuations, respond to changing demands, and capitalize on new opportunities in the global marketplace [7].

2. Applications of smart mining technology in winding system of metalliferous mines

Smart mining technology in the winding system of metalliferous mines involves integrating advanced automation, data analytics, and digital connectivity to enhance the efficiency, safety, and reliability of the mine's hoisting operations. Some key aspects of how smart technology can be applied are listed as follows:

2.1. Automation and Control Systems

- **Automated Hoist Operations**: Implementing automated systems for hoist control can optimize the speed and efficiency of ore transportation [6].
- **Remote Monitoring and Control**: Using sensors and real-time data analytics to monitor equipment health, performance, and operational parameters from a centralized control room [2].
- **Predictive Maintenance**: Applying machine learning algorithms to predict maintenance needs, reducing downtime and improving equipment lifespan [6].

2.2. Digital Connectivity

- **Internet of Things (IoT)**: Connecting various components of the hoisting system, i.e. hoists, conveyors, sensors to gather real-time data on performance and environmental conditions [4].
- **Wireless Communication**: Using Wi-Fi or other wireless technologies to transmit data from underground mines to surface control centers, enabling prompt decision-making [4].
- **Real Time Communication and Coordination**: Using advanced communication technologies such as Wi-Fi, RFID or LTE can improve coordination between surface control rooms and underground operations ensuring smooth efficient winding operations [4].

2.3. Safety and Monitoring

- **Collision Avoidance Systems**: Installing proximity sensors and collision avoidance technology to prevent accidents involving mining personnel and equipment [9].
- **Emergency Response Systems**: Integrating automated emergency response mechanisms to handle incidents swiftly and effectively [9].

2.4. Data Analytics and Optimization

- **Big Data Analytics**: Analysing vast amounts of data collected from sensors and historical records to optimize hoisting schedules, energy consumption, and resource allocation [6].
- **Optimization Algorithms**: Using algorithms to minimize energy usage during hoisting operations while maximizing ore throughput and overall efficiency [6].

2.5. Energy Efficiency

- **Energy Management Systems**: Implementing smart grid technologies to manage and optimize energy consumption, integrating renewable energy sources where feasible [3].
- **Energy Recovery Systems**: Utilizing regenerative braking and other energy recovery technologies to reduce energy costs and environmental impact [3].

2.6. Training and Integration

- **Operator Training Simulators**: Providing virtual training environments to simulate various hoisting scenarios and ensure operators are prepared for real-world challenges [6].
- **Integration with Mine Planning**: Aligning the hoisting system with overall mine planning and scheduling processes to optimize ore extraction and transportation [8].

3. Advancement of technology in safety devices used in winding system

The advancement of technology in safety devices for winding systems in mines has significantly improved over the years, focusing on enhancing workers safety and operational efficiency. Some key advancements can be listed as follows:

3.1. Proximity Detection System

This system uses sensors to detect the presence of personnel or vehicles near the winding equipment. They can issue warnings or automatically stop the equipment to prevent collisions or accidents [2].

3.2. Real Time Monitoring and Feedback

Modern safety devices incorporate real time monitoring of critical parameters such as speed, load and environmental conditions. This information is used to provide immediate feedback to operators and supervisors allowing for timely interventions if unsafe conditions arise [2].

3.3. Integration with AI and Data Analytics

AI algorithms can analyse data from various sensors to predict potential hazards and provide insights into improving safety protocols. Data analytics help in identifying trends and patterns that could indicate areas needing attention [6].

3.4. Emergency Response Systems

Advanced safety devices include emergency response features such as automatic shutdown procedures in case of emergencies, rapid communication systems for summoning assistance and evacuation protocols [9].

3.5. Improved Ergonomics and User Interfaces

User interfaces have become more intuitive and ergonomic, making it easier for operators to monitor safety parameters and respond quickly to alerts or warnings [3].

3.6. Training and Simulation Tools

Virtual Reality and Augmented Reality training simulators are increasingly used to train personnel in safe operating practices without exposing them to real hazards. This improves preparedness and reduces risks during actual operations [6].

3.7. Remote Monitoring and Control

Remote monitoring systems allow for continuous oversight of winding operations from control rooms located away from potentially hazardous areas. This reduces the need for personnel to be physically present near the equipment [2][7].

3.8. Integration with Overall Mine Safety Systems

Safety devices in winding systems are increasingly integrated with broader mine safety systems, ensuring a coordinated approach to safety management across all operations [9].

4. Application of ai in braking system of winder

Applying Al in the braking systems of winding mines enhances operational safety, efficiency, and reliability by enabling proactive maintenance, optimizing braking control, and facilitating quick responses to emergencies. These advancements contribute to reducing risks and improving overall productivity in mining operations. Several potential applications are listed here:

4.1. Predictive Maintenance

Al algorithms can analyse data from brake sensors and actuators to predict when maintenance or replacement of braking components is required. This proactive approach helps prevent unexpected failures and reduces downtime [6].

4.2. Optimized Brake Control

Al can optimize the control of braking systems based on real-time data such as load conditions, speed, and environmental factors. This ensures that the brakes are applied appropriately to maintain safe operating conditions while maximizing efficiency [6][7].

4.3. Emergency Braking Assistance

Al can assist in emergency situations by quickly assessing the severity of the situation (e.g., sudden load changes, equipment failures) and applying the brakes automatically or providing recommendations to operators for effective emergency braking [5].

4.4. Adaptive Braking Strategies

Al algorithms can adapt braking strategies based on varying operational conditions, such as different load weights, changes in incline, or environmental factors like temperature and humidity. This adaptive capability optimizes braking performance while ensuring safety [5][7].

4.5. Fault Detection and Diagnostics

Al can detect abnormalities or faults in the braking system's performance by analysing sensor data in real-time. It can diagnose the root causes of issues, such as brake wear, hydraulic leaks, or electrical failures, enabling prompt maintenance actions [6].

4.6. Integration with Overall Control Systems

Al can integrate with the overall control systems of the mine's equipment to ensure coordinated operation and safety protocols [9]. This includes communication with other systems to adjust braking responses in sync with other operational parameters.

4.7. Training and Simulation

Al-powered simulations can be used for training operators in optimal braking techniques and emergency procedures without real-world risk. Virtual environments can simulate various scenarios to enhance preparedness and decision-making skills [6].

5. Proposed measures for reduction of rope snapping accidents in the winding system

Smart mining technologies can play a crucial role in preventing rope snapping accidents in mine winding systems by leveraging advanced monitoring, automation, and data analytics. By adopting smart mining technologies, mines can significantly reduce the risk of rope snapping accidents in winding systems through proactive maintenance, real-time monitoring, and enhanced operational control. These technologies not only improve safety but also contribute to operational efficiency and sustainability in mining operations.

5.1. Real-Time Monitoring

Smart sensors can continuously monitor the condition of ropes, including tension, stress levels, and vibrations. Any anomalies or signs of wear can be detected early, allowing for proactive maintenance before a failure occurs.

5.2. Predictive Maintenance

By analysing data collected from sensors and historical maintenance records, predictive maintenance algorithms can identify potential issues with ropes and other components of the winding system. This proactive approach helps in replacing ropes before they reach a critical failure point.

5.3. Automation and Control Systems

Automated systems can optimize the operation of the winding system, ensuring that loads are managed within safe limits and minimizing sudden changes in tension that could stress the ropes.

5.4. Integration with Safety Systems

Smart mining technologies can be integrated with safety systems such as emergency braking mechanisms or automatic shutdown procedures in case of overloads or unexpected events.

5.5. Data-Driven Decision Making

Utilizing data analytics, mine operators can gain insights into the performance of the winding system over time. This information can inform decisions on equipment upgrades, maintenance schedules, and operational improvements to enhance safety.

5.6. Environmental Monitoring

Smart mining solutions can also monitor environmental factors such as temperature and humidity, which can affect the lifespan and performance of ropes in the winding system.

Using these measures accidents like ones which took place in Kolihan Copper mine of Khetri Copper Complex, Khetrinagar, Rajasthan on May 14, 2024 by snapping of winding rope and collision of cage at the pit bottom buffer resulting in one fatal and fourteen severe bodily injury could be avoided.

6. Other advantages of smart mining

By bridging the gap between work site devices, corporate network resources and edge computing, enterprises can increase productivity, and reduce their operational expenses. Below we will touch on a few of the key benefits of smart mining and explain how mining companies improve their business through this new technology.

6.1. Improved Workforce Safety

Both open pit and underground mining pose unique safety and logistical challenges. In mines, operators can use loT sensors to monitor seismic activity, structural integrity, and air quality. This data can be collected from underground and relayed to site offices above ground through a network of private cellular access points. This private wireless connectivity can improve communication underground in areas where traditional means of communication struggle to reach the surface due to lack of strong coverage. While open-pit mines don't struggle with underground conditions, landslides, flooding, and ground collapse still put miners at risk. Smart mining sensors can monitor ground stability and alert to sudden weather changes in real time [4][9].

6.2. Reduced Costs

Private communication system for smart mining opens up the autonomous operation of vehicles and equipment. This could save companies downtime by relying on the deterministic latency and bandwidth offered by cellular wireless technology across mining sites. By connecting machines with IoT sensors, maintenance staff can monitor the condition of machines more efficiently from a digital display. Metrics such as temperature, fluid levels, and conductivity can be recorded and set to alert when reaching certain thresholds [4]. IoT sensors are inexpensive and require little power to operate, allowing businesses to deploy multiple such sensors across their work environments. Even older analog equipment that lacks internet connectivity can use IoT sensors powered by a mobile network [4].

6.3. Security

In many cases, it's impractical to run Fiber for high-speed internet access in remote mining locations. This can leave mining equipment and tools vulnerable to theft or vandalism. CCTV and anti-theft devices can rely on a private connection to function in a smart mining operation. Private cellular connectivity offers the predictable network capacity needed to power live high-definition streaming video, alarm systems, and GPS tracking tags simultaneously. With network connectivity from back at the office, staff can monitor multiple sites and receive alerts if they suspect stolen equipment [3][6].

6.4. Enhanced Ore Body Knowledge

Technology has come a long way to aid the early stages of prospecting and ore detection. Mining companies can use radar data to map both subsurface and open-pit mines to identify opportunities and potential hazards. This technology has been applied to drones as well as underwater submersibles to help operators make better choices above ground [8].

6.5. Data Privacy

Private cellular networks encrypt traffic by default over the air and on the wire within the local area network at the mine sites. Instead of a network password, devices authenticate by device identity via SIM cards that hold the device's identity and level of network access. Officials have full control over their data and network resources on private networks [3][5].

7. Conclusion and future scope

From the above discussion it is clear that introduction of smart mining technologies in the daily mining activities can make a significant change in the mining industry as well as widen the scope of future research. Smart mining technology significantly improves safety by minimizing the need of human presence in dangerous areas and providing early warning for potential hazards. Smart mining technology is a convergence of 5G and AI, this advance technology drives automation, enhance safety measure, optimise resource management and promote environmental stewardship. Collaborative effort between mining firms, technology providers and regulatory bodies are crucial for successful implementation of these smart mining practices.

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From surface to subterranean: advancing sustainability with longwall and continuous miner technologies in the mining industry

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Abstract:

Opencast mining, though economically beneficial, poses significant environmental and socio-economic challenges, including extensive land degradation, deforestation, and pollution. This research paper explores the adverse impacts of opencast mining and evaluates the potential of longwall and continuous miner technologies as sustainable alternatives. Opencast mining operations result in habitat destruction, biodiversity loss, and soil erosion, alongside generating substantial dust and noise pollution that affects local communities and ecosystems.

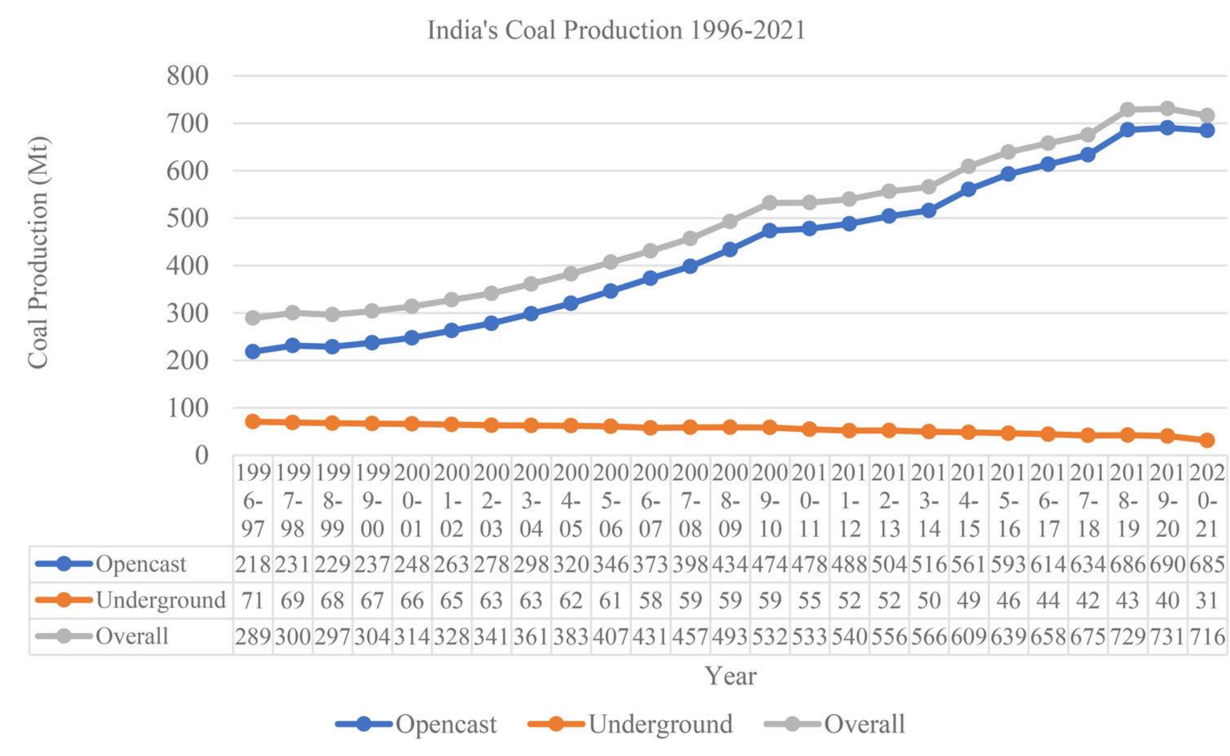
Longwall mining and continuous miner technology offer viable solutions by transitioning to underground operations. Longwall mining utilizes a mechanized shearer to extract coal along a lengthy face, significantly reducing surface disruption and enhancing resource recovery rates to 80-90%, compared to the 60-70% recovery rate of opencast mining. Continuous miner technology employs a rotating drum to cut and gather material, offering adaptability to varying geological conditions and continuous operation, thereby increasing productivity and safety by eliminating the need for explosives.

Through a comprehensive review of existing literature and case studies, this paper demonstrates that the adoption of longwall and continuous miner technologies can substantially reduce environmental impacts, including lower air and water pollution levels, reduced greenhouse gas emissions, and decreased land degradation. Furthermore, these technologies provide improved safety conditions for miners and promote socio-economic benefits for communities through more stable and less disruptive employment opportunities.

However, the transition to these advanced technologies entails challenges such as high initial capital investment and the need for specialized workforce training. The paper concludes with policy recommendations and strategic frameworks to facilitate the adoption of longwall and continuous miner technologies. These recommendations include financial incentives, regulatory support, and investment in research and development to optimize technology performance and accessibility. This research advocates for a shift towards sustainable and responsible mining practices that balance economic growth with environmental stewardship and social responsibility.

Introduction

Coal mining in India is currently characterized by a significant reliance on opencast mining, which contributes to the majority of the country's coal production. Despite the global trend where approximately 60% of coal is produced from underground mines, and countries like China, South Africa, the USA, and Australia showing substantial underground mining operations, India's underground mining contributes less than 5% to its total coal output. This is notably disproportionate given that 70% of India's coal reserves are suitable for underground mining, with around 42% of these reserves being located at depths that necessitate underground methods.



	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
Opencast	218	231	229	237	248	263	278	298	320	346	373	398	434	474	478	488	504	516	561	593	614	634	686	690	685
Underground	71	69	68	67	66	65	63	63	62	61	58	59	59	59	55	52	52	50	49	46	44	42	43	40	31
Overall	289	300	297	304	314	328	341	361	383	407	431	457	493	532	533	540	556	566	609	639	658	675	729	731	716

The disparity between the potential and actual underground coal mining in India can be attributed to various factors, including higher initial investment costs, technological challenges, and the historical development of mining practices. The dominance of opencast mining, while economically advantageous in the short term due to lower costs and higher production rates, poses significant long-term environmental and socio-economic challenges. Opencast mining activities lead to extensive deforestation, habitat destruction, soil erosion, and significant alterations to local ecosystems. Additionally, the displacement of local communities and the degradation of arable land further exacerbate the socio-economic stresses associated with opencast mining.

Mining activities put tremendous pressure on local flora and fauna, particularly where diversion of forest land for mining takes place. The effect of mining on groundwater levels, silting of surrounding water bodies, and land are also of great concern. Coal mining contributes greatly to the economic development of the nation, although it also has a significant impact on human health. The burning of coal releases harmful substances such as sulfur dioxide, nitrogen oxide, carbon dioxide, as well as particulates of dust and ash, contributing to air and water pollution in coal-burning areas. These pollutants have been recorded at dangerous levels in many regions, posing health risks to the local population.

Underground mining, while less visually intrusive than opencast mining, also presents its own set of challenges. The depletion of groundwater, subsidence, and the degradation of soil and land are common issues associated with underground mining. Subsidence beyond permissible limits requires filling of the subsidence area, which can be both costly and technically challenging. Additionally, the release of coal bed methane, a potent greenhouse gas, further contributes to the global environmental impact of coal mining.

Despite these challenges, underground mining is essential for tapping into the deeper coal reserves that are not accessible through opencast methods. According to the Central Mine Planning & Design Institute Limited (CMPDIL), about 42% (138.32 BT reserves) of India's coal reserves are located below 300 meters depth, making underground mining the only viable method for extraction. Modernizing underground coal mines through the adoption of Mass Production Technology (MPT) is crucial. MPT can help underground mining compete with opencast mining in terms of output per man-shift (OMS) and production rates, thereby making it economically viable and environmentally sustainable.

Coal India Limited (CIL) has recognized the need for a strategic shift towards underground mining. The company has launched a mission to increase coal production from underground mines to 100 million tonnes by 2027-28. This initiative includes the modernization of existing mines, the introduction of advanced mining technologies, and a focus on sustainable mining practices. By improving the efficiency and productivity of underground mines, CIL aims to reduce the environmental footprint of coal mining while ensuring a steady supply of coal to meet the country's energy demands.

Moreover, coal companies in India are now working towards "clean coal" strategies, which aim to reduce the environmental impact of coal mining and usage. One such strategy is coal washing, which involves the removal of impurities from coal to reduce ash content. This process not only increases the thermal efficiency of coal combustion but also significantly reduces the emission of pollutants. Although coal washing requires extra water, it represents a step towards a cleaner and more sustainable approach to coal usage.

The environmental and socio-economic impacts of coal mining necessitate a holistic approach to mining activities. This includes the identification of various sites where minerals exist, the determination of appropriate angles of slope for overburden dumps, and the implementation of safe disposal drains and silt control structures. Additionally, the adverse social and cultural impacts, such as the displacement and resettlement of affected people, changes in local culture and heritage, and the rise in criminal and other illicit activities due to sudden economic development, must be addressed.

2. Health and Environmental of Issues Opencast Mining

Opencast coal mining, while essential for economic growth, presents significant health and environmental challenges. This mining method, prevalent in regions like Odisha, India, underscores a critical trade-off between economic benefits and adverse impacts on local communities and ecosystems.

2.1 Environmental Impact

Opencast coal mining is notably harmful to the environment. The process generates extensive air pollution, primarily through the release of particulate matter (PM10), sulfur dioxide (SO2), methane, and oxides of nitrogen. These pollutants substantially degrade air quality, posing risks not only locally but also regionally and globally. The dust and emissions from mining operations contaminate water sources and reduce land fertility, leading to decreased agricultural productivity. Forest loss and degradation are also significant consequences, disrupting local ecosystems and biodiversity.

2.2 Health Impact

The health of communities living near opencast coal mining sites is severely compromised. The high concentration of pollutants, particularly PM10, leads to respiratory diseases such as chronic bronchitis, asthma, and other respiratory syndromes. Long-term exposure increases the risk of high blood pressure and heart diseases. Local populations are vulnerable to diseases like acute respiratory illness (RI), tuberculosis, gastric problems, and skin diseases due to the toxic elements released by mining activities. These health issues not only affect the quality of life but also impose economic burdens through medical expenses and loss of productivity.

2.3 Socio-Economic Considerations

The economic benefits of coal mining are undeniable. It creates direct and indirect employment opportunities, generates substantial tax revenues and mineral royalties, and attracts foreign direct investment (FDI). However, the socio-economic development derived from mining often comes at a high environmental and health cost. The irreversible damage caused by mining activities necessitates a careful evaluation of the long-term consequences versus immediate economic gains.

3. Need to Modernize Underground Mines in India

- In India, most underground mines operate using conventional methods. Consequently, when opencast mines become exhausted or are closed, the production shortfall cannot be compensated by traditional underground mining. To sustain productivity and meet demand, it is imperative to modernize these underground mines by swiftly introducing Mass Production Technologies.

- Opencast mining poses significant environmental challenges, causing substantial harm to the land, flora, and fauna. It disrupts the natural balance of the surrounding environment, leading to issues such as air pollution, dust, and noise. Therefore, finding alternative methods to opencast mining is essential.

- Given the typically longer gestation periods for underground mining projects, it is crucial to commence planning for the implementation of Mass Production Technologies well in advance.

- The safety record of India's underground coal mines needs improvement. Modernizing these mines can enhance safety standards, reducing risks and ensuring better protection for miners.

4. Present Practice and Drawbacks of Conventional Underground Coal Mining in India

In India, the majority of underground coal mines continue to rely on conventional mining techniques. This traditional approach involves the use of drilling and blasting technology to extract coal, followed by the transportation of the blasted coal using Load Haul Dump (LHD) machines and Side Discharge Loaders (SDLs). Subsequently, supports are installed to maintain the stability of the mine. A widely used method in conventional depillaring is the rib-and-slice technique. This involves leaving a rib or snook against the goaf (the void left after coal removal) and providing breaker-line support at the goaf edge. The remaining rib or snook is carefully reduced during retreat mining to facilitate the controlled caving of the roof strata, ensuring the safety of the operation and the structural integrity of the mine.

However, this conventional approach has several significant drawbacks. One of the primary issues is low productivity. The Output per Man Shift (OMS) in these conventional mines is notably low, making the operations economically unviable. The high operating costs associated with traditional mining methods further exacerbate this problem. Additionally, the rate of recovery in conventional mines is suboptimal, with only about 65% of the mineral being extracted. The remaining 35% of the coal is left unmined and is often irretrievable in the future, resulting in a considerable loss of valuable national resources.

Safety is another major concern with conventional underground mining. The traditional methods pose significant risks to the miners, contributing to a high incidence rate of accidents and fatalities. Over 90% of underground mining incidents occur in mines that utilize conventional techniques. These incidents can lead to severe injuries or even loss of life, highlighting the urgent need for improved safety measures.

Given these challenges, there is a pressing need to modernize India's underground coal mines. Adopting mass production technologies, such as Longwall Mining and Continuous Miner systems, can address many of the issues associated with conventional mining. Longwall Mining involves the use of a shearer that moves back and forth across a coal seam, cutting the coal, which is then transported out of the mine on a conveyor belt. This method significantly enhances productivity and recovery rates while also improving safety conditions for miners. Continuous Miner systems, on the other hand, use a machine with a large rotating steel drum equipped with tungsten carbide teeth that scrape coal from the seam, allowing for continuous and efficient extraction.

Modernizing the existing mines by incorporating these advanced technologies is essential to increase productivity, reduce operating costs, and enhance safety. This transition will not only ensure the more efficient extraction of coal but also help in preserving valuable national resources and protecting the lives of miners.

5. Longwall Technology

Longwall mining is a highly efficient underground coal extraction technique characterized by its use of a specialized shearer that traverses a designated area, known as the "longwall face." This face can extend for hundreds of meters, allowing for continuous coal removal. The process involves systematically removing coal along the face, creating a void behind the shearer. A crucial component of longwall mining is the longwall shield, a hydraulic support system that safeguards miners and equipment from the collapsing roof. As the shearer advances, these shields move forward, providing structural support to the excavated area.

5.1 Challenges in Implementing Longwall Mining in India

The implementation of longwall mining in India has faced numerous challenges, preventing it from achieving the desired success. A significant issue is the absence of a firm policy for the introduction of mass production technology. Despite the nationalization of coal mines, there has been no concerted effort by the government to promote mass production technologies, leading to a lack of interest from both private and government entities in manufacturing the necessary equipment. Additionally, the lack of standardization in longwall equipment has hindered progress. Equipment procured in India often had varying specifications, discouraging indigenous manufacturers from producing spare parts due to low demand. The small number of operating longwall faces further dissuaded suppliers from establishing manufacturing facilities or spare depots in India. Moreover, imported longwall equipment frequently proved unsuitable for Indian hard coal conditions.

Another major problem was the mismatching of the places where longwall technology was applied. Longwall faces were introduced in extremely challenging conditions, such as difficult geo-mining environments, steep and thin seams, high degrees of gassiness, and very high ambient temperatures. These conditions often led to failures, fostering the misconception that longwall technology was unsuitable for Indian mining in general. The lack of adequate infrastructure in existing mines further compounded these issues, as many did not possess the facilities needed to support the desired level of production.

Insufficient advanced geo-technical studies and research and development (R&D) facilities also played a crucial role in the unsuccessful implementation of longwall mining. Inadequate geological information and geotechnical knowledge, due to insufficient borehole density during exploration, led to poor planning and incorrect selection of powered roof supports. Misinterpretations of geological faults, variations in seam thickness, and insufficient understanding of hydro-geology often resulted in continuous water percolation and strata control problems. Notable examples include the failures at Churcha (SECL) and Khottadih (ECL), where powered supports collapsed under the load of the overlying strata due to being underrated. These incidents had a severe negative impact on the perception of longwall technology and hindered its broader adoption in Indian mines.

In summary, the lack of policy support, standardization, appropriate application, infrastructure, and advanced technical studies have all contributed to the inadequate success of longwall mining in India, highlighting the need for comprehensive reforms and investments to address these multifaceted challenges.

5.2 . Future Prospects for the Success of Longwall Technology

The future success of longwall technology in India hinges on several key factors and strategic initiatives.

Pre-planning and Scientific Studies: First and foremost, there must be thorough pre-planning for sites deemed feasible for the deployment of longwall technology. Scientific studies should be conducted to identify and address various constraints to ensure that the failures experienced in the past are not repeated. This includes detailed geological surveys, stress analysis, and hydro-geological assessments to select appropriate powered roof supports and plan panel orientations effectively.

Learning from Leading Countries: India can significantly benefit from studying and adopting best practices from leading countries in longwall mining, such as China. Both nations introduced longwall technology around the same time, but China has surged ahead, becoming a global leader in coal production. China’s success can be attributed to developing tailor-made equipment suited to their specific geo-mining conditions and investing heavily in skill development for their workforce. They have also prioritized applied R&D, focusing on product design and quality improvement. India should emulate this approach by investing in skill development and fostering a robust R&D environment to innovate and improve longwall technology suited to local conditions.

Encouraging Indigenous Manufacturers: To ensure the sustainability and economic feasibility of longwall mining, it is crucial to encourage indigenous manufacturers to develop their technical expertise. By producing equipment tailored to Indian geo-mining conditions at lower costs, these manufacturers can help reduce dependency on imported machinery. This move will also address issues related to spare parts and maintenance, making longwall mining more viable and cost-effective. Implementing economic instruments such as tax incentives and subsidies can further support these manufacturers, promoting domestic production and innovation.

6. Continuous Miner Technology

6.1 Overview

Continuous miner technology represents a significant advancement in underground mining, revolutionizing the extraction of coal and other valuable minerals. This method offers efficiency, safety, and increased production rates compared to traditional mining techniques. A continuous miner is a large machine with a rotating drum equipped with cutting bits. It can continuously extract material from the mining face, eliminating the need for intermittent drilling and blasting. This not only enhances productivity but also reduces downtime associated with manual tasks. One of the key advantages of continuous miners is their ability to operate in confined spaces, making them suitable for narrow coal seams

6.2 Reasons for the Success of Continuous Miner Technology in India

Continuous Miner (CM) technology has found considerable success in India due to several key advantages. One of the primary benefits of CM technology is its versatility in deployment. It can be effectively utilized in already developed galleries or ongoing projects, providing flexibility and ease of integration. This adaptability has been demonstrated in several successful projects, such as the Sarpi Mines in the Bankola Area and the Khottadih Mine in the Pandaveswar Area of Eastern Coalfields Limited (ECL), where CMs have been deployed in pre-existing panels. This practice facilitates the modernization of ongoing mining operations without the need for extensive new development.

Another significant advantage is the ability of CMs to operate in challenging geological conditions, making them particularly suitable for the diverse and often difficult mining conditions found in India. They can handle a wide range of coal seam thicknesses, further enhancing their applicability across different mining sites.

In terms of financial feasibility, Continuous Miner technology requires less capital investment compared to Longwall technology. This lower cost barrier makes it a more accessible option for many mining operations, enabling broader adoption and implementation.

Furthermore, CM technology is integrated with environmental monitoring systems, which is a crucial feature for its operation in gassy mines. This integration ensures better safety standards and compliance with environmental regulations, making CMs a safer and more sustainable choice for coal mining in India.

Overall, the success of Continuous Miner technology in India can be attributed to its flexibility in deployment, suitability for various geological conditions, cost-effectiveness, and enhanced safety features. These advantages have made it a preferred choice for modernizing and improving coal mining operations across the country.

7. Conclusion

Opencast mines in India face significant environmental challenges, including land degradation, impacts on flora and fauna, and pollution of air and noise. With shallow coal deposits expected to last only another 20-25 years, there is an urgent need to develop mechanized underground coal mines for mass production. To achieve this, substantial efforts are required in research and development (R&D) and skill development. Planning numerous mechanized faces will encourage indigenous manufacturers to produce cost-effective equipment, resolving past issues related to services and spare parts. In alignment with Coal India Limited's (CIL) objective to achieve 100 million tonnes from underground mines by 2027-28, existing mines must adopt mass production technology. Matching the ratio of coal production from underground and opencast mines to international standards will ensure India's coal import independence. Mechanized mines not only offer high productivity but also enhanced safety and minimal human resource engagement at hazardous sites. As India continues to embrace technological advancements in its coal mining sector, the introduction of mass production technology underscores a commitment to improving efficiency and safety. Balancing these advancements with environmental responsibility will be crucial to establishing a sustainable future for underground coal mining in the country.

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Mapping and prediction of formaldehyde and volatile organic compound sin underground metalmines

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Abstract:

The study investigates the environmental dynamics within development faces in underground metal mines, with a specific focus on emission of formaldehyde (HCHO) and Total Volatile Organic Compounds (TVOCs) by Load-Haul-Dumpers (LHD) during its operation. The study aims to collect data on air parameters including air quantity, air velocity, temperature, relative humidity, concentrations of Carbon dioxide, HCHO and TVOCs to elucidate the intricate relationship between different mine environmental parameters, particularly focusing on the efficacy of ventilation systems in regulating HCHO and TVOCs concentrations in underground metal mine. Real-time measurements were facilitated by the ET-99HT device, equipped with sensors for TVOCs and HCHO and other devices. Analysis of acquired data revealed notable inverse correlations between HCHO and TVOC levels with air velocity and air quantity, indicating the pivotal role of enhanced ventilation in reducing gas concentrations. Additionally, an understanding of the relationship between HCHO, TVOCs levels and CO2 concentrations demonstrated the quantitative interconnectedness of these diesel vehicle emitted gases within the underground mine environment. The outcomes of this study emphasize the critical importance of dispersion efficacy of targeted gases for reducing pollution levels within underground metal mines

Keywords: Environmental monitoring, Formaldehyde(HCHO), Total Volatile Organic Compounds(TVOCs), Ventilation systems, Air quality, Dispersion efficacy

Introduction

Diesel-powered machineries used in underground mining operations emit gases that pose significant challenges to both worker's health and environmental sustainability [1,2]. Among these emissions, formaldehyde (HCHO) and volatile organic compounds (VOCs) are particularly concerning due to their adverse effects on human health and air quality [1]. Formaldehyde, a colourless gas with a pungent odour, is produced as a byproduct of the incomplete combustion of diesel fuel in the engines of mining equipment. Classified as a carcinogen, formaldehyde presents risks such as respiratory issues and skin irritation to miners [1]. Similarly, Volatile Organic Compounds (VOCs) emitted from diesel engines during mining processes contribute to air pollution and pose health hazards to workers [2,3]. Efforts to mitigate formaldehyde and VOC emissions in underground mines are crucial for ensuring worker safety, regulatory compliance, and environmental responsibility [4]. A comprehensive understanding of these emissions requires examining various contexts, including studies on automobile emissions, indoor air quality, alternative fuel technologies, and urbanisation effects [5-10]. Furthermore, research has explored diverse strategies for monitoring and controlling formaldehyde and VOC emissions, including advanced measurement technologies, emission reduction techniques, and regulatory interventions [1, 6, 9, 11, 18, 19]. Advanced measurement technologies such as Fourier transform infrared (FTIR) spectroscopy, proton transfer reaction mass spectrometry (PTRMS), tunable diode laser absorption spectroscopy (TDLAS), quantum cascade laser infrared spectroscopy (QCL-IR), and other optical sensors have been developed to provide high- sensitivity, real-time measurements of formaldehyde and VOC concentrations [1, 11]. Techniques such as adsorption, catalytic oxidation, bio filtration, photo catalytic degradation, and platform technologies have been explored for their effectiveness in capturing and degrading pollutants in waste gases [9,29]. Government agencies and regulatory bodies have implemented emission standards, workplace safety regulations, and pollution control measures to limit emissions from industrial processes, transportation, and other sources [6, 18, 19]. Emissions of HCHO and VOCs can accumulate over time and contribute to poor air quality in underground mines. Inadequate ventilation can result in a higher concentration of these gases, posing a danger to the health of miners. [24-28]. It is of the utmost importance to concentrate on formaldehyde (HCHO) and volatile organic compound (VOC) emissions in underground mines because of the enormous influence these emissions have on the health of mine workers, the operational efficiency of mines, legislative standards, and the environmental responsibility of mines. Emissions of HCHO and VOCs, in addition to posing a threat to human health, can also contribute to air pollution and corrosion of equipment, having a negative impact on the environment as well as the operational efficiency of mining [4]. Therefore, controlling emissions is essential for extending the lifespan of mining equipment and minimising operational disruptions. [12-23, 29].Workers' health and safety in mining operations are paramount concerns, particularly regarding the long-term inhalation of formaldehyde (HCHO) and volatile organic compounds (VOCs).Again, compliance with legal regulations regarding emissions control is imperative for mining companies to avoid penalties and ensure worker safety. The literature study revealed that, very less number of the studies have been conducted on the emission, dispersion and health effect of HCHO and TVOCs considering underground mine environment. In this context, the study investigates the environmental dynamics within a development face in underground metal mine, with a specific focus on emission of formaldehyde (HCHO) and Total Volatile Organic Compounds (TVOCs) by Load-Haul-Dumpers (LHD) during its operation. The study aims to collect data on air parameters including air quantity, air velocity, temperature, relative humidity, concentrations of Carbon dioxide, HCHO and TVOCs to elucidate the intricate relationship between different mine environmental parameters, particularly focusing on the efficacy of ventilation systems in regulating HCHO and TVOCs concentrations in underground metal mine. Real-time measurements were facilitated by the ET-99HT device, equipped with sensors for TVOCs and HCHO and other devices. Analysis of acquired data reveals notable inverse correlations between HCHO and TVOC levels with air velocity and air quantity, indicating the pivotal role of enhanced ventilation in reducing gas concentrations. Additionally, an understanding of the relationship between HCHO, TVOCs levels and CO2 concentrations demonstrates the quantitative interconnectedness of these diesel vehicle emitted gases within the underground mine environment. The outcomes of this study emphasise the critical importance of dispersion efficacy of targeted gases for reducing pollution levels within underground metal mines

2. Methods and materials

In this study, data was collected from a mechanized underground metal mine through air quality and quantity survey and thenafter, mapping and mathematical modelling were performed. The collection of relevant environmental data from selected underground metal mine includes the levels of formaldehyde (HCHO), Total Volatile Organic Compounds (TVOCs) concentrations, airflow rates, temperature, and humidity and cross section of drift, drive or cross cuts etc. Overall research methodology includes following steps.

1. Collection of data from the field and data obtained from ET-99HT
2. Mapping the gases according to stations to see the distribution of gases.
3. Analyse the field data with the existing parametric conditions.
4. Design a program for the model to predict the concentration of gases. Overall, the objective of a prediction model is to provide engineers, safety experts, and decision-makers with a reliable tool for designing and assessing the effects of gases, ultimately ensuring safer and more efficient operations

2.1 Site details and Device Placement

Targeted mines are fully mechanized metal mine operating in eastern part of Jharkhand, India. It utilizes a trackless system with a decline access to underground and ramp accesses to the stope. Ore is transported to ore processing plants at nearby mill for metal recovery. The mine has one decline of size 5 m × 3.5 m at 7° inclination from the surface, used for flexible movement of trackless diesel equipment. A vertical shaft of 5 m finished diameter up to a depth of 355 m from the surface is utilized for personnel and material transport. Experimentation was conducted in different ramp down faces commenced from 315 ML to 275 ML. A particular LHD was deployed at the face for loading of fragmented waste rock. Measurements of air quantity, air velocity, temperature, relative humidity, concentrations of Carbon dioxide, HCHO and TVOCs etc. were taken at the stations marked on 10 m interval (from p1 to p10) as shown in Fig 1(a). The relevant data was recorded at six different ramp down faces during six consecutive shifts. Again all the measurements were conducted in two phases, (a) When LHD is in operation and (b) when LHD has left the face after operation.

The device is kept at 1.25 m (handheld position) on allocated stations as presented in Fig 1(b). The focus of the reading was to measure the exposure amount of the gases by the mine workers for 02 min TWA (Time Weighted Average). Data obtained from field measurements are shown in Table 1 to Table

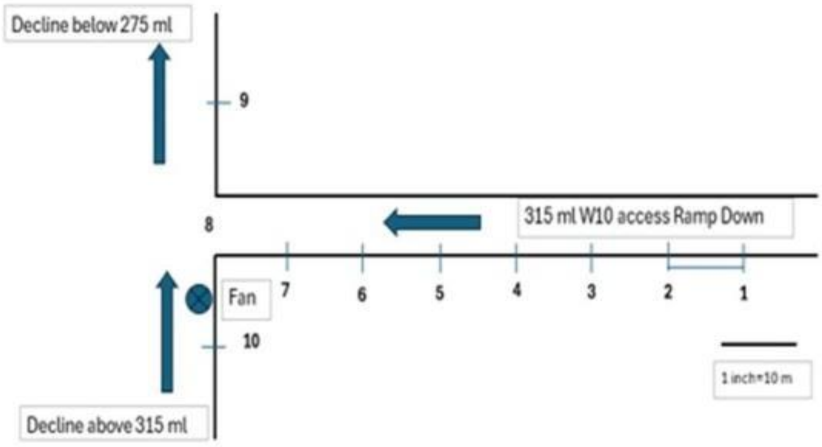


Fig.1 (a): Air quality measuring stations(Schematic Diagram)

Fig.1 (b): Device Positioning

2.1 Mathematical modelling: -

Mathematical modelling entails the utilisation of mathematical methods and equations to depict, examine, and grasp real-world occurrences or systems. It encompasses constructing a mathematical portrayal of a system, typically through equations or algorithms, to forecast outcomes, simulate behaviour, or enhance efficiency. Linear regression is a statistical technique that utilises one or more independent variables to predict the outcome of a dependent variable, enhancing traditional least-squares regression by modelling the linear relationship between the explanatory and response variables.

The coefficient of determination (R-squared) is a statistical metric that quantifies the proportion of variance in the outcome explained by the independent variables. It increases as more predictors are added to the model, even if they are unrelated to the outcome variable. R-squared can range from 0to 1, with 1 indicating that the outcome can be perfectly predicted by the independent variables.

3. Mapping and observations

3.1 Data Collection

Table 1 to 6 summarises air quality and environmental metrics at different undergroundmine levels. The table presents a detailed summary of the conditions in the mapped minearea (fig. 1), with each row representing a distinct monitoring station denoted by a code. During the experimental period, temperatureranged from 26 OC to 32 OC, indoor relative humidity ranged from 71% to 93%. According to the collected sampling data, concentrations of formaldehyde and TVOC in underground mines and their respective indooraffecting factors (air velocity, air quantity and carbon dioxide) were presented in Tables from 1 to 6.

Table 1: Air quality measurement in Shift 01-Ramp 01

Sr. No.	Particulars	Unit	When LHD in operation at Face										When LHD has left the Face									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	HCHO	mg/m³	0.22	0.22	0.15	0.09	0.08	0	0.07	0	0	0	0.02	0.02	0	0.06	0.04	0	0	0	0.18	0
2	TVOC	mg/m³	0.31	0.3	0.28	0.38	0.21	0.19	0.21	0.13	0.06	0	0.14	0.28	0.26	0.16	0.18	0.2	0.15	0.11	0.08	0
3	Air Velocity	m/sec	0.47	0.46	1.125	0.5	0.155	0.69	0.64	0.68	0.87	0.94	0.24	0.24	0.28	0.31	0.45	0.62	0.47	0.67	0.21	0.27
4	Air Quantity	m3/sec	7.88	8.89	10.48	14.26	15.1	20.08	16.68	20.06	20.93	21.08	6.12	6.02	5.12	11.21	10.24	11.2	9.45	10.05	5.45	6.22
5	CO2	%by vol.	0.16	0.15	0.14	0.12	0.1	0.1	0.1	0.09	0.02	0.08	0.12	0.15	0.15	0.11	0.12	0.11	0.09	0.11	0.07	0.05

Table 2: Air quality measurement in Shift 02-Ramp 02

Sr. No.	Particulars	Unit	When LHD in operation at Face										When LHD has left the Face									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	HCHO	mg/m³	0.23	0.19	0.25	0.23	0.2	0.21	0.23	0.24	0.21	0.23	0.19	0.14	0.21	0.2	0.19	0.18	0.08	0.11	0	0
2	TVOC	mg/m³	0.41	0.33	0.45	0.36	0.36	0.31	0.35	0.36	0.33	0.36	0.22	0.17	0.16	0.14	0.11	0.15	0.22	0.21	0.21	0.19
3	Air Velocity	m/sec	0.21	0.225	0.325	0.395	0.36	0.295	0.26	0.255	0.24	0.21	0.24	0.24	0.28	0.31	0.45	0.62	0.47	0.67	0.21	0.27
4	Air Quantity	m3/sec	6.12	6.02	7.12	11.21	10.24	11.2	9.45	14.05	13.78	12.83	6.12	6.02	5.12	11.21	10.24	11.2	9.45	10.05	5.45	6.22
5	CO2	%by vol.	0.21	0.19	0.21	0.21	0.19	0.18	0.17	0.21	0.2	0.16	0.12	0.15	0.15	0.11	0.12	0.11	0.09	0.11	0.07	0.05

Table 3: Air quality measurement in Shift 03-Ramp 03

Sr. No.	Particulars	Unit	When LHD in operation at Face										When LHD has left the Face									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	HCHO	mg/m³	0.22	0.09	0.11	0.09	0.11	0.14	0.18	0.29	0.22	0	0.16	0.08	0.09	0.07	0.1	0.16	0.16	0.21	0	0
2	TVOC	mg/m³	0.34	0.23	0.16	0.26	0.26	0.32	0.41	0.42	0.35	0.14	0.27	0.18	0.1	0.24	0.19	0.21	0.21	0.29	0.25	0.14
3	Air Velocity	m/sec	0.46	0.54	0.58	0.54	0.5	0.42	0.205	0.14	0.3	0.81	0.24	0.24	0.28	0.31	0.45	0.62	0.47	0.67	0.21	0.27
4	Air Quantity	m3/sec	13.45	22.78	15.82	15.06	14.09	12.03	6.04	3.8	10.64	23.48	6.12	6.02	5.12	11.21	10.24	11.2	9.45	10.05	5.45	6.22
5	CO2	%by vol.	0.18	0.12	0.12	0.13	0.13	0.13	0.15	0.21	0.14	0.07	0.12	0.15	0.15	0.11	0.12	0.11	0.09	0.11	0.07	0.05

Table 4: Air quality measurement in Shift 04-Ramp 04

Sr. No.	Particulars	Unit	When LHD in operation at Face										When LHD has left the Face									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	HCHO	mg/m³	0.25	0.18	0.25	0.23	0.21	0.27	0.22	0.23	0.21	0.23	0.14	0.06	0.06	0.22	0.08	0.11	0.16	0.14	0	0
2	TVOC	mg/m³	0.42	0.36	0.45	0.46	0.39	0.42	0.44	0.44	0.42	0.47	0.34	0.32	0.38	0.42	0.36	0.33	0.35	0.37	0.31	0.42
3	Air Velocity	m/sec	0.34	0.315	0.32	0.3	0.245	0.215	0.2	0.19	0.155	0.18	0.24	0.24	0.28	0.31	0.45	0.62	0.47	0.67	0.21	0.27
4	Air Quantity	m3/sec	6.58	7.55	6.24	5.54	4.9	3.94	3.29	2.4	1.91	4.21	6.12	6.02	5.12	11.21	10.24	11.2	9.45	10.05	5.45	6.22
5	CO2	%by vol.	0.22	0.16	0.21	0.22	0.18	0.19	0.18	0.21	0.12	0.23	0.12	0.15	0.15	0.11	0.12	0.11	0.09	0.11	0.07	0.05

Table 5: Air quality measurement in Shift 05-Ramp 05

Sr. No.	Particulars	Unit	When LHD in operation at Face										When LHD has left the Face									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	HCHO	mg/m³	0.21	0.22	0.24	0.23	0.28	0.29	0.3	0.28	0.27	0.26	0.12	0.08	0.04	0.07	0.13	0.12	0.09	0.07	0.08	0.14
2	TVOC	mg/m³	0.34	0.43	0.39	0.48	0.48	0.42	0.45	0.38	0.35	0.42	0.02	0.16	0.15	0.32	0.46	0.42	0.38	0.38	0.35	0.42
3	Air Velocity	m/sec	0.45	0.415	0.395	0.36	0.28	0.26	0.21	0.09	0.175	0.225	0.24	0.24	0.28	0.31	0.45	0.62	0.47	0.67	0.21	0.27
4	Air Quantity	m3/sec	7.12	5.14	8.11	5.01	4.35	4.84	3.14	2.45	4.12	2.24	6.12	6.02	5.12	11.21	10.24	11.2	9.45	10.05	5.45	6.22
5	CO2	%by vol.	0.18	0.2	0.19	0.21	0.21	0.2	0.24	0.18	0.19	0.16	0.12	0.15	0.15	0.11	0.12	0.11	0.09	0.11	0.07	0.05

Table 6: Air quality measurement in Shift 06-Ramp 06

Sr. No.	Particulars	Unit	When LHD in operation at Face										When LHD has left the Face									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	HCHO	mg/m³	0	0.22	0.24	0.17	0.25	0.27	0.2	0.25	0.3	0.19	0.16	0.12	0.06	0.06	0.22	0.08	0.11	0.16	0.12	0
2	TVOC	mg/m³	0.34	0.44	0.46	0.47	0.48	0.48	0.45	0.45	0.48	0.32	0.21	0.34	0.32	0.42	0.43	0.41	0.39	0.36	0.31	0.28
3	Air Velocity	m/sec	0.62	0.47	0.37	0.335	0.21	0.18	0.24	0.22	0.13	0.26	0.24	0.24	0.28	0.31	0.45	0.62	0.47	0.67	0.21	0.27
4	Air Quantity	m3/sec	6.12	5.01	6.11	5.12	3.22	3.03	3.02	2.55	1.14	2.01	6.12	6.02	5.12	11.21	10.24	11.2	9.45	10.05	5.45	6.22
5	CO2	%by vol.	0.22	0.21	0.21	0.18	0.21	0.25	0.24	0.21	0.22	0.18	0.12	0.15	0.15	0.11	0.12	0.11	0.09	0.11	0.07	0.05

3.1 Data Interpretation and Analysis

For the mean mass concentrations of formaldehyde, 06 shifts data were taken at 06 different ramps having 10 different data stations each (As per scheme revealed in Fig.1.). Fig. 2 to Fig 7 reveals the following: (a) during LHD operations, HCHO concentrations in the zone under experimentation were mostlyfound above the standard limit of **0.1mg/m³**,

(a) a drastic fall in the concentration of HCHO in same zone was found when the LHD is outof operations (c) air velocity has direct andsignificant effect on the HCHO concentration. Similarly, Fig. 8 to Fig. 13 reveals that the mean mass concentrations of TVOCremained near the standard or just crossedstandard limits in some cases while LHD wasin operating condition. No drastic fall in theconcentration of TVOC in same zone was found when the LHD is out of operations.

Fig. 2: Mass concentrations in each monitoringstation in shift 1 of HCHO (formaldehyde*)*

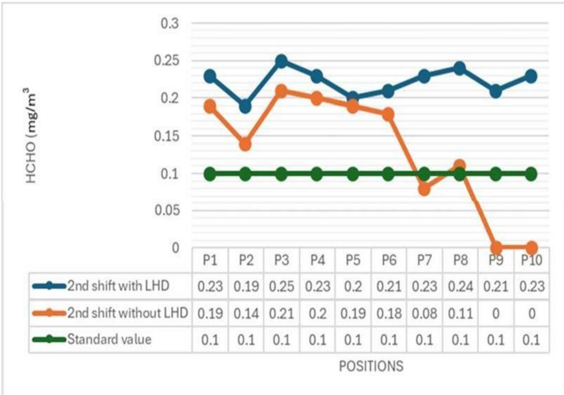


Fig. 3: Mass concentrations in each monitoringstation in shift 2 of HCHO (formaldehyde)

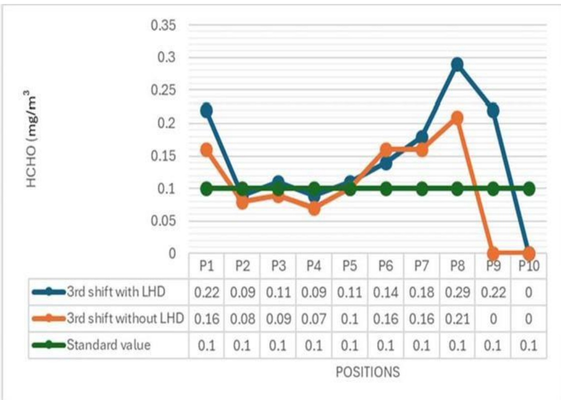
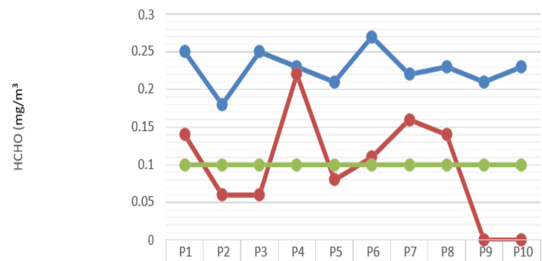
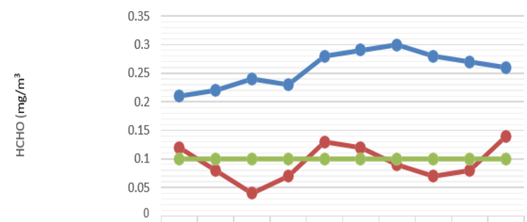


Fig. 4: Mass concentrations in each monitoring station in shift 3 of HCHO(formaldehyde)



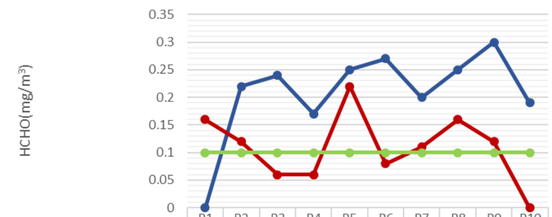
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
4th shift with LHD	0.25	0.18	0.25	0.23	0.21	0.27	0.22	0.23	0.21	0.23
4th shift without LHD	0.14	0.06	0.06	0.22	0.08	0.11	0.16	0.14	0	0
Standard value	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Fig. 5: Mass concentrations in each monitoring station in shift 4 of HCHO(formaldehyde)



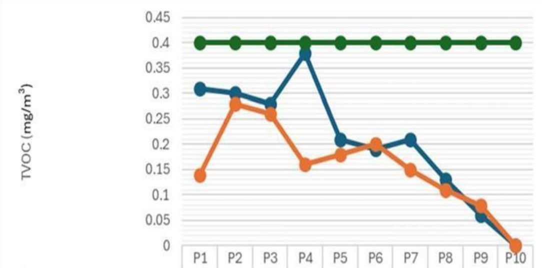
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
5th shift with LHD	0.21	0.22	0.24	0.23	0.28	0.29	0.3	0.28	0.27	0.26
5th shift without LHD	0.12	0.08	0.04	0.07	0.13	0.12	0.09	0.07	0.08	0.14
Standard value	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Fig. 6: Mass concentrations in each monitoringstation in shift 5 of HCHO (formaldehyde)

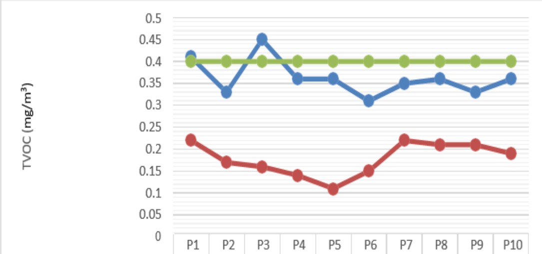


	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1st Shift with LHD	0	0.22	0.24	0.17	0.25	0.27	0.2	0.25	0.3	0.19
1st Shift without LHD	0.16	0.12	0.06	0.06	0.22	0.08	0.11	0.16	0.12	0
Standard Value	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Fig 7: Mass concentrations in each monitoringstation in shift 6 of HCHO (formaldehyde)



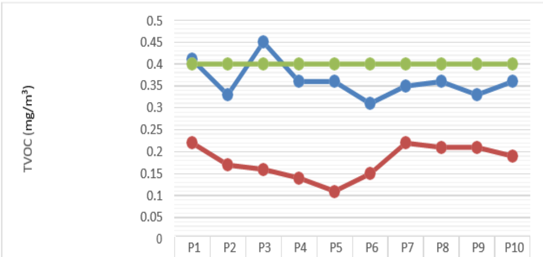
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1st shift with LHD	0.31	0.3	0.28	0.38	0.21	0.19	0.21	0.13	0.06	0
1st shift without shell	0.14	0.28	0.26	0.16	0.18	0.2	0.15	0.11	0.08	0
Standard value	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
2nd shif with LHD	0.41	0.33	0.45	0.36	0.36	0.31	0.35	0.36	0.33	0.36
2nd shift without LHD	0.22	0.17	0.16	0.14	0.11	0.15	0.22	0.21	0.21	0.19
Standard value	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

POSITIONS

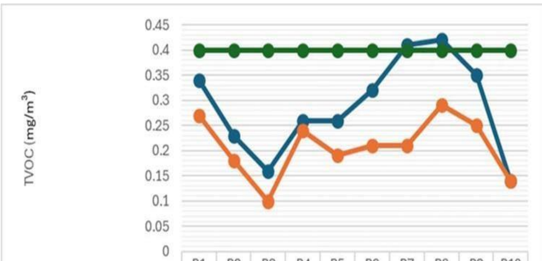
Fig. 8: Mass concentrations in eachmonitoring station in shift 1 of TVOC



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
2nd shif with LHD	0.41	0.33	0.45	0.36	0.36	0.31	0.35	0.36	0.33	0.36
2nd shift without LHD	0.22	0.17	0.16	0.14	0.11	0.15	0.22	0.21	0.21	0.19
Standard value	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

POSITIONS

Fig. 9: Mass concentrations in each monitoringstation in shift 2 of TVOC.



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
3rd shift with LHD	0.34	0.23	0.16	0.26	0.26	0.32	0.41	0.42	0.35	0.14
3rd shift without LHD	0.27	0.18	0.1	0.24	0.19	0.21	0.21	0.29	0.25	0.14
Standard value	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

POSITIONS

Fig. 10: Mass concentrations in eachmonitoring station in shift 3 of TVOC

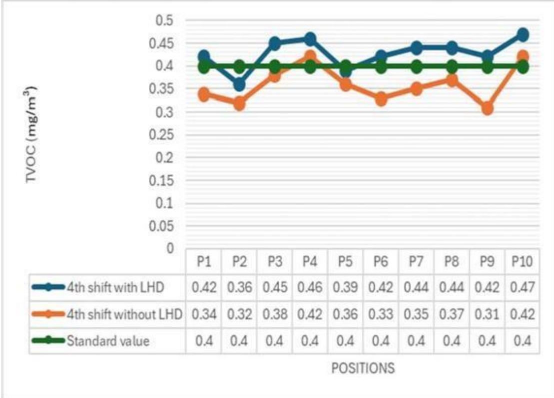


Fig. 11. Mass concentrations in eachmonitoring station in shift 4 of TVOC

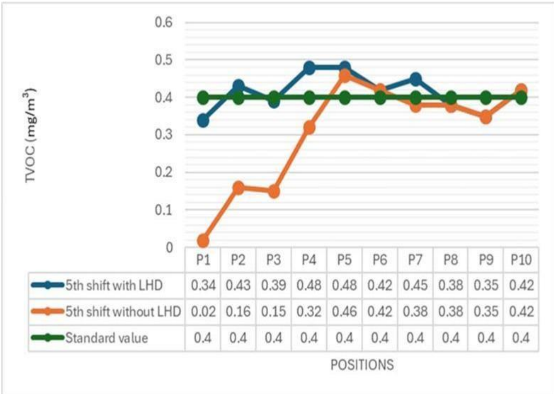


Fig. 12: Mass concentrations in eachmonitoring station in shift 5 of TVOC

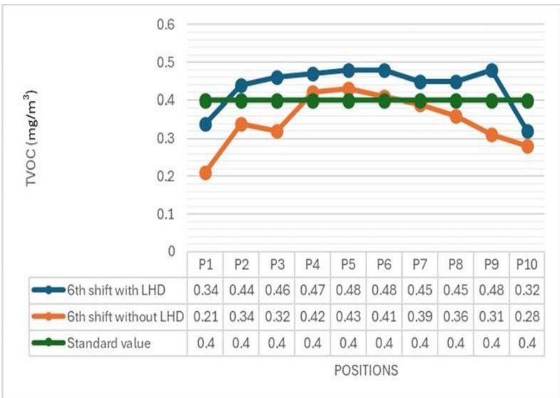
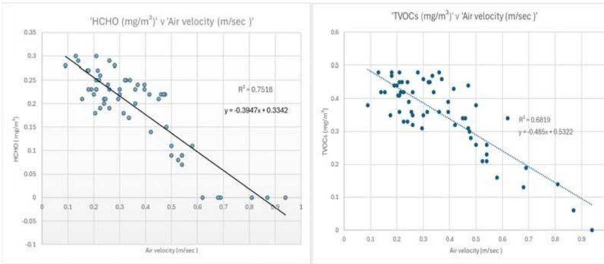


Fig. 13: Mass concentrations in eachmonitoring station in shift 6 of TVOC

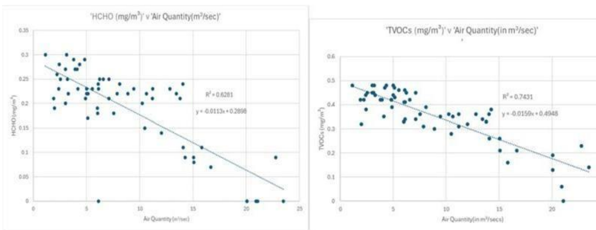
4. Determination of quantitative interconnectedness

The results obtained from the comprehensive data (Fig 14, 15, 16) analysis reveal key insights into the relationships between various environmental factors and gas concentrations, particularly TVOC, HCHO, and CO2.



(a) (b)

Fig. 14: The regression fitting curve of gasesconcentrations in underground mine and air velocity: (a) formaldehyde; (b) TVOC.



(a) (b)

Fig 15: The regression fitting curve of gasesconcentrations in underground mine and airquantity: (a) formaldehyde; (b) TVOC

The study reveals the change in the concentration of gases with respect to air parameters as follows. Here are some possible relations that can be drawn from the graphs:

- HCHO and TVOC levels are inversely proportional to air velocity and air quantity. The graphs show that as the air velocity and air quantity increase, the concentration of HCHO and TVOC decrease. This implies that more ventilation and air circulation can reduce the levels of these harmful gases in the underground mines.
- HCHO and TVOCs are directly proportional to CO2 levels. The graphsshow that as the CO2 levels increase, the concentration of HCHO and TVOC increases accordingly. Thus quantity of HCHO and TVOCs in mine air can be successfully predicted by CO2 measurement.
- HCHO and TVOC levels are independent of temperature and relative humidity. The research showed that there is no clear trend or pattern between the temperature and relative humidity and the concentrationof

HCHO and TVOC. This implies that these factors do not affect the levels ofthese gases significantly.

4.2 Outcomes of Multiple Linearregression:

After observing Linear regression MLR model was implemented to find the prediction equation for gases with respect to these

parameters air velocity, face dimensions and Carbon dioxide. The Relations were obtained as following:

Equation of the Multiple Linear Regression Model:

- Concentration of HCHO = *0.151* + -
  *0.218 * Air Velocity + -0.0004 * Face dimensions + 0.754 * CO2* with R- squared: 0.82.

- Concentration of TVOC = 0.331 + -
  *0.289 * Air Velocity + -0.002 * Face dimensions + 1.027 * CO2* with R- squared: 0.848.

The multi linear regression model obtained for both, HCHO and TVOC is giving a good R- squared value, representing high correlation in the variables.

5. CONCLUSION

Optimising air quality in underground mines necessitates a comprehensive plan that shouldaddress volatile organic compounds (VOCs)and formaldehyde**.**The impact of temperature fluctuations on pollutant concentrations, such as formaldehyde and volatile organic compounds (VOCs), in underground mines appears to be relatively minor due to the unique environmental conditions present.Ventilation emerges as a critical factor in mitigating pollutant levels within underground mines, as indicated by negative correlationsobserved between formaldehyde, VOCs, and air velocity. Increased air velocity, reflective of a well-functioning ventilation system, is crucial for effectively diluting and dispersing HCHOand TVOCs and thereby preventing their accumulation in the confined spaces of mines. Regular maintenance and monitoring are imperative to uphold the effectiveness of ventilation systems in safeguarding the health and well- being of mine workers. Prioritising higher air velocity ventilation proves to be an effective strategy in addressing formaldehyde and VOCs, thereby fostering healthier air conditions in underground mines.

Furthermore, carbon dioxide concentration is directly proportional to the mass concentration of HCHO and TVOCs. Thus the quantity ofHCHO and TVOCs in mine air can be successfully predicted by CO2 measurement. Although the execution of regression analysis and the presentation of comprehensive scatter plot outcomes rely on the consolidation of extensive datasets.

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NO :2.4

Identifying sub-system vulnerabilities for continuous miner operation in India: A reliability based analysis.

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Abstract:

Mining in India is one of the major revenue acquiring activity, which includes the extraction of ores, coal, and other minerals. The country is one of the world's top producers of coal, primarily through its opencast mining method. However, recent environmental concerns have made it necessary to increase the productivity of underground mining by utilizing cutting-edge technologies, such as Continuous Miner (CM). The case of a CM system installed in an underground coal mine in the nation's east is presented in this paper. For every CM subsystem, the data on operating and downtime was documented for duration of three months, which aided in the computation of the Time Between Failure (TBF) between two successive failures. Further, the reliability analysis for a ten thousand minutes operational period corresponding to the CM-based system's subsystems was conducted using the TBF data. Among all the sub-systems taken into consideration for the study, a thorough analysis revealed that the mine conveyor was the most vulnerable. In order to lessen the vulnerability of the top five most vulnerable subsystems and boost the overall efficacy of the system, several corrective actions were also recommended.

Keywords: Reliability analysis, Continuous Miner, Underground coal mining, Time Between Failure (TBF)

Introduction:

Owing to increased mining rates, surface coal reserves are getting depleted very fast, increasing the likelihood that coal from deeper seams may need to be produced in the near future. Up until now, the only practical method for extracting coal from reserves located farther below the surface of the earth has been underground mining. India ranks among the world's top five producers of coal. Paltasingh and Satapathy mentions that [1], by 2040 global coal production will get at least 10% increase, where India will be one of the key player for that. Effective underground coal mining may become one of the major technologies for replenishing that production demand. Utilization of Continuous Miner (CM) and Longwall machines for the purpose may be the viable solutions. Government of India have already implemented some of these machines to some selective underground coal mines. Current application scenario of the CM machines have revealed that, the performance of them are satisfactory to only few of the coal mining projects working with them for coal winning. Few publications on reliability analysis of CM and other coal mining machines are highlighted as follows- Vayenas and Peng focused on reliability analysis and a reliability centred maintenance planning for mining equipments deployed in Sadurbury area of Canada using statistical package GenRel [2]. Banerjee depicted reliability analysis through graphical approach for CM packages deployed in two underground coal mines in eastern part of India[3]. Sarkhel and Dey presented the availability estimation for maintenance planning of SDL machine in Indian underground coal mines[4]. Samanta et al. performed reliability analysis of shovel machines deployed in coal mining fields of India[5]. Harish Kumar et al. demonstrated the reliability analysis of shovel dumper system in connection with a coal mine [6]. Rahmani et al. presented a case study for reliability analysis in connection with mining trucks[7]. Banerjee and Dey further presented some results of reliability analysis through graphical approach for two CM machines deployed in India [8]. Boloz et al. presented a case study on failure rate analysis of a Longwall machine based on the type of failure [9]. Kumar et al. demonstrated the reliability, availability and maintainability analysis methodology corresponding to dragline machine deployed in opencast mine [10].

Here in this paper an effort has been made to identify the vulnerable sub-systems for a CM package working in India to further identify the reasons of low system availability. This information further helped in recommendation for mitigation of those causes of low system availability.

Methodology:

The following figure-1 depicts the schematic diagram of methodology for this research work. The first step is selection of a mine site working with CM package; here a Mine site was selected in the central part of country under the control of South Eastern Coalfield Limited. A field visit of almost three months was conducted to identify the potential factors and gather relevant information. This data include the geo-mining parameters of the working panel, equipment specification, working time and down time related information as well as daily production related data. For the course of study the overall CM package was divided into few sub-systems, namely- electrical, cutter, gathering arm, traction, hydraulic chassis , ram car, feeder breaker CM conveyor and mine conveyor. Subsequently, the gathered information was used to calculate the Time Between Failure (TBF) data for each sub-systems as mentioned above. Then those TBF datasets were tested for presence of any trend or correlation, further, trend and correlation free TBF data were used for reliability analysis through distribution fitter application of MATLAB. From where the best fit distribution for each TBF datasets corresponding to each sub-system were identified and the reliability depletion trend was obtained.

Further, some recommendations were suggested on the most vulnerable sub-systems showcasing lowest trend of reliability.

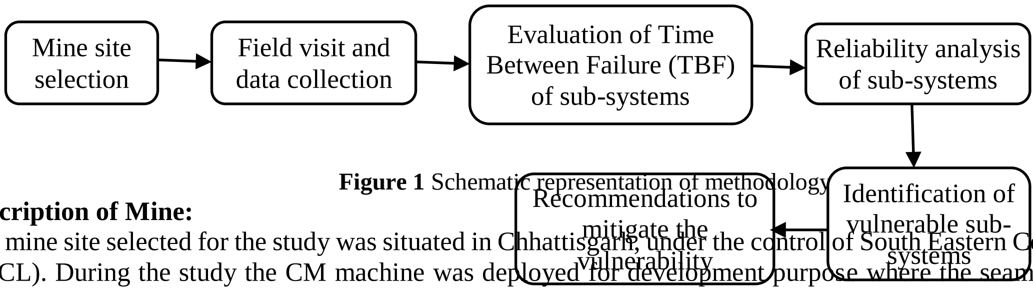

Figure 1 Schematic representation of methodology

Description of Mine:

The mine site selected for the study was situated in Chhattisgarh, under the control of South Eastern Coalfields Limited (SECL). During the study the CM machine was deployed for development purpose where the seam thickness of the mine was higher as compared to other CM projects. The geo-mining conditions of the panel can be seen from the following table-1.

Table 1 Geo-mining condition of the mine under study

Seam thickness (m)	Gradient	Pillar size (m × m)	Gallery width (m)	Uniaxial Compressive Strength of coal (MPa)	Pillar area (m^2)
5.05	1 in 16	36 × 36	6	19.77	900

Reliability analysis results:

Reliability analysis was performed using Time Between Failure (TBF) datasets for all the sub-systems. The steps for reliability analysis include- trend and serial correlation test for TBF datasets, distribution fitting and reliability analysis. At first the trend test and serial correlation tests were performed graphically for all TBF datasets. Trend test is the scatter plot between Cumulative Time Between Failure and Cumulative Failure Number [3]; a trend test plot showing linear trend signifies the TBF dataset is free from any trend. Whereas, the serial correlation test is the scatter plot between $(i-1)^{th}$ TBF and i^{th} TBF[3]; it must be a random scatter plot and should not represent any specific trend for the data sets free from any correlation. Datasets free from any trend and correlation are suitable for distribution fitting using software packages like MATLAB. The following figure-2 and 3 depicts the trend test plot and serial correlation plot for the electrical sub-system of the CM package considered for the study.

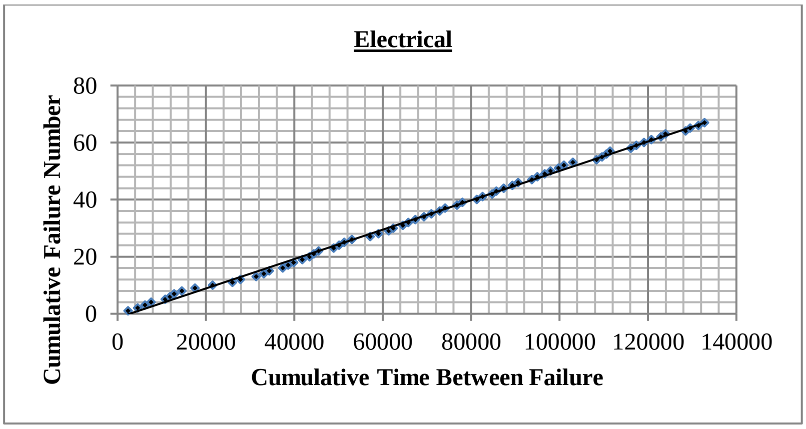

Figure 2 Trend test plot for electrical sub-system

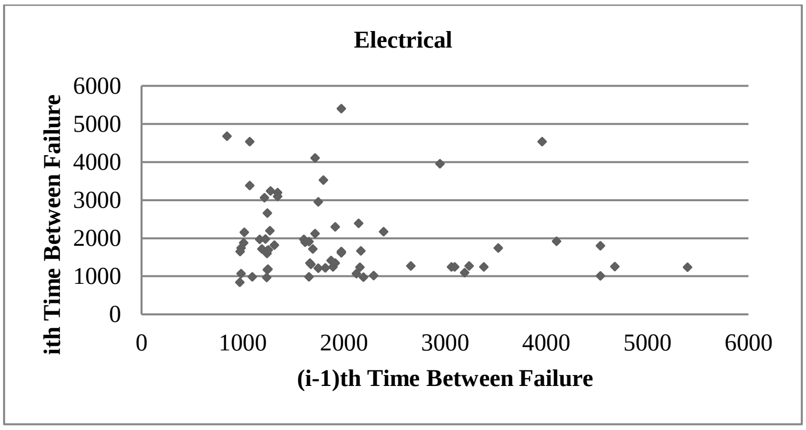

Figure 3 serial correlation plot for electrical sub-system

From above two figures (figure 2 and 3) it can be seen that the trend test depicts a linear trend whereas, the serial correlation test depicts a random scatter plot. Therefore, the TBF dataset corresponding to electrical sub-system is free from any trend and correlation and thus suitable for statistical distribution fitting [3]. Similar kind of trend and serial correlation were seen for TBF datasets corresponding to all sub-systems; therefore those are not shown here to reduce the redundancy. Therefore, TBF datasets of all sub-systems are suitable for distribution fitting through MATLAB. Further the distribution fitter application of MATLAB R2021a was used for identifying best fit statistical distribution for TBF datasets of each sub-systems and further the reliability depletion trends were identified. The compatible distributions as identified for all sub-systems are one of the three common for the purpose, namely- lognormal, weibull and exponential distribution. The compatible distributions for each sub-system can be seen from the following table-2.

Table 2 Details of best fit distributions for each sub-system

Sl. No.	Name of sub-system	Best fit distribution	Corresponding parameters for best fit distribution
1	Electrical	Lognormal	μ = 7.48133, σ = 0.455081
2	Cutter	Weibull	A= 5879.17, B= 0.913092
3	Gathering	Weibull	A= 12528.8, B= 1.35884
4	Traction	Exponential	μ = 11590.8
5	Hydraulic	Lognormal	μ = 8.22652, σ = 0.905537
6	Chassis	Exponential	μ = 8240.8
7	Ram car	Lognormal	μ = 7.83988, σ = 0.732925
8	Conveyor	Weibull	A= 2387.88, B= 2.22259
9	Feeder breaker	Lognormal	μ = 8.26759, σ = 0.909425
10	CM conveyor	Exponential	μ = 9984.67

The reliability depletion trend for five sub-systems showing highest reliability depletion tendency for a period of 15000 minutes of operation is depicted graphically in the following figure-4.

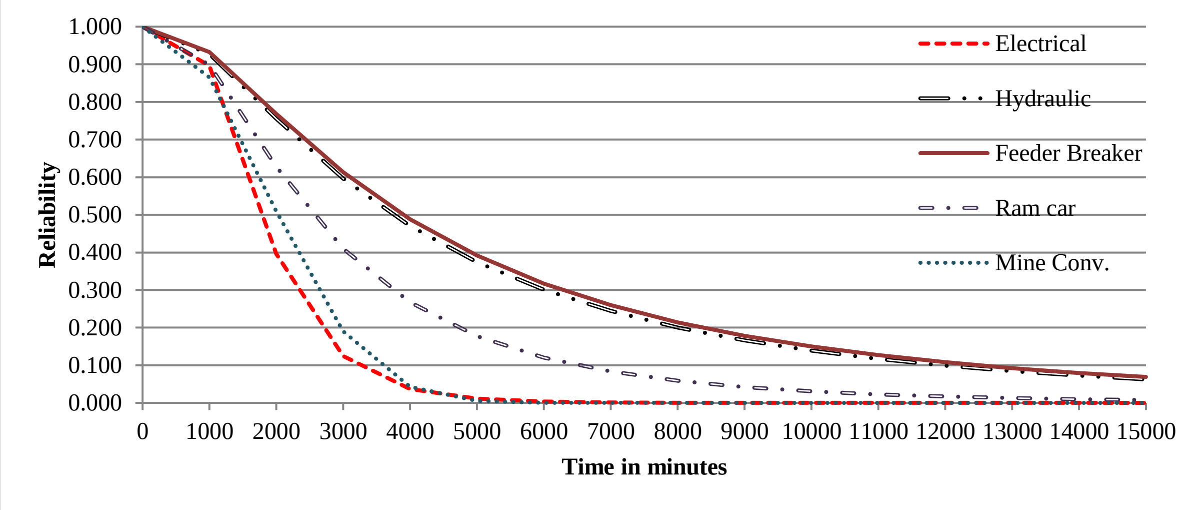

Figure 4 Reliability depletion trends for five sub-systems with highest reliability depletion tendency

Discussion:

From the above figure-4, it can be identified that electrical and mine conveyors are the sub-systems accounting for lowest trend of reliability and equipment downtime; they reached 50% reliability after 1700 and 200 minutes of operation. Whereas, other three sub-systems are- ram car, hydraulic and feeder breaker, they have reached 50% reliability after 2600 minutes, 3800 minutes and 3900 minutes of operation respectively. The other sub-systems however, depicted a better trend of reliability as compared to these five sub-systems, therefore are not shown here. The reliability trend of all five sub-systems mentioned above have shown an alarming trend, therefore a questionnaire based discussion was carried out with experienced mine personnel for identification of potential reasons of failures and recommendations for mitigation of such possibilities of failures. The details of which can be seen from the following table-3

Table 3 Potential reasons of failure and recommendations to mitigate them

Sl. No.	Sub-systems	Potential reasons of failure	Recommendations
1	Electrical	• Power transmission failure • Trailing cable rupture • Controller and remote malfunction	• Regular inspection of transmission lines and use of advance fault detection equipment. • Ensure that the trailing cable is properly anchored. • Maintenance of controller unit and drying of remote after every shift.
2	Mine conveyor	• Motor breakdown • Gear box problems • Bearing problem • Belt damage	• Regular monitoring of vibration levels of motor and allied attachments • Gearbox oil quality inspection after regular interval • Installing automated lubrication system of bearings
3	Ram car	• Drive failure • Conveyor motor malfunction • Braking system problems • Engine related problem	• Pre-operational check for aqny unusual noise • Maintenance of conveyor motor sealing • Frequent inspection of braking system and replacement of essential components when necessary

			• Engine oil analysis and take a note on the level of emission.
4	Hydraulic	• Hydraulic system piping failure • Hydraulic fluid pump motor failure • Water circuit hose assembly failure	• Regular inspection of pipes and hoses. • Cleaning of hydraulic filter during scheduled maintenance
5	Feeder breaker	• Jamming of chute • Jamming of crusher unit	• Monitor the crushing speed according to accommodate the output to the mine conveyor • Regular maintenance of the crushing unit

Conclusion:

This research work is aimed to identify the vulnerable sub-systems in connection to operation of a CM package deployed for underground coal mining in India. The sub-systems that constitute the overall CM package were studied for reliability analysis through which the sub-systems with highest trend of reliability depletion were identified as most vulnerable sub-systems. From the study it can be observed that electrical and mine conveyor are the two most vulnerable sub-systems; with depletion of 50% reliability within 2000 minutes of operation since inception from the previous repairing. Other vulnerable systems are ram car, hydraulic and feeder breaker. Further based on this analysis a questionnaire based investigation to identify the causes was performed and further some measures were recommended to mitigate those causes. This paper may serve as a base to identify the vulnerable sub-systems for CM based operation and further in-depth analysis may help to design a proper maintenance program for CM based underground mine operation system.

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NO : 2.5

Effect of thick shale roof strata and control measures during underground extraction of a coal seam under multi-seam conditions

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Abstract:

Strata control in underground coal mines becomes difficult if the immediate roof strata consist of shale. It was observed that at the time of excavation, the shale roof appeared competent but it deteriorated in a faster manner causing bed separation and roof fall. The major causes of shale roof failure are the presence of umpteen bedding planes and its moisture sensitivity. Shale roofs degrade in humid environments as found in underground mines, due to their characteristics of moisture absorption. In this paper, laboratory experiments are performed to know the extent of reduction in the strength of shale samples under saturated conditions. It is found in the experiment that the strength degradation is not uniform in all types of shale rock. The maximum and minimum strength reductions are observed as 86% and 4.2% respectively. This paper also deals with the control strategy of shale roof strata during underground extraction of a coal seam under multi-seam conditions. It is found that under loading conditions, micro tensile/shear cracks are formed in the shale roof which increases moisture absorption and leads to swelling. By the field investigations, it is observed that the failure of moisture-sensitive shale roof starts from its skin and propagates upwards. Thus, the roof fall occurs in the form of small pieces of rock in between the roof bolts. When the roof fall extends above the bolted horizon, it triggers a massive fall.This study shows the control strategy for this type of shale roof failure by designing a proper extraction methodology and support systems. As observed in the field and our study, the pre-tensioned support system is found to be suitable for controlling the failure of the shale roof because the pre-tension increases friction among the bedding planes in the shale roof strata.

Key words: Shale roof, moisture, bedding plane, pre-tensioned support, multi-seam

1. Introduction

In the realm of underground coal mining, managing thick shale roof strata during depillaring in multi-seam conditions is a critical challenge that demands comprehensive understanding and effective mitigation strategies. The geological and operational complexities associated with shale roofs significantly influence safety, productivity, and economic outcomes in mining operations worldwide.

Shale, a sedimentary rock characterized by its fine-grained composition and layered structure, plays a pivotal role as an immediate roof in many underground coal mines (Peng, 2008). Its geological characteristics, particularly its tendency for moisture absorption and variable mechanical properties along bedding planes, pose significant challenges in strata control. Shale often exhibits anisotropic behaviour, meaning its strength and stability can vary significantly depending on the orientation of the bedding planes relative to the applied stresses (Hoek & Brown, 1997). It was observed that at the roof and pillar intersection, where stress concentrations are high, the shale beds are progressively crushed, creating instability (Hill, 1986). During the extraction of pillars, stresses redistribute within the rock mass, potentially leading to the initiation and propagation of fractures along weak bedding planes in the shale (Molinda & Mark, 2003). This phenomenon, commonly referred to as "cutter roof" failure, is a critical concern as it can result in roof collapses and concomitant safety hazards. The process initiates the development of micro-tensile and shear cracks in the shale, exacerbated by moisture absorption and swelling under pressure (Mark et al., 2007). As these cracks propagate, they weaken the structural integrity of the shale roof, leading to localized collapses where small rock fragments may fall between roof bolts and support systems. If not adequately controlled, these localized failures can escalate into larger-scale roof collapses that extend beyond the bolted horizon, posing significant safety risks to underground personnel and disrupting mining operations.

Moreover, the presence of interlaminated sandstone layers within shale roof further complicates the stability aspects (Gadde & Peng, 2005). While sandstone layers can provide localized zones of higher strength, they also create stress concentrations that contribute to the destabilization of adjacent shale layers. It is found that the behaviour of thick shale roof strata during depillaring is influenced by various factors, including the depth of mining, seam thickness, geological conditions, and mining methods. In multi-seam mining scenarios, where multiple coal seams are extracted at different depths within the same geological strata, the interaction between seams and overlying shale roofs can further complicate strata stability (Molinda & Mark, 2010). Interactions between mining-induced stresses from different seams can create complex stress distributions within the shale, increasing the risk of cutter roof failures and other ground control challenges. Effectively mitigating the challenges posed by thick shale roof strata during depillaring requires a multifaceted approach that integrates geological understanding, engineering solutions, and proactive monitoring strategies. Geological assessment through detailed mapping and characterization of shale properties (Bieniawski, 1984) is crucial for predicting roof instability zones. Engineering solutions like roof bolts, meshing, and shotcrete provide immediate support and stability enhancement before shale roof failure. Pillar design optimization strategies (Galvin & Fourie, 2016) can also minimize stress concentrations during extraction. Continuous ground monitoring (Molinda & Mark, 2010) using advanced technologies offers early warning of potential instability, ensuring proactive intervention.

In addressing the challenges presented by thick shale roof strata during depillaring, advanced numerical modelling studies were found to offer valuable insights into stress regimes and failure characteristics of the surrounding rock mass. This paper presents the failure characteristics of shale rock under saturated conditions and its control during underground extraction of a coal seam under multi-seam conditions. The laboratory tests are carried out to know the effect of water saturation on the tensile strength of shale samples. Based on the results and numerical simulations by FLAC3D (Itasca, 2016), a suitable extraction methodology of the coal seam vis-à-vis the control strategy of shale rock strata is designed to ensure the safety of underground workplaces.

2. Laboratory testing of shale samples

The effect of water on the tensile strength of shale is assessed by laboratory testing of samples under dry and saturated conditions. A total of 24 sets of samples have been collected from the borehole cores and prepared for Brazilian tensile strength testing. From each pair, one sample is tested uder dry conditions and another sample is tested under saturated conditions by submerging it into the water for 24 hours. Figure 1 shows the Brazilian tensile strength testing of shale samples under dry and saturated conditions. The comparisons of the tensile strength are shown in Figure 2. It is found that the tensile strength of shale rock reduces under saturated conditions. During the loading process, microtensile/shear cracks are formed in the shale roof. It increases water absorption and leads to swelling. Due to the swelling, the shale roof easily disintegrates by forming more cracks as a result of downward pressure. The extent of reductions is not uniform in all shale rock samples. From the experiment, it is found that maximum and minimum reductions in the tensile strength are 86% and 4.2% respectively as shown in Figure 2b. It happens due to the variation in clay mineralogical and microstructural characteristics of shale.

Figure 1: Brazilian tensile strength testing of shale samples under dry and saturated conditions.

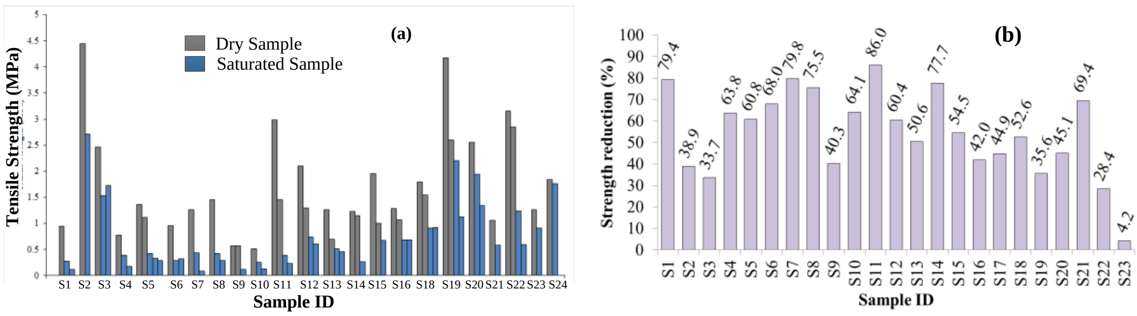


Figure 2: Comparison among the tensile strengths of shale rock under dry and saturated conditions.

3. Description of the mine site

Strata control problems in shale roof are observed at 3(S) panel of 13 seam in Bhelatand Amalgamated Colliery of M/s Tata Steel Limited as shown in Figure 3. It is found that the immediate shale roof strata disintegrate from the bedding plane, resulting roof fall in the form of small pieces of rock in between the roof bolts. The thickness of 13 seam in the panel is ~3.8 m which is developed by driving galleries of 4.5 m wide and 2.70 m height along the roof, leaving approximately 1.06 m of coal on the floor. The parting of 12-16m exists with the overlying 14 seam which is standing on pillars. The parting consists of shaly coal and sandy shale rock strata. Above the 14 seam, mostly the caved goaves exist in the 15, 16 and 17 seam. The 3(S) panel of 13 seam has 16 pillars having a dimension of 45 x 45 m (center to center) of each pillar. The depth of cover over the panel ranges from 402.2 m to 438.8 m, with an average depth of 420.5 m. The compressive strength, Young's modulus and density of 13 seam coal are determined to be 6 MPa, 0.80 GPa, and 1406 Kg/m^3 respectively. Similarly, the compressive strength, Young's modulus and density of immediate 2.0 m thick shaly coal above the 13 seam are 17.50 MPa, 1.44 GPa, and 1618 Kg/m^3 respectively having unadjusted RMR value of 50.7. In 13 seam, the depillaring with hydraulic sand stowing is being practised. Thus, an extraction methodology and support systems have been designed to control shale roof failure during depillaring operations.

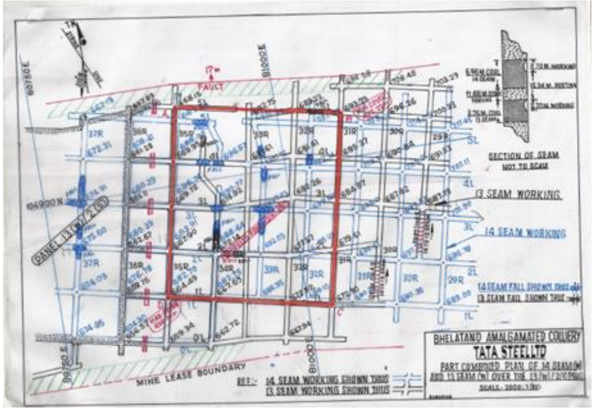


Figure 3: Part plan showing the roof fall details of the 3(S) panel in 13 seam working.

4. Extraction methodology of coal pillars

It is decided that as practised in the mine, extraction of the pillars using conventional depillaring in conjunction with hydraulic sand stowing is commenced from the dip (inbye) of the panel and proceed systematically towards the rise (outbye) of the panel by maintaining a diagonal line of face and avoiding the formation of 'V' in the line of extraction. Each pillar is divided into two equal parts by driving one level split of not more than 4.5 m in width and 3.0 m in height. Each half of the pillar is extracted by driving dip slices of not more than 4.5 m in width and 3.0 m in height leaving a rib of coal not less than 2.4 m between two slices and not less than 4.35 m against the original gallery. The rib of coal is reduced judiciously while retreating from the slice. Keeping the above restrictions in view, the number and width of the slices in each pillar are so adjusted that while driving the last (outbye most) slice, a block of not less than 4.35 m in thickness is left against the original gallery. The block of coal may be reduced judiciously during the retreat from the original gallery. Not more than one slice in a pillar and not more than two slices in the entire panel are extracted at a time. The voids created as a result of driving slices including part of original / split gallery is completely stowed with sand hydraulically. Not more than two voids or 1000 m^3 (whichever is less) are left un-stowed in the entire panel at any time. The manner of extraction is shown in Figure 4.

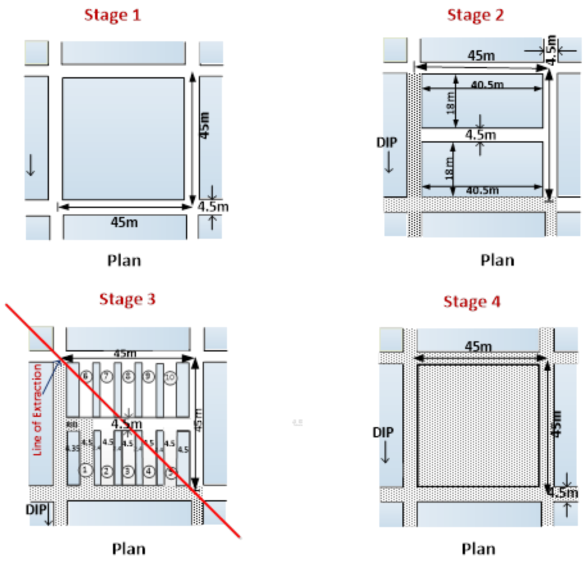


Figure 4: Extraction methodology proposed for depillaring the panel 13W/3(S).

5. Numerical simulation to assess the rock mass behaviour

Before commencing depillaring operations, a stability analysis is conducted on various structures affected by the non-superimposed development of the 13 and 14 seams under thick shale roof strata (Figure 3). A numerical modelling study using FLAC3D software (Itasca, 2016) is performed to analyze stress distribution and potential failure from non-superimposed development between the 13 seam and overlying 14 seam prior to depillaring the 13W/3(S) panel.

Similarly, stability analysis of different structures during depillaring operation is also carried out by running the model after extracting half of the 13W/3(S) panel and then stowed with sand to simulate the maximum possible stress conditions. The method of modelling generally involves the generation of grid as shown in Figures 4 and 5, discretization of the model, selection of an appropriate constitutive model for material behaviour, incorporation of material properties, gravity, in-situ stresses, and boundary conditions, solution to the equilibrium of the initial elastic model to generate the in-situ stresses in the model, change the model to ubiquitous joint model, development and extraction of pillars and assessing the model behaviour like sagging, stress, failure zones, etc. In numerical modelling in-situ stresses play a crucial role in assessing the stability of underground structures. Sheorey (1994), using a thermo-elastic shell model of the Earth, predicted the average horizontal stress within the seam, which is used in this study. This theory gives the value of the mean horizontal and vertical stresses as follows:

$$\sigma_H = \sigma_h = \frac{\upsilon}{1-\upsilon}\sigma_v + \frac{\beta E G}{1-\upsilon}(H+1000); \qquad \sigma_v = \gamma H \qquad (1)$$

Here, H denotes the depth of cover (in meters), σ_v represents the vertical in-situ stress (in MPa), σ_H indicates the major horizontal in-situ stress (in MPa), σ_h specifies the minor horizontal in-situ stress (in MPa), E stands for Young's modulus (in GPa), γ denotes the unit weight of the rock (in MPa/m), β is the coefficient of thermal expansion (per degree Celsius), and G refers to the geothermal gradient (in degrees Celsius per meter). In the study by Sheorey, this equation is shown to fit in-situ stress measurement data with the values of β = 30 x 10-6 /°C for coal and 12 x 10-6 /°C for other formation, G = 0.03°C/m.

The rock properties utilized in numerical modelling are obtained by scaling or converting the physico-mechanical characteristics from laboratory tests conducted on intact rock samples. Sheorey's failure criterion (Sheorey, 1997) is applied to convert these intact rock properties into appropriate rock mass properties, necessary for effective simulations (Mohan et al., 2001; Kushwaha and Banerjee, 2005; Kushwaha et al., 2010; Das et al., 2017). In numerical modelling, the failure of bedding planes within the strata is simulated using a widely accepted ubiquitous joint model. For these interfaces, cohesion and friction angle values are set at 0.18 MPa and 24°, respectively (Das et al., 2017).

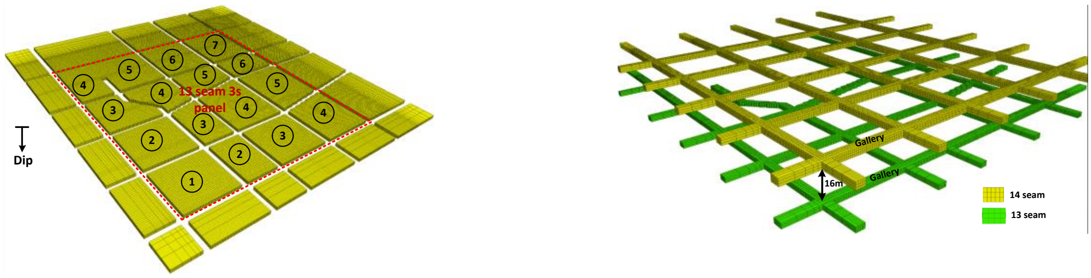


Figure 4: 3-D grid used for numerical modelling during development.

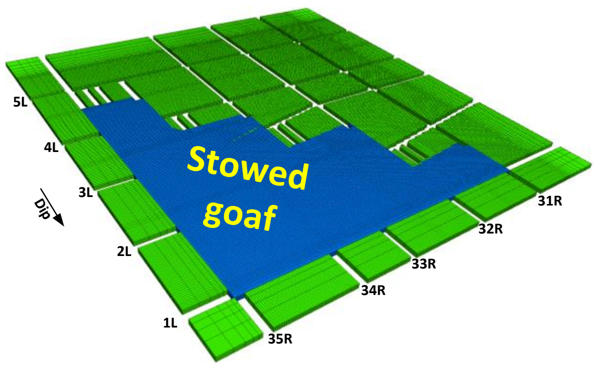


Figure 5: 3-D grid used for numerical modelling during depillaring study in 13W/3(S) panel.

6. Results of numerical simulation

Stability analysis is conducted on various structures affected by the non-superimposed development of the 13 and 14 seams. Figure 6 illustrates the distribution of major principal stress, resulting from the development of these seams, while Figure 7 provides a combined view of the yield zones of both seams prior to depillaring. The figures indicate that the yield zone extends up to 6.8 m and 4.7 m in the roof of junctions due to the development of the 13 and 14 seams respectively, and up to 4.3 m and 3.6 m in the roof of galleries of the 13 and 14 seams respectively. Figure 8 illustrates side spallings, roof deformations, and floor heavings observed in galleries developed in both seams (13 and 14). This comprehensive analysis helps in understanding the structural implications and supports decision-making before initiating the depillaring operations.

Based on the above figures 6 to 8, it is evident that the heights of the yielded roof rocks are susceptible to failure unless adequately supported. Additionally, floor heaving and side spalling are anticipated in the developed galleries. The condition of the 13 seam is worse compared to the 14 seam due to its comparatively weak immediate roof mostly composed of shaly coal and shale intercalated with very fine-grained sandstone. These findings underscore the rationale for the depillaring decision in the previously worked 13W/2(S) panel within the 13 seam, where many pillars were left unextracted due to significant roof falls in junctions and galleries. Similarly, results from numerical modelling affirm the current state of the proposed depillaring panel 13W/3(S) in the 13 seam, highlighting roof deformations, floor heaving, side spalling, and cracks as corroborated by Figure 3. These issues arise due to the presence of weak coal and easily separable roof strata. The separation of beds occurs particularly where the roof strata interface is weak, transferring the load of separated roof sections onto the coal pillar and its supporting system. Moreover, due to the presence of soft coal in the floor, pillars may penetrate the floor under the weight of overlying strata, leading to floor heaving. This detailed assessment supports the necessity for careful structural reinforcement and management strategies during depillaring operations to mitigate these potential hazards effectively. Stability analysis of different structures during depillaring operation is also assessed by running the model after extracting half of the 13W/3(S) panel and then stowed with sand as shown in Figure 5 to simulate the maximum possible stress conditions. Figure 9 shows the vertical stress contours on different structures during depillaring operation. Safety factors of different structures are also determined and are found to be stable during depillaring operations with sand stowing.

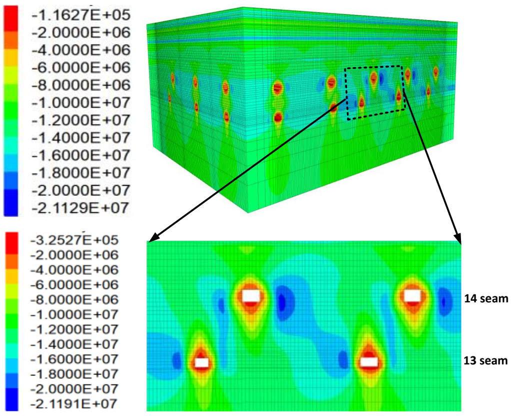


Figure 6: Major principal stress (Pa) contours due to the development of the 13 and 14 seams.

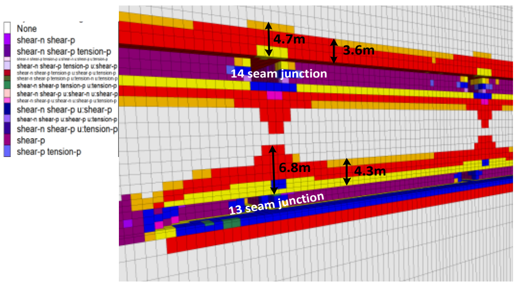


Figure 7: Combined view of yield zones of 13 and 14 seams development workings.

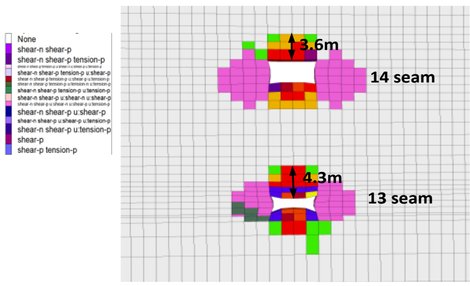


Figure 8: Side spallings and floor heaving in the developed galleries of 13 seam and 14 seam.

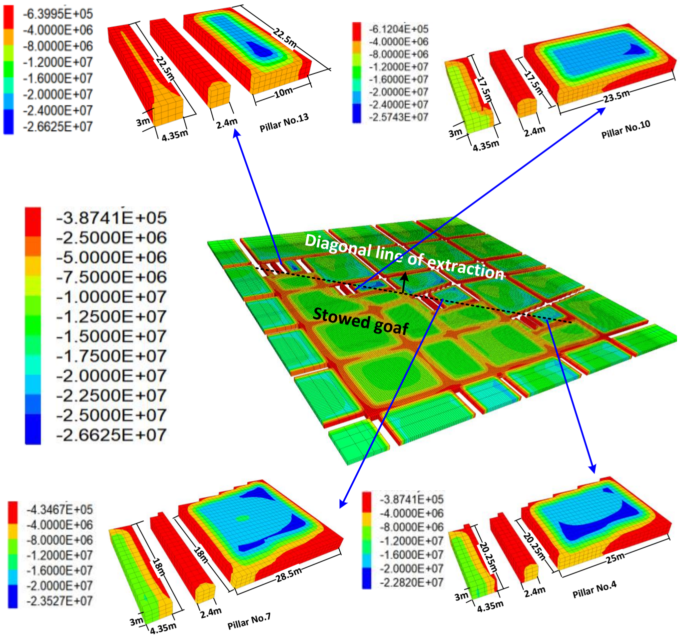


Figure 9: Vertical stress (Pa) contours on different structures during depillaring operation.

7. Support design during extraction of coal pillars

The support system for depillaring operations is designed based on the rock load height as shown in Figures 10 to 14, which is determined by identifying yield zones in the roof of openings through numerical modelling. Given depillaring as a medium-term process, supports must be capable of withstanding the weight of these yielded rocks. In this study, a support safety factor of at least 1.5 is considered to ensure stability. Analysis of these figures reveals that the maximum height of yielded roof rock reaches 4.3 m above the roof line in the adjacent original gallery, 6.8 m in the adjacent junction, 6.8 m in the split junction, 5.4 m in the split gallery, 6.8 m in the slice junction, and 5.4 m in the slice gallery.

A roof bolt support system using resin grout is preferred due to its convenience and superior anchorage strength compared to cement grouted bolts. Generally, a resin grouted roof bolt of at least 1.95 m in length and 20 mm in diameter, made from TMT/MS cold-rolled M20 threaded ribbed bar, provides an anchorage strength of 19 t. Additionally, to address potential failure heights at junctions, 6 m long full column cement grouted bulbed cable bolts are installed as these bolts exert pre-tension and increase the friction among the bedding planes in shale rock strata. A bulbed cable bolt offers anchorage strengths of 25 t. The designed support system in the original gallery and that of the four-way junction are shown in Figures 15 and 16 respectively. Due to a higher depth of cover and weak coal, it is desgined to support the sides of the original gallery, split gallery and slice with two rows of full column cement grouted side bolts in a grid pattern of 1.0 m x 1.0 m along with wire netting. The support safety factor for various locations is kept at more than 1.5.

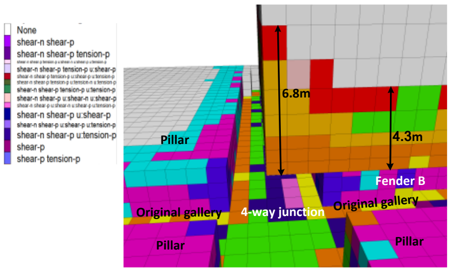


Figure 10: Height of the yielded roof rock above the original gallery and 4-way junction during depillaring of 13W/3(S) panel in 13 seam.

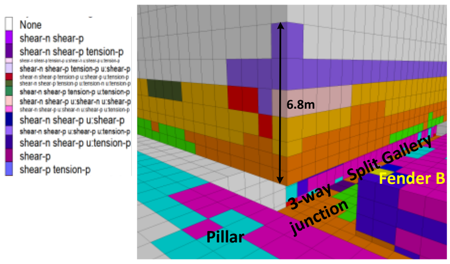


Figure 11: Height of the yielded roof rock above the 3-way split junction during depillaring of 13W/3(S) panel in 13seam.

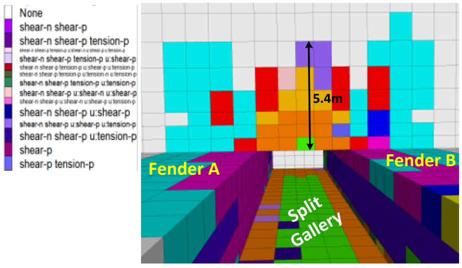


Figure 12: Height of the yielded roof rock above the split gallery during depillaring of 13W/3(S) panel in 13 seam.

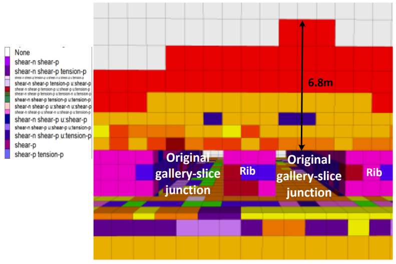


Figure 13: Height of the yielded roof rock above the 3-way slice junction during depillaring of 13W/3(S) panel in 13seam.

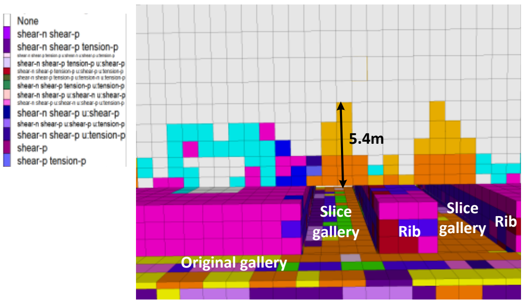
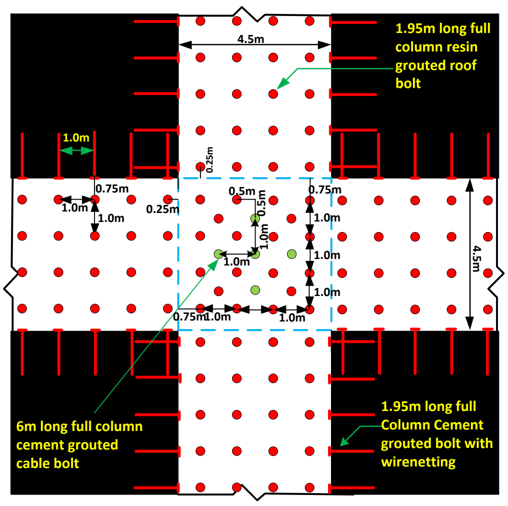


Figure 14: Height of the yielded roof rock above the slice gallery during depillaring of 13W/3(S) panel in 13seam.



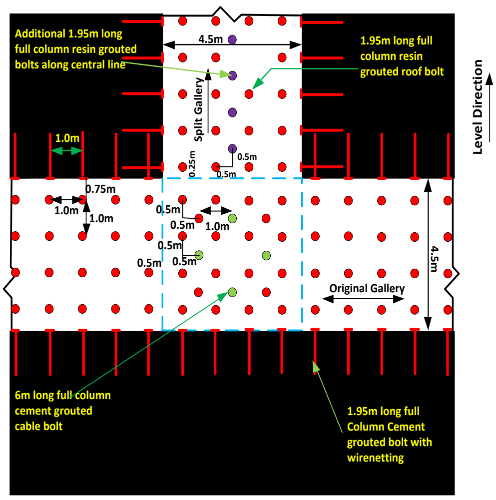


Figure 15: Support system in the original gallery and four-way junction during depillaring of 13W/3(S) panel in 13 seam.

Figure 16: Support system in the 3-way junction and split gallery during depillaring of 13W/3(S) panel in 13 seam

8. Conclusions

Shale rock often occurs in the immediate roof of underground coal mines. Its geological characteristics, such as its tendency to absorb moisture and its variable mechanical properties along bedding planes, present significant challenges for strata control. Managing thick shale roof strata during depillaring in multi-seam conditions is a complex issue for safe and efficient mining. Before designing any mining methods and support system, the characteristics of the shale rock under humid/water saturated conditions need to be assessed to avoid failure of the strata. As observed in the experiment, some shale rocks exhibit a significant reduction of strength under saturated conditions. Working under these types of shale rocks requires proper support systems vis-à-vis extraction methodology. The pre-tensioned support system is found to be suitable for controlling the failure of the shale roof because the pre-tension increases the friction among the bedding planes in the shale roof strata.

Acknowledgement

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Conceptualization and implementation of greenfield powered support longwall projects - the future for sustainable coal mining in Indian context

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Abstract:

Despite of severe challenges in the context of global warming and climate change and the commitment of India to progressively reduce the carbon footprint with an aim to obtain the ambitious target of Net Zero Emission by 2070, coal based thermal power will continue to dominate the Indian energy mix at least for the next few decades. Though in relative terms the contribution of renewable forms of energy and other forms of alternative sources of energy will substantially enhance in the overall Indian energy mix, the total installed capacity of coal based thermal power plants will continue to grow requiring a continuous enhancement of the coal demand in the country. But in the process of achieving continually increasing target of coal production, there would be a paradigm shift in the strategy of deployment of coal mining methods. In place of unilateral concentration on opencast mining method, there would be focusing on underground coal mining methods as well with the intension to strike a balance between the production of coal from both opencast and underground mines. This strategic endeavor is an outcome of the realities that the coal resources within the top 300m depth from the surface is gradually depleting, that India needs to explore and exploit more the deep seated coal deposits by underground mining methods and also the need to focus on improved quality of coal from deeper coal seams. All these areas are in alignment with the principles of sustainability in coal mining sector.

Towards this end, large scale introduction of Mass Production Technologies (MPT) has become imperative in Indian underground coal mines. The Ministry of Coal, GoI and all the major coal producing companies have set up a roadmap in this direction. Both the Continuous Miner Technology and the Powered Support Longwall Technology are destined to play significant roles in implementing this strategic endeavor. But their areas and conditions of application are distinct and different. In this article an attempt has been made to analyze the needs and scopes of Powered Support Longwall Technology, specifically in Indian context as an efficient and economic underground coal mining method to meet the technological as well as sustainability challenges.

Key words: Coal based Thermal power, Indian Energy Mix, Global warming & Climate change, Mass Production Technology, Net Zero Emission, Reduced Carbon footprint, Sustainable mining Practice.

1. Introduction:

"The Underground Vision Plan of Coal India Ltd" has set a focal point of enhancing the production of coal from underground mines to the tune of 100 Million Ton by 2030 as a measure to gradually improve the status of underground coal mining in India in contrast to traditional unilateral dependence on opencast mining. At present, the contribution of underground coal mining in India is a mere figure of 4% only. This paradigm shift is necessitated on account of the following basic considerations: Primarily, gradual depletion of opencastable coal resources and secondly, in comparison to opencast mining, underground coal mining is more environment friendly, socially acceptable and most importantly, paves the way for yielding superior quality coal from deep seated coal deposits in Indian context. Unlike in many leading major coal producing countries, India still preserves a huge reserve base of superior quality coal in comparatively deeper deposits between 300m to 600m and 600m to 1200m depth ranges from the surface practically untouched. The energy security of India in the future decades will largely depend on efficient exploration and subsequent exploitation of these coal deposits. But the most important challenge lies in the selection of state of the art technologies in all phases of mining activities starting from modern exploration techniques to sustainable forms of exploitation of the coal seams and adaptation of clean coal technologies during the utilization of the extracted coal for generation of thermal power and other forms of coal utilization like Coal Gasification, Integrated Gasification Combined Cycle (IGCC) technology, commercial Coal Bed Methane (CBM) etc.

2. Strategies taken by CIL in its Underground Vision plan:

For enhancement of underground coal production, the following radical changes and interventions have been enumerated in the CIL vision plan-

2.1 Conducting feasibility studies for more and more introduction of Continuous Miner Technology in underground mines

2.2 Implementing large number of Highwall Mines wherever feasible to improve percentage of extraction of coal and to exploit the otherwise non-extractable coal resources in the old/discontinued/running OC mines

2.3 Transformation/revival of existing underground coal mines by replacing conventional mining technology with Mass Production Technology, mainly Continuous Miners subject to technical/feasibility study

2.4 Identifying seams amenable to Longwall mining in virgin area and within leasehold area of mines where upper horizons have been de-coaled and where possibility exists to extract lower seams.

2.5 Enhancement in productivity by reengineering and amalgamation of current mines

Besides these technical aspects as stated above, there are other important financial and commercial aspects, such as-

2.6 Adopting the concept of composite pricing mechanism for assessing viability of underground mines, &

2.7 Policy intervention for sale of coal produced from UG mines exclusively through e-auction route, specially for the coal grades of G10 and above.

In this article we would mainly concentrate on point no.4 related to scope and conceptualization of Powered Support Longwal mining in Indian context as a part of fulfillment of the Underground vision plan of Coal India Ltd.

3. Scope of Powered Support Longwall Technology in Indian Underground Coal Mining:

Unlike in majority of the leading coal producing nations in the world, India has always remained a laggard in underground coal production in general and implementation of the state of the art underground coal mining technologies in particular. Though the first introduction of powered support longwall technology was commenced at Moonidih mine in Jharia coalfields way back in 1978, its mass scale deployment in a sustainable manner could not take place so far in Indian coal mining sector. Of course, some other mines in different subsidiaries of Coal India and SCCL have come up in subsequent years, some of them are adorned with the experience of severe failure and some other projects have exhibited limited to moderate success. However, till today, in none of the Indian mines deploying PSLW technology, the production and productivity parameters could even remotely attain the world standards. There are several reasons for that about which already a number of analytical discussions have been held at different forums and further in-depth studies in this regard are still going on. But at present it has become immensely important that unless we go for Powered Support Longwall Technology en-mass scale in Indian underground coal mines, the future of coal mining industry as a whole will be facing severe and practically irreversible crisis in near future.

4. Analysis of the perspectives of the main Mass Production Technologies in Indian Context:

As has been envisaged in the Underground Vision Plan of CIL, all the forms of Mass Production Technologies (MPTs) for UG coal mining have to play major and significant roles for enhancement of underground coal production in India which is the need of the hour for sustainable mining practices as well as the energy security of the nation. But the role of every such technology is distinct and different.

4.1 Highwall mining:-The role of Highwall mining is very distinct and site specific. This is the mining method for extraction of remnant coal from the highwall bench side of an opencast mine, which can neither be efficiently or economically extracted either by extension of opencast mining or by general underground mining methods.

4.2 Continuous Miner Mining- Continuous Miner (CM) Technology as a mass production technology applicable with B&P method of mining has got enormous scope in Indian underground coal mining sector. It has two very distinct directions. Firstly, new projects with Continuous Miner Technology with planning for high level of production, productivity and techno-economic parameters from the new project and secondly, revival or transformation of existing underground coal mines by replacing conventional mining technology with Continuous Miner Technology leading to enhanced production, productivity and techno-economic parameters, wherever feasible. But the applicability of this technology is limited to the specific geo-mining conditions suitable for efficient B&P method of mining like depth range of deposits, nature of roof and floor of the coal seams being worked, degree of gassiness of the coal seams etc.

4.3 _Powered Support Longwall mining- Powered Support Longwall (PSLW) Technology has been globally acclaimed as the most versatile mass production technology for underground coal mining, which can be applied in the widest range of geo-mining conditions. The technology can be adopted at such shallow depth of hard cover as only 10 times the extraction thickness of a coal seam to any depth of deposit beyond 1000m & more. Practically beyond 400m depth, PSLW is the most suitable mining method from operational point of view. So far as roof strata are concerned, it can cover wide range of strata sequence from moderately hard strata to weak roof condition and practically , where the weak roof strata poses very serious challenge for B&P method of mining, PSLW technology provides the solution. In highly gassy coal seams, PSLW is the most suitable mining technology not only from the ventilation and environmental management point of view, but also from the point of view of effective control and monitoring for the explosion risk measurement and alleviation of the dangers associated with it. Besides the above stated, Powered Support Longwall Technology is the most productive with very high level of productivity and the safest globally accepted UG coal mining technology.In Indian context at present it is needed to identify the practical domain and scope for Powered Support Longwall Technology as a strategic measure to implement the underground vision plan of CIL.

5, Strategic planning for Powered Support Longwall Mining in India:

Though the PSLW technology can be deployed at a wide depth range of coal deposits, at present in Indian coal fields the main concentration for deployment of this technology should be at comparatively deeper deposits, mainly deeper than 300m and exclusively beyond 400m depth. The following are the reasons behind such strategic endeavor:

5.1 Since traditionally the Indian miners are predominantly practiced to B&P method of mining, for them it is very convenient to adopt Continuous Miner Technology as a Mass Production Technology applicable with B&P mining method. The coal deposits in India up to 300m depth from surface have already been widely exploited either by opencast method or by conventional B&P underground mining method. While open cast mining will continue to dominate the Indian coal mining scenario, the scope of underground mining upto 300m depth is limited and the same can be best exploited either by new Continuous Miner projects or wherever feasible by replacement of conventional mining technology with Continuous Miners even in partially developed and existing underground coal mines.

5.2 Compared to Continuous Miner Technology, the equipment cost of Powered Support Longwall Technology is much higher requiring a much larger extractable coal resource for its economic deployment. If with an estimated extractable coal resource of 7-10 Million tons, one can plan for one set of Continuous Miner Equipment set, it will need at least 25-30 million tons of extractable resource totally earmarked for deployment of one set of PSLW equipment. In Indian context at present it is very difficult to identify such coal blocks with all suitable geo-mining and geo-mechanical characteristics within upper 300m depth level. But the same is very much convenient when we consider the coal deposits below 300m from surface, where the huge coal resources are still practically virgin.

5.3 The major advantage of this situation is that the coal mining industry in India is in a very favorable position to conceptualize and implement Greenfield projects with PSLW technology in large numbers in comparatively deeper coal deposits involving selection of geologically compatible huge virgin resources, planning for large, high capacity and highly productive powered support longwall equipment sets of world standard with completely compatible systems, which might be not only techno-economically competent in respect of any individual project, but would pave the way for sustainable en-masse implementation of state of the art underground coal mining technology capable of supplementing the progressively increasing coal demand of the nation.

5.4 One of the most important aspects of the conceptualization for such Greenfield PSLW projects is that In India in near future we must be able to implement a series of highly productive mines of minimum 4-5 million tons of coal production capacity per annum that would place Indian Underground coal mining industry on proper track in alignment with world trends. This will also improve the feasibility of these projects and would genuinely pose the underground coal mining sector as genuine, competent and compatible supplement or in certain cases alternatives for opencast mining projects.

6. Important Parameters for conceptualization and planning of Greenfield Powered Support Longwall (PSLW) Mines from Deeper Deposits:

While planning for a Greenfield PSLW project in Indian context, it is important to consider the following realities concerning Indian coalfields and its challenges-

6.1 equirement of coal Resources & Production Capacity of Greenfield Projects:-

The Greenfield PSLW projects, mainly in deeper deposits should be planned with high rated capacity of 4-5 Million Tons/annum to facilitate high return against highly capital intensive infrastructure build up required for deep mines and the market price of PSLW equipment sets. This would require substantially high coal resources within the project to ensure a reasonably long mine life with such level of rated production potentiality. The minimum requirement of extractable coal reserves for deploying one set of PSLW equipment should in the range of 25-30 Million ton.

6.2 Exploration for Identification of Suitable Coal Blocks:-

In consideration of the above it is needed to identify suitable coal blocks with minimum or negligible geological inconsistencies mainly in virgin coal seams. Thus, in Indian context the huge potentiality for PSLW mining lies in deeper coal deposits. It necessitates the application of intensive exploration of coal resources with modern exploratory methods. Exploration models for new deep areas should include detailed research on regional geological coal accumulation on the basis of sufficient collection and arrangement of regional geological data. After the commencement of exploration work, Geophysical exploration such as seismic exploration and magnetic exploration should be carried out to gain preliminary data on the distribution range, continuity, natural boundaries and denudation boundaries of the coal seams. Preliminary master models of occurrence and geological data in exploration areas should be applied to the development of the next construction scheme.

For proper exploration, a minimum borehole density of 10-12 Boreholes/Sq.Km should be adopted.

6.3 Need for Scientific Studies for Geo-Mining Conditions & Geo-Mechanical Properties of Coal and Mother Rock:-

The obtained data from the exploration should be sufficient for proper geo-mining and geo-mechanical studies required prior to deployment of highly capital intensive PSLW equipment sets for compatibility of the technology in given geo-mining conditions. This is the most important aspect for successful implementation of the PSLW mining in India. In early stage for introduction of PSLW technology in Indian coal fields, two major failures related to strata control (In Khottadih mine of ECL and Churcha West mine in SECL) extreme adversely affected on the en-masse adaptation of this world acclaimed technology in our coalfields and sent a wrong signal as if this technology is not suitable for Indian geo-mining conditions.

6.4 Determination of the Loading Pattern on Support System and Selection of Powered Supports and a totally compatible Powered Support Longwall Equipment set:

The most important parameter for the successful and safe planning of a Greenfield Longwall Project is the proper selection of Powered supports based on numerical modeling, computer simulation and expert analysis of the obtained geo-mining and geo-mechanical data. A continuous interface of industry-academia-research institution is extremely essential right from the conceptualization and planning phase to operation phase of the Longwall projects. Selection of the Powered Support Longwall Equipment set must be tailor made for compatibility with the specific geo-mining conditions of the mine.

6.5 Need for planning larger panels to limit the impact of salvaging and installation period on Longwall Equipment utilization time. **Selection of suitable development machine:**

The world trend today is forming of larger panels with increased dimension of panel length as well as face length containing larger quantity of coal for uninterrupted production from the panel for a substantial long period of time. It improves the equipment utilization period by limiting the number of face moves. But at the same time it involves enhancement in motor powers of the equipment, availability of robust metallurgy and also in behavioral changes on the loading pattern at face, ahead of face and the side pillars of the panel requiring proper scientific studies and R&D activities. It is also important that the panels must be developed by chain pillar system with at least two sets of main gate roadways and two tail gate roadways with interconnections between then at suitable intervals. The most suitable machines for such type of development activity are Bolter Miner Machines.

6.6 Planning for conduciveness of environmental conditions, monitoring and control over probable hazards in deep seated highly producing mine environment:

Deep seated coal mining inherently poses serious challenges of strata control, mine climatic conduciveness and larger emission potentiality of inflammable gases leading to higher explosion risks. It requires to develop a very systematic and effective Strata Control and Monitoring Plan (SCAMP) with proper instrumentation at all vulnerable locations like the face line, 50m ahead of the face line in all the gate-roads, at the coal pillars and barrier pillars. The T-junction of the face with tail gate is the most vital location for environmental monitoring of the district where suitable instrumentation is needed for monitoring and control of environmental hazards like methane emission or formation of CO. The system must be interlinked with precautionary measures to eliminate the possibilities of dangerous occurrences. Mines must be equipped with continuous tele-monitoring systems providing data of underground environment to surface control station.

7. Strategic Planning Aspects at the Highest Policy Making Level and by Apex Management towards implementation of Greenfield Powered Support Longwall Projects in Indian Coalfields:-

7.1 Taking strategic measures for large scale introduction of PSLW projects in place of piece meal application of the technology in isolated mines

7.2 Creation of conducive environment for developing indigenous vendors for catering the needs for operational smoothness of PSLW projects. This can be done in phases like at initial stage to develop vendors for manufacturing of fast moving spares for all the machines of PSLW set and then gradually within a well planned time frame develop manufacturing hubs for complete machines and ultimately complete PSLW sets.

7.3 Designing proper curriculum for skill development training for PSLW equipment operators, supervisors, managers, manufacturers and researchers in this field. Industry-academia-research organization interface at large scale must be encouraged. The same area must be developed for the mining regulatory authorities as well.

8. Analysis of the Perspectives of Greenfield PSLW Projects from Sustainability Point of View:

8.1 As a general rule any underground coal mining method is more eco-friendly compared to opencast mining and PSLW is no exception. If executed properly based on scientific studies, the technology is the safest, most productive and techno-economically competent method which makes it potentially more acceptable both socially and environmentally.

8.2 Amongst the underground coal mining methods, the PSLW technology can be applied for maximum extraction ratio of coal resources which is in alignment with the national mineral policy and the sustainability principle of conservation of mineral resources.

8.3 Better quality power grade coal in Indian coalfields are located in deeper coal deposits which constitutes the major area of operation for Greenfield Longwall projects. With improvement of coal quality and improvement of the burning efficiency, the generation of Greenhouse Gases (GHGs) can be quantitatively reduced which constitutes the most important parameter for sustainability. In addition to this, it will facilitate the coal consumption pattern by substantially reducing the quantity of coal required for generation of 1KWH electrical power in comparison to present day due to mining of improved quality coal from deeper deposits.

9. Conclusion:

Sustainability is attainable only through multidimensional approach. While from one angle the environmental impact of coal mining and coal utilization in form of thermal power generation is fraught with serious environmental challenges, from the other angle the coal based thermal power is the most economic and convenient form of primary energy generation, fulfilling the bottom-line sustainability parameters of availability and affordability. During the 2nd world summit on “Energy and Sustainable Development” held in Johannesburg, South Africa in 2002, the then General Secretary of The United Nations Kofi Annan proclaimed: “There is no possibility of the early demise of fossil fuels in the foreseeable future, …… that there must be a shift from the purely eco-centric approach to the techno-centric approach” for sustainable development. This principle is extremely relevant for Indian energy security and the Greenfield PSLW projects from deeper deposits subscribes to the execution of this principle. This must be one of the multi-dimensional major approaches including different other forms of clean coal technologies and continual growth of different forms of renewable sources of energy towards achieving the ultimate bottom-line parameters of sustainable Development principles of **Availability, Affordability and both Social and Environmental Acceptability.**

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NO : 2.7

Importance of detailed geological and geotechnical domains in underground metal mine stope design

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Abstract:

Sublevel open stoping is widely used in many underground metal mines both in India and abroad. The major risk associated with this method, in terms of both stability and economy is overbreak. For assessing stability, numerical analysis is adopted in many mines. The significance of varying geological and geotechnical parameters in geotechnical design, especially numerical analysis is often ignored or underestimated. Geological information about the hostrock and other concomitant geological disturbances are the major factors to assess any potential failure. The challenge in the analysis is partly because most geotechnical design methods—whether empirical, numerical, or analytical are primarily developed for isotropic rock mass conditions, not anisotropic ones. Consequently, there is a tendency to overlook the impact of anisotropy to simplify the design process or apply conventional methods. However, anisotropy can play a critical role in the stability of underground excavations and subsequent geotechnical design. Experience suggests that in many cases, anisotropy can even override other geotechnical factors, such as stress, in controlling the failure mechanism. This paper demonstrates the importance of lithological contacts in stope design through numerical modelling in FLAC3D, using the Improved Unified Constitutive Model (IUCM) as the constitutive model. By comparing the results of an isotropic model with one that considers weak lithological contacts, it is found that accurate geological modelling and geotechnical characterizationarecrucialforanycriticalstopedesign.Thepaperalsoillustratestheadoption ofIUCMasaconstitutivemodelandvalidatesitseffectivenesswithfieldresults,highlighting the benefits of using IUCM in daily geotechnical model preparation.

Key words: Sublevel open stoping, numerical analysis, geological domains, geotechnical domains, FLAC3D, Improved Unified Constitutive Model (IUCM)

10 Introduction

Many underground metal mines in India and other countries employ sublevel open stopping method. Due to the formation of large voids in this method, comparatively high mining-induced stresses cause overbreak unless the stope is designed properly (Scoble and Moss, 1994; Heidarzadeh et al., 2019). The consequences of overbreak include increased costs due to additional mucking and ground support, reduced stope efficiency, and potential safety hazards such as rock falls and collapses. Mitigating overbreak requires a comprehensive approach involving detailed geological investigations for an apropos design of stope.

Geological information about the host rock and other concomitant geological disturbances are the major factors to assess any potential failure. Detailed geological analysis provides crucial insights into the characteristics of the rock mass, including the distribution and orientation of ore bodies, fault lines, fractures, and other structural features (Suorineni et al., 1999). On the other hand, geotechnical data offers an in-depth understanding of the rock's mechanical properties, such as strength, deformability, and in situ stress conditions, which are crucial for evaluating stope stability and designing appropriate ground support systems (Vallejos and Díaz, 2020). Such data enable the prediction and management of ground control issues, helping to prevent catastrophic events like stope collapses or rockfalls that could endanger workers and disrupt operations. Moreover, detailed geotechnical analysis supports advanced numerical modelling and simulation techniques, allowing engineers to predict the behaviour of the stope under various loading conditions and to optimize the design accordingly. The challenge in the analysis is partly because most geotechnical design methods irrespective of empirical, numerical, or analytical are primarily developed for isotropic rock mass conditions, not anisotropic ones (Mathews et al., 1981; Trueman et al., 2000; Mawdesley et al., 2001; Henning and Mitri, 2008). Consequently, there is a tendency to overlook the impact of anisotropy to simplify the design process or apply conventional methods. However, anisotropy can play a critical role in the stability of underground excavations and subsequent geotechnical design. When the rock mass is anisotropic, the orientation of planes of weakness, such as foliation, or joint sets, can lead to differential deformation and stress distribution around the stope. For instance, if these planes of weakness are oriented unfavourably relative to the stope boundaries, they can act as potential failure surfaces, increasing the likelihood of rock falls or collapses. This necessitates meticulous planning and the implementation of apposite stope design to mitigate the risk. Additionally, the presence of anisotropy requires more sophisticated modelling techniques to accurately predict the stope behaviour under various loading conditions. Traditional isotropic models may not adequately capture the complex interactions within the rock mass, leading to potentially unsafe designs (Vakili, 2016). Thus, it is paramount to consider the anisotropic properties of the rock mass during the design phase, employing advanced geotechnical analysis and rock mechanics principles. This might include the use of numerical simulation tools that can account for anisotropic strength and deformability, as well as the orientation of structural discontinuities (Wang et al., 2007). This paper demonstrates the importance of considering detailed geological information and anisotropic conditions in stope design through numerical modelling.

11 Geology

The stope of interest is in a shallow depth mine approx. 200m below a hilly terrain as shown in Figure 1. The rocks of this area form a part of Paleo Proterozoic age. Meta sedimentary rocks belonging to this group have a polyphase deformed complexly folded geological structure formed out of two distinct epochs of orogeneses. The mine hill represents the N-S trending & northerly plunging first generation fold system. The rock units consist of Dolomite, Greywacke, Sub greywacke, Phyllite / Quartzite as shown in Table 1. The mineralization is confined to dolomitic horizons of the mine formation and controlled by faulted contacts, shear fractures and tensional fractures related to fold pattern. The mineralization occurs as veins, stringers and dissemination forming lenticular bodies. The 3D design of the mine demonstrates lithology, major fault system and future stopes as illustrated in Figure 2.

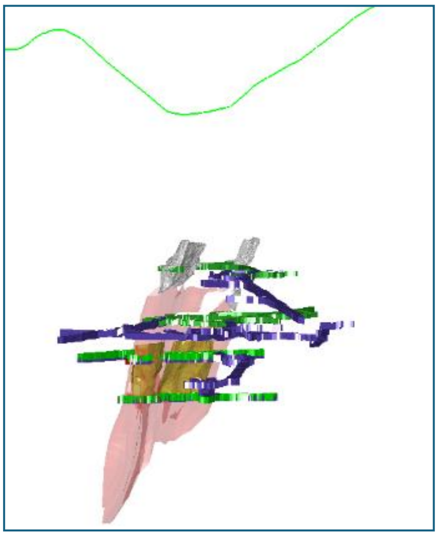


Figure 3: Stoping below 200m hilly terrain.

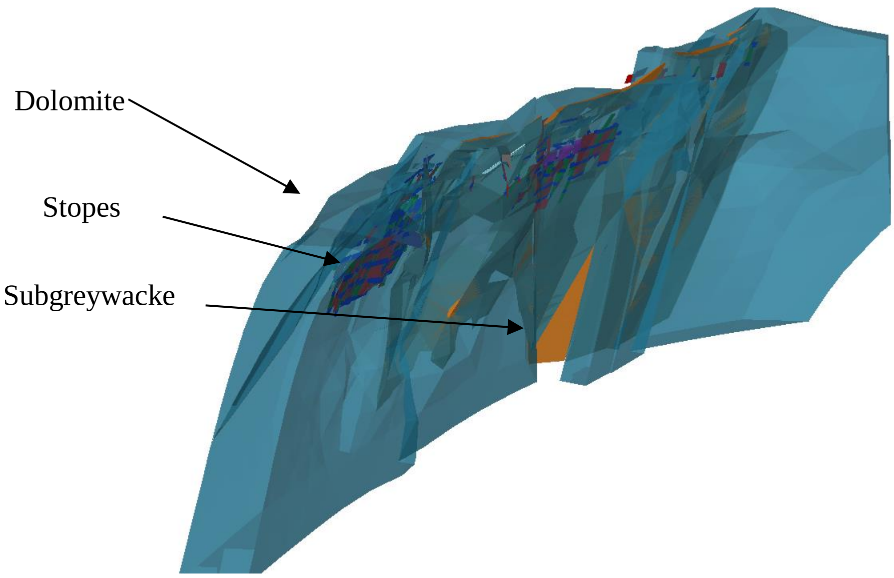


Figure 4: 3D model of mine litho structure.

12 Geotechnical Domains

The mineralisation is confined along the brittle fractures that were developed during various orogeneses that the deposit has undergone in the geologic past. The fractures trend almost 30 degrees from the E-W. There are three sets of regular, persistent joints. These are N-S trending dipping 85 degrees either due E or W; sub-horizontal joints and joints trending 45 degrees either due 105 or 285 degrees. These joints are sympathetic to a set of conjugate faults. The joints in general are rough and continuous, indicating high inter block shear strength. Figures 3 to 4 show different geological features present in the rock mass.

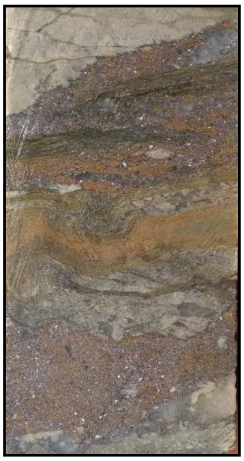


Figure 3: Mineralised veins

Figure 4: Fault observed in core.

Figure 5: Fold closure.

The general RQD percentage as derived from mapping underground using the volumetric joint count method is

- Siliceous Dolomite – 85%-95%
- Phyllitic Dolomite – 65% – 80% - it is dependent upon the dolomite and phyllite ratio in the rock.
- Phyllite - approximately 55%

However for more accuracy in the numerical model, RQD from exploratory borehole is logged and RQD model is prepared as demonstrated below.

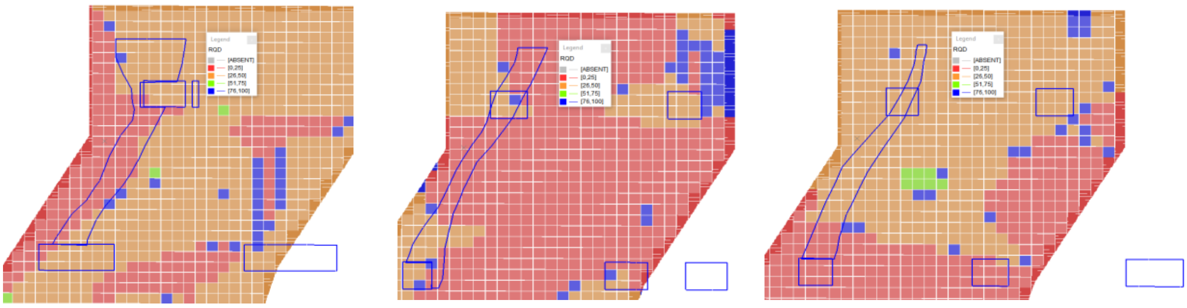


Figure 6: RQD model demonstrating varying RQD throughout the strike length of the stope.

13 In-situ StressES

In-situ stress measurement has been done by hydro fracturing and the details are laid below in Table 2. The in-situ stress ratio (K) indicates moderate magnitudes of stresses. The in-situ stresses are represented by the following equations:

$$\begin{aligned} \sigma_H &= 6.13 + 0.0126z \\ \sigma_h &= 3.9 + 0.0066z \\ \sigma_v &= 0.028z \end{aligned} \tag{1}$$

Where, σ_H = Major horizontal in-situ stress (MPa), σ_h = Minor horizontal in-situ stress (MPa), σ_h = Vertical in-situ stress (MPa) and z = Depth of cover (m).

Table 1: Measurement data of in-situ stresses.

Rock Covers in m	Test Depth in m	σh in Mpa	σH in Mpa	ϴ in degs	σv calculated in Mpa	K based on σv calculated
530.4	75	6.394±0.145	12.788±0.29	120	14.55	0.87
605.4	150	9.219±0.357	13.828±0.535	110	16.61	0.83
680.4	225	7.34±0.186	14.68±0.372	100	18.67	0.78

14 Numerical Modelling

The stability of the stope is evaluated by numerical simulation through FLAC3D (Itasca, 2017) where the Improved Unified Constitutive Model (IUCM) is adopted as the constitutive model for the simulation of rock mass response during stoping operations (Vakili, 2016). The IUCM gathers the most notable and widely accepted previous research work in rock mechanics and integrates them into a unified constitutive model that can better and more accurately predict the stress-strain relationships in a continuum model. A key advantage of the IUCM is that it accounts for all important and fundamental aspects of rock failure from simple to more complex ones in a unified model. These aspects include the transition from brittle to ductile response, confinement-dependent strain-softening, dilatational response, strength anisotropy, and stiffness softening.

The IUCM is a commercially available model and is currently implemented in Itasca's FLAC3D code as a FISH function and a C++ DLL plugin. The guidelines outlined were used to derive the input parameters for the IUCM model. An important advantage of the IUCM is that the rock mass properties, post-peak behaviour, dilatational response and residual properties are automatically controlled and assigned according to rock mass characterization (GSI) and intact laboratory test results (UCS, mi and Ei) that are often readily available (Vakili, 2014). The IUCM employs the Hoek-Brown criterion to determine the instantaneous Mohr-Coulomb parameters cohesion (c) and friction (φ) at each level of confining stress.

In the numerical modelling, the intact rock properties given in Table 3 are converted to the rock mass properties for the simulation of field conditions. At first, a 3D model has been created for stope geometry to be excavated in the area as shown in Figure 7. Historical stope geometry is used to ensure that the impact of stoping is preserved in the numerical analysis. After that lithological domains and shear zones are updated in this geological model as shown in Figure 8. Now, the numerical models are simulated without and with shear zone conditions to compare the results.

Table 2: Physico-mechanical properties of different rock formations.

Properties	Unit	Dolomite	Phyllite	Shear	Ore	Greywacke
Density	t/m^3	2.9	2.8	2.8	3	2.8
Youngs Modulus	GPa	40	35	21	40	35
UCS	MPa	100	50	20	80	78
Cohesion	MPa	9	3	1	11	9

Friction Angle	Degree	45	40	20	40	55
Tensile Strength	MPa	8	3	1	10	8

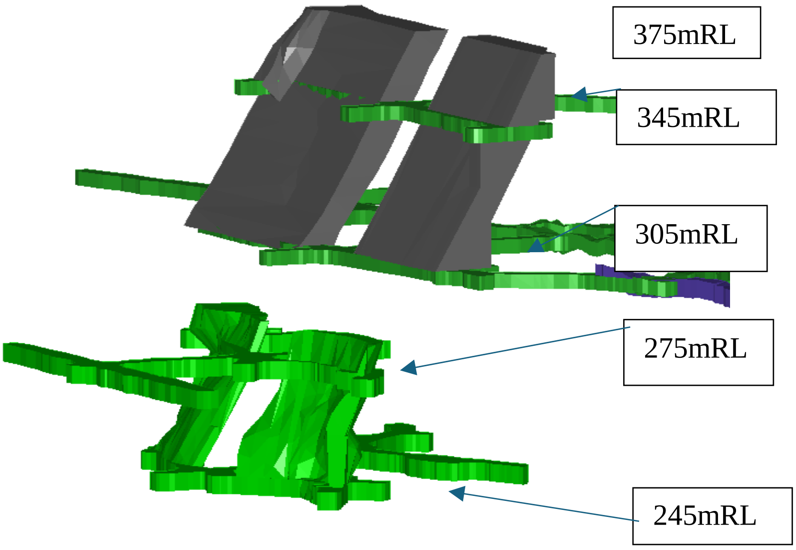


Figure 7: Creation of 3D geometry of stope.

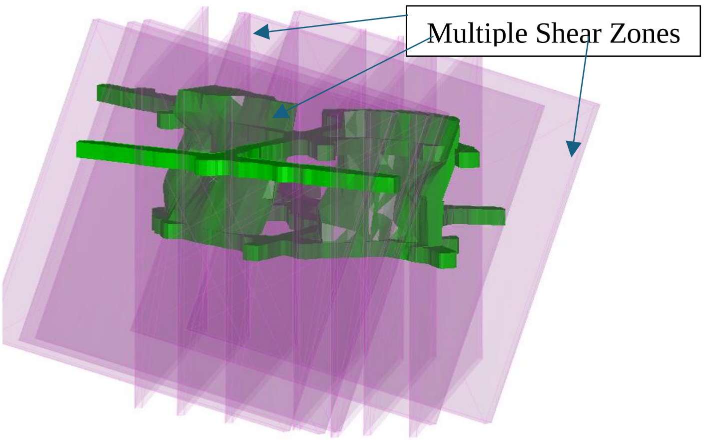


Figure 8: Incorporation of lithology and geological features in excavation wireframe.

15 Results of numerical modelling

15.1 Modelling Results Considering Without Shear Zone

The model state plot in Figure 9 shows minor shear and tension failure near the slot area and at the lower-level development undercut. The volumetric strain iso-surface at 0.05% also did not demonstrate any potential major failure. The major principal stress plot in Figure 10 also does not show a major stress increment or reduction to detect a potential failure.

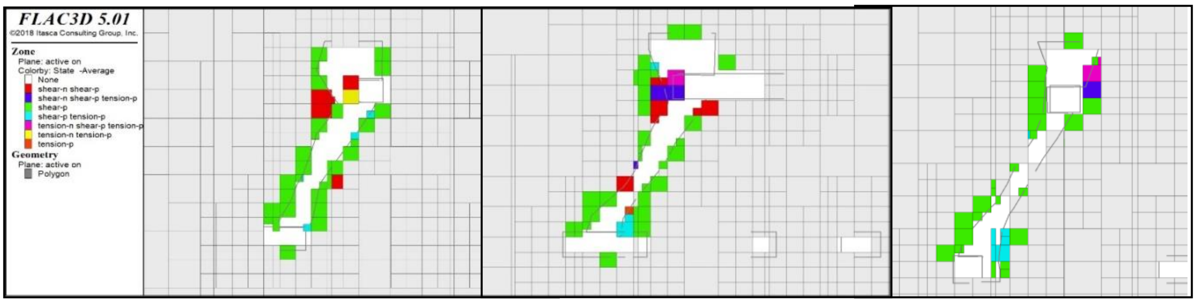


Figure 9: Model state showing minor failure.

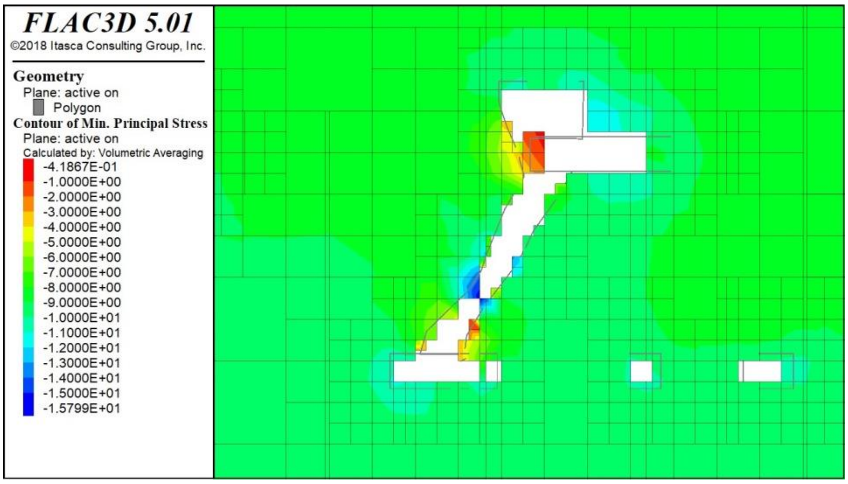
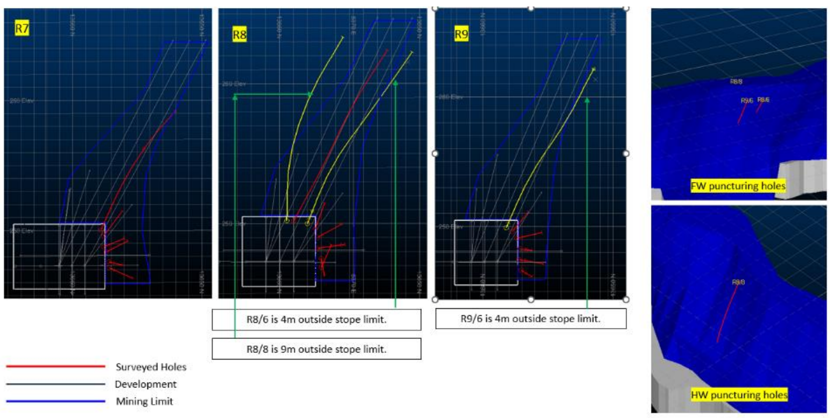


Figure 10: Maximum principal stress (Pa) near the slot.

A standard drill and blast design for a narrow vein is deployed and a parallel blast hole survey is also done through a borehole camera. Based on the deviation observed, necessary precautions like control blasting of remaining holes, and leaving of uncharged holes were done.

Figure 11: Result of blast hole survey.



15.2 Modelling Results Considering Shear Zone

After considering all the shear planes, the model was re-run, and the results were analyzed in detail. Shear and tension failure in the hangwall is visible in the results as shown in Figure 12. The volumetric strain plot at 2% almost matches with the cavity monitoring scan (CMS) profile of the stope after blasting.

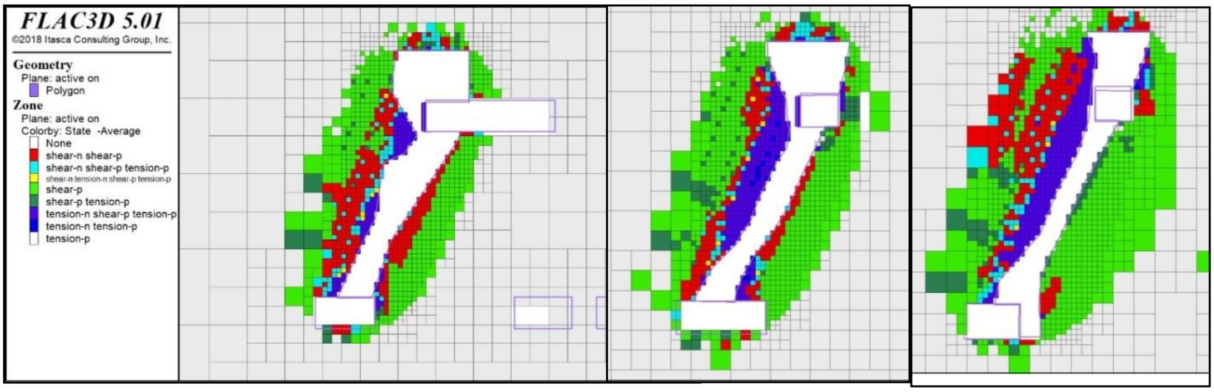


Figure 12: Result of model state after considering the shear zone in the numerical model.

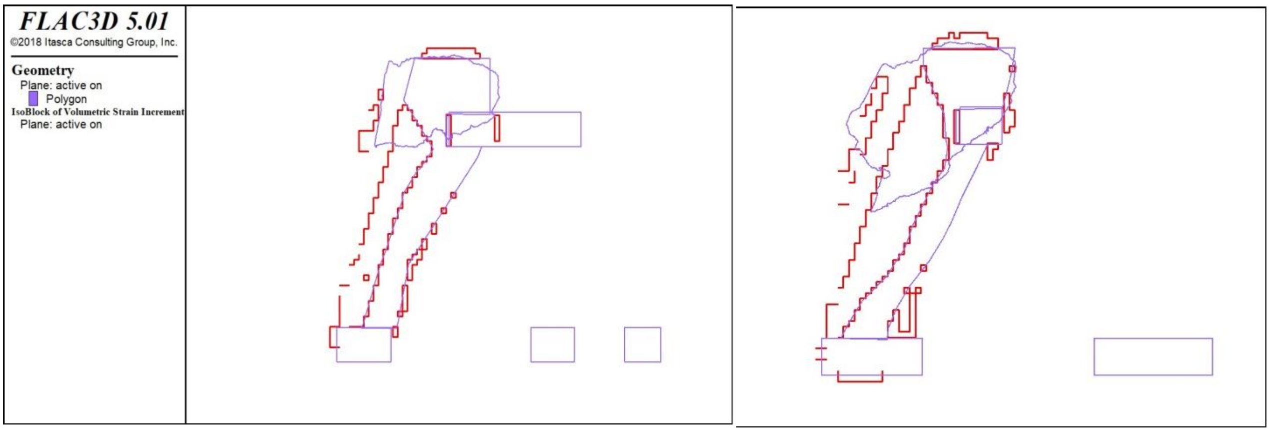


Figure 13: Volumetric strain at 2% vs CMS.

16 Conclusion

While drilling and blasting parameters significantly influence the stability of large excavations, a thorough consideration of geotechnical factors is equally crucial for ensuring wall stability. Effective numerical modelling for evaluating failure zones requires accurate incorporation of lithological variations and Rock Quality Designation (RQD) data. This comprehensive approach ensures that the model accurately represents the actual failure zone, allowing for the implementation of necessary precautions. Such measures may include modifying stope dimensions, reinforcing critical areas, adjusting the stope sequence, and utilizing filling options. By integrating detailed geotechnical information into the numerical model, more reliable predictions and safer excavation practices can be achieved.

17 Acknowledgement

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Theme 3: Innovation in Digitization, remote Operation, AI and ML

NO : 3.1

An innovative and efficient IoT based approach of coal mine environmental monitoring for security aspects

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Abstract:

In general, in a coal mine below the surface activity is characterized by tough working condition and hazardous environment. The hostile environment in the coal mine is due to the fluctuation of subsurface atmosphere. Normally there is various gaseous leakage (particularly methane CH_4) and land slip which makes the mining environment for the workers dangerous. These environment changes are stochastic and workers during mining operations risk their life unknowingly which causes frequent mishaps. Under such circumstances, effective data transmission and proper monitoring of the underground mines are crucial. In this work an innovative approach of environmental monitoring by deploying wireless sensor nodes/wireless multimedia sensor nodes (WSN/WMSN) and its IOT based application is targeted. This proposed IOT based sensor network with proper and real time monitoring in terms of gas sensing, multimedia surveillance and indoor localization will ensure an extra degree of precaution inside the coal mines. The proposed system will give the real time data of the incidents inside the coal mine through its gas sensing and multimedia sensing module. This will give miners and all mining authorities informed about the present condition inside the mine. Moreover, with its indoor localization system continuous location of the miners will be tracked to provide complete safety to them especially if any rescue operation inside the mine is desired. In addition, a prediction model will also be created based on the stored data at the cloud to predict future incidents. Technically the supremacy of this work will be judged by its efficacy and socially it will be appreciated for the sake of humanity.

Keywords: WSN/WMSN, Multimedia Surveillance, E-nose, Indoor localization,IoT

Introduction

In the modern era, numerous technological developments have been produced that improve our quality of life. The most crucial and cutting-edge technology across them is the Internet of Things (IoT), which has a profound impact on many people's perspectives. The Internet of Things can be defined as the integration of common place items with network-enabled control systems. It is how different objects connected with the network can communicate with one another [1]. IoT based systems have three phases: sensors for data collection, transmitting data to the designated location through the network, and storing, and analysing the data [2-5]. IoT is currently being successfully used in a variety of industries, including coal mines and chemical facilities, where constant surveillance base system is required for the safety of employees. For this, here a creative and effective IoT-based method for monitoring the coal mine environment has been established. The objective of this work includes the creation of network inside coal mines using wireless sensor network/wireless multimedia sensor network (WSN/WMSN) and Internet of things (IoT).

The proposed system electronically monitors, detect and update information about the abnormality condition of the subsurface atmosphere throughout the underground mine. Sensor nodes will be deployed and a network will be created throughout the mine to identify the places of gas leakage and land slip with precision. Upon sensing the place of abnormality, the location and image of the place will be communicated to the IoT server and to all the workers related to the mine. The multimedia monitoring on demand will work in accordance with the area that is affected. In addition, there is a concept of indoor localization which will detect the location of a worker who goes underground due to mining and suffers from hazardous condition. It will allow accessing the rescue team promptly for any casualty faced by any workers. Application wise this method will serve as a protective and preventive measure related with the safety issues in mining activity.

Literature Survey

One of the energy resources in the country is coal and the safety measures taken for production of coal are quite serious. However, the prediction and estimation of the risk involved during coal mining is weak. The unfaithful nature of the underground of a coal mine causes fatal accidents with loss of life frequently. WSN/WMSNs have come a long way in providing effective solutions for the betterment of humanity. The monitoring and detecting system using WSN/WMSN will provide an effective solution. Until now many works have contributed to the effective deployment, sensing and monitoring in the coal mines. In order to have a model to provide safety in the coal mines proper deployment of sensor nodes, sensing gaseous parameters, multimedia surveillance and indoor locations are needed. These four things are a complete package to provide safe and secure mining. Based on this information a detailed survey is provided here. Thus, for better understanding of the researches around the world the review is divided into three subparts.

Sensor node deployment

Wireless sensor network works on distributed network protocols and have wireless communication and data processing capabilities. To get the best efficiency in terms of coverage area, prolong network lifetime and other qualities proper deployment of the nodes is an important factor.

In one of the works [6] a node deployment scenario is proposed for a coal mine tunnel to meet the maximum coverage. The work gives an idea of probabilistic sensing model using WSN for getting the coverage to sense abnormal events inside the mines.

In another work [7] the chain of sensors along with its cluster head is discussed. It is proposed that these sensors are used to monitors various phenomena inside the coal mine. A dynamic choice algorithm is proposed to improve the adaptability of the network. The authors also claimed that non uniform deployment strategy is better than uniform deployment in terms of network lifetime.

A deployment scheme in case of long wall mining is proposed in [8]. The authors here claim that due to hostile environment in the mine the deployment strategy follow a random deployment. However, the long walls allow following linear or chaining type deployment with sometimes poor coverage and connectivity. In order to mitigate these problems a rectangular deployment of nodes can be used with probabilistic sensing model.

In one of the works [9] a comparison of the deployment schemes is focused. The authors claimed that in WSN the number of sensor nodes has a close relation with the cost and is also related with the performance of the network. According to their findings it is proposed that sensor node deployment in form of equilateral triangle is better than square for efficient coverage area ratio.

In one of the versatile works [10] to obtain real time monitoring the sensors are deployed in strategic locations in the underground of a coal mine. The deployment scheme ensures 1-coverage and 3-comnnectivity. Hexagonal cells are considered as deployment strategies. The network coverage area is divided into N layers containing hexagonal cells and the Sink is placed at the corner. It is assumed that heterogeneous nodes are deployed in each of the hexagonal cells. Routing scheme and energy efficient condition of the nodes are also highlighted in this work.

Sensing gas leakage

After the deployment of sensor nodes inside the coal mine an important factor to sense the gaseous parameter. It is a known fact that frequent gas explosion causes loss of life inside the coal mines. Therefore, gas detection and alarming system is a requirement inside the coal mines. In one of the works [11] an intelligent gas detecting system is proposed where it uses catalytic combustion type of gas sensor to detect the concentration of methane CH_4 above the threshold level.

In another work [12] the working principles and operating procedure and applications of different types of gas sensors are discussed. A technique of developing intelligent gas sensor to detect methane is proposed in [13]. The sensor has capability of automatic calibration and offset calculation. Beside these facilities the methane sensor can be interfaced with host computers and abnormality of methane level is communicated through sensor network.

Recently a concept of electronic-nose (E-nose) is becoming very prominent because of its capability to sense the order and to make prediction about the gaseous condition at a particular place. In the works of [14-15] the application area of E-nose is highlighted to sense different gaseous composition mainly CH_4 and CO for safe mining. The authors also stated that application of neural network for analysis of gaseous sensing using E-nose can greatly improve the coal mine prediction.

In a modern approach to communicate the prediction and measurements of the E-Nose related with the gaseous variations in the coal mines the involvement of WSN has provided an open area of research. In the works [16 -17] the authors have showed that the sensed gaseous extracts are measured and analyzed for detect any abnormal gaseous extract over a particular threshold. These measurements are sent from the sensors to the sink through wireless links.

Multimedia Sensing

Besides this sensing of gas leakage another important aspect of the coal mines is environmental monitoring and surveillance. Normally if the picture of the tunnel such as continuous monitoring or event-based monitoring is configured inside the coal mines then due to this real time monitoring mishaps can be prevented. As the sensors are normally energy resource device and raw multimedia (image/video) transmission requires huge energy so suitable compression techniques for multimedia data processing is required. In some of our earlier works [18 -19] related with disaster management energy saving multimedia compression using WSN and WMSN, the same has been shown. These works not only save transmission energy but also give appreciable reconstruction at the sink end in terms of peak signal to noise ratio PSNR.

Methodology

Considering the facts as seen from the literature survey we propose a system to have a unique method of deployment so that it takes care of the coverage and energy constraint resource of the sensor nodes. The deployment of the gas sensor is done for the purpose of detecting gas leakage and also for surveillance purpose effective compression algorithm will also to be designed. Lastly indoor localization will also be done to provide additional security to the miners. All these information will be passed from the sensors to the sink and up to the cloud server. This server will develop predict and analyses the situation based on its results and will convey the information to the professional related with that mine. All of these operations are depicted pictorially through the system architecture as represented in Figure 1. It is to be noted that the blocks of sensor can be divided into even and odd rows of hexagonal cells. Multimedia sensors are placed only in the odd row of the cells in addition to other sensors. Even row cells consist of all type of sensors except multimedia sensors. As the objective of the work is to build a wireless sensor and IoT based system for smart environmental monitoring inside the coal mines the project as estimated is divided into a number of sub tasks. The sub tasks are described in ascending and in a sequential manner. The subtasks of Figure 1 along with a brief description are mentioned as follows:

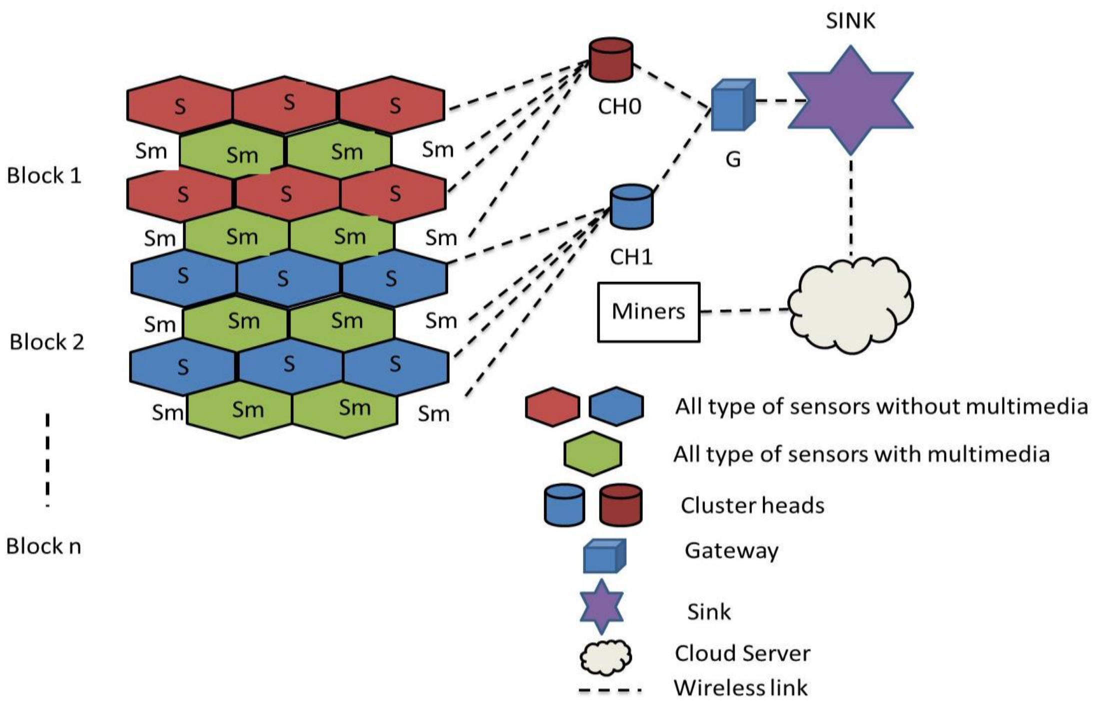

Figure1. System Architecture

Sensor node deployment

This section will consider the deployment of the sensor node inside the coal mine. It is always to be mentioned that coal mine is a hostile area so deployment of the sensor node needs to be planned in a generic way. In our approach we have planned to divide the total inside the mine into hexagonal cells. Combination of four rows of hexagonal cells makes one block. Each block is divided into odd row and even row cells. On the centre of each hexagon, we will deploy sensor nodes to monitor the necessary operations such as gas leakage, multimedia surveillance and indoor localization. Multimedia sensors are placed only in the odd row cells. Gas sensors and location sensors are placed at the odd and even row cells throughout the block. This is because multimedia sensors have a greater coverage than other sensors. These sensors of the blocks are connected to the cluster heads of that block. The cluster head will communicate with the gateway to send its information to the sink and the cloud server. The sensor type and the type of sensing operations are discussed in the following subsections.

Sensor Node

The deployed sensor motes at each hexagonal cells and its clusters are basically made with arduino board. The gateway is designed with Raspberry pie Zero W. At each hexagonal cell an arduino board is placed which is interfaced with an E-nose and beacon node for indoor location. Cameras using Infrared (IR) technology is placed only in the odd row cells. A routing will be provided to these sensor nodes after deployment. This is required to pass the sensed information from the nodes to its Cluster head and through the gateway to the Sink/ Server. These sensor nodes are connected through wireless access and more over they are also connected by WI-FI to process their data in the IoT cloud.

The detailed process of the projected system is depicted through a suitable e process diagram as illustrated in Figure 2.

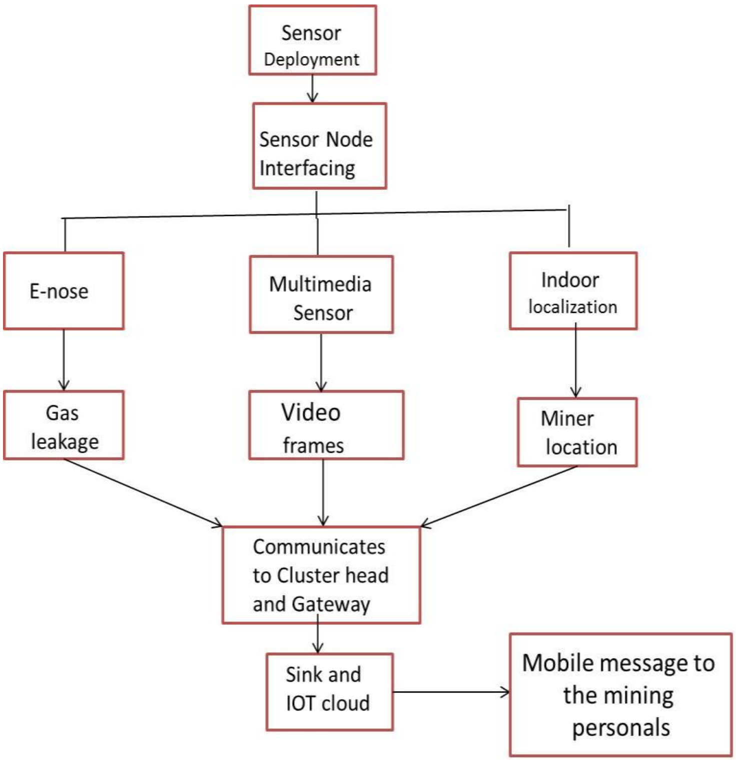

Figure 2. Process diagram

Efficiency of the projected system

Generally, there are many sudden unknown environmental changes that happen inside the coal mines and unknowingly it causes damage to the mining operations or mining personals involved with it. In such a situation proper monitoring and prediction of the incidents inside the coal mines for security purpose is of prime importance. The efficacy of the system is realised through the following points.

- With the advance and rapid adoption of wireless sensor networks (WSNs) and its IoT based applications in the last decades, source localization and boundary estimation have become the priority of research works.

- Atmospheric changes through gas leakage and its abnormality are a major concern inside the mine. A technique to sense these changes will be sensed by the sensors placed and the measured value will be communicated to the server for analysis purpose. This technique will allow spotting the area.
- Normally WSN are resource constraint network so transmission of raw image/video frame will consume huge transmission energy. So, under this situation low overhead transmission without affecting the quality of the picture is required. This will allow surveillance of the mining area with a degree of reliability.

Performance Analysis

We did multiple analyses to gauge the performance metrics, including communication latency, transmission efficiency, and variance in the time it took to get the data. To reduce the amount of manual labour required for running tests and taking measurements, the entire assessment procedure was automated and rigorous simulation has been performed using MATLAB. The studies were carried out in indoor within a building, in a controlled setting and also in outdoor in an uncontrolled environment outside of the building using 40 nodes. Following provides the outline of performance analysis of the projected system.

The transmission efficiency of the proposed system is assessed in terms of the number of packets received with the variation of distance as shown in Figure 3. For instance, it can be seen from the accompanying plot, that the suggested system can effectively transmit 109 packets over a distance of 20 meters in both indoor and outdoor situations. While at a distance of 60 meters, this value changes to 107 packets for an enclosed environment, and 109 packets for the outdoor one.

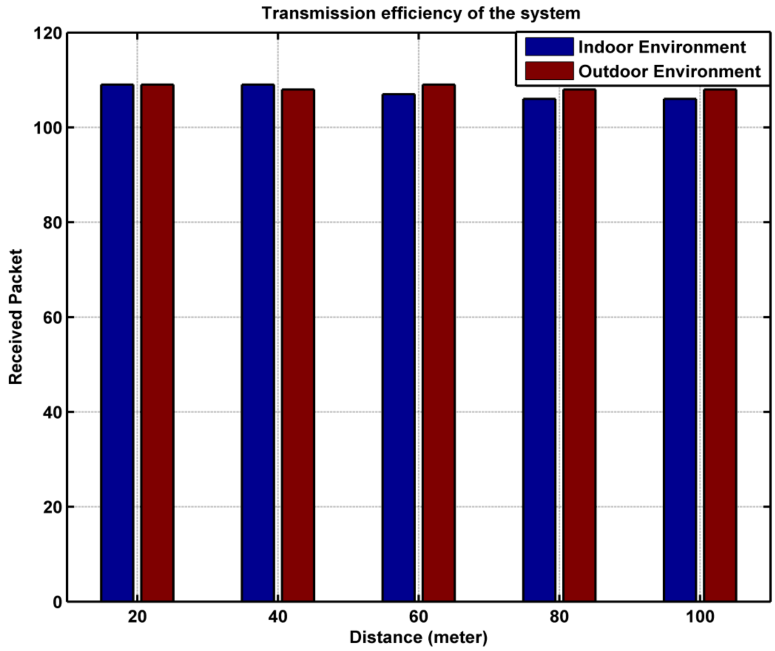

Figure 3. Transmission efficiency of the proposed system in various environmental conditions

In the same way, for a distance of 100 meters, this value changes to 106 packets for an indoor environment and 108 packets for the outdoors. From this, it can be concluded that the suggested system's transmission efficiency in the outdoor setting is marginally higher than in the indoor setting. Additionally, it was shown that the suggested system effectively transmits data over a wide range of distances and in a variety of environmental conditions while maintaining a transmission efficiency that is within acceptable bounds.

For the statistical analysis of the system, the box plots of time duration with variation in distance have now been used to investigate the variance of the time interval of the received data set. The variation of time interval to receive the data at various points of distance in different environments is shown in Figure 4. It is observed from Figure 4 that the proposed system can efficiently transmit the data with a time interval variation of 2 to 4 seconds at different point of distance.

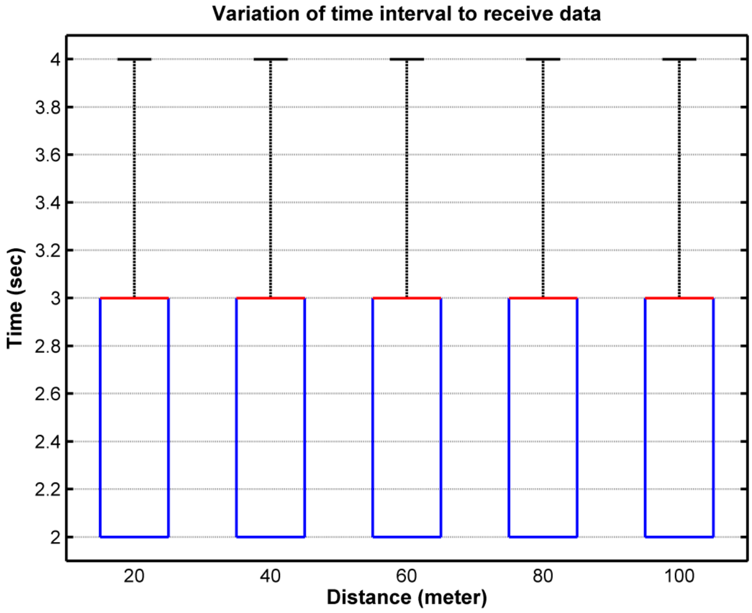

Figure 4. Variation of time interval to receive the data at various points of distance for different environmental settings

With respect to various points of distance, we evaluate the system's Standard Deviation, Standard Error, Variance, and the Mean Time Overhead to transmit the data as shown in Table I. According to Table I, the mean data transmission time will also significantly rise along with the distance within an acceptable range for idle or packet loss conditions in various environmental circumstances. Additionally, it had been found that when the distance from the target point increases, the Standard Error, Standard Deviation, and Variance also alter slightly, for different circumstances. This analysis has shown that the suggested technology is quite effective at transmitting data over a wide range of distances. It was also observed that the system takes a negligibly small amount of time delay to transmit the data over a vast distance.

Table I- Statistical Analysis of the Proposed System

Environment	Distance (meter)	Mean Time (sec)	Variance	Standard Deviation	Standard Error
Indoor Environment	20	2.7047619	0.26776557	0.51746069	0.050498992
	40	2.7047619	0.22930403	0.478857	0.046731658
	60	2.7333333	0.33205128	0.57623891	0.056235159

	80	2.752381	0.32271062	0.56807625	0.055438565
	100	2.7619048	0.35622711	0.59684764	0.058246366
Outdoor Environment	20	2.7102804	0.33979898	0.58292279	0.056353273
	40	2.7102804	0.26432728	0.51412769	0.049702599
	60	2.7009346	0.24933874	0.4993383	0.048272856
	80	2.728972	0.29377535	0.54201047	0.05239813
	100	2.7383178	0.34597073	0.58819276	0.056862741

Conclusion

In this work, an effective IoT based environment monitoring system has been design for the coal mines. The proposed system provides the real time surveillance for the mining areas to maintain the safety of the miners. The system efficiently utilizes the sensor property by creating a sensor-based network and its connection over IoT. The suggested method works effectively in terms of efficiently transmitting the data to the server with minimal latency. Following the experiment, it was further discovered that the recommended system functioned effectively in various environments with respect to both reduced transmission delays and effectively transmission of data. Subsequently, the system under consideration could be refined by devising novel approaches for tracking the surroundings, enhancing the overall system's precision, and contrasting the system with other schemes to demonstrate its superiority.

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NO : 3.2

Optimization of petrographic effects on coal spontaneous combustion propensity using machine learning algorithm

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Abstract:

Coal spontaneous combustion is a major safety and environmental concern in the coal industry. This study explores how different combinations of petrographic properties of coal influence its self-heating tendency, with the aim of optimizing the combined effects using predictive models for spontaneous combustion risk. The complex interplay between multiple petrographic properties and their collective influence on this risk remains poorly understood. To address this, we employed a machine learning approach using a multilayer perceptron (MLP) neural network model. This model was developed to capture the intricate correlations between various combinations of petrographic properties and the Crossing Point Temperature (CPT) of coal, a key indicator of self-ignition risk. The study analyzed 54 coal samples, examining different combinations of vitrinite, liptinite, inertinite, and mineral matter percentages in relation to CPT. Our results revealed that the optimal combination for predicting CPT included inertinite, liptinite, and mineral matter percentages, suggesting these components play a crucial role in coal's self-heating behavior. The addition of vitrinite to the predictive models produced unexpected effects, highlighting the complex nature of these relationships. This research provides a foundation for optimizing assessments of spontaneous combustion risk in coal mining and storage operations. It also emphasizes the need for further investigation into how these petrographic properties influence coal's tendency to self-heat, potentially leading to improved safety measures in the coal industry.

***Keywords*:** Self-Ignition Tendency, Spontaneous Combustion Susceptibility, Petrographic Analysis, Multilayer Perceptron, Machine Learning

Introduction

In the coal mining industry, spontaneous combustion poses severe safety hazards and economic consequences. The intrinsic properties of coal, such as petrographic composition, maceral content, and mineral matter, significantly influence the likelihood of spontaneous combustion occurrence [1]. Gaining a comprehensive understanding of the complex interplay between these intrinsic properties is crucial for accurately assessing and effectively mitigating spontaneous combustion risks in coal mining operations.

The Crossing Point Temperature (CPT) is a critical parameter in evaluating a coal's susceptibility to spontaneous combustion. It represents the temperature at which the exothermic heat release from oxidation reactions exceeds the heat dissipation rate, leading to thermal runaway and spontaneous combustion [2]. While correlation analyses can provide insights into the individual effects of petrographic properties on CPT, a Multilayer Perceptron (MLP) model is employed to comprehensively capture the combined and potentially effects of multiple petrographic properties. An MLP is a type of artificial neural network that excels at modeling complex, relationships between input variables and output targets. In this context, the MLP model is trained on a comprehensive dataset comprising various petrographic properties (e.g., vitrinite, liptinite, inertinite and mineral matter) as input features and corresponding CPT values as the target output. By analyzing the feature importance scores or rankings from the MLP model, the combination of petrographic properties that has the most significant combined effect on CPT can be identified. These properties, which may have exhibited weaker individual correlations with CPT, can collectively exert a substantial influence on the model's CPT predictions due to their interactions and combined effects.

The findings from this approach provide valuable insights into the intricate interplay of multiple petrographic properties in determining the CPT and, consequently, the spontaneous combustion susceptibility of coal. This knowledge can aid in the development of effective preventive measures, such as selective mining, blending, or pretreatment strategies, to mitigate spontaneous combustion hazards and ensure safer coal mining and handling practices [3]. The evaluation of coal's susceptibility to spontaneous combustion (SC) has been extensively investigated by numerous researchers employing various techniques and approaches. Gouws et al. (1991) evaluated the Russian U-index for assessing SC liability, while Panigrahi et al. (1997) determined the SC liability of South African coal. Uludag (2007) evaluated SC liability based on mine environment indices, and Mahadevan & Ramlu (1985) utilized Differential Scanning Calorimetry (DSC) for the same purpose. Sahu et al. (2004, 2005) employed X-ray Powder Diffraction (XPD), Differential Thermal Analysis (DTA), and DSC to evaluate SC liability [4].

Several researchers have investigated the influence of maceral composition and coal rank on SC liability. Choudhury et al. (2007) studied the effects of maceral and mean reflectance, while Chandralal et al. (2014) explored the impact of high moisture on low-rank coal stockpiles. Tognotti et al. (1988) focused on determining the ignition temperature of coal, and Küçük et al. (2003) studied the influences of gas absorption, moisture, and particle size on SC [4]. Researchers have also developed specialized techniques and equipment to study spontaneous combustion. Sensogut (2008) determined temperature variations within coal stockpiles, Zhang et al. (2011) developed a nested spontaneous combustion furnace, and Zhang et al. (2013) investigated low-temperature oxidation of coal. Taraba & Pavelek (2014) utilized pulse flow calorimetry to identify coal liable to SC, and Gürdal et al. (2015) investigated the SC liability of Can Basin coal. Statistical analyses and relationships between intrinsic properties and SC liability indices have been explored by several researchers. Nimaje & Tripathy (2016) conducted statistical analyses between intrinsic properties and XPT, while Kaymakçi & Disari (2000) investigated relationships between spontaneous combustion and coal properties. Singh & Demirbilek (1987) performed statistical analyses between intrinsic properties and SC tests, and

Sahu et al. (2009) employed Principal Component Analysis (PCA) to classify coal seams based on SC liability. Onifade & Genc (2018, 2019) studied the relationships between intrinsic factors, spontaneous combustion indices, and coal properties [4].

This body of research highlights the various approaches and techniques employed by researchers to understand and evaluate the complex phenomenon of spontaneous combustion in coal, with a focus on intrinsic properties, maceral composition, coal rank, environmental factors, and the development of specialized analytical methods. The study of macerals, the organic constituents of coal, has been a subject of extensive research in the context of understanding coal's behavior, particularly its susceptibility to spontaneous combustion. Stopes (1935) and Spackman were among the early pioneers who defined macerals as organic substances with distinct properties in coal, sedimentary, metamorphic, and igneous materials. Early coal petrologists pioneered the use of transmitted and reflected light microscopy to identify and examine different maceral types, such as vitrinite, liptinite, and inertinite. Geologists established that the vitrinite content in coal helps determine its susceptibility to spontaneous combustion. Morris and Atkinson's work revealed that fusain (inertinite) is the least reactive maceral, while liptinite (exinite) is more reactive than vitrinite. Didari found that structured inertinite has higher porosity, potentially allowing air passage and increasing the risk of combustion [3].

Several researchers, including Chandra and Prasad, Karmakar, Tarafdar, Misra, and Singh, concluded that the content of vitrinite and liptinite influences coal's susceptibility to spontaneous combustion, with higher coal rank (degree of coalification) reducing the risk. Kruszewska, Labuschagne, and Cann established that higher vitrinite content leads to faster oxidation, but higher coal rank reduces the oxidation rate [3]. The Multilayer Perceptron (MLP) is a powerful artificial neural network architecture that mimics the structure of the biological brain. It consists of multiple layers of interconnected nodes (neurons) sandwiched between the input and output layers. These hidden layers, along with adjustable connection weights between nodes, allow MLPs to model and learn complex relationships within data. Each layer processes the information received from the previous layer using nonlinear activation functions. During training, the MLP compares its predicted outputs to the true outputs and employs an algorithm called backpropagation to iteratively tune the weights, minimizing the prediction errors. This iterative weight adjustment process enhances the MLP's ability to accurately map a diverse range of input data to the desired outputs. The layered structure and nonlinear processing capabilities of MLPs make them effective at capturing intricate patterns and nonlinear interactions within data [5].

Researchers have successfully applied Multilayer Perceptron (MLP) neural networks to various environmental prediction tasks. Prybutoks utilized MLPs for ozone prediction, while Boznar et al. employed them for short-term forecasting of sulfur dioxide (SO2) levels. In the realm of severe weather prediction, Marzban & Stumpf demonstrated that MLPs outperformed other techniques in forecasting tornadoes. Although Comrie found MLPs to have comparable performance to regression models for daily ozone prediction, McCann showcased the ability of MLPs to identify precursor patterns for thunderstorms, highlighting their capability to learn complex relationships even when the underlying mechanisms are not well understood. These diverse applications underscore the versatility and effectiveness of MLP neural networks in environmental analysis and forecasting, making those valuable tools for extracting insights and patterns from intricate environmental data [6].

Current research works on the petrographic analysis overlooking the effect of individual and multiple petrographic properties. The objective of this study is to identify the optimal combination of petrographic properties that influence coal's susceptibility to self-ignition. The research expands the sample size to 54 coal specimens, encompassing a diverse range of coal types and considering four input features derived from petrographic analysis. The paper is structured as follows: the methodology outlines data collection and processing methods employed and evaluates the model's learning state by examining the learning curve. The prediction results, along with a discussion of the study's limitations and finally conclusion drawn from the study, are presented further.

Methodology

The methodology begins by defining the work system, objectives and approach. It then investigates how coal petrographic properties influence the susceptibility of coal to spontaneous combustion. Site selection ensures diverse geological, environmental, and mining conditions are represented. Subsequently, the CPT data is analyzed and correlated with the petrographic properties of coal samples, providing insights into how the combined influence of various properties affects coal susceptibility. The CPT method evaluates coal's vulnerability to spontaneous combustion by focusing on thermal behavior and oxidation characteristics. Correlation analysis associates CPT values with the coal properties, such as petrographic analysis parameters, shedding light on their contribution to susceptibility. Predictive models are developed using these properties to estimate the combined influence on spontaneous combustion susceptibility. Model validation and interpretation involve comparing predicted CPT values with experimental results from additional coal samples, helping understand how specific properties interact to influence overall susceptibility.

Spontaneous Combustion Experiment

The crossing point temperature (CPT) is used as a risk assessment index to classify susceptibility of coal to spontaneous combustion. It is defined as the temperature at which the coal sample's temperature surpasses the temperature of the vessel containing it. A lower CPT value indicates a higher tendency for the coal to undergo self-heating and spontaneous combustion. The CPT test involves several steps. First, the coal sample is ground to a particle size less than 250 µm and placed in a 750 ml flask, which is then sealed. The flask is flushed with nitrogen at a rate of 250 ml/min for one hour before being placed in a cool oven and heated to 110°C for 16 hours to dry the coal. After cooling under nitrogen to 40°C, approximately 70g of the dried coal is transferred to a spontaneous combustion vessel purged with nitrogen. The vessel is then placed in a hot storage oven at room temperature for 50 minutes before the oven temperature is raised to 40°C. The coal and oven temperatures are allowed to stabilize for 3-6 hours under a nitrogen atmosphere before initiating the CPT program. During the CPT test, air is flowed through the vessel at a rate of approximately 80 ml/min, and the oven temperature is increased at a rate of 0.6°C/min. Two thermocouples are used: one embedded in the center of the coal sample to monitor its temperature, and another placed on the vessel to monitor its temperature. The test continues until either the coal temperature exceeds the vessel temperature or reaches 200°C. The CPT is recorded as the temperature at which the coal temperature surpasses the vessel temperature. The CPT method is a modern and effective technique for evaluating the spontaneous combustion propensity of materials by monitoring temperature changes within the sample over time.

Petrographic Analysis

Petrographic analysis of coal is a fundamental technique for characterizing its microscopic constituents, providing crucial insights into its composition and potential behavior. The process involves meticulous sample preparation followed by detailed microscopic examination and quantification. Sample preparation begins with drying the coal to a constant mass at 110 ± 5°C, followed by cooling to room temperature. The fine aggregate portion (<4.75 mm) is reduced to 250-300 g through systematic splitting. This sample is then fractionated using a series of sieves (2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and 75 µm); with each fraction bagged separately. Microscope slides are prepared by creating a 5 mm sand-free border using masking tape on 50 x 75 mm glass slides. A 1:1 mixture of epoxy resin and hardener is applied evenly to the slides, onto which sand grains are uniformly distributed. For larger fractions (≥1.18 mm), additional pressure is applied to ensure proper adhesion. After a brief setting period, excess grains are removed, and the process is repeated for each size fraction. The analytical phase utilizes a reflected light microscope with oil immersion objectives at 10x magnification. Quantitative assessment is conducted via the point-counting method, involving the systematic analysis of 500 readings from each faces of the polished block. A mechanical stage, integrated with an automatic point counter, facilitates precise point-to-point movements. At each point, the coal constituent intersecting the microscope's crosshair is identified and categorized based on its distinctive optical properties, including reflectance, morphology, and relief under oil immersion. Classifications are made into the primary maceral groups (vitrinite, liptinite, inertinite) and mineral matter.

This systematic approach yields quantitative data on the relative abundances of macerals and mineral matter, providing a comprehensive petrographic profile for each sample. The resultant data set forms the foundation for subsequent analyses of coal quality, behavior prediction in industrial applications, and interpretations of geological origin. The standardized methodology employed throughout the preparation and analysis stages ensures the reliability and reproducibility of the petrographic data, critical for its application in both scientific research and industrial contexts. This comprehensive characterization of coal's microscopic constituents offers valuable insights into its potential behavior in various industrial processes and its geological history.

Experimental Data

The study utilized 54 coal samples collected directly from the field across different coal mines in India for petrographic analysis. The crossing point temperature (CPT), an indicator of spontaneous combustion propensity, exhibited a wide range across the samples, varying from 105.7°C to 191.7°C. The analysis shows that, vitrinite was the dominant maceral, often comprising over 70% of the composition. Inertinite was the second most prevalent maceral, followed by liptinite and mineral matter, which were generally present in lower proportions. This data highlights the diverse distribution of maceral and mineral matter content across different coal samples from various Indian coalfields, with CPT values covering a broad temperature range.

Figure 1 represents multiple data distribution graphs characterizing petrographic properties of coal samples. The first four graphs in figure 1; (a) to (d) display the distributions of vitrinite, inertinite, liptinite and mineral matter percentages respectively, which are the main groups of macerals or organic components that make up coal. The Figure 1(e) shows the distribution of CPT which is an important parameter related to the thermal behavior of coal. It is crucial to consider these petrographic properties in conjunction with other factors, such as moisture content, particle size distribution, and environmental conditions, to comprehensively assess the spontaneous combustion risk for a given coal mine or deposit. The interplay between these various factors can significantly influence the coal's susceptibility to self-heating and spontaneous combustion.

Multilayer Perceptron (MLP) neural networks are powerful machine learning models capable of capturing complex nonlinear relationships within data. In this study, the MLP model is employed to predict the Crossing Point Temperature (CPT), a crucial indicator of coal's susceptibility to spontaneous combustion, based on various petrographic properties (Figure 1). The model's working principles in this study are concisely described as follows:

1. MLPRegressor Function and MLP Algorithm

The MLPRegressor function from the scikit-learn library is used to create a Multilayer Perceptron (MLP) regression model. The MLP is a type of artificial neural network that is well-suited for solving complex, non-linear regression problems by learning the underlying patterns and relationships within the data.

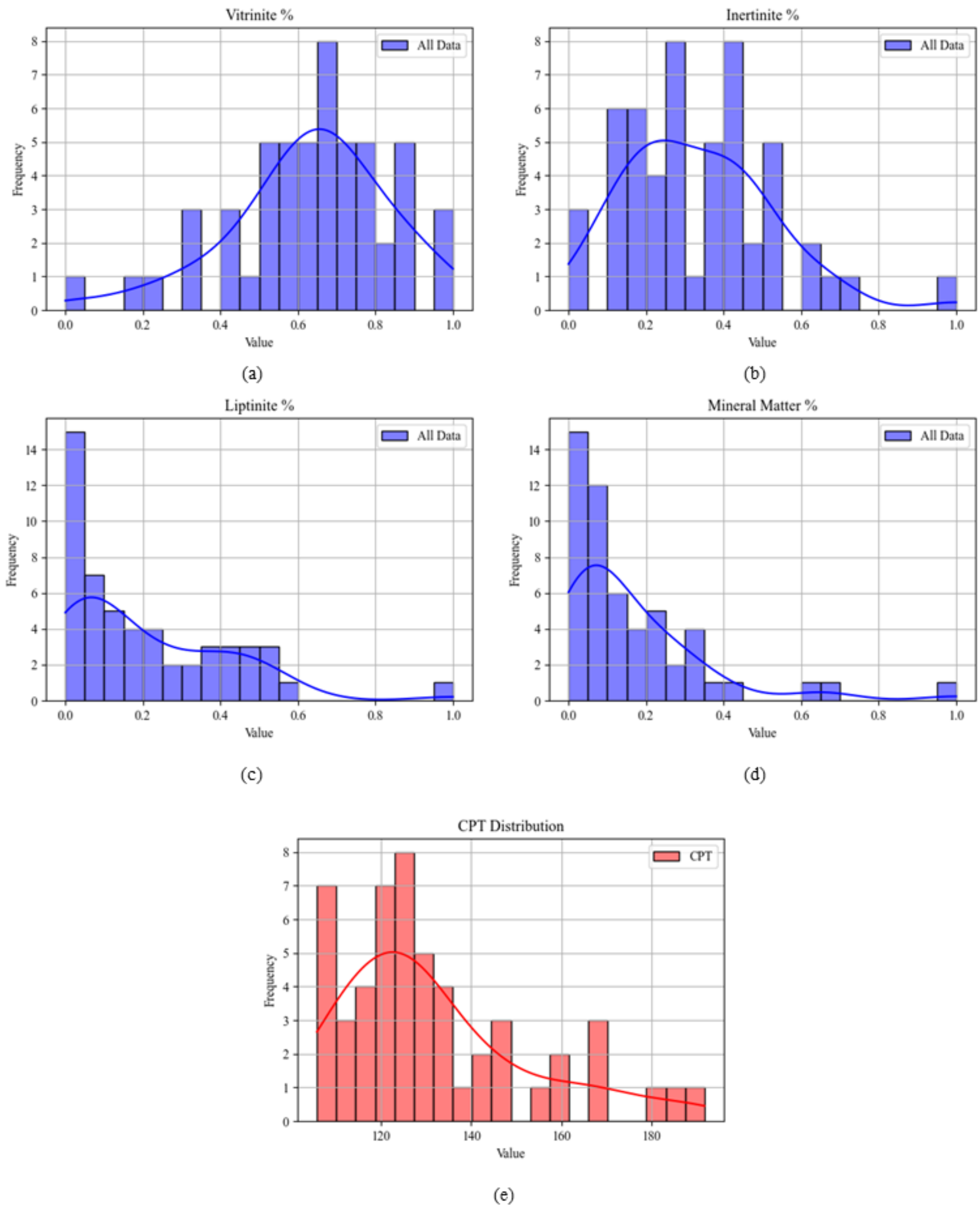

Figure 5 Distribution of four input properties along with CPT; (a) Vitrinite (b) Inertinite, (c) Liptinite, (d) Mineral Matter & (e) CPT

2. MLP Algorithm Working Principle

The MLP algorithm works by iteratively adjusting the weights and biases of the interconnected nodes (neurons) across multiple hidden layers, with the goal of minimizing the difference between the predicted and actual target values. During the training process, the input data is propagated forward through the network, and the output is compared to the true target values. The error is then back propagated through the network, and the weights and biases are updated using an optimization algorithm, such as gradient descent or its variants (e.g., Adam, L-BFGS).

3. Application in the Study

In this study, the MLPRegressor function is employed to train and evaluate the MLP regression model for predicting the Crossing Point Temperature (CPT) based on various combinations of input features (Vitrinite %, Inertinite %, Liptinite %, and Mineral Matter %). The function allows for the specification of hyperparameters, such as the number and size of hidden layers (hidden_layer_sizes), the activation function (activation), and the optimization algorithm (solver).

4. Hyperparameter Optimization

To find the optimal hyperparameter configuration, a Grid Search Cross-Validation (GridSearchCV) approach is employed. This technique exhaustively searches over a predefined grid of hyperparameter values, evaluating the model's performance using cross-validation. The best-performing model, as determined by the lowest mean squared error, is selected and further evaluated on the test set.

By leveraging the MLPRegressor function and the Grid Search Cross-Validation approach, this study aims to identify the optimal combination of input features and hyperparameters that yield the most accurate predictions of the Crossing Point Temperature. The MLP model's ability to learn complex nonlinear relationships makes it a suitable choice for this application, and the rigorous hyperparameter optimization process ensures that the model's performance is maximized.

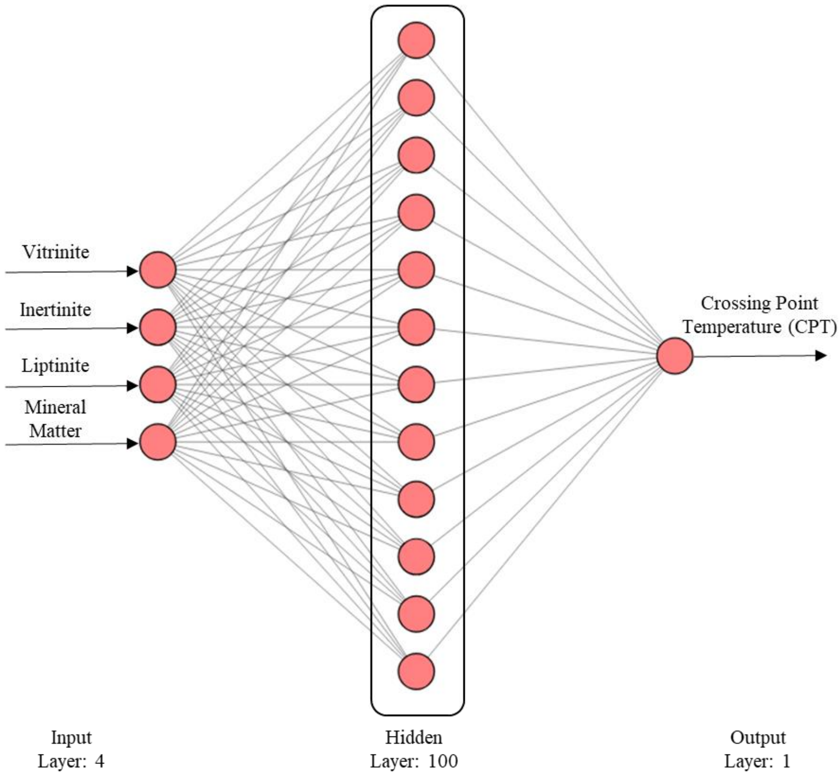

Figure 6 Prediction of CPT using Multilayer Perceptron Prediction Model based on Petrographic Properties

The illustration depicts a multilayer perceptron (MLP), an artificial neural network employed for tasks such as predicting the Crossing Point Temperature (CPT) of coal. Input data consisting of coal properties from petrographic analysis, including percentages of Vitrinite, Liptinite, Inertinite, and mineral matter, enters the network through the input layer on the left-hand side. This data then propagates through weighted connections to the hidden layer, where computational processing takes place. Labeled as "Hidden Layer 100," although it may comprise multiple layers, this segment houses neurons that analyze the information using mathematical functions. These hidden layers enable the network to discern intricate patterns within the data. Subsequently, the processed information reaches the output layer, which features a single node representing the target variable, CPT. The connections spanning all layers possess adjustable weights that are fine-tuned during the training process to minimize the discrepancies between predicted and actual CPT values. By adapting these weights, the MLP effectively captures the relationships between coal property data and CPT, rendering it a valuable tool for assessing the risk of spontaneous combustion in coal mines.

Assessment of Model Performance

The petrographic analysis of coal provides insights into its maceral composition (vitrinite, inertinite, and liptinite) and mineral matter content, which significantly influence the Crossing Point Temperature (CPT) and overall spontaneous combustion susceptibility. Vitrinite, being the most reactive maceral, tends to have a strong negative correlation with CPT, making coals with higher vitrinite content more prone to self-heating and lower CPT. Inertinite, the least reactive maceral, typically exhibits a positive correlation with CPT, as its higher content can inhibit self-heating and raise the CPT. Mineral matter components like pyrite can act as catalysts for oxidation reactions, promoting self-heating and lowering the CPT, while clays and carbonates can act as heat sinks, absorbing heat and increasing the CPT. The combined effect of maceral composition and mineral matter content on CPT is complex and non-linear, as their interactions can either offset or reinforce each other's effects on self-heating and CPT.

The table 1 presents the coefficients of determination (R^2) for various combinations of petrographic parameters in a multilayer perceptron (MLP) model designed to estimate the Crossing Point Temperature (CPT) of coal samples. The analysis explores the effectiveness of different input feature combinations, including vitrinite, inertinite, liptinite, and mineral matter percentages.

Among the two-parameter combinations, liptinite and mineral matter percentages yield the highest R^2 value (0.997714453), indicating the best performance for a two-input MLP model. This combination demonstrates excellent model fit and generalization capability for CPT estimation. For three-parameter combinations, the set of inertinite, liptinite, and mineral matter percentages shows the highest performance (R^2 = 0.980118361). This combination proves to be the overall best and maximum performing feature set among all tested combinations, suggesting that these three parameters together provide the most effective inputs for the MLP model in estimating CPT. The four-parameter model, which includes all petrographic properties (vitrinite, inertinite, liptinite, and mineral matter percentages), unexpectedly shows the poorest performance with an R^2 value of 0.077979874. This result suggests that the inclusion of all four parameters may degrade the model's performance.

Table 1 Prediction of CPT Using MLP Model Based on the Combinations of Different Petrographic Properties

Combination of Parameters	Parameters	Coefficient of Determination (R^2)
2	Vitrinite % & Inertinite %	0.252556359
2	Vitrinite % & Liptinite %	0.152152593
2	Vitrinite % & Mineral Matter %	0.386951601
2	Inertinite % & Liptinite %	0.923402422
2	Inertinite % & Mineral Matter %	0.600478751
2	Liptinite % & Mineral Matter %	0.997714453
3	Vitrinite %, Inertinite % & Liptinite %	0.147411424
3	Vitrinite %, Inertinite % & Mineral Matter %	0.154784709
3	Vitrinite %, Liptinite % & Mineral Matter %	0.958432244
3	Inertinite %, Liptinite % & Mineral Matter %	0.980118361
4	Vitrinite %, Inertinite %, Liptinite % & Mineral Matter %	0.077979874

These findings indicate that the optimal input features for the MLP model to estimate CPT are inertinite, liptinite, and mineral matter percentages. This three-parameter combination offers the best balance of model complexity and performance.

The composition of coal, comprising organic and inorganic constituents, plays a crucial role in determining its Crossing Point Temperature (CPT), a key parameter influencing thermal behavior and combustion characteristics. This analysis evaluates the predictive power of various coal composition models in estimating CPT.

i. The combination of inertinite (%) and liptinite (%) (Figure 3; a), two organic components of coal, yields an R-squared (R^2) value of 0.9234. This strong correlation indicates that 92.34% of the variance in CPT can be explained by variations in the concentrations of these macerals. Higher levels of inertinite and liptinite tend to elevate the CPT.

ii. Incorporating mineral matter (%), which encompasses inorganic components such as clays, quartz, and carbonates, alongside inertinite (%) and liptinite (%) further enhances the correlation, with an impressive R-squared of 0.9801(Figure 3;b). This finding underscores the significant contribution of mineral matter to the thermal behavior and combustion characteristics of coal.

iii. The addition of vitrinite (%), another organic constituent, to the model results in a drastic reduction in the R-squared to 0.077, suggesting a weak correlation between vitrinite content and CPT. This unexpected observation warrants further investigation to understand the underlying factors influencing this relationship.

iv. The combination of liptinite (%) and mineral matter (%) alone exhibits an exceptionally strong correlation with CPT, with an R^2 of 0.9977(Figure 3;c). This near-perfect correlation indicates that these two components are the primary determinants of CPT, collectively accounting for approximately 99.77% of the variance in CPT values.

v. The inclusion of vitrinite (%) to the liptinite (%) and mineral matter (%) combination results in a slightly lower but still significant R-squared of 0.9584(Figure 3;d). This suggests that while vitrinite's contribution to CPT is less pronounced compared to liptinite and mineral matter, it still plays a role in influencing thermal behavior.

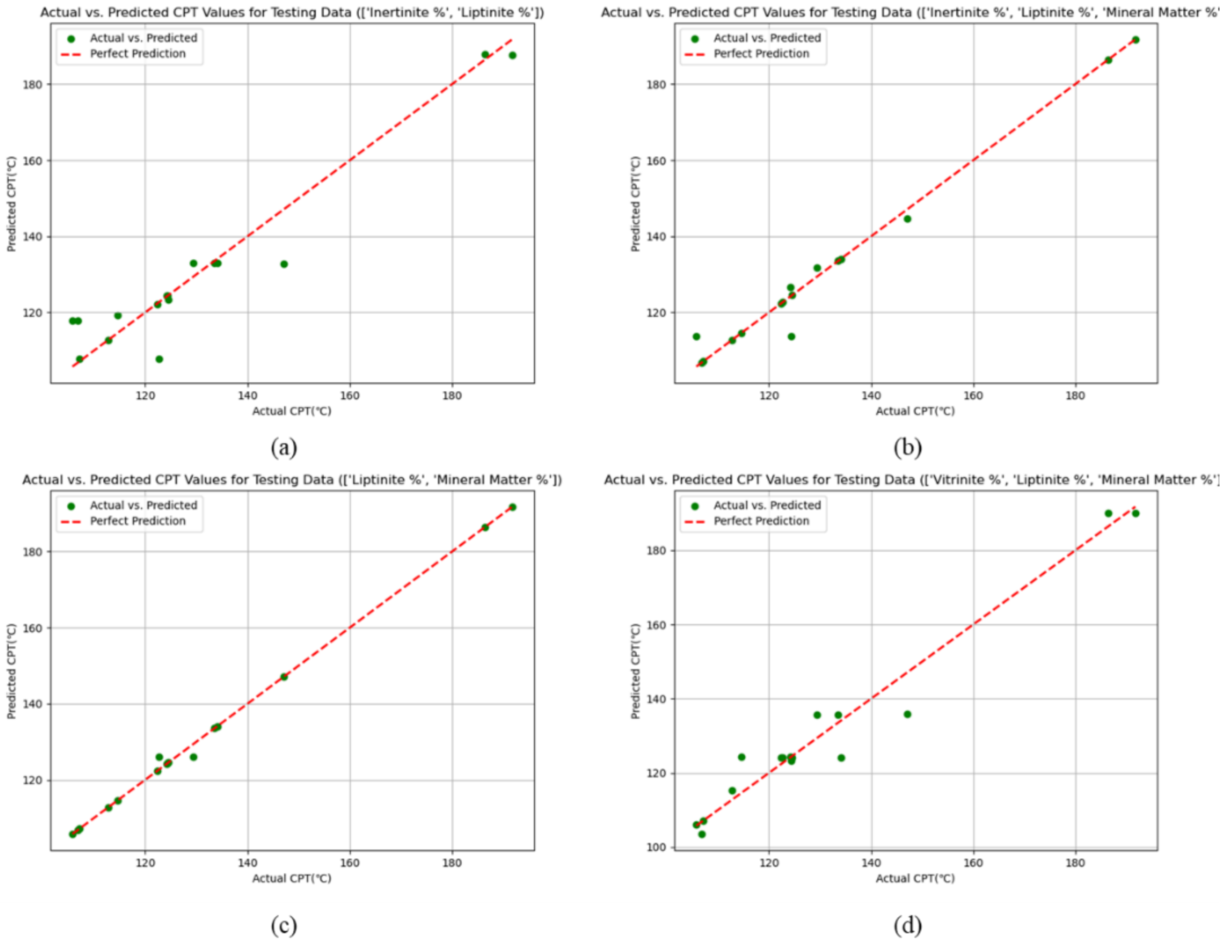

Figure 7 Combination of Multiple Petrographic properties on CPT; (a) Inertinite and Liptinite, (b) Inertinite, Liptinite and Mineral Matter, (c) Liptinite and Mineral Matter & (d) Vitrinite, Liptinite and Mineral Matter

These findings highlight the importance of considering the interplay between organic and inorganic components of coal, particularly liptinite and mineral matter, in assessing and optimizing the thermal properties and combustion behavior of coal for various industrial applications, such as power generation and metallurgical processes.

Results and Discussion

The assessment of different coal composition models in predicting the Crossing Point Temperature (CPT) has yielded significant insights into the relative contributions of various petrographic constituents. The results underscore the importance of considering the interplay between these components to accurately estimate and optimize the thermal behavior and combustion characteristics of coal. The combination of liptinite (%) and mineral matter (%) emerged as the most robust predictor of CPT, exhibiting an exceptionally strong correlation ($R^2 = 0.9977$). This finding highlights the pivotal roles played by liptinite, an organic component derived from lipid-rich plant materials, and mineral matter, comprising inorganic constituents such as clays, quartz, and carbonates, in determining the thermal properties of coal. These two parameters are common to all high-performing combinations, underscoring their fundamental importance in CPT prediction. The incorporation of inertinite (%), another organic constituent, into the model alongside liptinite (%) and mineral matter (%) further strengthened the correlation, achieving an R-squared of 0.9801. This result underscores the significant contribution of inertinite to the thermal behavior and combustion characteristics of coal. Interestingly, while the combination of only vitrinite (%) and inertinite (%) showed poor predictive capability for CPT ($R^2 = 0.2526$), their addition to models including liptinite (%) and mineral matter (%) enhanced overall performance. This observation suggests a complex interplay between these petrographic components in influencing CPT. These findings emphasize the importance of considering the collective influence of multiple organic and inorganic components in coal, particularly the effects of liptinite, mineral matter, and inertinite, for accurate CPT prediction models. The addition of vitrinite (%), a key organic maceral, to the model resulted in a drastic reduction, suggesting a weak correlation between vitrinite content and CPT. Further investigation is warranted to unravel the underlying factors contributing to this discrepancy and to better understand the relationship between vitrinite content and CPT. Despite the observed decrease in correlation when vitrinite (%) was included, the combination of vitrinite (%), liptinite (%), and mineral matter (%) still exhibited a strong correlation with CPT. This finding suggests that while vitrinite's contribution to CPT may be less pronounced compared to liptinite and mineral matter, it nonetheless plays a role in influencing the thermal behavior of coal.

These results have significant implications for optimizing coal utilization processes, such as combustion, gasification, and pyrolysis, where precise control over thermal conditions is critical for efficiency, environmental compliance, and overall performance. By considering the interplay between organic and inorganic components, particularly inertinite, liptinite and mineral matter, coal quality can be more accurately assessed, and processes can be fine-tuned to achieve desired outcomes. Furthermore, the insights gained from this analysis can inform coal blending strategies, enabling the tailoring of coal compositions to meet specific thermal requirements and mitigate potential issues associated with ash formation, slagging, and fouling during combustion processes. Overall, this study highlights the importance of comprehensive characterization of coal petrographic composition and the application of predictive models to understand and optimize the thermal behavior of coal for various industrial applications, ultimately contributing to improved energy efficiency, reduced environmental impact, and enhanced process control.

Conclusion

This study demonstrates the significant influence of coal petrographic components on Crossing Point Temperature (CPT), a critical parameter in assessing coal's propensity for spontaneous combustion. The analysis focused on identifying the optimal combination of petrographic constituents that could effectively predict CPT based on the R-squared (R^2) value, which measures the proportion of variance explained by the regression model.

The combination of inertinite, liptinite, and mineral matter emerged as the most effective predictor of CPT, utilizing the maximum number of properties that ultimately yielded the best predictive result. This combination exhibited an exceptionally strong correlation with CPT, underscoring the importance of considering multiple petrographic factors in predictive modeling. The combination of liptinite and mineral matter alone also showed remarkable predictive power, indicating their primary role in determining CPT. However, the addition of vitrinite to the predictive model resulted in a substantial decrease in correlation strength. This unexpected finding suggests a complex relationship between vitrinite content and CPT, warranting further investigation to elucidate the underlying mechanisms. The observed discrepancy challenges conventional understanding and highlights the need for a more nuanced approach to interpreting the role of vitrinite in coal's thermal behavior. It is important to note that the lack of comprehensive petrographic data from comparable fields limited our ability to fully explore the combined effects of all petrographic components. This constraint potentially hinders a more comprehensive understanding of the intricate relationships between coal composition and its thermal properties.

Future research endeavors should focus on exploring the incorporation of advanced analytical techniques, such as thermal analysis or oxidation kinetics studies, to gain deeper insights into the chemical and structural factors influencing coal's spontaneous combustion tendency and CPT. Additionally, investigating the potential of machine learning algorithms, like artificial neural networks or support vector machines, for predicting CPT could provide valuable insights and improve model performance. Furthermore, developing a comprehensive database of coal petrographic properties, CPT values, and spontaneous combustion incidents from diverse sources, encompassing a wide range of coal ranks and origins, is crucial for enhancing the model's generalizability and applicability in various coal handling and storage scenarios. Integrating the predictive model into existing coal characterization and risk assessment frameworks would enable real-time monitoring and optimization of coal handling and storage practices based on the predicted CPT and spontaneous combustion susceptibility. Conducting an in-depth study on the influence of different coal ranks and origins on the predictive model's performance is also recommended, as the relationship between petrographic properties and CPT may vary depending on the coal's rank, geological characteristics, and mining conditions.

Overall, this study highlights the potential of utilizing petrographic data, particularly the combination of inertinite, liptinite, and mineral matter, as well as the combination of inertinite, liptinite and mineral matter, to predict CPT, a critical parameter for assessing spontaneous combustion risk in coal. The findings provide a foundation for further research and development in this area, ultimately contributing to enhanced safety, efficiency, and environmental sustainability in coal handling and utilization processes.

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Application of artificial intelligence (AI), internet of things (IoT) & machine learning (ML) in mining industry for overall improvement

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Abstract:

The integration of Artificial Intelligence (AI), the Internet of Things (IoT), and Machine Learning (ML) in the mining industry is revolutionizing the sector by enhancing efficiency, safety, and sustainability. Here's a detailed overview of how these technologies are being utilized:

1. Artificial Intelligence (AI) in Mining

Predictive Maintenance:

Equipment Monitoring: AI algorithms analyze data from sensors to predict when equipment might fail, allowing for proactive maintenance and reducing downtime.

Slope Stability: AI algorithms analyze data from the sensors to predict slope movement before failure.

Under Ground Mine: Automation of underground Mines

Anomaly Detection: AI identifies patterns that deviate from the norm, indicating potential issues before they become critical.

Resource Estimation:

Geological Data Analysis: AI processes geological survey data to improve the accuracy of resource estimation, helping in more efficient mine planning.

3D Modeling: AI assists in creating detailed 3D models of mining sites for better visualization and planning.

Operational Optimization:

Process Automation: AI algorithms optimize various mining processes, such as drilling and blasting, by determining the best parameters for maximum efficiency and safety.

Supply Chain Management: AI helps in managing the supply chain by predicting demand, optimizing inventory levels, and reducing logistical costs.

2. Internet of Things (IoT) in Mining

Real-Time Monitoring:

Equipment Sensors: IoT devices installed on mining equipment provide real-time data on performance, health, and location.

Environmental Monitoring: IoT sensors track environmental conditions such as air quality, gas levels, and temperature to ensure safety and compliance with regulations.

Safety Enhancements:

Wearables: IoT-enabled wearables monitor the health and location of miners, providing alerts in case of emergencies or hazardous conditions.

Autonomous Vehicles: IoT facilitates the operation of autonomous mining vehicles, improving safety by reducing the need for human presence in dangerous areas.

Energy Management:

Energy Usage Monitoring: IoT sensors track energy consumption throughout the mining operation, identifying areas where efficiency can be improved.

Smart Grids: IoT integrates with smart grid technology to optimize energy use and reduce costs.

3. Machine Learning (ML) in Mining

Data Analysis:

Pattern Recognition: ML algorithms analyze large datasets to identify patterns and trends that can inform decision-making and improve operational efficiency.

Predictive Analytics: ML models predict future trends based on historical data, helping in strategic planning and risk management.

Exploration and Discovery:

Exploration Data Integration: ML integrates and analyzes diverse data sources, such as seismic data and satellite imagery, to identify promising exploration targets.

Mineral Identification: ML algorithms assist in identifying and classifying minerals from drill core samples and other geological data.

Process Optimization:

Drilling Optimization: ML models optimize drilling operations by analyzing data on drill bit wear, rock properties, and drilling parameters.

Ore Sorting: ML enhances ore sorting processes by classifying ore and waste materials more accurately, increasing the efficiency of mineral processing.

Combined Use of AI, IoT, and ML

Autonomous Operations:

Self-Driving Vehicles: Combining AI, IoT, and ML enables the deployment of self-driving trucks and drills that operate autonomously, reducing human risk and increasing operational efficiency.

Automated Drilling and Blasting: AI and ML algorithms analyze data from IoT devices to automate and optimize drilling and blasting operations.

Integrated Systems:

Smart Mining Platforms: Integrated platforms use AI, IoT, and ML to provide a holistic view of mining operations, enabling better decision-making and real-time adjustments.

Digital Twins: Digital twin technology creates a virtual replica of the mining site, allowing operators to simulate

and optimize processes using real-time data.

Benefits and Challenges

Benefits

Increased Efficiency: Enhanced operational efficiency through predictive maintenance, process optimization, and better resource management.

Improved Safety: Reduced risk to human workers through real-time monitoring, autonomous vehicles, and wearable technology.

Cost Savings: Lower operational costs through reduced downtime, optimized supply chain management, and efficient energy use.

Sustainability: Improved environmental monitoring and resource management lead to more sustainable mining practices.

Challenges

Data Security: Ensuring the security of sensitive data collected and transmitted by IoT devices.

Integration: Integrating new technologies with existing systems and processes can be complex and costly.

Skill Gaps: The need for skilled personnel to develop, implement, and maintain these advanced technologies.

In summary, AI, IoT, and ML are transforming the mining industry by enhancing operational efficiency, improving safety, and promoting sustainability. These technologies enable smarter decision-making and provide a competitive edge in a highly demanding industry.

1. Introduction:

The mining industry has traditionally been labor-intensive and faced significant challenges related to operational efficiency, safety, and environmental impact. With the advent of AI, the industry is witnessing a paradigm shift. AI technologies are being deployed to optimize various processes, improve decision-making, and enhance overall productivity. This paper delves into the specific applications of AI in mining, highlighting its transformative potential and the associated challenges.

The mining industry is a vital component of the global economy, providing raw materials for various industries, from construction and manufacturing to electronics and energy. However, the industry faces numerous challenges, including:

- **Safety concerns:** Mining operations are inherently risky, with a high incidence of accidents and fatalities.
- **Efficiency and productivity:** Traditional mining methods are often inefficient and time-consuming, leading to lower productivity and higher costs.
- **Resource depletion:** Finite natural resources are increasingly scarce, demanding sustainable and responsible extraction practices.
- **Environmental impact:** Mining activities can have significant negative environmental consequences, including land degradation, air and water pollution, and habitat destruction.

These challenges necessitate innovative solutions to improve safety, efficiency, and sustainability. Artificial intelligence (AI), machine learning (ML), and the Internet of Things (IoT) have emerged as powerful technologies with the potential to revolutionize the mining industry by addressing these challenges and enabling intelligent mining.

2. Artificial Intelligence (AI) in Mining:

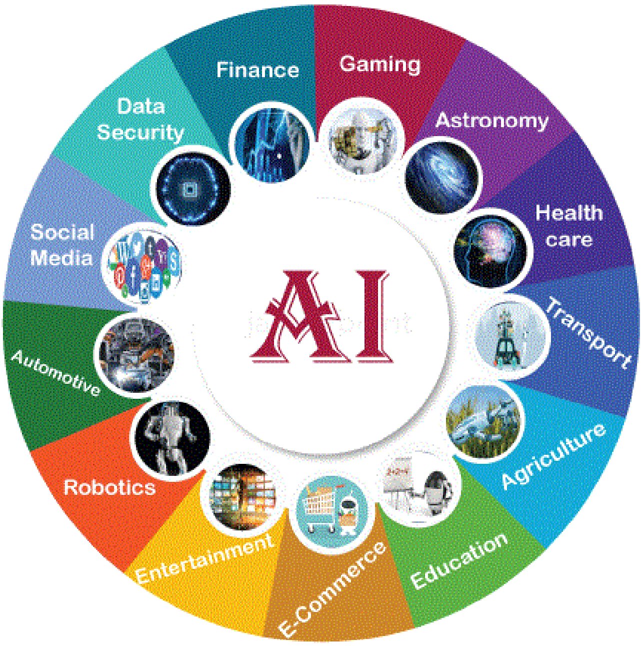
Artificial Intelligence (AI) is a branch of computer science focused on creating systems capable of performing tasks that typically require human intelligence. These tasks include problem-solving, learning, reasoning, perception, language understanding, and decision-making. AI systems can be designed to perform specific tasks (narrow AI) or to possess general intelligence similar to human cognitive abilities (general AI).

2.1.1 Key areas and techniques within AI include:

1. **Machine Learning (ML):** A subset of AI where systems learn from data to make predictions or decisions. It includes:

- Supervised Learning: Learning from labeled data.
- Unsupervised Learning: Finding patterns in unlabeled data.
- Reinforcement Learning: Learning through rewards and punishments.

2. **Natural Language Processing (NLP):** Enabling machines to understand, interpret, and generate human language.
3. **Computer Vision:** Enabling machines to interpret and make decisions based on visual inputs.
4. **Robotics:** Designing and programming robots to perform tasks.
5. **Expert Systems:** AI systems that emulate the decision-making ability of a human expert.
6. Neural Networks: Computational models inspired by the human brain, used in deep learning, a subset of ML.



sed systems can monitor real-time data from sensors and cameras to detect potential safety hazards and alert workers, reducing accidents and improving overall safety.

3. Machine Learning (ML) in Mining:

Machine learning (ML) in mining refers to the application of ML algorithms and techniques to various aspects of the mining industry. This includes optimizing operations, enhancing safety, predicting equipment failures, improving ore grade estimation, and more. By leveraging large datasets and advanced analytics, ML can significantly improve efficiency, reduce costs, and increase productivity in mining operations.

3.1.1 Here are some specific applications of ML in the mining industry:

1. **Ore Grade Estimation**: ML algorithms can analyze geological data to predict the distribution of ore grades within a mine. This helps in planning extraction processes and maximizing the value of mined ore.

2. **Predictive Maintenance**: ML models can analyze sensor data from mining equipment to predict when a machine is likely to fail or require maintenance. This helps in scheduling maintenance activities proactively, reducing downtime and repair costs.
3. **Exploration**: ML can assist in identifying potential mineral deposits by analyzing geological, geochemical, and geophysical data. This improves the accuracy and efficiency of exploration efforts.
4. **Safety Monitoring**: ML models can process data from various sensors to monitor environmental conditions, equipment status, and worker health and safety. This helps in detecting hazardous situations early and preventing accidents.
5. **Resource Estimation**: ML techniques can improve the estimation of mineral resources by integrating various data sources and creating more accurate models of ore bodies.
6. **Autonomous Operations**: ML is used in the development of autonomous mining equipment, such as haul trucks and drilling rigs. These autonomous systems can operate continuously, improve efficiency, and reduce human exposure to hazardous conditions.
7. **Operational Optimization**: ML can optimize various mining processes, such as drilling, blasting, hauling, and ore processing. By analyzing historical data, ML models can identify patterns and recommend adjustments to improve efficiency and reduce costs.
8. **Environmental Monitoring**: ML algorithms can analyze data related to environmental impact, such as water quality, air quality, and land usage. This helps in ensuring compliance with environmental regulations and minimizing the ecological footprint of mining activities.
9. **Supply Chain Optimization**: ML can optimize the supply chain by predicting demand, managing inventory, and optimizing logistics. This ensures that materials and products are available when needed, reducing costs and improving efficiency.
10. **Data Integration and Analysis**: ML can integrate and analyze diverse datasets from various sources, providing comprehensive insights into mining operations and enabling data-driven decision-making.

4. Internet of Things (IoT) in Mining:

The Internet of Things (IoT) in mining refers to the integration of connected devices, sensors, and data analytics to monitor and manage mining operations more effectively. IoT technologies enable real-time data collection and communication, providing insights that can optimize operations, enhance safety, and reduce costs. Here are some key applications of IoT in the mining industry:

1. **Remote Monitoring and Control**: IoT devices can remotely monitor and control mining equipment and processes. This includes tracking the performance and status of machinery, monitoring environmental conditions, and adjusting operations in real time.
2. **Predictive Maintenance**: Sensors installed on mining equipment can collect data on machine performance and condition. IoT systems analyze this data to predict when equipment will need maintenance, helping to prevent unexpected failures and reduce downtime.

3. **Safety and Health Monitoring**: Wearable IoT devices can monitor the health and safety of mine workers, tracking vital signs, location, and exposure to hazardous conditions. This enhances worker safety by providing early warnings and ensuring rapid response in emergencies.
4. **Asset Tracking**: IoT solutions can track the location and status of assets such as vehicles, tools, and materials within the mining site. This improves asset utilization, reduces losses, and enhances inventory management.
5. **Environmental Monitoring**: IoT sensors can continuously monitor environmental parameters such as air quality, water quality, and ground stability. This helps in ensuring compliance with environmental regulations and mitigating the impact of mining activities on the environment.
6. **Energy Management**: IoT technologies can monitor and optimize energy consumption in mining operations. This includes managing the energy usage of machinery, reducing waste, and improving the overall energy efficiency of the mine.
7. **Automation and Autonomous Vehicles**: IoT systems are integral to the development of autonomous mining equipment and vehicles. These autonomous systems can operate continuously, improve efficiency, and reduce human exposure to hazardous conditions.
8. **Data Integration and Analysis**: IoT devices generate vast amounts of data that can be integrated and analyzed to provide comprehensive insights into mining operations. This data-driven approach enables more informed decision-making and process optimization.
9. **Supply Chain Optimization**: IoT can enhance the mining supply chain by providing real-time visibility into the movement of materials and products. This helps in managing inventory levels, reducing delays, and optimizing logistics.
10. **Blasting and Drilling Optimization**: IoT sensors can provide detailed data on rock properties and drilling

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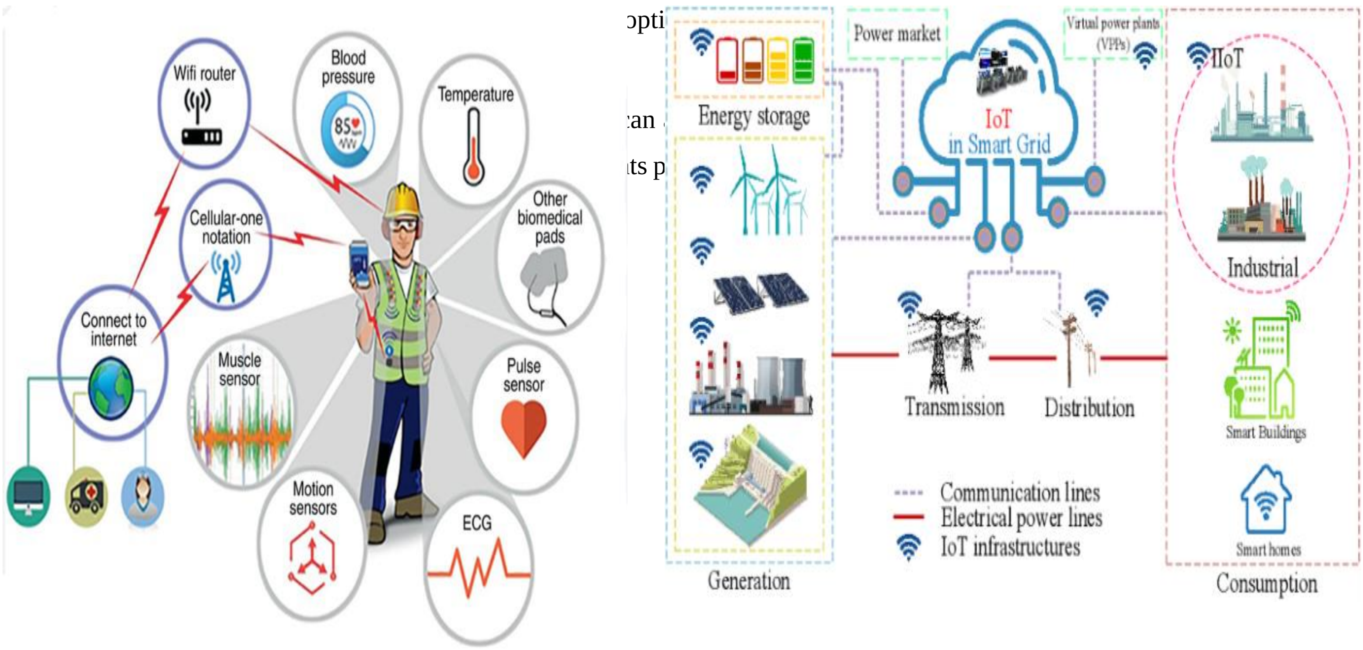

Figure Use of IoT in different field

5. Synergistic Integration of AI, ML, and IoT:

The synergistic integration of Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT) in mining can transform the industry by optimizing operations, enhancing safety, and improving sustainability. This integration leverages real-time data collection, advanced analytics, and intelligent decision-making to create more efficient and effective mining processes. Here's how AI, ML, and IoT can work together in mining:

5.1 . Data Collection and Real-Time Monitoring (IoT)

IoT devices and sensors are deployed throughout the mining site to collect data on various parameters such as equipment performance, environmental conditions, worker safety, and ore quality. This data is transmitted in real-time to central systems for processing and analysis.

Examples:

- **Environmental Sensors**: Monitor air quality, temperature, humidity, and seismic activity.
- **Equipment Sensors**: Track the operational status, vibration, temperature, and load of mining machinery.
- **Wearable Devices**: Monitor the health and safety of workers by tracking vital signs and location.

5.2. Data Processing and Initial Analysis (IoT)

Edge computing processes data locally at or near the mining site to reduce latency and enable quick responses to critical issues. This step involves filtering, aggregating, and performing preliminary analyses on the collected data before sending it to cloud-based systems for deeper analysis.

Examples:

- **Local Processing**: Detects immediate issues such as equipment overheating or abnormal vibration patterns and triggers alerts.
- **Data Aggregation**: Combines data from multiple sensors to provide a comprehensive view of specific areas or processes.

5.3. Advanced Analytics and Pattern Recognition (ML)

Machine Learning algorithms analyze the collected data to identify patterns, trends, and anomalies. These models can predict equipment failures, optimize resource extraction, and enhance operational efficiency by learning from historical data.

Examples:

- **Predictive Maintenance**: ML models predict when machinery is likely to fail based on sensor data, enabling proactive maintenance scheduling.
- **Ore Grade Prediction**: ML algorithms analyze geological data to predict ore grades and optimize extraction plans.
- **Anomaly Detection**: Identifies unusual patterns in sensor data that may indicate potential safety hazards or operational issues.

5.4. Decision-Making and Optimization (AI)

AI systems use insights derived from ML to make informed decisions and optimize mining operations. AI can automate processes, adjust operational parameters in real-time, and improve overall efficiency.

Examples:

- **Automated Drilling and Blasting**: AI optimizes drilling patterns and blast sequences based on real-time data and ML predictions.
- **Dynamic Resource Allocation**: AI adjusts the deployment of machinery and personnel based on current operational needs and predicted demands.
- **Energy Management**: AI optimizes energy usage by adjusting power distribution and machinery operation schedules.

5.5. **Feedback Loop and Continuous Improvement**

The integration creates a continuous feedback loop where IoT devices provide real-time data, ML models analyze this data to generate insights, and AI systems implement decisions based on these insights. The performance of ML models and AI systems is continuously improved using new data, enhancing their accuracy and effectiveness over time.

Applications in Mining

5.6 Predictive Maintenance

- **IoT**: Sensors monitor equipment health.
- **ML**: Analyzes data to predict failures.
- **AI**: Schedules maintenance activities and orders replacement parts in advance.

5.7 Operational Optimization

- **IoT**: Collects data on machinery performance and ore quality.
- **ML**: Optimizes drilling and blasting processes by analyzing historical and real-time data.
- **AI**: Adjusts operational parameters in real-time to maximize efficiency and minimize costs.

5.8 Safety and Health Monitoring

- **IoT**: Wearable devices and environmental sensors monitor worker health and site conditions.
- **ML**: Analyzes data to identify potential safety hazards and health risks.
- **AI**: Implements safety protocols, sends alerts, and coordinates emergency responses.

5.9 Resource Management

- **IoT**: Tracks the location and status of assets such as vehicles, tools, and materials.
- **ML**: Optimizes inventory levels and predicts material requirements.
- **AI**: Manages supply chains and logistics to ensure timely delivery of materials.

5.10 Environmental Sustainability

- **IoT**: Monitors environmental impact metrics such as emissions and water usage.
- **ML**: Analyzes data to identify ways to reduce environmental footprint.
- **AI**: Implements measures to optimize resource use and minimize waste.

5.11 Benefits of Synergistic Integration

- **Enhanced Efficiency**: Real-time data and advanced analytics optimize mining operations and reduce downtime.

- **Improved Safety**: Continuous monitoring and predictive analytics enhance worker safety and prevent accidents.
- **Cost Savings**: Predictive maintenance and operational optimization reduce costs associated with equipment failures and inefficient processes.
- **Sustainability**: Data-driven insights enable more sustainable mining practices by minimizing environmental impact and optimizing resource use.
- **Informed Decision-Making**: Real-time insights and predictive analytics enable better decision-making and strategic planning.

By combining the capabilities of AI, ML, and IoT, mining companies can achieve significant advancements in efficiency, safety, and sustainability. This integration creates a smarter, more responsive mining operation that can adapt to changing conditions and continuously improve over time.

6. Specific Applications and Case Studies:

The following sections delve into specific applications of AI, ML, and IoT in various mining operations, highlighting real-world examples and their impact:

6.1. Safety and Security:

- Real-time worker tracking and safety monitoring: Wearable sensors and cameras can monitor worker location, vital signs, and environmental conditions, alerting authorities in case of accidents or emergencies.
- Predictive risk assessment and hazard detection: AI algorithms can analyze historical data to identify potential hazards and predict accidents, allowing for proactive safety measures and risk mitigation.
- Autonomous safety systems: AI-powered robots and drones can inspect mining infrastructure, detect potential hazards, and ensure worker safety, reducing the need for manual inspection in hazardous environments.

Case Study: Rio Tinto uses AI-powered robots to inspect its mines in Australia, reducing the risk of accidents and improving worker safety.

6.2. Efficiency and Productivity:

- Autonomous mining equipment: AI-powered autonomous trucks and excavators can operate 24/7, improving productivity, reducing operating costs, and minimizing human error.
- Predictive maintenance and equipment optimization: AI and ML algorithms can analyze sensor data to predict equipment failures and optimize maintenance schedules, reducing downtime and extending equipment lifespan.
- Process optimization and automation: AI and ML can optimize various mining processes, such as crushing, grinding, and flotation, improving efficiency and reducing waste.

Case Study: BHP Billiton uses AI and ML to optimize its mining operations in Australia, increasing productivity by 10% and reducing operating costs by 5%.

6.3. Resource Management and Exploration:

- Geospatial analysis and orebody modeling: AI and ML can analyze geological data to create accurate models of mineral deposits, enabling better resource planning and exploration.

- Automated ore sorting and resource recovery: AI and ML can analyze ore composition and automatically sort it into different grades, reducing waste and improving resource recovery.
- Predictive ore grade and reserve estimation: AI and ML can predict ore grade and reserves, enabling more accurate resource planning and inventory management.

Case Study: Freeport-McMoRan uses AI and ML to optimize its copper mining operations in Indonesia, increasing resource recovery by 5% and reducing environmental impact.

6.4. Environmental Sustainability:

- Environmental monitoring and compliance: IoT sensors can monitor air and water quality, noise levels, and other environmental parameters, ensuring compliance with regulations and mitigating environmental impact.
- Predictive environmental impact assessment: AI and ML can analyze historical data to predict the environmental impact of mining activities, enabling better planning and mitigation strategies.
- Waste management and recycling optimization: AI and ML can optimize waste management and recycling processes, reducing environmental impact and promoting circular economy principles.

Case Study: Anglo American uses AI and ML to optimize its mine water management system, reducing water consumption by 20% and mitigating environmental impact.

7. Challenges and Limitations:

While AI, ML, and IoT hold immense potential for transforming the mining industry, they also face several challenges and limitations:

- Data quality and availability: The success of AI and ML relies on high-quality and readily available data. Mining operations often lack standardized data collection and management practices, hindering the development of effective AI and ML solutions.
- Cost and complexity: Implementing AI, ML, and IoT solutions can be expensive and complex, requiring significant investment in hardware, software, and expertise.
- Security and privacy concerns: Sharing sensitive data with third-party AI and ML providers raises concerns about security and privacy.
- Ethical considerations: The use of AI and ML in mining raises ethical considerations related to job displacement, bias in algorithms, and potential environmental risks.
- Integration and interoperability: Integrating AI, ML, and IoT technologies into existing mining systems can be challenging due to compatibility issues and legacy systems.

8. Future Research Directions:

Addressing the challenges and limitations of AI, ML, and IoT in mining requires ongoing research and development. Future research directions include:

- Developing more robust and reliable AI and ML algorithms: Research on advanced algorithms, including deep learning and reinforcement learning, can enhance the accuracy and reliability of AI and ML solutions.
- Improving data quality and availability: Implementing standardized data collection and management practices can ensure the availability of high-quality data for AI and ML models.

- Developing secure and privacy-preserving AI and ML frameworks: Secure and privacy-preserving AI and ML frameworks are crucial to address concerns about data security and privacy.
- Investigating the ethical implications of AI and ML in mining: Research on the ethical considerations of AI and ML in mining can ensure responsible and sustainable development of these technologies.
- Developing hybrid solutions that integrate AI, ML, and IoT: Exploring the integration of AI, ML, and IoT into hybrid systems can unlock the full potential of these technologies.

9. Conclusion:

AI, ML, and IoT are transforming the mining industry by addressing key challenges related to safety, efficiency, and sustainability. These technologies are enabling intelligent mining by automating tasks, improving decision-making, and optimizing resource management. While challenges remain in terms of data quality, cost, and ethical implications, ongoing research, and development will continue to enhance the capabilities of these technologies, leading to a safer, more sustainable, and profitable future for the mining industry.

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Applications of digitalization in Greenfield Chakla Coal Mine project of M/S. Hindalco industries limited

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Abstract:

Geographic Information system (GIS) based methods and applications are frequently implemented in mining operation for monitoring purposes as well as to take smart mining decision. A case specific study in Chakla Coal Mine, owned by M/s. Hindalco Industries Limited has been carried out towards the implementation of digitalization in green field coal mining project. ArcGIS based in-house "Land Management System" (LMS) has been developed by using the data source from land Schedule of that coal mine along with the cadastral map.The objective of this Real time Land Management project is as follows:

Color code on different types of land (Notified forest, Govt. land, Private land) for easily identification.

Detailed on different types of lands has been incorporated i.e. land type, plot number, area, number of trees etc.

All the progress on purchase of Private Land has been marked with different color code.

Stage-wise mining plan has been superimposed with the LMS-

(a) to identify specific area required for pit, dump, infrastructure and the status on those land

(b) Monitor on land acquisition progress.

For that, first the cadastral map has been imported and georeferenced to define the project which followed by land schedule data import and spatial join with each of the plot's strings.By applying Symbology, color code on different land types has been generated. In later phase, stage-wise mine plan also has been integrated with this LMS to better understand the land acquisition status and subsequently to prioritize the lands those are required to be targeted earlier.

The resultant product of this LMS is as follows where all the land types with land details can be easily viewed and analyzed.

This pilot scale in-house LMS project of greenfield coal mine comes out with a great purpose in solving prioritization of land acquisition with respect to mine planning and to take smart decision on land acquisition prospectives.

1. Introduction-

Latehar district of Jharkhand is one of the richest district abounds in mineral with large reserve of coal. Several coal blocks have been already allotted to different mining companies and also many coal blocks are under auction process. Among these, Chakla coal mine is already owned by M/s. Hindalco Industries Limited and lot of pre-operation work has been started since 2021. Among these, identification of land and digitalization of these land identification, procurement related work is one of our major focus area as we need to be ready for future smart mining (Radulescu et al., 2011). GIS has powerful capabilities for designing and optimizing mine development stages in terms of spatial data management, decision-making support, and multi-parameter consideration (Chang et al., 2010; Choi et al., 2020). As Geographic Information system (GIS) based methods and applications are frequently implemented in mining operation for monitoring purposes as well as to take smart mining decision; ArcGIS based in-house "Land Management System"

(LMS) has been developed by using the data source from land Schedule of that coal mine along with the cadastral map (Craynon et al. 2016). This helps to fix our priority based on our stage-wise mine plans.

2. Objective and methodology-

The objective of this Real time Land Management project is as follows:

- Color coding of different types of land (Notified forest, Govt. land, Private land) for easy identification.
- Details on different types of lands has been incorporated i.e. land type, plot number, area, number of trees etc.
- Different stages of Private land acquisition have been marked with different color code.
- Year-wise mining plan has been superimposed with the LMS-

(a) to identify specific area required for pit, dump, infrastructure and the status of respective land

(b) Prioritize and Monitor its land acquisition progress.

In order to do this, first the cadastral map has been imported and georeferenced to define the project which is followed by importing of land schedule data and spatial join with each of the plot's strings. By applying Symbology, color codes of different land types have been generated. Thereafter, stage-wise mine plan has also been integrated with this LMS for better understanding of the land acquisition status and to, subsequently, prioritize the plots which needs to be acquired earlier.

3. Result and observation-

The result output of doing the spatial join of data with the cadastral map is given as Fig.1. where different types of land can be easily identified with different color-codes. This helps to understand the distribution land types within the block. For example- through color coding we can clearly conclude that all the raiyat lands are mostly distributed in two patches; major raiyat land is central to northern part and a small part is in the south-western part. Thick forest cover observed in the central to south-eastern part of the coal block. Govt land (GM- Aam and Khas) is distributed in an un-even nature within the block but completely absent in the south-eastern part.

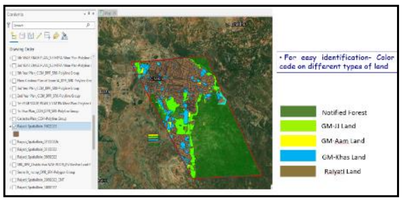

Fig 1: Color coding based on land nature within the coal mine

As the Raiyat lands are being purchased directly through CNT (Chotannagpur Terrain) Act process, we have also monitored the acquisition status of land by developing different color code. Fig 2. Can clearly identify the area from where documents received from the Raiyati Land-owner for CNT application process. Similarly, Fig. 3 is clearly showing the land has been CNT awarded, mostly is in the central part of the block. Spatial join of data also leads to display of each plot data including area, land owner, status on acquisition etc (Fig. 4).

Further, this LMS has been integrated with stage-wise mine plan (Fig. 5) which clearly shows that, initial pit and dump area are in the Raiyat land's and through GIS data analysis land acquisition status can be easily identified.

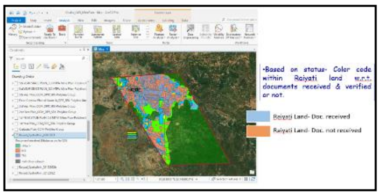

Fig 2. Showing the area from where raiyati land documents have been received for CNT application.

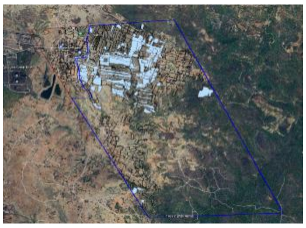

Fig 3. Showing the CNT awarded Raiyati Land with blue color within the coal mine

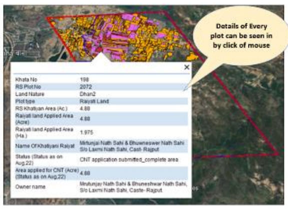

Fig. 4 Glimpses of land management system with detail of lands

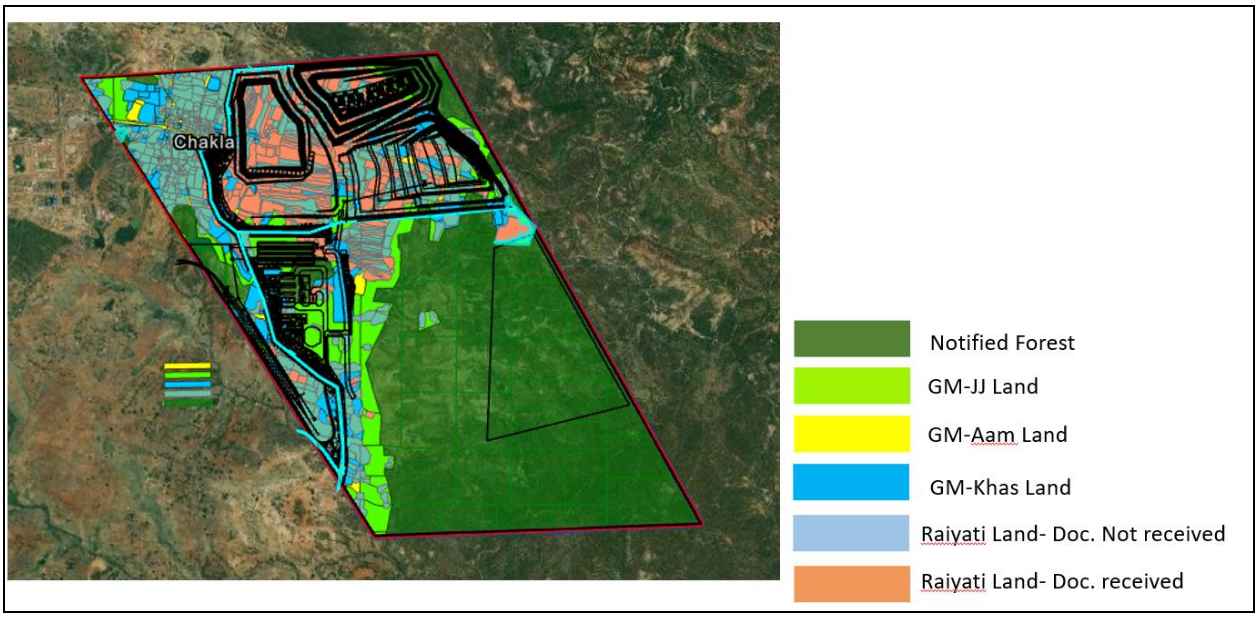

Fig 5. Integration of mine plan with Land management system

4. Discussion and conclusions-

The main objective of this study was to precisely demarcate different land types within the coal mine. The study has witnessed time to time change in land acquisition status on Raiyati lands based on several stages of acquisition. Integration of stage-wise mine plan with this land management system also helps to fix the target to prefer the land acquisition. This pilot scale in-house LMS project of greenfield coal mine comes out with a great purpose in solving prioritization of land acquisition with respect to mine planning and to take smart decision on land acquisition prospectives.

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Sustainable mining-digital interventions

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Abstract:

Mining and Agriculture are the most ancient professions of humans. Sustainable Mining of finite resources is a myth, however, learned influentials have worked out a midway to adopt best practices in mining making the process clean green, and blood-free. With rapid growth in every sphere along with the population explosion, the world is experiencing tremendous change in doing business and trade, and one of the most vulnerable is mining. Automation, Mechanisation, use of Artificial Intelligence, and the Internet of things have become a prerequisite and criteria for best practice evaluation be it in Non-Coal or Coal Mining enforced by IBM and the Ministry of Mines.

The Author has created model mining solutions and picked up a few Mining Operators working for Central & State government mines. It is only in India; that we have a model where MDO/MO must acquire all the Mining Assets from global OEMs and struggle with ever-changing technology-linked operations and maintenance of these HEMMs. To optimize and make the operation and maintenance efficient, the Author has partnered with International Automation Solutions providers to customize and localize them into day-to-day working like the use of Drones in Land Management, creating a dashboard for monitoring mining operations, implementing Asset Management Systems to improve OEE of the HEMM and be compliant to the statutory and regulatory requirements. Customizing software and coding based on the data and analytical tools have been a tedious task. This digital initiative is getting a very good response from academia, mine owners, regulators, and mining operators as the entire mining process becomes very transparent and efficient.

International Sustainable Mining efforts under SDG, ESG, and LME criteria are built into the digital mining model. however, challenges and pressing issues are bothering the initiatives (Tendering process, Bidding process, Asset Acquisition Process, technology availability, and indigenization along with Govt policies on R&R, Peripheral Development, CSR, Forest Diversions, etc are some of the issues that act as barrier to Digital Mining) it is only a few more years of wait that Digital Initiatives in Mining will be the norm for evaluating Sustainable practices.

Introduction

The Mining Industry Globally as well as in India is going through a major change, be it capacity utilization, use of technology, migration to Automation, and adoption of SDG initiatives. Under such a situation, introducing new and unknown technology to manage mining activities in the open-cast mines is a big challenge. Taking a plunge into this ever-changing landscape, the Author has valiantly planned to adopt Smart Mining and HSE compliance for OC mines using the latest Digital Technology.

This idea of migrating from conventional mining to Digital and Autonomous mining is conceived during a study cum research tour to **German Mining Museum Bochum**. Here the Author experienced the everyday life of a miner extremely realistic. Many of the machines on display are kept functional and set in motion at the push of a button; this is a must for every mining enthusiast. Also, he travelled to South Africa Gold Mines, Vietnam Coal Mines, Cambodia Gold Mines, and Several Mines in India to understand the Mining Eco-system, especially the Open Cast mines.

This awareness of mining activities led to various ideas to monitor and measure the mining work in a Digital Platform and accurately forecast the outcomes as planned in the Approved Documents by the Legal and Statutory Authorities who observe compliance.

The valiant struggle to implement Automation and Digital Solutions in mines started with various projects, but as the eco-system goes, the biggest hurdle is the initial cost of setting up a digital dashboard which is very high and the ongoing projects cannot afford the set-up cost be it may from the Lease owner or its Contractor.

This led the Author to look for Open Source Solutions and International Applications both in hardware as well as in Software, and he started to interact with various OEMs for need-based solutions for all activities involved in mining like surveying, bore-hole drilling, blasting, face cutting, transporting, value addition to the mined ores and handling the wastes, all these activities were initially mapped and documented physically using conventional methods. Studies for applicability and ease of technology use were evaluated using various solutions that are available from various OEMs and a best-fit option was selected that is affordable, easy to use, and can be relied upon on the data captured.

The Digitization work started with prospecting various opportunities that are available in the open market and a particular open cast mines work was picked up in very remote and old mine sites. Based on the site condition, a survey was made using a Drone (UAV), and the complete site study was mapped digitally. This led to forecasting a few realistic indicators like selecting the Dumpsite, Haul Road location, elevation, and other dynamics complying with the applicable Compliance Obligations. Face cutting was planned to expose the ore body in various seams and use safe benching. All these activities were planned and reviewed by drone mapping using expert advice from premier Mining Institutes, Technology suppliers, software developers, and experts in this field. The Author himself got involved in every activity.

Describing the digitization, the Author picked up key areas like compliance obligations to start the operation of the mine like the Initial Survey after allotment of the OC patch, physical site survey, setting up the campsite, sourcing and hiring the best-fit Assets (HEMM) as required for OB & Ore Extraction and headhunting. The Author used the open source information that is available on the web and started the long Journey.

The major issue in OC Mines is Land acquisition and relocating the land losers as well as job losers from previous contractors and mine operators that were engaged, every location has a unique challenge and the one under discussion had major issues being in the tribal setting. However, with the help of the client and local authorities, this was resolved to some extent and the work started with development works like haul road development, opening the face, and cleaning the land from vegetation. The initial drone mapping has been immensely helpful in estimating, selecting, and deciding the way forward based on the annualized targets.

The challenge to start the mining work is the humongous paperwork that is required at every step forward: clearance from DGMS, PESO, Labour Dept. Local Authority, Dist. Administration, Fuel Supplier, HEMM Suppliers, and Manpower Suppliers, and hence the tedious journey started.

This process made the Author understand the mining ecosystem between what is taught and what is done at the ground level. Patch drawings were digitized using high-ended software and a mine excavation plan was prepared using available bore-hole data, area allotted as per initial survey, and targeted production.

Nowadays, OEMs have also made Digital platforms accessible and made affordable with machine learning using telemetry and IoT. Selection of HEMM that best fits the project requires lots of skill and experience of similar work.

Steps taken to digitize the mining work are as follows: drilling and blasting, digging, loading and transport of waste and ore product, benching, dump slope, and haul road, all these were planned using various Automation solutions available for all activities, these are briefly explained by the Author: Use of drone is very precise and is very handy for creating a dashboard view of the entire gamut of services. However, the software used is expensive and complex requiring a very high level of skills.

Outsourced works have little margin for adopting digital solutions that are very costly at the beginning of the project, therefore Regulators and Mine Lease Owners invest in the capital cost giving the Mine Operator a complete predesigned platform to work on, the author strongly feels that if this is achieved then Mining Industry in India shall bring landmark changes in terms of compliance obligations, increased productivity and better ore quality as well as Meeting the HSE standards set by National as well as International Regulators.

Another area the mining fraternity suffers is fuel management, the Author has successfully attempted to address this issue using a German-based OEM's hardware and software enabling the mine operator to achieve the best performance with optimum fuel consumption thereby improving the health of the Asset deployed and reducing spillage, pilferage, and losses during handling of fossil fuel.

Mine operation requires constant skill up-gradation and capacity building to handle high-end Automation and Digital Solutions. The Author has tied up with premier institutions (IIT KGP & ITT BHU) as well as OEMs to provide simulator-based training as well as make the team aware of the technical details of the various automated solutions.

Insights to the following solutions adopted are as follows:

Drone Survey: Government Regulators and Monitoring Agencies like the Indian Bureau of Mines, Directorate General of Mines Safety, CMPDI, Geological Survey of India, and Central/State Authorities in Transport, Land Use, Water Use, Energy use as well as other governance matters also opted for digital communication during this Pandemic Crisis and accepted Drone Survey and its reports.

Refer: Ministry of Mines (GSR 780 (E) dt. 03.01.2021 incorporated rule 34 A in the MCDR 2017 for submission of Digital Aerial Images of Mining Lease areas to the Indian Bureau of Mines (IBM)

The advantages of Drone Surveys are to improve the overall efficiency of large mine sites and quarry management by providing accurate and comprehensive data detailing site conditions in a very short time.

The data accuracy and authenticity are better than the traditional survey.

High-resolution (cm level) data from drone surveys provides high accuracy and more precise volumetric measurements than traditional surveying methods. Stockpiles of irregular shapes and exhibiting crates can be easily surveyed with greater precision than traditional survey and calculation methods. Drone surveys are faster, with less human intervention in mines, and easily repeatable mining surveys at low cost. Changes between two surveys can be tracked and highlighted automatically. Drone aerial images can be used to generate point clouds, digital surface models, digital terrain models, and a 3D reconstruction of a mining site, including its stockpiles. Helps in creating a digital database that can be used and retrieved at ease and compared.

Data generated over some time can be stored on a digital platform and the data can be compared. The data can be used for systematic and scientific mine closure planning, monitoring of reclamation, and rehabilitation activities in lease areas. Work in the mines has significantly eased out and structured activities that are planned could be easily executed.

Digitizing Fuel Management: getting a consumer fuel point within the mines site with all approval is a very long process and once this approval is obtained fuel purchase, unloading, transfer to fuel bowser, and fuelling the HEMM and support assets is a constant challenge from the mines operation point of view, the major challenge is witnessing the unloading of fuel from the trailer truck to the fuel tank supplied by the Fuel Company, there is always a messy discussion of shortage and error. This was tackled largely by installing a digital 5-letter fuel dispensing pump along with a digitized flow meter fitted to the unloading pump. This enables the mine operator to witness unloading in-situ and accurately at a remote location in the comfort of his office/anywhere wherever he is.

Fuel being a major resource in Mining, must be judiciously used with all possible controls digitally reducing losses, pilferages, leakages as well as efficiency issues of HEMM and other utilities due to maintenance failures in mine sites.

Digitizing Operation Management: Open Cast Mines that are operated need strategic planning like:

1. **Land Management and obtaining clearance** and marking with pillars as per the initial survey, this is further planned with clear drawings and design for face cutting and removing OB as per the Borehole data submitted by the client. With the available data, a mine excavation plan is prepared using the latest software containing all necessary operating information that would be an input to the planning document for mine excavation.
2. **Site mobilization** and other facilities were planned and established. Here this can be remotely monitored using CCTV, biometrics, and simple auto-cad and Excel spreadsheet for monitoring the project progress.
3. **Mine excavation planning and execution**: this starts the mining activity, based on the initial survey and proposed production plan, the development works are started like haul road design and cutting, dump area identification and demarcation, face selection and cutting based on the benching plan, drilling and blasting plan approval based on the bore-hole data available. All these are converted into a pert chart and work begins, nowadays these are digitized, and precise operation and maintenance plans are made using PM software.
4. **Asset Selection and Deployment**: based on the annualized production target for waste and product, the HEMM and other associated equipment are selected, and the hiring cum owning process is initiated. This is an area where a high level of automation could be planned as OEMs are also keen to offer these so that the asset health is retained and higher productivity could be achieved thus reducing breakdowns and stoppages due to the non-availability of spares and consumables in remote mine locations.
5. **Transportation and evacuation of waste and product:** the particular project is planned in such a manner that the Leads for the trip are pre-decided and accordingly the route plan is prepared. Automation solutions using IoT and AI are available for this and can be customized and adopted.
6. **Survey and estimation of production:** for the OC patch, every fortnightly drone survey is done to review the progress made, and further plan correction is done for the Dump slope, Haul Road elevation, berm elevation, and curvature width meeting Statutory and safety requirements. On a monthly and quarterly the production targets are measured traditionally using Survey instruments and the findings are matched with the

Drone survey reports. This has enabled the project team to document the progressive mining excavation and production.

Since the Author and Co-Author are involved in an ongoing project where Automation is adopted progressively, therefore the learning and augmentation have ample scope to further improve upon the technology and latest solutions that could be deployed keeping the price tag and ease of use. Further competence building and Human resource development are constantly taken up with the help of premier Institutes and experienced experts.

Conclusion: To achieve Green, sustainable, and safe mining, there is no doubt that Digitization and adopting best practices can convert any conventional mining into a Smart and Sustainable Mining Project. The Journey has just begun and by the next opportunity, there will be very precise solutions as a basket could be proposed for having a Dashboard view of the mining from the comforts of our board rooms. The challenges like cost to Automate, acceptance by Regulators, and ease to employees are just a mile away. While the issues of indigenous and low-cost hardware and software along with retrofitted sensors and instruments are a concern of the pandemic, the crisis of semiconductors and other imported chips' non-availability has badly hit the speed at which Automation is applied in different projects. Large Mining Companies like CIL, NTPC, NLC, NMDC, and Private Miners provide the entire Digital ecosystem to the Mine Operator and Contractor as a ready-to-use Package.

Reference:

1. *Robert Bosch Business Solutions, 2. Reactore SA, 3. IPACS Australia, 4. IIT Kharagpur, 5. IIT BHU, 6. VIMAN (a Drone Start-up), 7. OEMs of HEMM like Caterpillar, HITACHI, Hectronics, Matrix, and PIX 4D to name a few.*

About the Author: *Subrat Panigrahi, born and brought up in the backyard of IIT Kharagpur has graduated in Electronics and Instrumentation and has a PGDBM. He worked initially with PWC as a project engineer and then took up Business Management Consulting and ran a very successful Consulting and Training Institute. He has a special interest in Mining especially in the non-coal area, where at a very young age he was exposed to his father's Stone quarry. This leads to a special interest in Mining Automation. He has visited Several Countries to enrich his knowledge and skills in mining. Today he is one of the key resources in various projects. He has delivered several National and International Talks in Mining Automation. His vision is to set up a Centre of Excellence (CoE) with expert guidance from Prof Asis Bhattacharya, former HOD, Department of Mining Engineering, IIT Kharagpur, and Prof Kailash N Sriram, Chairman & Founder IPACS Australia.*

NO : 3.6

Integrated mine management and information system implementation by Hindalco Industries Ltd.

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Abstract:

Hindalco Industries Ltd. has16 operating bauxite mines in Jharkhand and Chhattisgarh area. Thekey challenges being faced by us was as follows:

Disintegrated bauxite supply chain with little or no visibility in real or near-real time.

Adherence to the quality and quantity requirements of processing plants, multiple instances of mismatch between dispatch from mine and receipt by plant resulting in productivity loss of costly assets.

Systematic blending of ore was not being done; sampling process needed to be aligned real time with supply chain processes.

No real time tracking, monitoring of exposure/stock quantity and quality.

We were using different platforms or software in different operations. Like drone survey, mine planning in Datamine software, LMS for land management, LIMS for lab data management, RFIDetc. but all were working separately with no synchronisation in between.

Objectives

Building custom dashboards for users at different levels to monitor the operation at Hindalco Bauxite mines.

Streamlining the ore/concentrate movement from the pit to the railway siding.

Eliminating data redundancy and reduce manual interference in data collection points.

Reducing load of manual report generation by implementing report engine.

Provide form-based application for various operations with auto data transfer capabilities to centralised server on the availability of network to reduce the data redundancy.

Streamline sample collection procedure from various collection points to processing of samples at the lab. Enable users to view the status of samples from multiple transaction point and reduce the reporting time of sample lab test results.

Enhance stockpile monitoring by implementing the digitised data collection referring to different integrated systems.

Ensuring safety and efficiency of the equipment utilisation by implementing the form-based application for pre and post check of equipment. Digitalised application of safety forms extends its visibility to key persons for viewing.

Land management has been custom developed for the utilisation of the Hindalco bauxite team as and when needed to fetch land acquisition details and the current stages of new acquisition to be made available in the system for better decision-making and planning.

Methodology adopted

Hindalco Industries ltd has implemented integrated mine management and information system for the bauxite mines that addresses various operational challenges. The system provides real-time operational statuses, track material movement, and optimize processes at individual mines. The solution aims to improve efficiency and productivity in the bauxite mining process.

After implementing the solution, "Integrated Mine Management and Information System" at Hindalco's bauxite mines, operations are streamlined by utilizing the available near real-time data of the operations carried out at different transaction points of different mines in single unified system dashboard, where the data is fetched via multiple system integrations and digital forms. The blending operation based on the plant requirement has been achieved by streamlining the material quality, quantity, and transaction details from pit to railway siding. The transportation of sample material is being tracked as part of the scope to define the grade of materials at various transaction points from pit operations to rake loading and dispatch at railway siding. The sample collection form multiple locations are tracked, and the lab results are captured for reporting and reconciliation purpose. The System has reporting system that has Production Data Dashboards with KPI to Monitor the activities and track the Material. Quality Sample data of the ore is recorded at each stage of the Ore Production and Supply chain Process. The system is capable of Reconciliation at every stage of the material movement for both Quality and Quantity tracking. All the existing software in scope has been integrated with each other for single source of Information. The existing manual intervention has been drastically reduced by utilising the digital form-based applications at the necessary operational sites which helps in increasing the data transparency, reduce data redundancy, increased data accuracy, and efficiency of operation.

1. Introduction:

The development of digital technology has played a pivotal role in impacting mining industry development across world (Hui et al., 2010). Hindalco Industries Ltd. Has 16 operating bauxite mines in Jharkhand and Chhattisgarh area. The key challenges being faced was as follows: disintegrated bauxite supply chain with little or no visibility in real or near-real time, multiple instances of mismatch between dispatch from mine and receipt by plant resulting in productivity loss of costly assets, systematic blending of ore was not being done; sampling process needed to be aligned real time with supply chain processes and different platforms or software was in different operations like drone survey, mine planning in Datamine software, LMS for land management, LIMS for lab data management, RFID etcetera working separately with no synchronisation in between. Hindalco industries limited had come up with an innovative solution “Integrated mine management and Information system” by which operations has been streamlined by utilizing the available near real-time data of the operations carried out at different transaction points of different mines in single unified system dashboard, where the data is fetched via multiple system integrations and in digital forms. This paper discusses the designing objective and implementation technique (Wu, 2004) of the integrated mine management and information system.

2. Project objectives:

Hindalco has achieved a great success in meeting the project objectives, like – building custom dashboards for users at different levels to monitor the operation at Hindalco Bauxite mines, streamlining the ore/concentrate movement from the pit to the railway siding, eliminating data redundancy and reduce manual interference in data collection points, reducing load of manual report generation by implementing report engine, providing form-based application for various operations with auto data transfer capabilities to centralised server on the availability of network to reduce the data redundancy, streamlined sample collection procedure from various collection points to processing of samples at the lab, enabling users to view the status of samples from multiple transaction point and reduce the reporting time of sample lab test results, enhancing stockpile monitoring by implementing the digitised data collection referring to different integrated systems, ensuring safety and efficiency of the equipment utilisation by implementing the form-based application for pre and post check of equipment, land management has been custom developed for the utilisation of the Hindalco bauxite team as and when needed to fetch land acquisition details and the current stages of new acquisition to be made available in the system for better decision-making and planning.

3. Data flow: A series of Key performance indicators has been determined for each mine and based on that below data flow had been proposed-

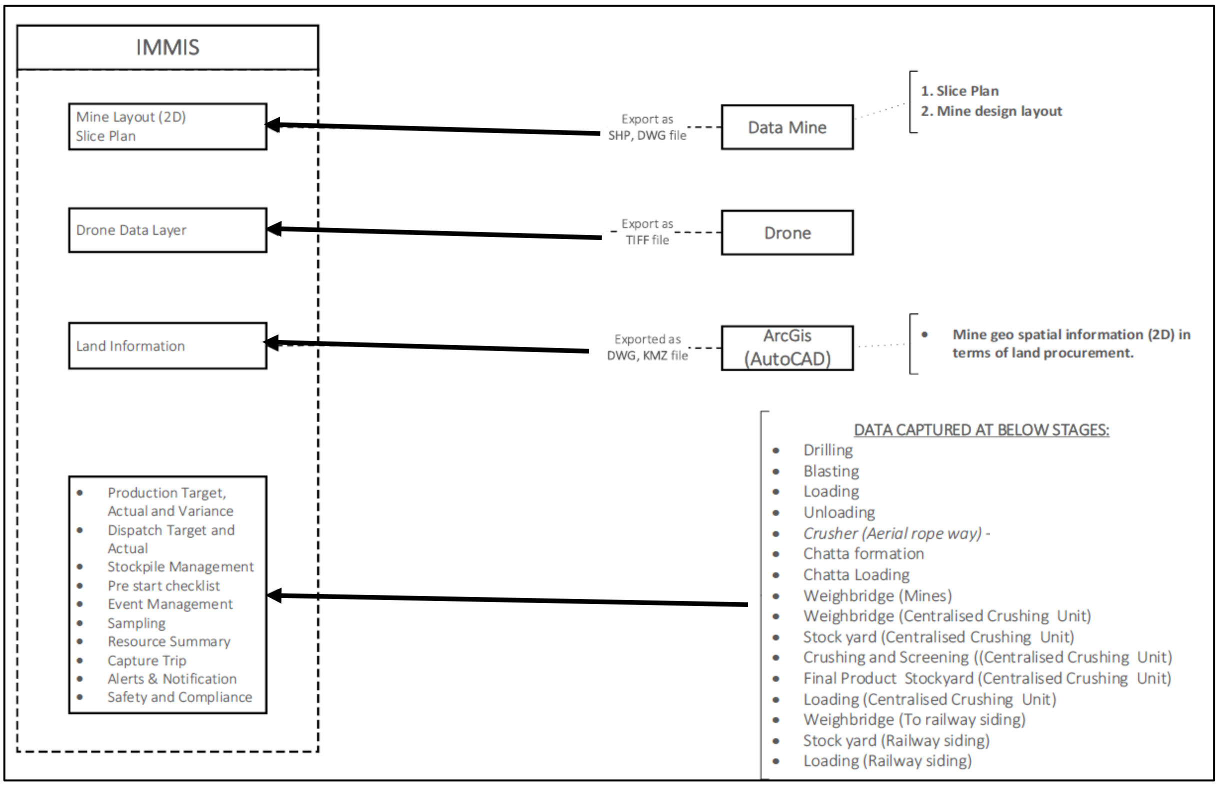


Figure 1 – IMMIS dashboard for each mine.

4. Scope of the project: The scope of the project has been resented in subsequent tables-

Table1- Scope of the Integrated mine management and information system project

Sr No	Scope	Description
1	Integrations	• Datamine Studio – Import reserve model data / Slice plan. • Drone survey and drone data processing software - Ortho mosaic file, Volumetric data to be manually captured during file import. • Land Management System (LMS) – Land Acquisition (Import .csv file and .dwg file) • Quality Lab Reports (LIMS) • Weighbridge (ILMS) • Ropeway • Ropeway weigh scale • Centralised Crushing Unit • LIMS -Laboratory information management system

2	Custom dashboard creation	Creating unified custom dashboards with required KPIs for monitoring key parameters of operations in the Bauxite mines of Hindalco. • Mine wise Production Dashboard • Land Management Dashboard • Centralised Crushing Unit Monitoring • Rail Siding Dashboard • Safety Dashboard • Cluster Wise Dashboard • Plant Dashboard
3	Web - UI	Sampling (Integration) • Stock Yard Management • Safety and Sustainability • Personnel Master Data • Asset Master Data
4	Mobile tablet	• Trip Transaction (Tablet Screen) • Sample Collection (Tablet Screen) (TBD) • Resource Allocation (Tablet Screen) • Stockyard (Chatta) creation (Tablet Screen) • Drilling and Blasting • Rail Siding Stockyard Management • Centralised Crushing Unit (Material loading into crusher and dispatch of ore)
5	Land Data Management	Import Yearly plan, Mine Plan (5-year plan), Drone data, .csv file (Land information) • Status of Land Procurement, • Procured. • to be procured. • Procurement in Progress. **Procurement Steps:** • Under discussion. • Under DC Consideration. • Awaiting payment. • Procured.
6	Mineral Resource modelling	Data Mine File imported to system. • Display of block details from Geological model (Quantity and quality). • Import of Slice plan every month.
7	Mine Development and Extraction Mapping	• Importing Orthomosaic file to system and visualisation in a dashboard • Feeding volumetric data into the system and post updating the file after the second survey with the volume, a volumetric analysis of the material excavated displayed on the dashboard.

8	Mine Operation Monitoring	Captured using a mobile tablet. **Form-Based Application** A form-based application provided to the supervisor is used to capture the drilling and blasting details offline and once the network is available the data gets pushed to the server. • Number of drill holes. • Drill hole location (pit/mine). • Blasting location, date/time • Operator details For hauling, data gets captured by the site supervisor on a form-based application and uploaded to the server on the availability of network and gets displayed on the dashboard. • Operating Pit Name (From the dropdown list of pits) • Time and Date (Auto captured). • Truck (Truck ID) carrying material OB/ORE (From drop down) • Destination of the Truck (pit/stockyard) • Truck Trip Count calculation • • Shift Status
9	Stockyard Management System	Captured using a mobile tablet. Data is captured by the site supervisor on a form-based application and uploaded to the server on the availability of the network and to be displayed on the dashboard. • Chatta UID (autogenerated). • Chatta Location - Stockyard #/Name available on the dashboard. • Chatta measurement - LxWxHxDensity= xx MT entered on to the form-based application gets captured and displayed on the dashboard. • Chatta Grade – quality details get updated by the lab supervisor and aligned to its specific Chatta UID and displayed. • Mine-wise stock at the centralized crushing unit. • The mobile device is used in capturing the number of resources loading the dispatch truck, Chatta being loaded (chatta Id from QR scanning / dropdown), Date-Time, captured by.
10	Grade Movement Monitoring System (Data Integration with LIMS)	• Sample collected from each phase (Drilling, blasting, stockpile, hauling, rail siding and Wagons) are tagged with a Unique bar/QR Code, scanned, and added basic information such as site location, date/time, receiver. • The sample during dispatch is scanned to update the status with data/time using a mobile tablet. • Material arrived at the lab is scanned to update sample status with date/time and receiver.

11	Blend Optimisation System (Reconciliation of Material Balance)	Blending modules are constructed by data integration with the systems and an inbuilt system to calculate the optimum blending pattern to achieve the desired grade of material at the plant.
12	Railway Side Monitoring System	Data is captured by the site supervisor on a form-based application and uploaded to the server on the availability of the network which is displayed on the dashboard. • Current stock. • Number of scoops Loaded into wagons by front loader (Manual entry on form-based application). • Rail siding (Auto populated), stockyard location captured by form-based application. • Loader Id (Dropdown) captured on form-based application. • Operator name (Manual notation) captured on form-based application. • Pre-check form-based application.
13	Contractor management	Data will be captured by the site supervisor on a form-based application and uploaded to the server on the availability of the network. • Number of chatta created is entered in the form-based application with UID for each chatta. • Excavator OHM & CHM reading captured by the supervisor at the • beginning and closing of the shift. • Loader OHM & CHM reading captured by the supervisor at the beginning and closing of the shift on form-based application. • Contractor employee attendance is marked on a form-based application by the supervisor and populated on the dashboard. • Number of trip counts of dumper entered manually in the form-based application is populated on the dashboard. • Volume handled by the contractor day/month-wise.
14	Reports	• Daily Summary Report • Trip-wise Report • Sampling Report • Drilling Report • Blasting Report • Stock Report • Dispatch Report • Railway Siding Stock Report • Railway Siding Dispatch Report • • Centralised Crushing Unit Stock Report

5. Project output: Below are the major modules that have been integrated to produce major KPIs on the dashboard as part of the Integrated Mine Management and Information System:

- Land Management Module
- Mineral Reserve Modelling
- Mine Development / Extraction Data Mapping
- Mine Operation Monitoring (Form based application)
- Stockyard Management
- Dispatch Operation Monitoring / Vehicle Tracking Integration
- Grade Movement Monitoring System (Reconciliation of material balance)
- Blend Optimization System
- Railway Siding Monitoring
- Contractor Management Application UI
- Safety and Sustainability Application (Form based application)
- Reports

6. Risk management and mitigation plan: The below risks, consequences and mitigation plan had been prepared and risk rating had been assigned for each identified risk.

Table 2- Risk matrix for the project

Potential Risks	Probability Rating	Impact Rating	Risk rating	Brief Description of Potential Risk Consequences and Remedial Actions
Deployment Process	3	3	9	Delay to deployment go live. To have a detailed Project Charter with manageable Project Timelines that are agreed by all Stakeholders.
Deployment Environment	3	3	9	Delay to deployment go live. To have a detailed Project Charter with manageable Project Timelines that are agreed by all Stakeholders.
Project Delays by Client	3	3	9	Delay to deployment go live. To have a detailed Project Charter with manageable Project Timelines that are agreed by all Stakeholders.
Integration System unavailable	3	5	15	Ensure delayed data synchronization support, manual input of data where required.

Scope Creep	4	5	20	Delay to deployment go live. To have a detailed Project Charter with manageable Project Timelines that are agreed by all Stakeholders.
Business Continuity	1	4	4	Project Delivery Impact and potential delays.
LEGEND	Probability: 5=Very High, 1 = Very Low Impact: 1— Minor Impact, 5 Major Impact			

7. Conclusion: The solution provides tracking of Ore or Concentrate movements from Mines to delivery of the product to processing plants. The System has reporting system that has Production Data Dashboards with KPI to Monitor the activities and track the Material. Quality Sample data of the ore is recorded at each stage of the Ore Production and Supply chain Process. The system is capable of Reconciliation at every stage of the material movement for both Quality and Quantity tracking. All the existing software in scope has been integrated with each other for single source of Information.

8. Acknowledgements: The authors would like to extend their sincere gratitude to all stakeholders who have been instrumental in the successful implementation of the "Integrated Mine Management and Information System" at Hindalco Industries Limited. Our deepest appreciation goes to the entire team at Hindalco Industries Limited and Reactore India Pvt Ltd for their relentless efforts, valuable inputs, and unwavering support throughout the project. Special thanks to Mr Kailash Pandey (Business head- Mining and Cluster Head- Sambalpur), Mr Bijesh Jha (President-Head Bauxite vertical) and Mr Mirajul Haque (Vice President- Head Technical, planning and business development) for their leadership and guidance. We are grateful to the technical and operations teams for their dedication and hard work in integrating various systems and ensuring the seamless functioning of the unified system dashboard. Additionally, we would like to acknowledge the contributions of our colleagues Mr Ashutosh Jha (Lead- Technical services & Projects), Mr Satish Kumar (Manager-Technical and planning), Mr Shantanu Karmakar (GM-IT), Sunil Pandurang Chowdhuay (AGM-IT) and collaborators who provided crucial feedback and insights, helping us to refine and improve the system. Their expertise and collaboration have been vital to the success of this project. Lastly, we express our gratitude to the Aditya Birla Group for their continuous support and for fostering an environment of innovation and excellence that made this project possible.

9. Appendices-

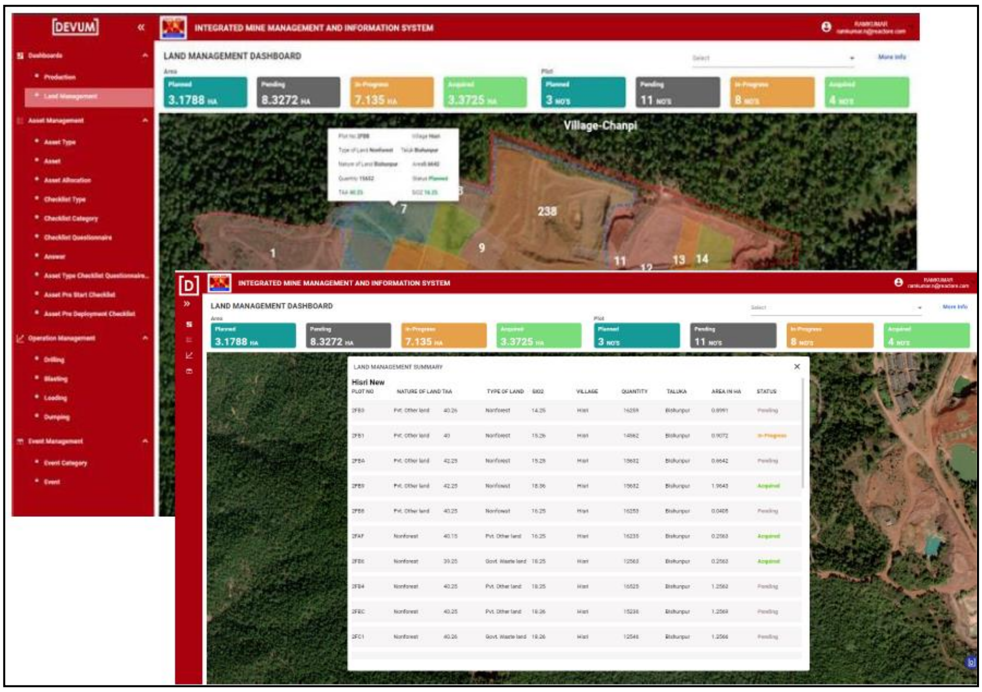


Figure 2- Land management dashboard

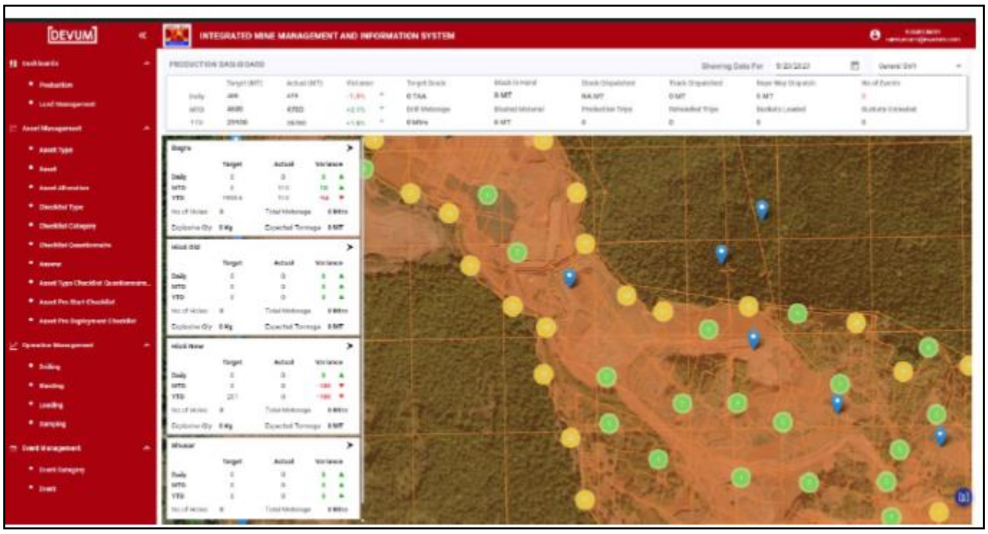


Figure 3- Production dashboard

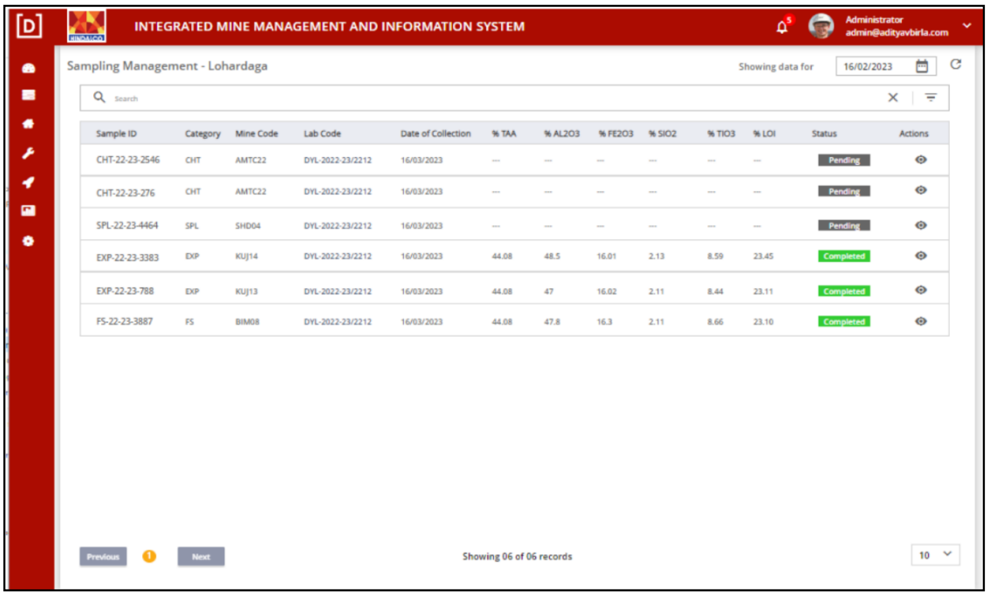


Figure 4- Sample management at Lab (Web UI)

Figure 5- Login screen of form-based application

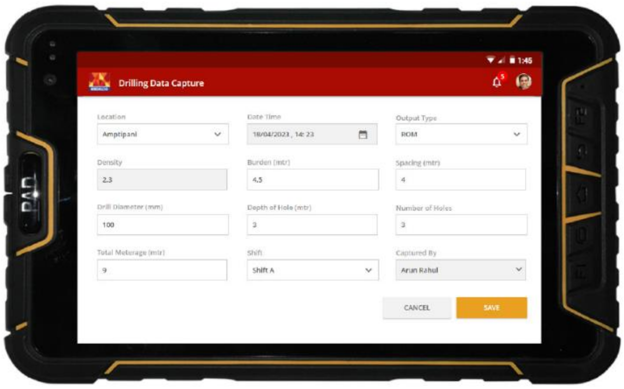
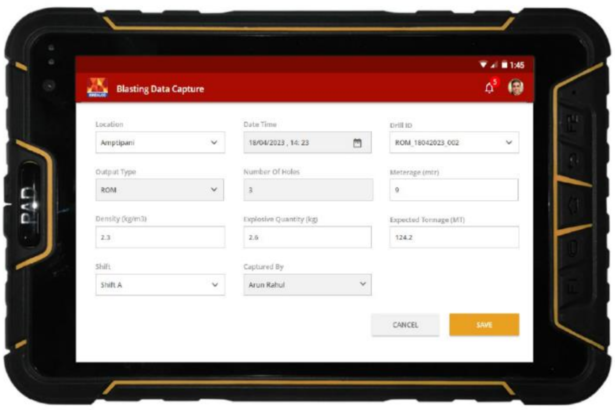


Figure 6- Capture drilling data



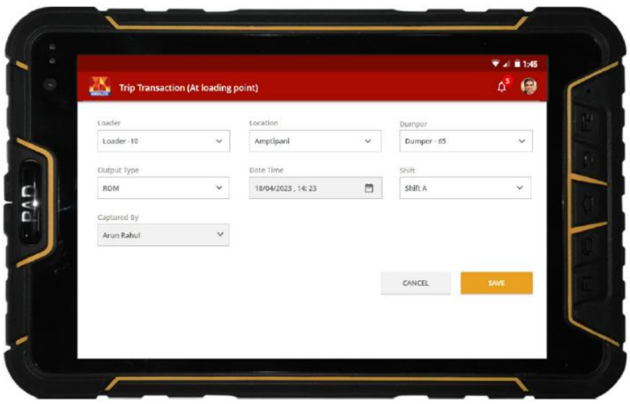


Figure 7- Capturing blasting data

Figure 8- Capturing trip transaction data

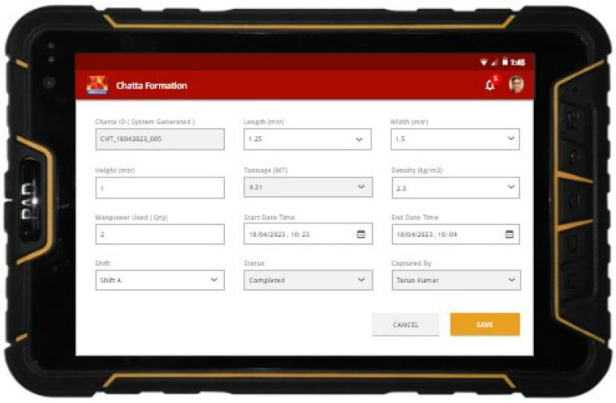


Figure 9- Chatta formation

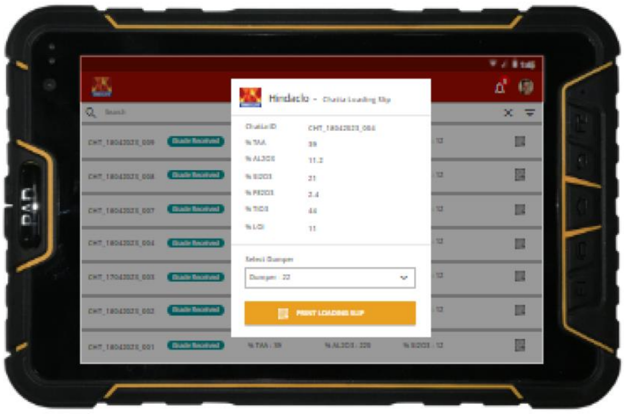


Figure 10- Chatta loading and dispatch data

10. References

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Theme 4 : Land acquisition , mine planning and resource management

NO : 4.1

Strategic depth determination for transitioning from open-pit to underground mining: A mathematical approach

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Abstract:

The transition from open-pit (OP) to underground (UG) mining presents a significant challenge in mining engineering. Mines with the potential to transition from OP to UG operations will eventually encounter a 'transition point' where a critical decision must be made: either to extend the open pit further or to commence underground mining. This study aims to determine and analyse the appropriate depth for this transition, using allowable and economically feasible overall stripping ratios as the basis. To achieve this, an economic-mathematical equation is introduced to calculate the transition depth. This equation, coupled with an analytical procedure applied to a two-dimensional hypothetical tabulate deposit, leads to the establishment of an effective formula. The model calculates the transition depth by comparing the block economic values of OP and UG mining methods and the Net Present Value (NPV) generated by each method. The NPV of OP mining is evaluated against that of UG mining at similar levels. The analysis is illustrated with a hypothetical example, based on certain assumptions, such as a discount rate of 12%.The findings suggest that the introduced formula and methodology can be applied by mining design engineers to determine the optimal transition point in various mining scenarios. This approach aids in making informed decisions about whether to extend the open pit or shift to underground mining operations, ensuring economic feasibility and maximizing resource utilization. The practical application of this model offers a structured framework for evaluating the economic and technical aspects of transitioning from OP to UG mining. The formula and procedure presented can thus serve as a standard reference in the industry, facilitating more efficient and economically sound mining practices.

Keywords: Open-pit (OP) to underground (UG) transition, NPV, Block economic value.

1. Introduction

Mining primarily employs two methods: surface mining and underground mining. Open-pit (OP) mining, a form of surface mining, is often preferred over underground (UG) mining for several reasons. OP mining typically offers higher recovery rates, greater production capacity, better mechanization, and more precise grade control. It also usually has lower cut-off grades, reduced ore loss and dilution, and is often more economically viable and safer compared to UG mining. However, UG mining is frequently favoured for its environmental and social benefits, as it generally has a smaller surface footprint than an equivalent open pit mine. One of the major challenges in the mining industry is determining the optimal point at which to transition from OP to UG mining to balance these various factors effectively. This decision is critical as it directly influences the economic feasibility and technical efficiency of mining

operations. The choice to transition from OP to UG mining involves several factors, such as the depth of the ore body, extraction costs, market conditions, and the overall stripping ratio. Identifying this transition point requires a thorough understanding of both economic and technical parameters.

The transition from open-pit (OP) to underground (UG) mining has been extensively analyzed, with researchers proposing various models and methodologies. K. Oraee et al. (2008) discussed transitions for tabulate deposits, utilizing state formulas based on allowable and overall stripping ratios. They introduced a basic model for determining transition points, highlighting the significance of stripping ratios in decision-making. Bakhtavar et al. (2009) provided an analytical approach for comparing the net present value (NPV) of OP and UG methods, crucial for assessing the economic viability of transitioning to UG mining. Bakhtavar et al. (2010) introduced the concept of allowable stripping ratios as a key determinant for deciding the transition depth, offering a practical approach to balancing extraction costs and ore value. Whittle et al. (2015) developed a model to assist in evaluating the economic feasibility of mining transitions, emphasizing the role of technological advancements in decision-making processes. N. Badakhshan et al. (2023a) conducted a study on OP to UG transitions, considering various sustainability indexes, and provided valuable insights into the practical aspects of such transitions. Xia Li et al. (2021) applied mathematical models to evaluate economic thresholds for mining transitions, demonstrating the applicability of quantitative methods in determining transition points. Afum et al. (2020) developed a mathematical programming model to optimize the decision on whether a mineral deposit should be exploited using simultaneous, non-simultaneous, sequential, or a combination of these methods. Chung et al. (2022) introduced a simultaneous optimization technique for determining the transition time from open-pit to underground mining based on production scheduling. Badakhshan et al. (2023b) examined the environmental impacts of transitioning from OP to UG mining, stressing the need to incorporate environmental sustainability into mining practices.

This study seeks to enhance existing models and methodologies by initially examining a hypothetical tabular deposit and calculating the transition depth using a mathematical formula derived from the geometry of the orebody, based on the maximum allowable stripping ratio. Following this, a 2-D combined economic block model is created, integrating supplied open pit and underground block models according to the calculated transition depth. The extraction sequences for both the OP and UG sections are then generated. Finally, the NPV is calculated based on the developed extraction sequence. The overall framework of this proposed methodology is illustrated in Figure

2. Methodology

In the initial phase of the transition, we assume a tabular deposit. The overall stripping ratio (OSR) is calculated to ensure the economic viability of mining operations. Stripping ratio (SR) in mining signifies the ratio of waste material (overburden) to the valuable ore or coal extracted in surface mining operations (Hartman, 1992). The break-even stripping ratio (BESR), calculated following Equation 1, denotes the point where the cost of excavating overburden to access ore at a certain depth equals the revenue from selling that material. As depth increases, the stripping ratio typically rises due to the

heightened excavation and handling of overburden, thereby increasing costs and potentially affecting the economic feasibility of mining. To maintain profitability, the OSR must consistently remain below the break-even stripping ratio (Taylor, 1972).

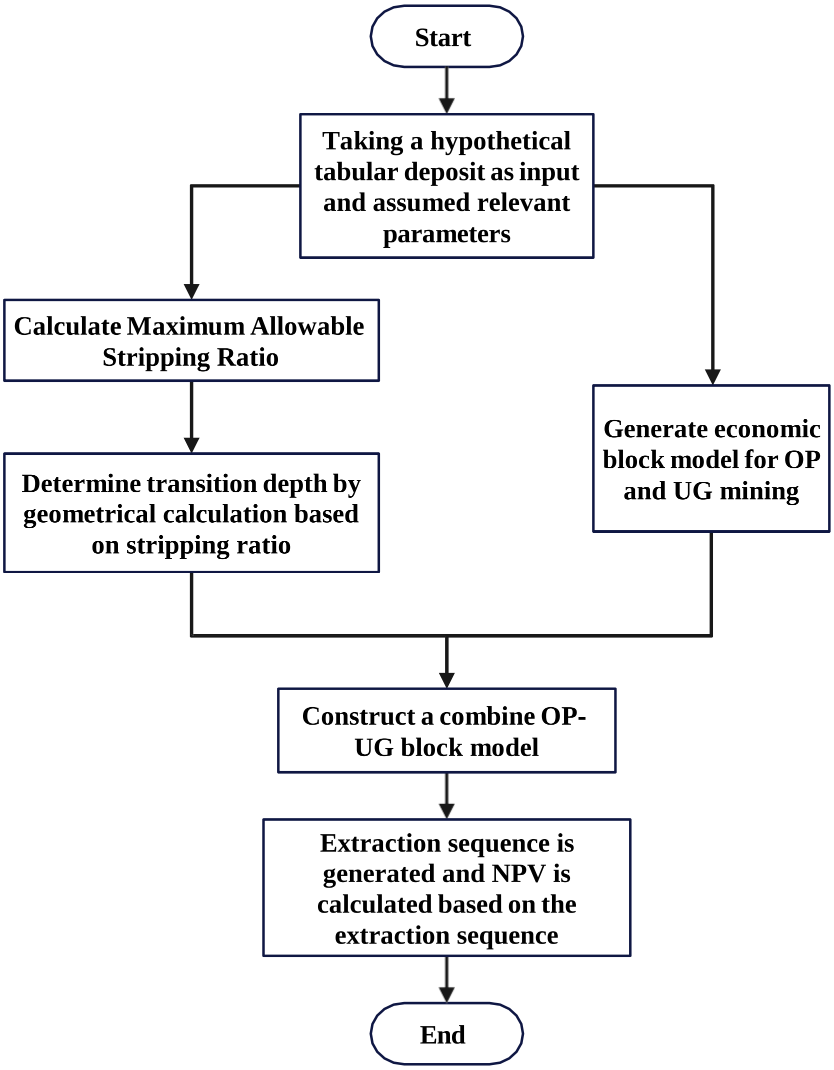

Figure 1: Flow diagram of the Methodology

The BESR can be calculated by the following formula

$$BESR = \frac{(Revenue/tonne\ of\ ore - Production\ cost/tonne\ of\ ore)}{OB\ removal\ cost/tonne\ of\ OB}$$

Equation 1

In scenarios where both open-pit (OP) and underground (UG) mining are feasible, the maximum allowable stripping ratio (MASR), equivalent to the break-even stripping ratio (BESR), can be determined using Eq 2. In this study, MASR is used to determine the transition depth (TD).

$$MASR = \frac{UG\ production\ cost/tonne\ of\ ore - OP\ production\ cost/tonne\ of\ ore}{OB\ removal\ cost/tonne\ of\ OB}$$

Equation 2

-G	-G	0	18	G	-G	-G	0	0	0	0	0	0	-G
-18	-G	0	G	18	27	G	-G	-18	-G	-G	-18	-G	-G
-18	-18	-18	-18	-G	27	18	18	-G	-G	-18	-18	-18	-18
-27	-27	-27	-18	-G	0	27	45	27	0	-18	-27	-27	-27
-36	-36	-27	-27	-G	G	G	54	18	27	-G	-27	-36	-36
-45	-45	-36	-36	-18	0	27	27	36	18	-G	-27	-36	-36
-54	-54	-36	-45	-36	-G	G	18	18	G	0	-45	-45	-45
-63	-63	-45	-54	-45	-36	-G	G	G	18	G	0	-45	-45
-72	-72	-63	-63	-54	-54	-36	-18	0	G	-G	-18	-54	-54
-81	-81	-72	-72	-72	-63	-63	-36	-36	-G	-18	-36	-63	-72

Figure 2: Economic block model for OP

-G	-G	-G	0	G	G	-G	-G	-G	-G	-G	-G	-G	-G
-G	-G	0	0	18	G	G	-G	-18	-G	-G	-G	-G	-G
-G	-G	-G	-G	-G	G	0	G	G	0	-G	-G	-G	-G
-18	-18	-18	-18	-G	G	18	0	G	-G	-18	-18	-18	-18
-18	-18	-18	-18	-G	0	-G	0	G	18	-G	-18	-18	-18
-18	-18	-18	-18	-G	0	18	0	18	G	-G	-18	-18	-18
-18	-18	-18	-18	-18	-G	0	G	G	G	-G	-18	-18	-18
-27	-27	-27	-27	-27	-27	-18	G	G	18	18	0	-27	-27
-27	-27	-27	-27	-27	-27	-27	-18	-G	G	18	-18	-27	-27
-36	-36	-36	-36	-27	-27	-27	-36	18	-G	27	-18	-27	-27

Figure 3: Economic block model for UG

A 2-dimensional hypothetical uniform tabular deposit is assumed here, outcropping at the surface and extending to a depth of 500 meters. The economic block model of the deposit for OP and UG mining is illustrated in Figures 2 and 3, respectively. Each block in the model has dimensions of 50 meters by 50 meters, providing a spatial distribution of the deposit's economic value.

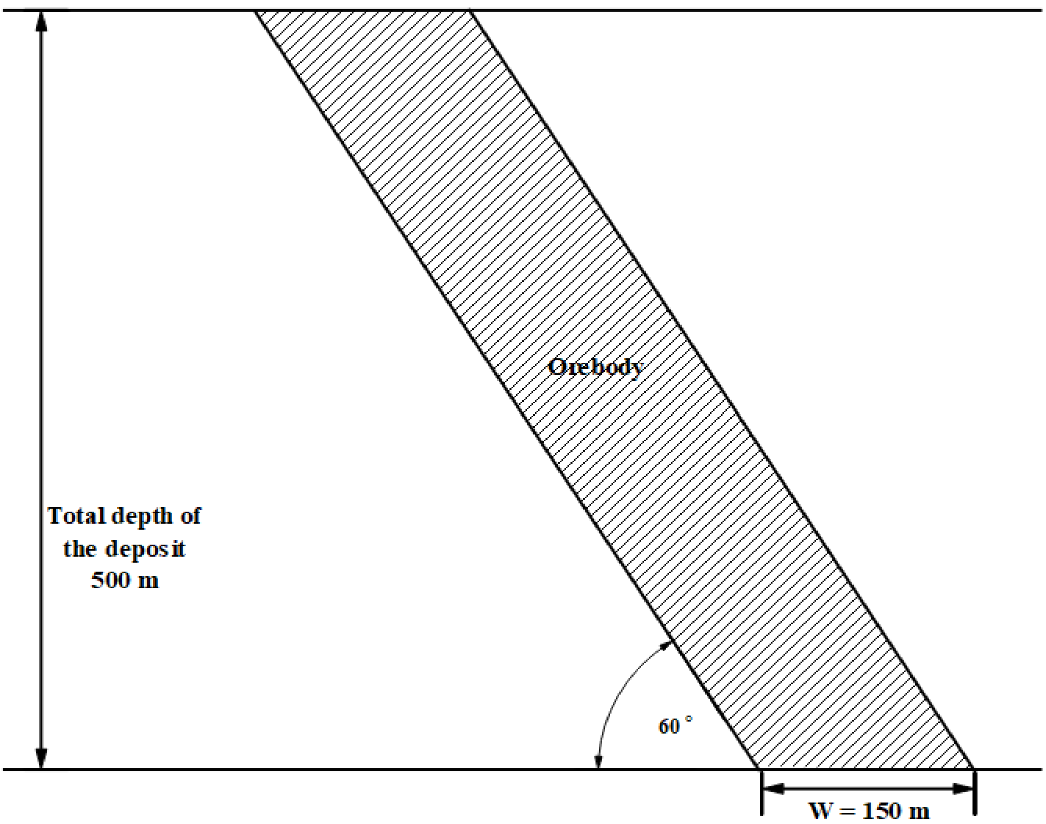

Figure 4: Geometry of the orebody

Figure 2 depicts the block model for OP mining, offering a clear visualization of economic value based on open pit mining operation. Conversely, Figure 3 presents the block model for UG mining, mapping the economic value if the deposit is extracted by underground mining method. These block models are generated based on several key parameters, such as ore price, overburden (OB) removal costs (stripping costs), production costs for both OP and UG mining, ore recovery rates via OP and UG methods, and allowable slope angles. The price of ore, ore production costs for OP mining, ore production costs for UG mining, overburden removal cost, ore recovery via OP, ore recovery via UG and allowable slope angle are considered as 2.5 Lacs INR per tonne, 1500 INR per tonne, 3500 INR per tonne, 1000 INR per cubic meter, 90%, 80% and 45 degrees respectively. The geometry of the ore body is shown in Figure 4. The deposit, considered here, is an outcropping in nature. The maximum width of the pit floor (at the deepest point of the open pit) is equal to the width of the ore body (W). The width of the orebody considered for this study is 150 m. So, at the transition depth,

$$MASR = \frac{total\ waste\ removal}{total\ ore\ production}$$

Equation 3

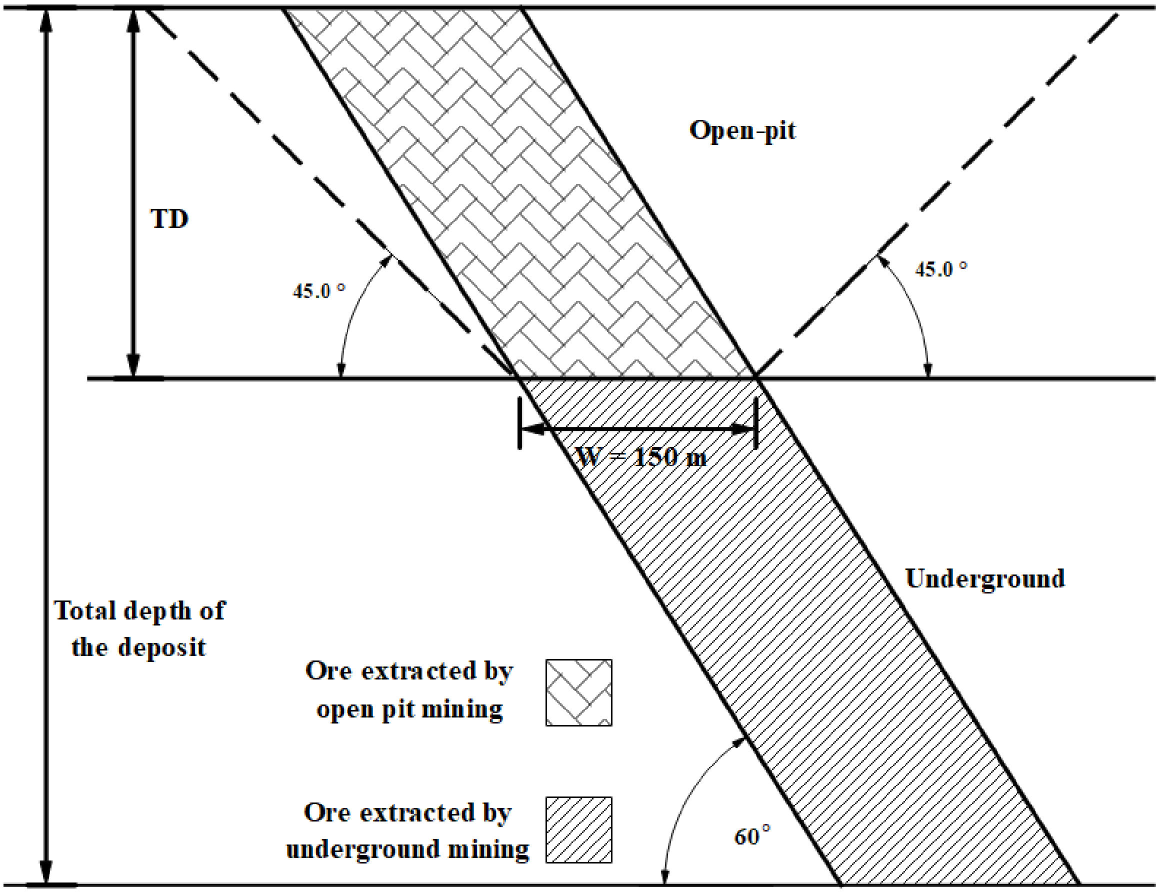

Figure 5: Open pit to Underground transition depth for the orebody

$$\frac{TD \times TD}{W \times TD} \quad — \quad = \frac{TD}{W}$$

From Equation 2 and Equation 4, we obtain the following.

$$\frac{TD}{W} = \frac{(\text{ore recovery via UG} \times UG\ production\ cost/tonne) - (\text{ore recovery via OP} \times OP\ production\ cost/tonne)}{OB\ removal\ cost/tonne\ of\ OB}$$

The following section illustrates the results of transition depth and net present value of the combined OP and UG mining.

3. Results and Discussion

We calculate the transition depth (TD) based on the parameter values given in Section 2.

$$TD = \frac{150\times(0.8\times3500-0.9\times1500)}{1000} = 217.5 \text{ meter}$$

Depending on the transition depth, the demarcation of OP and Ug is performed. Additionally, a combined economic block model is created, as shown in Figure 6. In our study, a 50-meter crown pillar is considered for safety. A crown pillar is a horizontal layer of rock left intact between the open pit (OP) and underground (UG) mines to provide stability and prevent collapse. It acts as a protective barrier, ensuring the structural integrity of the transition zone between the two mining methods.

In real scenarios, the length of the crown pillar is determined by the geotechnical assessment of the orebody and surrounding rocks.

Crown pillar

-G	-G	0	18	G	-G	-G	0	0	0	0	0	0	-G
-18	-G	0	G	18	27	G	-G	-18	-G	-G	-18	-G	-G
-18	-18	-18	-18	-G	27	18	18	-G	-G	-18	-18	-18	-18
-27	-27	-27	-18	-G	0	27	45	27	0	-18	-27	-27	-27
-18	-18	-18	-18	-G	0	18	0	18	G	-G	-18	-18	-18
-18	-18	-18	-18	-18	-G	0	G	G	G	-G	-18	-18	-18
-27	-27	-27	-27	-27	-27	-18	G	G	18	18	0	-27	-27
-27	-27	-27	-27	-27	-27	-27	-18	-G	G	18	-18	-27	-27
-36	-36	-36	-36	-27	-27	-27	-36	18	-G	27	-18	-27	-27

Figure 6: Combine Open-pit Underground block model with crown pillar

The extraction sequences of the open pit are generated using Korabov algorithm (Korabov, 1974) from the combined block model. On the other hand, the extraction layout of the underground part is solved using Floating Stope Optimizer (Alford, 1995). For optimizing the stope, the minimum stope length and height are both set at 100 meters. The combined extraction layouts are shown in Figure 7.

-G	-G	0	18	G	-G	-G	0	0	0	0	0	0	-G
-18	-G	0	G	18	27	G	-G	-18	-G	-G	-18	-G	-G

-18	-18	-18	-18	-G	27	18	18	-G	-G	-18	-18	-18	-18
-27	-27	-27	-18	-G	0	27	45	27	0	-18	-27	-27	-27
[redacted]													
-18	-18	-18	-18	-G	0	18	0	18	G	-G	-18	-18	-18
-18	-18	-18	-18	-18	-G	0	G	G	G	-G	-18	-18	-18
-27	-27	-27	-27	-27	-27	-18	G	G	18	18	0	-27	-27
-27	-27	-27	-27	-27	-27	-27	-18	-G	G	18	-18	-27	-27
-36	-36	-36	-36	-27	-27	-27	-36	18	-G	27	-18	-27	-27

Sequence 1	
Sequence 2	
Sequence 3	
Sequence 4	
Sequence 5	

Figure 7: Combine Open-pit Underground extraction layout

The profits gained from the extraction from OP and UG are given as follows.

Table 1: Year-wise and total profit from Combine Open-pit Underground mining

Mining Method	**Open pit mining**	**Underground mining**

Year	1	2	3	4	5	6	7	8	9	10
Profit (in millions of rupees)	63	45	27	27	9	45	27	54	18	36

For the open pit, yearly extraction follows the specified sequence. In the underground section, each level is extracted annually. The extraction begins with the open pit operations, followed by the extraction of the underground portion.

Now, the NPV of the extraction sequence is calculated considering 12% discount rate. The calculation of NPV is shown in Table 2.

Table 2: NPV calculations for Combine Open-pit Underground mining

Mining Method	**Open pit mining**					**Underground mining**					**Net Present Value (NPV)**
Year	1	2	3	4	5	6	7	8	9	10	
Profit (in millions of rupees)	63	45	27	27	9	45	27	54	18	36	
Present value (in millions of rupees)	56.25	35.87	19.22	17.16	5.11	22.80	12.21	21.81	6.49	11.59	208.51

The combined approach of using the stripping ratio method along with NPV analysis provides an efficient and economical transition from OP to UG mining. The stripping ratio method calculates the TD in a computationally simple way, while the NPV analysis accounts for the time value of money, ensuring that the overall transition is economically viable.

4. Conclusion

This paper proposes a viable solution for transitioning from open pit to underground mining. The study has employed a combined method using the maximum allowable stripping ratio and NPV calculations to ensure an efficient and economical transition. Various parameters have been considered, including ore price, overburden removal costs (stripping costs), production costs for both OP and UG mining, ore recovery rates via OP and UG methods, and allowable slope angles. Based on these parameters, the transition depth has been calculated using a mathematical equation. This transition depth is crucial for determining the combined NPV for OP and UG mining. The results demonstrate an efficient and economic transition with minimal computational cost. Future scope of the study could extend to other types of deposits, such as those that do not outcrop, deposits with minimum pit-bottom width, and 3- dimensional models.

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Formulation of a policy for procurement of land on lease for mines

Saptaswa Sahana[1], Amartya Pal[2], Nilanjan Dey[3] and Saroj Kanti Sahana[4]

Abstract:

The Theme:

To meet the energy demand of the nation continuous supply of coal to the power plants is to be ensured. Thecoalcompaniesareoccupyinghugequantumoflandfortheirgreenfieldorbrownfieldprojects.After extracting minerals, the discontinued and is not returned to and owners due to statutory bindings. There is a need for a suitable policy for procuring land on lease to eliminate this problem.

Objectives:

Help Coal companies formulate a policy for land procurement on lease;

Computer-simulated decision-making tools to outline the policy;

Ensure the floor limit of the compensation is not less than the statutory provisions;

Compensate the lively hood loss of the land owners ; and

Minimise the cost of land acquisition.

Input Parameters:

State-governed indices for lease settlement, market price of the land, availability of coal below ground, livelihood compensation mandate in the acquisition Acts, annuity increment rate etc.

The Process:

Theinputparameterswouldbeprocessedthroughcomputeralgorithmsandprogramstoproducethe desired output tables.

Output:

Policy out line stables like lease tenure, up front payment, annuity tables for land owners, cost-benefit analyses for the mine, etc.

Keywords: Lease; Land; Land owner; Up front-Payment; Annuity

A. Introduction – Need for an Alternative Model for Procurement of Land for Mining:

Government Companies generally procure land mostly through sale deeds by direct negotiation with Landowners and acquisition of land under the Coal Bearing Areas (Acquisition & Development) Act, 1957 (CBA (A&D) Act 1957) or Right to Fair Compensation and Transparency in Land Acquisition Rehabilitation and Resettlement (RFCTLARR) Act 2013. However, present land procurement patterns are characterized by the following attributes –

- Ownership/ title of the land is transferred to the company permanently.
- The landowner has no right over the land after handing over the title and possession.
- The company has to pay Land revenue and all other admissible taxes, rents etc. continuously and perpetually.
- The company cannot transfer/ sell/ lease or alienate the land without permission of the Central/State Government as per existing circulars.
- The company cannot return the land to the original landowner in future under any condition.
- The company has to provide R&R benefits including employment in addition to the land value which is quite high particularly in case of land acquisition under the CBA (A&D) Act after the cut-off date i.e. 1st September 2015

The Government Companies require land only for the mining operation and other project activities of a particular mine and there is practically no need to hold the procured land after their completion. Given the above, there is a need for an alternative land procurement model for the Government Companies that will eliminate the problems and difficulties as described above. But what are the desirable qualities of the alternative model?

B. Desirable Attributes of the Alternative Land Procurement Model for Mining

- Transfer of land should be non-permanent;
- It should be coherent with the policies of the State Government;
- Legal title of the land should remain with the landowner;
- It should suit the character of land and landowners of the locality;
- It should be able to meet the expectations of the landowners;
- It should be able to improve the business opportunity of the Company;
- It should promote trust and the image of the company in society

To formulate a suitable model for the aforesaid purpose, some decision points have been identified and it has been tried to draw conclusions based on logical selection from available alternatives. Computer-aided tools have been used in several places for this purpose.

C. Decision Point 1: What Type of Land Transfer?

From the available options it is found that a suitable lease or Rent Policy of the organization, which will be acceptable to the landowners, can be a good solution of the above riddle. From the two alternatives, it is found that, renting a land to an organization is far less attractive to landowner and the company because renting is characterized by –

i. Short term lending;
ii. No/ minimum upfront payment and only annual or monthly rent is received;
iii. Less opportunity of recovering true value of the land;
iv. When the land is degraded by mining operation there is less scope of getting the land back with restored fertility level
v. Landlord has the authority to change terms and conditions providing short notice which may pose uncertainty of land availability over the planned period of project operation.

Decision:

Hence, it appears a proper lease model may only be treated as a good alternative to permanent land-procurement practices which are in vogue now. However, to identify the basic attributes of an acceptable land procurement model we have to understand the private tenancy land ('Raiyat Land') and appetite of its owners at first.

D. Private Land- Attachment and Appetite of Landowners (In Return of Their Land)

Private tenancy lands are the lands recorded in favour of private entities in the revenue records of the State Government. Psychological involvement and expectations of owners of the land are characterized by the following factors:

1. Lands have been either inherited from ancestors through generations or have been obtained by investing a substantial share of hard-earned income.
2. Lands are viewed as assets that will never depreciate.
3. Lands are capable of supplying livelihood to the generations to come.
4. Lands can be easily sold or mortgaged to pull out the owner from distress or sudden financial need.
5. Landowner expects a guaranteed return which will not be dependent on market volatility or business decisions of a company.
6. Keeping in view the fact that, the value of land appreciates faster than any other asset or liquid money, the Landowner wants a suitable return which should be higher than the gain obtainable through opportunity of normal investment in the market.
7. There is emotional attachment also for the land which has been inherited through generations. Alienation of such land generally gives the owner a psychological shock. Only a provocation of a hefty return can relieve such psychological pain.

E. Decision Point 2: Returning Land After Expiry of Lease

Returning land to the landowner is an important aspect in the case of a lease. Unlike other normal cases, where land is generally taken on lease and developed for different purposes, Government Companies will take the land for excavation that will eventually degrade the land. So, the Landowner will not take the land back into his possession unless it is properly recycled to restore the shape and productivity level up to a certain degree close to the pre-mining condition. So, merely filling the voids and doing physical reclamation, which the companies are doing at present, probably will not suffice in the case of a lease of land. For the restoration of land, which is basically an *environmental remediation* process, the following broad tasks are to be carried out.

Pre-mining Stage:

- Geomorphological, hydro-geological and other scientific studies to ascertain thickness, character and chemical composition as well as water permeability/ retention characteristics of the bedrock and top cover.

Mining Stage:

- Specific plan and technique to be adopted to excavate and preserve the top cover (soil) separately.

Post-mining Stage:

- Filling the voids with landfills and cover the same with topsoil. Do necessary dozing operation for compaction of filled layers. The degree of compaction should be determined in consultation with experts in the field of environment and agriculture because many experts prefer a lower degree of compaction for subsequent farming.
- Ensure proper gradient to match the terrain of nearby areas for natural drainage for run-off water. This is needed to stop the accumulation of water in the filled area that may be contaminated mixing with filling material and ultimately discharging to rivers/ ponds etc. causing water pollution.
- Biological reclamation- to reinstate the ecosystem of the area by (a) selective plantation and (b) leaving the area undisturbed and hydrated for some period for self-colonization of flora and fauna.
- Alternatively, for restoration of fertility and production level of the land, pilot farming of vegetation for a few years may be carried out. Landowners may be involved in this process or this can be done by deploying a third-party farming organization.

Decision:

Restoration of land productivity before returning it to the landowner after the lease period is needed. If the filling and reclamation operation takes 2-3 years and post-reclamation farming is done for at least 5 to 7 years the total time required after completion of mining operation is 8 to 10 years or more. Land can be returned ensuring chemical composition and consistency level of the top layer and productivity level of the land on a par with the pre-mining stage or close to the same.

F. Decision Point 3: Tenure Of Lease:

Land can be obtained under

(a) Short term lease (8 to 15 years);

(b) Mid-term lease (more than 15 and less than 30 years) or

(c) Long-term lease (30 years or more).

In the computer simulation, lease tenure is automatically determined by adding 7 years of reclamation and restoration period to the project life. The minimum and maximum value of the lease tenure has been set as 8 years and 30 years because for less than 8 years, the lease contract gets all the poor attributes of land rent and loses its lustre and for a period over 30 years, total investment of the company becomes so high that the permanent acquisition of land becomes more beneficial.

G. Decision Point 4: Selection of Lease Model for Payout

Government Companies have no specific in-house lease policy and guidelines for determining components of the payments to the landowner. However, the States, where the mines are situated, have their own lease policies. We may formulate a lease policy for the Government Companies in coherence with the State policies which will not only provide a justified and acceptable basis for the model but will also do away with the possibility of future legal conflict regarding inappropriate payment or exploitation of common people. Generally, the Government settles lease agreements for thirty years. However, some States collect the total payable amount at the time of execution of the lease whereas others bifurcate the total amount in two parts. One is the lease premium which is an initial upfront payment and another one is the Annual Lease rent which is paid annually.

Decision:

The bifurcated payment type is preferable because –

1. The company has to incur a small initial capital investment as an upfront payment
2. Total Lease rent is paid over a long period which provides financial advantage to the project.
3. Payment of guaranteed annuity stabilises the financial condition of the landowner for a certain duration.

H. Basis of the Assumptions and Criteria Used in Calculations

The capitalized value of the returned land: The company is going to use the land for mining purposes. So, the value of land is going to appreciate as happens in the case of land developed for commercial/ infrastructural projects. True value can be obtained only by valuation done by registered valuer after the restoration process and the same will depend on actual quality and efficacy of the restoration. However, for the sake of calculation, the value of the degraded land returned to the landowner is anticipated as half of the market price.

I. Decision Point 5: Selection Of Payment- Rates and Frequency

Every State's policy defines processes and calculation patterns for determination of the total compensation amount payable to the landowner. The computer simulation prompts the user to input the name of the States where the company is situated. Names of more than one State can be entered separated by commas. The computer database will preserve the model calculations applicable in the case of lease settlement for particular States. Total compensation amounts for the selected States would be calculated separately by the computer. The highest compensation amount among the selected States would be chosen. Upfront payment amount would be equal to 40% of the total compensation and the rest 60% would be paid as an annuity over the lease tenure in place of the land price. It should be kept in mind that the minimum amount of annuity as per the second schedule of the RFCTLARR Act 2013 is ₹ 2000 per month irrespective of the holding of land. This has been taken care of by adding a matching premium to the annuity. This has been discussed in the next para.

The simulation has been tested with the data available for West Bengal and Jharkhand.

1. **Jharkhand:** As per Sankalp 48/Ra dated 04-12-2018 of Jharkhand Government. Salami=Market price, Lagan=1% of Salami, Cess=75% of Lagan.
2. **West Bengal**: As per WBLR Manual for settlement of Government land on lease: Lease Premium = 40% and Annual Rent = 4% of Market price.

If the land value is assumed as12 Lakh per acre and the lease tenure is 20 years, the matrix for the two States would be –

Jharkhand:

Salami	Lagan	Cess	Lagan + Cess	Lease Tenure (Yr)	Total Lagan & Cess	Total Amount	Remark
1200000	**12000**	**9000**	**21000**	**20**	**420000**	**1620000**	**Variant-1**

West Bengal

Initial Lease Premium:		Annual Lease Rent		Total Lease Rent	Lease Tenure (Yr)	Total Amount	Remark
Rate (% of Market Value)	Amount	Rate (% of Market Value)	Amount				
40%	480000	**4.75%**	57000	1140000	20	1620000	**Variant-1**

Finding: When the annuity is set @ 4.75% of the market price, total compensation in lieu of land becomes equal for both the selected States. The amount upfront payment and annuity at the rate are- ₹ 480000.00 and ₹ 4750.00 respectively.

J. Decision Point 6: Additional Payments as Premiums on Annuity

These payments are not mandatory by any existing law, but premiums are the incentives to the landowner that attract him to build a cosy relationship with the business of the organization. Premiums impregnate trust in the mind of the landowner that the organization wants to take care of his livelihood and financial stability in addition to paying him fair compensation for the land. This payment has two suggested components.

a. **<u>Livelihood Premium</u>**:

This is for compensating loss of livelihood of the landowner due to the alienation of his land. Guidance for this premium has been taken from the second Schedule of RFCTLARR Act, 2013. The suggested rate there is ₹ 2000/ month per affected family. In our model premium cannot be family dependent. In the R&R Policy of CIL, 2012 there is a provision for a one-time lump-sum payment of ₹ 5 Lakh/ acre in lieu of employment. The monthly annuity on account of this for 20 years is ₹ 2083/acre.

Decision:

The livelihood premium for our model has been set to ₹ 2000.00/ acre/ month irrespective of land holding and periods of lease.

b. **Additional Premium to ensure a guaranteed growth on investment:**

This is a premium provided to guarantee the landowner a minimum amount of return over the invested capitalized land price. Based on the lease tenure, the simulation assigns a particular percentage of growth on the land price that is supposed to be invested by the landowner throughout the lease tenure. The chosen percentage is compounded annually on the initial principal amount (i.e. the land price). At the end of the tenure half of the land price (i.e. the value of the degraded land) is returned to the landowner. Thus, the annuity for the landowner, payable at the beginning of each year, is calculated by the computer considering the chosen rate of growth and net capitalized value of the land. The gap between the payable annuity according to the intended growth on the investment and the entitled annuity obtained from the sum of the annual lease premium as per the State Policy and livelihood premium is made up by adding this additional premium.

K. Effect of the Selected Parameters from the Point of View of the Landowner:

As it has been already discussed earlier the landowner has the expectation for a commendable financially stable and guaranteed return over a reasonably long period when he decides to hand over the land to THE COMPANY for mining. So, it is necessary to assess whether our selected criteria and parameters can meet his expectations up to a certain degree. The simulation illustrates and displays basic information like amounts of annuity, payback period, annual growth rate of the capitalized value of land etc. for the particular land price and lease period:

L. Effect of the Selected Parameters from the Point of View of the Company:

The simulation takes input of some technical parameters like seam thickness, density of coal, grade of coal and number of Project affected families per acre of acquired land. It does the cost-benefit analysis and displays the results regarding available coal reserve/ acre, earning of revenue/acre, cost of land acquisition with the provision of land compensation at circle rate and employment cost at NCWA XI rate, cost of acquisition with compensation and benefits as per the RFCTLARR Act, cost of land acquisition as per this lease model, percentage of revenue consumed by the land procurement under different modes etc. The results based on some assumed parameters and some charts showing key metrics, highlighting the efficacy of lease model, are furnished below:

I. Assumed Parameters:			
Land Value/ Acre:	12 Lakh	Project Life:	13 Years
Seam Thickness:	30M	Coal Grade:	G4
Cost of Employment:	Rs. 6 Crore	Coal Density:	1.5 Te/ Cub. M.

Multiplying Factor:	2	State:	Jharkahnd & West Bengal
Land Requirement/ Employment:		2 Acres	
Project Affected Families/ Acre:		1.8	

II. Land Owner Compensation:					
Upfront Pay:	480000	% Market Val for Annuity:	4.75	Annuity for Land:	57000
Cashflow for Annuity:	1140000	Livelihood Annuity/Acre:	480000	Extra Premium on Annuity:	1973920.476
Payback Period Of Land Value:	6	Additional paying period after payback:	14	Total Compensation:	4073920.476

Fig.1 : Components of Cost of Acquisition: Lease Model

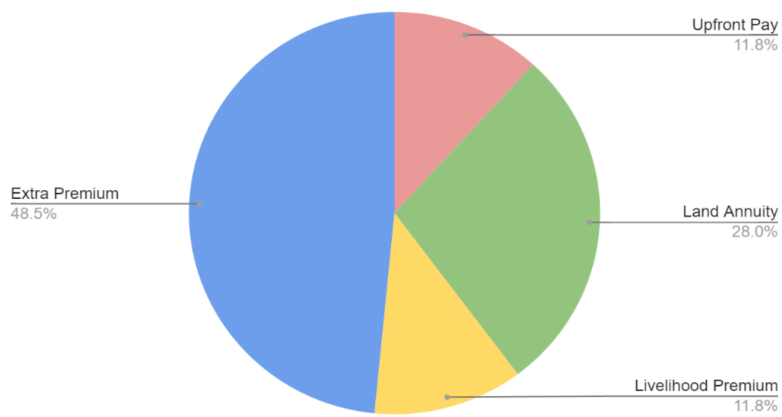
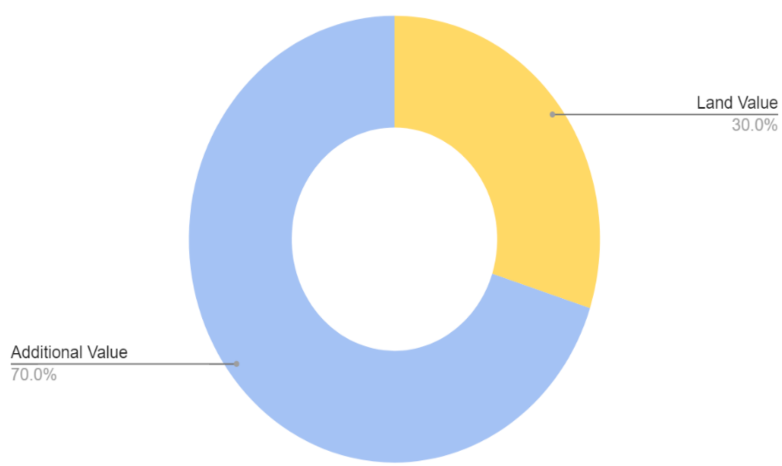
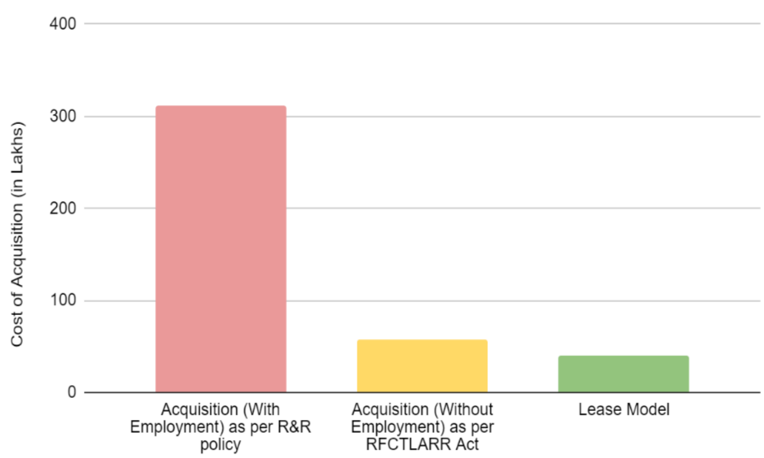


Fig. 2 : Payback Period



III. COST BENEFIT ANALYSIS			
Revenue Earning/ Acre:			
Land (Sq.M.)	Reserve (Te)	Sell Price (₹/T)	Revenue/ Acre
4047	182108.7	9247	16839.60 Lakh
Cost of Acquisition as per RFCTLARR Act 2013 (Without Employment)			
Land Cost	Employment Cost	Total Cost/Acre	Share of Revenue
48	9	57	0.34%
Cost of Acquisition as per R&R Policy (With Employment)			
Land Cost	Employment Cost	Total Cost/Acre	Share of Revenue
12	300	312	1.85%
Cost of Acquisition as per Lease Model			
Land Cost	Employment Cost	Total Cost/Acre	Share of Revenue
40.74	0	40.74	0.24%

Fig. 3 : Cost of Acquisition Comparison on Models



M. Algorithm For Computer Simulation

Input from User

1. Land Value (in Rs)
2. Project Tenure (in years)- with minimum acceptable value of 2
3. States
4. Thickness of Coal Seam (in meters)
5. Grade of Coal- accept only valid coal grades
6. Density of Coal Patch (in Te/m^3)

7. Cost of Employment to company (in Rs)
8. Minimum requirement of land for Employment (in acres)
9. Multiplying factor as declared by the concerned State under the RFCTLARR Act
10. Number of Project affected Families/ acre of acquired land (Obtained from Social Impact Assessment/ Baseline socio-economic Survey)

Transformations and Calculations

1. Lease Tenure = Project Tenure+7 years (taking into consideration 7 years are required for Land Reclamation and restoration.
2. If the Lease Tenure > 30 years, assume the Lease Tenure as 30 years. Give a message to the user suggesting adoption of Permanent Acquisition of Land.
3. Calculate the 'return percentage' (a percentage decided for growth of invested land value) based on the following criteria:
    a. if Lease Tenure>25 years and Lease Tenure<=30 years, return percentage=4.75%
    b. if Lease Tenure>20 years and Lease Tenure<=25 years, return percentage=6%
    c. if Lease Tenure>15 years and Lease Tenure<=20 years, return percentage=7.5%
    d. if Lease Tenure<15 years return percentage=9%
4. Calculate the Selling Price of coal (per Te) for the Grade of Coal taken as input
5. Calculation for State 1 Lease Model (Jharkhand lease Policy here):
    a. Salami=Land Value
    b. Lagan=1% of Salami
    c. Cess=75% of Lagan
    d. Total amount =Salami(Lagan+Cess)*Lease Tenure
6. Calculation for State 2 Lease Model (West Bengal lease Policy here):
    a. Initial Lease Premium=40% of Land Value
    b. Annual Rent=4% of Land Value
    c. Total amount=Initial Lease Premium+Annual Rent*Lease Tenure
7. [Calculate Total Amount for other State Lease Models as per availability in database and input]
8. Compare the Total amounts for all the states as per input and store the maximum value of 'Total amount'.
9. Calculation for Curated Model:
    a. Total amount for model = maximum of the competing State Lease models
    b. Upfront payment=40% of Land Value.
    c. Annual Rent% = ((Total amount for model-Forefront payment)/ Lease Tenure) * (100/Land Value)
10. Calculation of Livelihood premium:
    a. Livelihood premium per year=2000*12 (The premium value is Rs 2000 per month)
    b. Total Livelihood premium=Livelihood premium per year*Lease Tenure
11. Calculation of minimum compensation value:
    a. Minimum compensation value/ year = [(0.6*Land Value)/Lease Tenure] + Livelihood premium per year
12. Calculation of Extra Premium:
    a. Total Compensation value = Land Value*(1+ return percentage)^Lease Tenure (Compounded amount over the Lease Tenure period)
    b. Extra Premium=Total Compensation Value-'Total amount' for model-Total Livelihood premium
13. Calculate Annual Lease Rent:

   a. Principal amount = (Total Compensation value-Upfront payment)/(1+ return percentage)^Lease Tenure (Principal amount on which annual interest component will be payable)
   b. For i<--1;i<=Lease Tenure;i=i+1
      i. Calculate compound interest= compound interest for each year
      ii. Annual amount= compound interest+Principal amount/(2*Lease Tenure) [Half of the Land Value is returned as principal]
      iii. If Annual amount<Minimum compensation value/ year, then Annual amount=Minimum compensation value [Ensuring minimum value of annuity]

14. Calculate Cost Benefit Analysis:
   a. Revenue=Thickness of Coal Seam*4047*Density of Coal Patch*Selling Price of coal (1 acre=4047 m^2)
   b. Calculate the cost of Acquisition (Without Employment) as per RFCTLARR Act 2013
      i. Employment cost=500000*Average Project Affected Families/acre
      ii. Land cost=Land Value*2*Multiplying factor for RFCTLARR Act
      iii. Total cost=Employment cost + Land cost
   c. Calculate the cost of Acquisition (With Employment) as per R&R policy
      i. Employment cost = Cost of Employment to company/ Minimum requirement of land for Employment
      ii. Land cost=Land Value
      iii. Total cost=Employment cost + Land cost
   d. Calculate the cost of acquisition for Lease Model
      i. Employment cost=0
      ii. Land cost = Total Compensation value
      iii. Total cost = Employment cost + Land cost

Output

1. Display Components and Total amount of each of the State models as per user input (State)
2. Display the Land Annuity as per Curated Lease Model with all components
3. Display the Annuity for each year during Lease Tenure
4. Display Final Payment Ledger with Land annuity components, Livelihood components and Extra premium components
5. Display for Cost Benefit Analysis
   a. Components of Total Revenue Earning including Thickness of Coal Seam, Selling Price of coal and Total Revenue
   b. Components of the Calculation for cost of Acquisition (Without Employment as per RFCTLARR Act 2013)
   c. Components of the Calculation for cost of Acquisition (With Employment as per R&R Policy of the company)
   d. Components of the Calculation for cost of Acquisition as per Lease Model

N. Other Additive Benefits

Few more benefits may also be offered to have good social bonding with the land losers. A Photo-Identity card as a recognition of land provider to the company may be issued to each landowner. Following benefits may be extended to them by virtue of the said card:

I. Facility of free medical treatment at the company Hospitals;

II. Facility of schooling of their children at the company-funded schools;
III. Facility of attending skill development programs at Training Institutes of the company or customized programs arranged by the company for them

O. Pros And Cons

Pros:

1. No permanent acquisition of land hence no risk of legal complications related to ownership of land
2. Cost of employment is avoided;
3. Unnecessary intake of unskilled workforce is avoided
4. No revenues and dues are to be paid;
5. Total cost on account of land procurement will be much less compared to land purchase/ acquisition.

Cons:

1. Employment is the prime attraction of local landowners. They may not be interested even though compensated sufficiently by the company;
2. The company is doing some social duty towards employment generation through land procurement mode at present. This will cease to happen in the current model.
3. Additional work for the restoration of land will need additional effort. (The requirement of additional funds for this purpose will be minimal as there is already a provision of this in the 'Mine-closure-plan')

P. Further Actions Required

- All the activities for data and information collection regarding geo-morphological and chemical qualities of soil and strata at the pre-mining stage are to be carried out. Expert agencies are to be engaged for this job.
- Activities as described above during mining and at the post-mining stage are to be carried out religiously. Proper SOP is to be formulated and institutions/ departments are to be established for implementation and monitoring of the same.
- Back-filling of voids and restoration of the land to its original shape and fertility level is a very important criterion in this model. Actions required for this purpose have been described above. Till now company funded has not practised this. Sufficient infrastructure and investments are required to ensure the actual implementation of this aspect.
- This model has been prepared based on available records and ideas regarding the coalfields of West Bengal and Jharkhand under the command area of the company funded. Further study may be required by some expert agencies before making actual decisions.
- Sufficient propaganda and counselling camps might have to be organized to make landowners aware of the lease options and the benefits admissible to them. Expert organizations/ NGOs may be engaged for this purpose.

- Legal provisions regarding the lease mode need to be examined also.

Acknowledgement

We extend our heartfelt gratitude to the Almighty for guiding us throughout this research journey. Additionally, we are deeply thankful to our parents for their unwavering support, encouragement and sacrifices. Their love and belief in our abilities have been instrumental in our pursuit of knowledge.

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Ascertaining the faster waste dump reclamation and agriculture enhancement option for mined-out area: Development of eco-friendly mine specific soil conditioner

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Abstract:

The vibrant landscapes of various mining zone in India, once teeming with mining activity, now bear the indelible scars of abandoned mine sites. The ecological devastations rendered the land incapable of sustaining life. The research delves deep into the ecological and societal ramifications of abandoned mines. By extensively studying the detrimental effects of these neglected sites, the research lays the foundation for crafting a sustainable solution. The objectives of the research include the development of mine specific Superabsorbent Polymer Variant (SAPV) ,assessing the effectiveness of SAPV (which is basically an organic hydrogel) in improving soil fertility and water retention, evaluating its impact on vegetation growth, and investigating its potential to reduce reliance on synthetic fertilizers.

To ensure a representative sample, the research meticulously selected samples from dumps of an eminent Limestone Mines in Rajasthan. These samples encompassed a diverse range of dump materials w.r.t. size and sandy soil/ crushed rock etc., allowing for the development of a robust solution for converting infertile soil-rock entity to fertile soil material. To explore the adaptability and effectiveness of this reclamation approach across diverse landscapes, a series of trials were conducted encompassing various environmental conditions, soil types, and ecological contexts. The on-field implementation phase was meticulously planned, outlining a detailed timeline for each step, from developing a fortified, mine-specific SAPV to establishing dedicated experimental plots and meticulously collecting and analysing data. It was observed that, the application of SAPV significantly accelerated the regenerative growth of overburden soil, leading to a notable increase in essential soil elements like nitrogen, potassium, phosphorus, and organic carbon. Additionally, SAPV treatment effectively neutralized the highly alkaline soil, potentially improving its overall health. Soils treated with SAPV exhibited a significant enhancement in moisture retention capacity, a critical factor for combating aridity and enhancing agricultural prospect.

Keywords: Superabsorbent Polymer Variant (SAPV), reclamation, organic hydrogel, regenerative growth, agricultural prospect, combating aridity

INTRODUCTION

The vibrant tapestry of Rajasthan bears the scars of numerous abandoned mine sites. These stark landscapes, once bustling with activity, now stand as desolate reminders of the resource extraction process [1, 2, 18]. Aridity casts a long shadow, and the sandy soil, devoid of inherent fertility, crumbles under the relentless sun. This barrenness is further compounded by the removal of topsoil during mining, leaving behind a desolate expanse, incapable of sustaining life [6,16].

However, amidst this seemingly hopeless landscape, a beacon of hope emerges from the Project. This innovative initiative aims to breathe life back into these forgotten corners of Rajasthan, transforming them into verdant oases once again [22]. By harnessing the power of organic hydrogel, the project seeks to improve the nutrient content and water retention capacity of the degraded soil [8,21]. This transformative process will create a fertile canvas, ready to support the re-emergence of vegetation [17]. This ambitious initiative aims to utilize the power of organic hydrogel to reclaim these barren landscapes, restoring not just the land, but fostering a future of environmental and social well-being [4].

Driven by a deep concern for the ecological and societal ramifications of abandoned mines, the project delves into the heart of the problem [3]. By extensively studying the detrimental effects of these neglected sites, the project lays the foundation for crafting a solution.

The project acknowledges the need to:

- ***Adapt reclamation techniques:*** The diverse contexts surrounding abandoned mines necessitate adaptable

  solutions, ensuring the project's effectiveness across varied landscapes [3, 5, 28].

- ***Quantify socio-economic benefits:*** While acknowledging the potential for positive societal and economic impacts, the project emphasises the need for a comprehensive analysis to quantify these benefits [12,9].

- ***Harness indigenous knowledge:*** The project recognizes the invaluable knowledge held by indigenous communities and seeks to integrate their wisdom into the reclamation process [5, 28].

- ***Prioritise Eco-friendly amendments:*** The project underscores the importance of employing sustainable and environmentally friendly soil amendments for lasting restoration [15,11].

- ***Embrace Holistic Ecosystem restoration:*** Going beyond surface - level improvements, the project emphasises the need for a holistic approach that restores the entire ecosystem [19, 20, 16].
- ***Foster Trans - disciplinary Collaboration*:** Recognizing the complexity of mine reclamation, the project advocates for collaboration across diverse disciplines to ensure comprehensive solutions [24, 25, 26, 27,28].

The initial stages of the project have laid the groundwork for this ambitious endeavour. The crucial information has gathered on the importance of mine reclamation and conducted thorough literature reviews. Additionally, valuable insights were gleaned from analysing past successes and failures in reclamation efforts [14]. Establishing collaborations with mining agencies has facilitated the acquisition of samples for further testing and analysis.

The reclamation of abandoned mines is an issue of paramount significance in contemporary environmental and agricultural contexts. Unrehabilitated mines pose severe ecological and societal challenges, including soil degradation, habitat destruction, and potential health hazards [7, 18]. With the global demand for sustainable land use practices and the pressing need to restore the environment, innovative solutions like the utilisation of organic hydrogel for mine reclamation have emerged as transformative strategies [10]. This project is not only pioneering an eco-friendly approach to reclaiming abandoned mining sites but also addressing critical concerns related to water scarcity, soil fertility, and socioeconomic development. By converting barren mine lands into fertile agricultural grounds, the project contributes to long-term environmental restoration and sustainable resource management. This research project holds the promise of creating a ripple effect, inspiring similar initiatives worldwide to rehabilitate degraded landscapes and nurture a more sustainable future.

The overarching goal of this project is to address the pressing issues associated with abandoned and un-rehabilitated mine sites, which have far- reaching ecological and societal implications. Through innovative approaches, this project aims to transform these barrens and often hazardous landscapes into fertile agricultural land while adhering to sustainable practices. The project encompasses a wide range of activities, from in-depth research into the challenges posed by abandoned mines to the development and implementation of groundbreaking solutions [23,13,29]. It also involves collaborating with mining authorities and local communities to ensure a holistic approach to mine reclamation.

Further, the objective of the project is to assess the feasibility and effectiveness of using the organic hydrogel in mine reclamation, particularly for improving soil fertility and water retention in abandoned mines and to evaluate the impact of the organic hydrogel (as a biofertilizer) on vegetation growth and overall ecosystem restoration in reclaimed mining areas.

METHODS AND MATERIALS

The work is a meticulously planned on-field implementation phase, outlined in a detailed timeline. This phase will encompass:

*i).**Preparation of SAPV:*** To develop a fortified product from the base Super Absorbent Polymer which will be mine soil specific in nature

*ii).**Selecting and preparing suitable abandoned mine sites:*** Identifying the ideal locations for implementing the project's solutions and ensuring they are prepared for the experiment.

*iii).**Setting up experimental plots:*** Establishing dedicated areas within the chosen site to conduct controlled trials and gather data.

*iv).**Applying the Super Absorbent Polymer Variant (SAPV):*** Implementing the innovative approach on the experimental plots, carefully following the established protocols.

*v).**Collecting and monitoring data:*** Rigorously gathering data throughout the experiment, ensuring comprehensive information is captured for analysis.

*vi).**Analysing and evaluating results:*** Diligently analysing the collected data to identify patterns and trends, forming the foundation for drawing conclusions and informing potential adaptations.

2.1 Soil Quality Parameters

The development of novel superabsorbent polymers (SAPs) necessitates a thorough understanding of the soil quality in mined-out areas.

Figure-1*: Equipment Setup for testing Soil Quality*

Table-1: List of Considered soil Parameters before Application of SAPV

Parameters Considered	Adequate Soil	Current Mining Soil (case study)

pH	6.5 to 8.5 (slightly acidic to slightly alkaline)	9 (alkaline)
Electrical Conductivity	2 dS/m	3.9 dS/m
Nitrogen	150-250 kg/ha	125 kg/ha (free form)
Phosphorus	25-50 kg/ha	22 kg/ha(free form)
Potassium	100-200 kg/ha	173 kg/ha (free form)
Organic Carbon	0.5-1 %	No trace
Organic Matter	1-2 %	0.3%

These areas often exhibit significant degradation compared to standard soil data, rendering them unsuitable for plant growth without interventions. To address this challenge and establish minimal requirements for plant survival, it is crucial to identify essential soil amendments that can restore the ecological balance within the mined-out soil.\

In comparison with standard soil data, it can be inferred that the quality of soil from the mined-out area under case study has been degraded. Now, to meet up the bare minimum criteria for the plant growth, there is the need for addition of some sort of inputs to balance the ecosystem of soil.

2.2 Synthesis of SAPV

This section details the synthesis procedure for the super absorbent polymer variant (SAPV). The process involves cross-linking a base SAP powder with the incorporation of biochar, followed by washing and drying.

1. *SAP dissolution*: Dissolve the basic SAP powder in ethanol at a 1:100 (w/v) ratio using a stirrer. Ensure proper mixing to form a uniform solution.

2. *Biochar incorporation:* Add 2% (w/w with SAP) of untreated biochar to the SAP-ethanol solution and stir thoroughly for even distribution.

3. *Cross-linking:* Add 0.5% (v/v with ethanol) of the chosen cross-linking agent (glutaraldehyde or divinyl sulfone) to the solution and continue stirring.

4. *Thermal treatment:* Heat the solution in a controlled temperature environment at 100-150°C using a heating mantle. Maintain this temperature until the solution's colour changes from black to grey or off-white,

indicating the completion of the cross-linking reaction.

5. Washing: Wash the resulting composite thoroughly with several washes of distilled water using a filtering apparatus to remove unreacted cross-linking agents.

6. Drying: Dry the washed composite under vacuum in a vacuum oven or in a well- ventilated oven at a low temperature (around 50°C) until completely dry.

2.3 Modification with N-amino Acid

1. This section describes the procedure for incorporating N-amino acid extracted from legumes into the synthesised SAPV.
N-amino acid solution preparation: Dissolve 4 ml of N-amino acid extract in 1 litre of distilled water using a stirrer to prepare a solution.

2. N-amino acid incorporation: Thoroughly mix 200 ml of the prepared N-amino acid solution with 1 kg of the dry SAPV composite in a suitable container. Ensure uniform distribution of the N amino acid throughout the composite.

3. Palletisation: Use a pelletizer to convert the mixture obtained in step 2 into pellets of desired size and shape.

2.4 Granulation with Potassium Sulphate Coating

This section details the coating process for the prepared SAPV pellets with potassium sulphate (K_2SO_4).

1. Potassium sulphate coating preparation:
Dissolve 100 grams of potassium sulphate in 1 litre of distilled water using a stirrer to prepare a coating solution.

2. Coating process: Utilise a spray coating apparatus to apply the potassium sulphate solution onto the prepared SAPV pellets, creating a uniform outer coating.

3. Drying: Dry the coated granules in a well- ventilated oven at a low temperature (around 50°C) until completely dry.

3. LABORATORY AND FIELD EXPERIMENTATION

3.1 Acquiring Mined-Out Area Samples (Overburden)

The acquisition of samples from mined-out areas was done frommine under case study **, located in Chittorgarh, Rajasthan.** Those samples served as the foundation for our subsequent laboratory experiments and on-field trials. The selection and collection of these samples was conducted meticulously to ensure that they represent a diverse range of mining contexts.

Figure-2: *Mine Location*

Figure-3: *Mining Area - Working*

Figure-4: *Overburden Sieving through Conveyor*

Figure-5: *Overburden Spread - Crushed*

Figure-6: *Marking of Experimental Plots*

3.2 Testing the Capability of Organic SAP (Pot test)

One of the central elements of our study involves the utilization of an organic superabsorbent polymer (SAP) for mine reclamation. Extensive laboratory testing was initiated to assess the efficacy of the developed organic SAPV in enhancing soil properties, water retention and nutrient availability. The treatments during experimentation are demonstrated in Table-2 and Figure-7 to Figure- 15.

Table 2 Testing the Capability of Organic SAP with VAM

TREATMENT CODE	TREATMENTS
T1	Control (No SAPV & No VAM)
T2	5% SAPV+ [illegible]M
T3	[illegible]PV + [illegible]M

VAM – Vesicular Arbuscular Mycorrhiza

Day 1

Figure-7

VAM Testing - Day 1: Control

Figure-8

VAM Testing – Day 1: 5% SAPV +

Figure-9

VAM Testing - Day 1: 10% SAPV+ VAM

Day 5

Figure 11

VAM Testing - Day 5: Control

Figure- 11

VAM Testing - Day 5: 5% SAPV + VAM

Figure- 12

VAM Testing - Day 5: 10% SAPV + VAM

Day 10

Figure-13

VAM Testing -
Day

Figure-14

VAM Testing -

Day 10: 5%
SAPV + VAM

Figure-15

VAM Testing
-
Day 10: 10%
SAPV + VAM

Vesicular arbuscular mycorrhiza (VAM) is the most common and universal mycorrhiza. It has been associated with increased plant growth and enhanced accumulation of plant nutrients mainly phosphorus, zinc, copper, and Sulphur mainly through greater soil exploration by the mycorrhizal hyphae. It was found that VAM provided additional root growth and growth stimulants which provided a favourable growth environment. Along with VAM, SAPV helps increase water retention and reduce water demand.

3.3. Field Layout

The experimental layout was designed to facilitate the application of various doses of SAPV. Three different application rates were implemented: 0 kg/ha (control), 15 kg/ha, and 20 kg/ha. These specific doses were chosen based on the results of pot testing conducted on overburden samples collected from mined-out areas. To ensure data accuracy and adhere to established agricultural trial protocols, each dose was replicated three times. The land under experimentation was divided into several blocks as the layout shown in Figure-16**.** The treatment plan for the proposed experimentation is shown in Table-3.

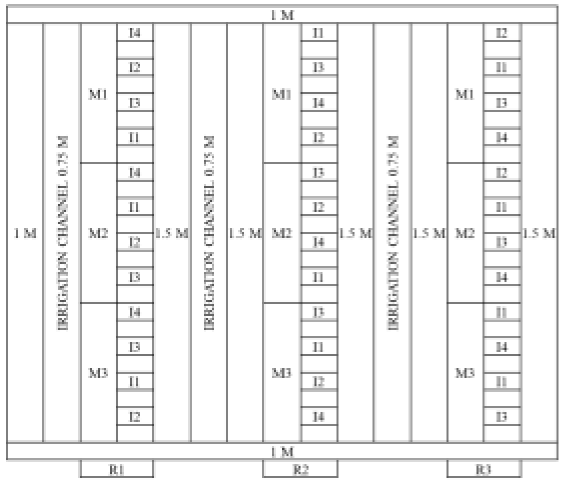

Figure-16: *Experimental Field Layout*

Table-3: *Treatment Plan for the Proposed Field Layout*

Treatment	
Product Level	**Irrigation**
M1 (0 Kg/ha)	I1 (T+0)
	I2 (T+4)
	I3 (T+7)
	I4 (T+10)
M2 (15 Kg/ha)	I1 (T+0)
	I2 (T+4)
	I3 (T+7)
	I4 (T+10)
M3 (20 Kg/ha)	I1 (T+0)
	I2 (T+4)
	I3 (T+7)
	I4 (T+10)

3.5 Biodegradability

The primary motivation for selecting organic Super Absorbent Polymers (SAPs) in reclamation efforts lies in their biodegradability. Unlike traditional SAPs, these organic variants completely decompose in the soil, leaving no residual material. This characteristic can potentially contribute to enhanced soil fertility, as evidenced by the attached biodegradability graph in

Figure-17 and Biodegradability Test Readings in

Table-4.

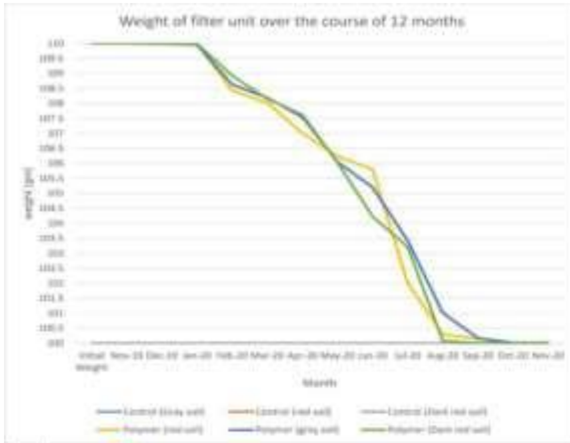

Figure-17: *Biodegradability Graph*

Table-4: *Biodegradability Test Readings*

Treatment	**Initial Weight**	**End Weight**
Control	100 gm	100 gm
Super Absorbent Polymer	110 gm	100.01

4. OUTCOMES OF EXPERIMENTATION

4.1 Reclamation Work on the Overburden Soil by Vegetative Growth

The vegetative grown scenarios at the mine site under case study are depicted by Figure-18 to Figure-21.

Figure-18: *Plant Tagging – Growth*

Tr. #	Soil Moisture % before every irrigation						
	1st Irrigation	2nd Irrig-ation	3rd Irrig-ation	4th Irrig-ation	5th Irrig-ation	At Harv-est	Avg.
M1I1	19.73	19.64	19.32	23.93	19.19	15.09	19.48
M1I2	14.68	14.51	14.03	15.01	13.98	10.57	13.80
M1I3	12.00	11.90	12.68	12.50	12.05	9.21	11.72
M1I4	10.59	10.44	10.30	10.22	10.70	7.32	9.93
M2I1	23.76	20.39	22.09	25.42	24.21	17.84	22.29
M2I	21.	21.	21.	20.68	20.98	18.	20.

2	04	30	55			55	68
M2I3	20.66	20.77	20.63	20.15	20.98	20.11	20.55
M2I4	19.44	19.56	19.33	19.84	18.22	14.02	18.40
M3I1	24.81	21.74	23.22	27.89	22.98	17.93	23.10
M3I2	22.65	23.70	22.51	22.30	21.51	18.29	21.83
M3I3	22.88	22.54	21.68	21.79	21.66	17.54	21.35
M3I4	21.35	20.41	20.45	32.41	24.45	16.30	22.56

Figure-19: *Field Tagging - Growth*

Figure-20: *Field showing SAPV Impact*

Figure-21: *Patches in Untreated Area*

4.2 Variation in Soil Moisture Percentage

Table-5: *Soil Moisture percentage before every irrigation*

Table-5 and Figures 22,23 ,24 and 25 demonstrates the Variation in Soil Moisture Percentage after using different quantities of SAPV with separate Irrigation plans.

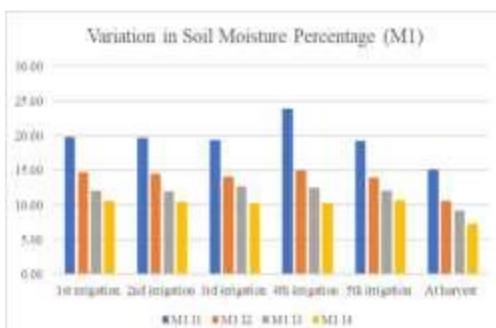

Figure-22: *Variation in Soil Moisture Percentage (M1)*

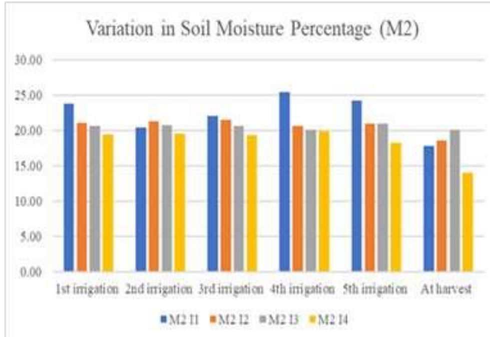

Figure 23: *Variation in Soil Moister Percentage (M2)*

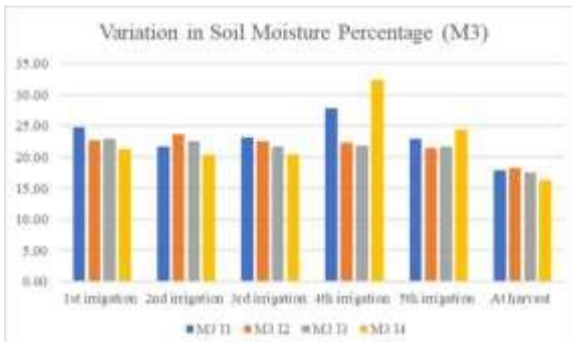

Figure-24: *Variation in Soil Moisture Percentage (M3)*

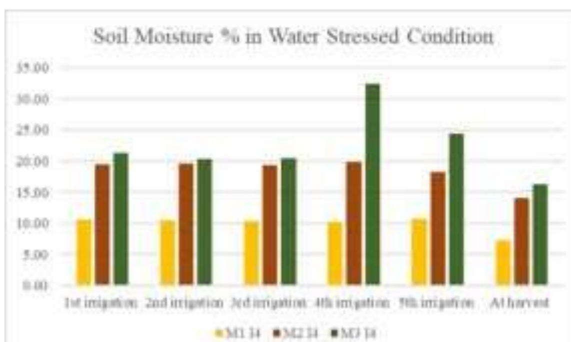

Figure-25: *Soil Moisture % in Water Stressed Condition*

1.1.1 Effects of SAPV Treatments on Soil

17.1 Properties and Soil Fertility after Harvest

The positive effects of SAPV Treatment on Soil Properties and soil fertility after Harvest can be revealed by Table-6 and Figure 26to Figure 35**.**

Table-6: *Effect of SAPV Treatment on Soil Properties and Soil Fertility after Harvest*

Treat. #	E.C. (µS/c)	pH	O.C. (%)	N (Kg ha⁻¹)	P (Kg ha⁻¹)	K (Kg ha⁻¹)	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)
Initial Sample	380	9	0	125	22	173	0.39	1.36	1	3
M1 I1	435	7.39	0	130	25	177	0.39	2.26	1.20	3.3
M1 I2	406	7.41	0	129	26	180	0.38	2.43	1.38	2.9
M1 I3	461	7.44	0	131	24	182	0.36	2.33	1.49	3.3
M1 I4	459	7.52	0	128	25	185	0.30	2.39	1.63	3.2
M2 I1	430	7.1	0.25	135	27	180	0.4	2.87	1.54	3.8
M2 I2	415	7.23	0.22	130	26	189	0.39	2.6	1.78	3.8
M2 I3	436	7.45	0.2	127	24	175	0.36	2.73	1.56	3.6
M2 I4	429	7.2	0.19	129	24	160	0.37	3.54	1.65	3.5
M3 I1	505	7.36	0.45	140	26	190	0.36	3.1	1.86	4.1
M3 I2	501	7.39	0.41	135	24	175	0.38	3.02	1.55	3.88
M3 I3	442	7.5	0.32	132	23	173	0.30	2.98	1.45	3.54
M3 I4	420	7.44	0.3	130	23	174	0.36	2.77	1.65	3.5

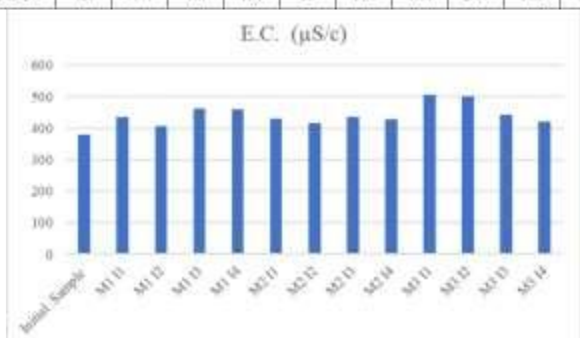

Figure-26: *Variation in EC after Application of SAPV*

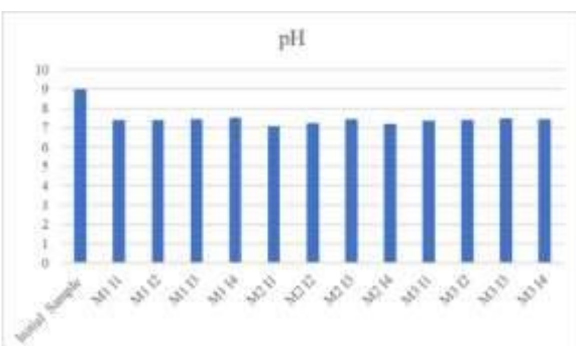

Figure-27: *Variation in pH after Application of SAPV*

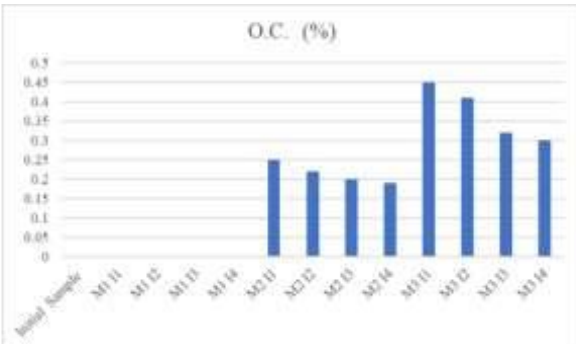

***Figure-29: Variation** in OC% after Application of SAPV*

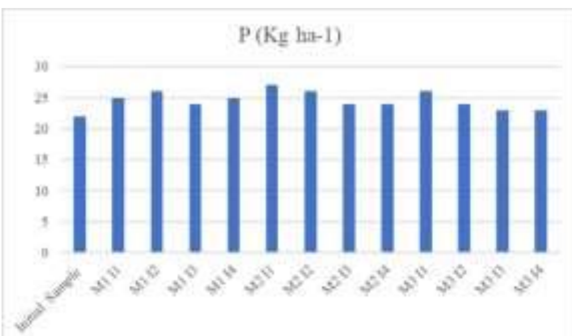

***Figure-30: Variation** in P after Application of SAPV*

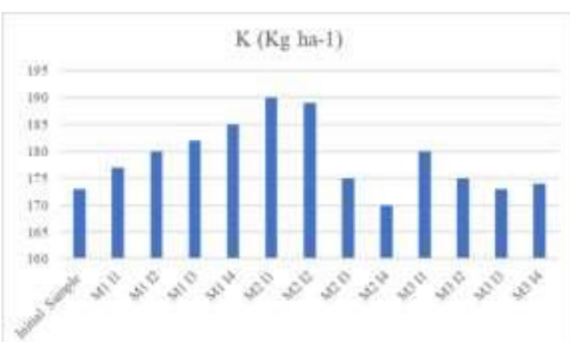

***Figure-31:** Variation in K after Application of SAPV*

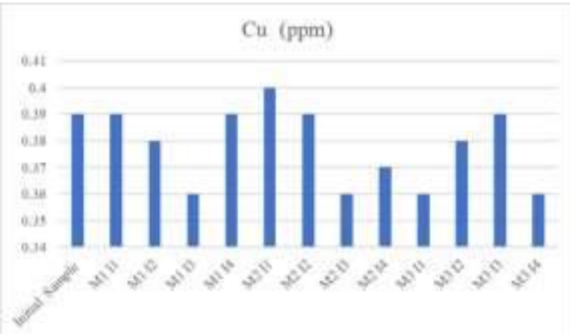

Figure-32: *Variation in Cu after Application of SAPV*

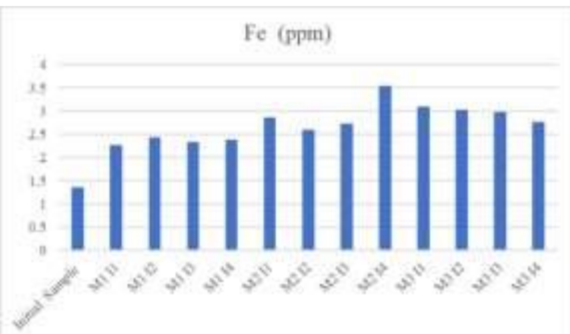

Figure-33: *Variation in Fe after Application of SAPV*

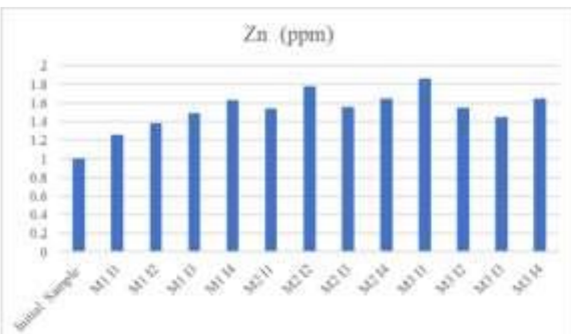

Figure-34:*Variation in Zn after Application of SAPV*

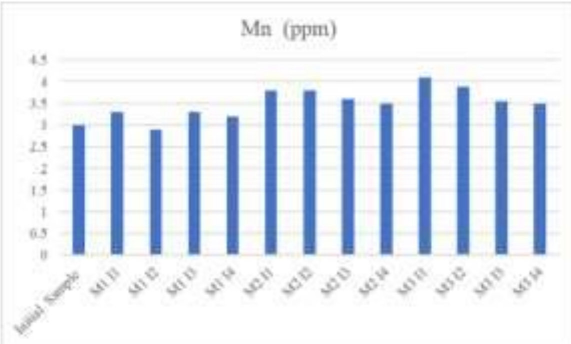

Figure-35: *Variation in Mn after Application of SAPV*

5. Discussion

Our research investigated the feasibility and effectiveness of organic hydrogel in mine reclamation, specifically focusing on improving soil fertility and water retention in abandoned mines. The findings demonstrate that organic hydrogel significantly improves soil moisture content and nutrient availability compared to the control group. This directly addresses the research question by confirming the potential of organic hydrogel as a viable tool for mine reclamation.

Previous research highlights the detrimental effects of abandoned mines on the environment and emphasises the importance of sustainable reclamation practices. Our findings align with this established knowledge by showcasing a novel method (organic hydrogel) for achieving successful mine reclamation. The research did not encounter any unexpected results. However, further investigation is needed to determine the long-term effects of organic hydrogel on plant growth and ecosystem restoration.

In continuation, to quantify the findings of the soil properties, we observed a 12% increase in Nitrogen content, an 18% increase in Phosphorus content, and a 9% increase in Potassium content. Specifically, we found that the Organic Carbon percentage now stands at around 0.45%, compared to the previous stage where no Organic Carbon was present.

Overall, this research contributes to the ongoing efforts to develop innovative and eco-friendly methods for mine reclamation, paving the way for a more sustainable future in the mining industry.

6. Conclusion:

The research has yielded the following key conclusions:

1. *Enhanced Regenerative Growth:* The application of SAPV significantly accelerated the regenerative growth of overburden soil.

2. *Improved Soil Health:* A notable increase was observed in essential soil elements, including Nitrogen, Potassium, Phosphorus, Iron, Copper, Zinc, Organic Carbon, and Manganese, following SAPV treatment.

3. *Neutralised pH:* SAPV application effectively shifted the highly alkaline pH of the overburden soil of around **9** towards a more acidic state of around **7.5**, potentially improving its overall health.

4. Increased Moisture Retention**:** Soils treated with SAPV exhibited a significant enhancement in moisture retention capacity, up to **33%** greater than untreated areas.

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NO : 4.4

Statistical analysis of past deformation data to determine the failure strain rate of backfill dump, as well as material flow analysis to determine the zone of influence at Ostapal chromite mine- a case study

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Abstract:

Slope management in opencast mines is one of the most important parameters for the continuation of mining activity smoothly. As per the safety management plan under the guidelines of the director general of mine safety, slope-related hazards come under principal hazards amongst all the high-risk hazard mechanisms. Identification of hazardous slopes, hazard map preparation, and taking precautionary measures can only tackle the adverse effects and consequences of slope instability/ failure. Out of all the pillars of slope management plans, slope monitoring, and data analysis are the major and proven techniques to know the behavior of any slope. Back analysis of old failure data for different rock masses and dump masses as well as the failure mode analysis can give miners a tentative picture of the future behavior of other hazardous slopes and in turn that can help us to save man machinery before any failure occurs.

In this regard not only the monitoring data analysis but also the material flow analysis in term of run-out distance is equally important to identify the zone of influence of a particular failure. This article presents a case study of how the past material flow analysis and back analysis of monitoring data helped miners decide on the zone of influence for another big-size slope failure to restrict mining operation and ultimately helped save man-machinery and minimize production loss.

Keywords: Slope management plan (SMP), Back analysis, Debris Flow, Run out Distance, Slope Stability Radar.

1.0INTRODUCTION:

Opencast mine operators always focus on stripping ratio optimization to produce more quantity of ore with minimum waste handling. During stripping ratio optimization, increase in overall pit angle always invites unnecessary slope instability. To mitigate the instabilities, there are many stabilization methods but this stabilization of slope is possible only for some particular and semi-critical slopes. For hazardous and critical slopes- monitoring and data analysis to save man machinery is the only solution. Tons of instruments are available in the market for slope monitoring which includes sub-surface monitoring, slope surface monitoring, indirect monitoring etc. but after data analysis, implementation of proper Trigger Action Response Plan (TARP) is also a major factor to save man machinery in mitigating hazard. Action of a mining engineer or a manager shall be dependent on not only the cumulative deformation and velocity of deformation but also it will depend on the zone of influence and how much area has to be restricted. In case of maintaining stand-off distance in between pit crest and dump toe, it is completely dependent on the zone of influence of a particular instability which is vulnerable for failure. Obviously after detecting any instability through monitoring instruments, there will always be an option for a

miner to completely stop the total operation and restrict man-machinery insidethe total mine premises but that will not be economical. Hence determination of zone of influence and act accordingly is the best and optimal solution for an unstable slope.

Determining zone of influence is not an easy task both for insitu rock as well as the dump mass, because of DIANE behaviour of rock (for insitu) and different geometrical parameter, strength properties of mass, compactness and level of saturation (for dump mass). Theoretical calculations and numerical simulations can be done to get an idea and till date all the miners are doing exactly same to determine zone of influence but engineers don’t have sufficient site specific failure data to calibrate their digital models.

Ostapal Chromite mine of M/s Ferro Alloys Corporation Ltd, having lease area of 72.843 Ha, in Jajpur District of Odisha is one of the major chromite producers in India. Space constraint inside the lease is a major challenge for this mine. The mine was in operation since 1985 and was being operated by M/s Ferro Alloys Corporation Ltd. In 2020 all the mining lease of FACOR was acquired by Vedanta Ltd and since then Vedanta is operating this Ostapal mine. During taken over those leases, already dump was erected just at the pit crest without maintaining proper standoff distance and there were many geotechnical challenges. The only option for dumping was backfill dumping. The orebody is discontinued at a length of 275m at the pit bottom. That length was utilized for backfill dumping. Mine management couldn’t able to completely fill the pit because at other side, the ore body is continuing and in approved mining plan that ore has to be excavated. Hence the backfill dump was created in bench shape at the western part and south-western part of the pit.

In rainy season- the complete backfilled mass was saturated in 2023 and ultimately failed. But as there was one Slope Stability Radar installed inside the mine and was continuously monitoring that area 24x7, hence the failure was predicted well in advance and there was no harm to manmachinery. But the problem is that during this failure-complete mine was stopped because there was no idea about zone of influence, how much the failure material can flow. Hence, for more than one month operation was stopped and accepted hence huge loss of production. Management had to accept completely zero production for more than a month time.

After this failure- back analysis was done to determine the failure rate of deformation. Also the Geotech team analyse the material flow pattern. The analysis result of this failure was applied to another slope instability which occurred just after one month. This time engineers had the idea about zone of influence and also they had the idea about threshold rate of deformation. As a result for this second failure- the operation was stopped for only 2 days and only the south western part of the mine was restricted for man-machinery.

2.0 DETAILS OF THE MINE:

- **Mine type:** Open pit- fully mechanized
- **Fleet Management:** Through Backhoe-tipper combination•**Pit area**: 850m x 650m
- **Pit depth:** 120m
- **Overall slope angle:**
  - **▪Pit**
    - o 33^0 in southern and western side
    - o 22^0 in northern and eastern side
  - **▪Dump:**
    - o 26^0 for main dumps
    - o 23 degree for backfill dump

•**Permissible angle:** **▪Pit:**

- o 36^0 in South, west and east side

o▪**Dump:** 24^0 in northern side

- o 28^0

- **Bench configuration:** 8m x 8m; Angle: 60-70^0
- **Location of the mine:**Sukinda Valley, Jajpur District of Odisha
- **Mineral:** Chromite
- **Production capacity:** 0.3 Million ton per annum

3.0 GEOLOGY:

3.1 Topography

The entire lease area is a flat terrain having a gentle slope of 2^0 from north to South. The highest ground elevation in this area is lying in the Northern part of the lease area at an altitude of 158 mRL and the lowest relief in this area is 135 mRL laying in the Southern part. On account of recent Mining activities in lease area the Topography has been changed considerably due to quarry bottom, waste dumps and sorting yard. The average lowest elevation of the quarry bottom as on date is +30mRL and highest elevated area is located in Northern part of the lease area is occupied by waste dump, which is barren area. The average top RL of the dump is +242 mRL

3.2 Lithology

The ultramafics of Sukinda region, along with associated Chromite ore bodies are intrusive into the lower sequence of the basal group of the Iron ore super group. It is made up igneous rocks and constituted lithologically ultramafic intrusive of Dunite - Peridotite – Pyroxenite and acid differentiates of Granites and Granophyre. All these rocks traversed by dolerite dyke.

3.3 Regional Stratigraphic Sequences

Generalized stratigraphic sequence of the Sukinda ultramafic complex is as follows.

Recent to Pleistocene — soil, Alluvium, Laterite

- - - - - - - -Unconformity - - - - - - - -

Dolerite, Granites & Granophyre

Pre-Cambrian

Ultramafics: Pyroxenite, Dunite } Peridotite with Chrome Ore

Meta Sediments And Meta volcanic } Quartzite, Meta-volcanic

- - - - - - - -Base not seen - - - - - -

3.4 Lithological Units within lease area

- Laterite
- Serpentinite
- Pyroxenite
- Nickeliferous limonite
- Quartzite
- Chrome Ore Bands

4.0 METHODOLOGY:

4.1 Description of the First Incidence of mass failure: On 5th September 2023 at around 02:20 AM in the night, a big size Slope failure occurred at the Northwestern Corner of the Pit area (including dump mass, (size of the failure is 165mx 70m x 30m) From mRL150 to mRL78 with approximately 4.0 lakh cum of material, which could resulted into a disaster; but nothing happened, not even a small injury to any man-machinery.

After proper hazard identification and preparing a hazard map, FACOR team installed a Slope stability Radar at one of its mines- Ostapal Chromite mine. This Radar detected the failure one month prior to the failure. As per the site's Trigger Action Response Plan (TARP) mine management took the decision to evacuate all man machinery from the area and alsowhen slope deformation observed through the radar. Ultimately even after the collapse of huge material, there was no injury to anyone.

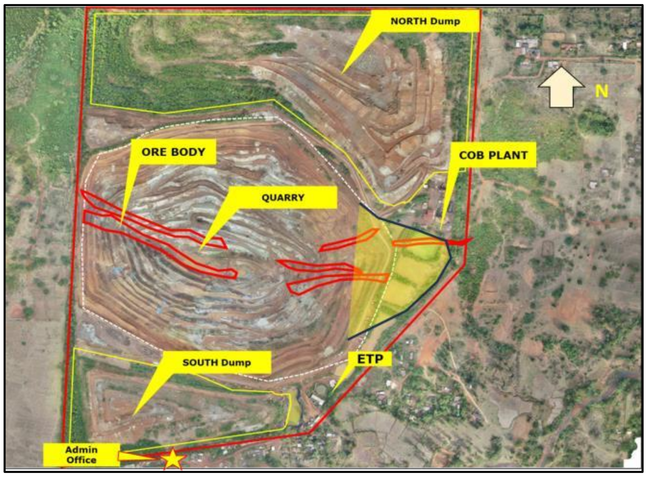
As per the strategic plan of Radar installation- this movable radar is generally installed in 4 different locations inside the mine to cover the whole pit and dump area. Before this incident, inhouse Geotech team assessed the hazard of different areas and decided to install the radar to monitor this particular NE corner location in mid-July '2023. The deformation captured through radar one month before the failure. On 12th August progressive Slope deformation was observed in that NE corner area through this Slope Stability Radar. Slope deformation trend was observed with the velocity of 3-5mm/hr in Slope Stability Radar on 12th August at around 3:00 AM in the morning. After receiving the alert from Slope Stability Radar, at around 5 O'clock, the area was checked and found lot of tension cracks on the surface. Immediately the upper surface area was also barricaded after assessing the influenced zone. But as the team was not confident, hence consequently the total mining operation was stopped and also the beneficiation plant which is there inside the lease at NE corner, was also stopped from 16th Aug to 4th Sept.

Monitoring was continuous, and upto 4th Sept'23, total deformation occurred 2600mm. Till then operation was stopped in the total mining area. On 5th Sept' 23 the area failed with the deformation rate of 30mm/hour.

4.2 Analysis of the pre failure condition: In 2023-24, the pit excavation was extended towards eastern part of the pit. Previously, before the expansion of pit – this area was used to store tailing generated from the exiting Chrome Ore Beneficiation (COB) plant. Also one intake pond was thre to feed water continuously to the plant. Hence since last few years the area was completely saturated. But this saturation was at the eastern part. And failure occurred at the north eastern corner. Whether the effect of these tailing ponds was there at the NE corner or not, that is still unknown.

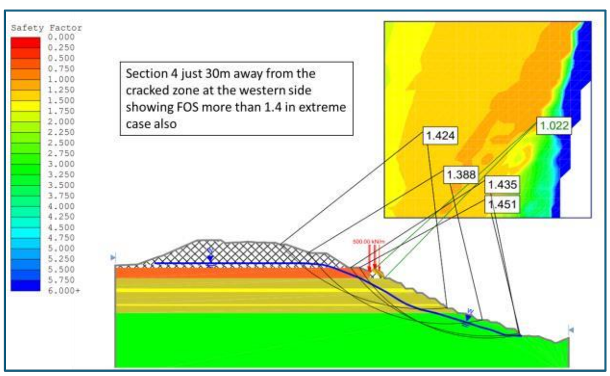
We observed continuous water seepages having 4-10m3/hr from that particular zone. Hence it was the initial assumption that these seepages were the effect of saturation due to tailing pond but after complete excavation of these ponds also, we observed the same amount of seepages. The tailing ponds were completely excavated in February'23 but seepages were continuous till before the onset of failure. At that time followings were implemented and observed the situation continuously.

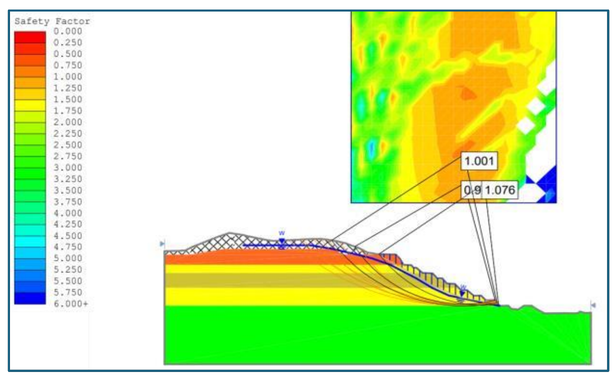
- Piezometer installation and pore pressure monitoring
- FOS analysis of oblique sections from Sec 1 to 7
- Bench scale spalling
- Exposure of Nickelleferous limonite
- Installation of monitoring system
- Off loading of upper part
- Crack formation



Picture 01: Ostapal Chromite Mine *Picture 02: Eastern part of the Mine where Crack observed*

Pre-failure simulations —



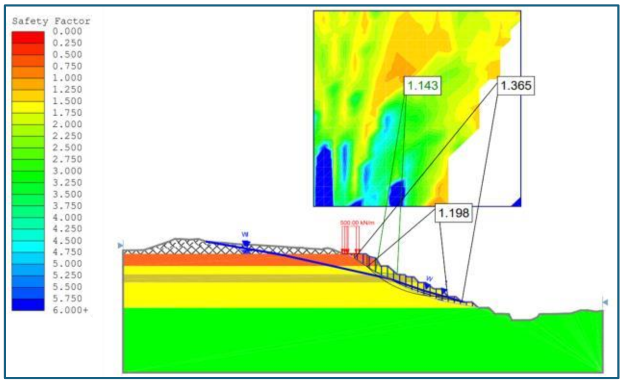


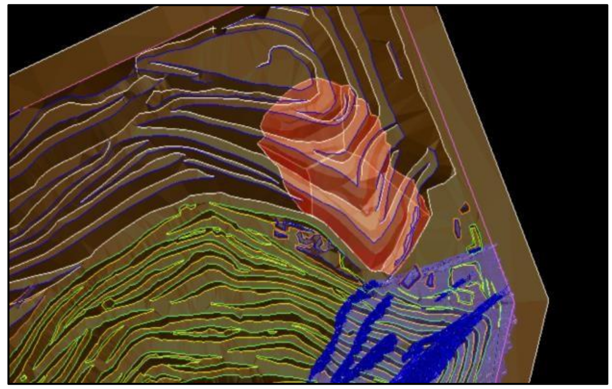
Picture 03: Simulation result of cross section 4 *Picture 04: Simulation result of cross section 6*

Section 4 just 30m away from the cracked zone at the western side showing FOS more than 1.4 in extreme case also

Section 6 just on the unstable area/ crack zone:

Sensitivity analysis showed FOS just near the 1.0 and in a case it is less than 1.0, if ground saturation crosses 45%, dump load @500KN/m and water table just 8m below surface with the cohesion of 40kPa for Ni-Limonite

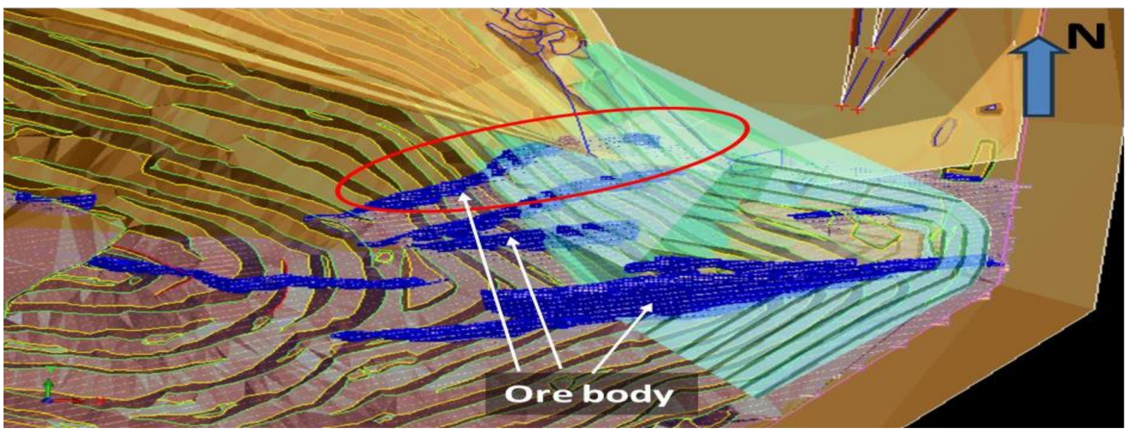




Picture 5: : Simulation result of cross section 7 corner

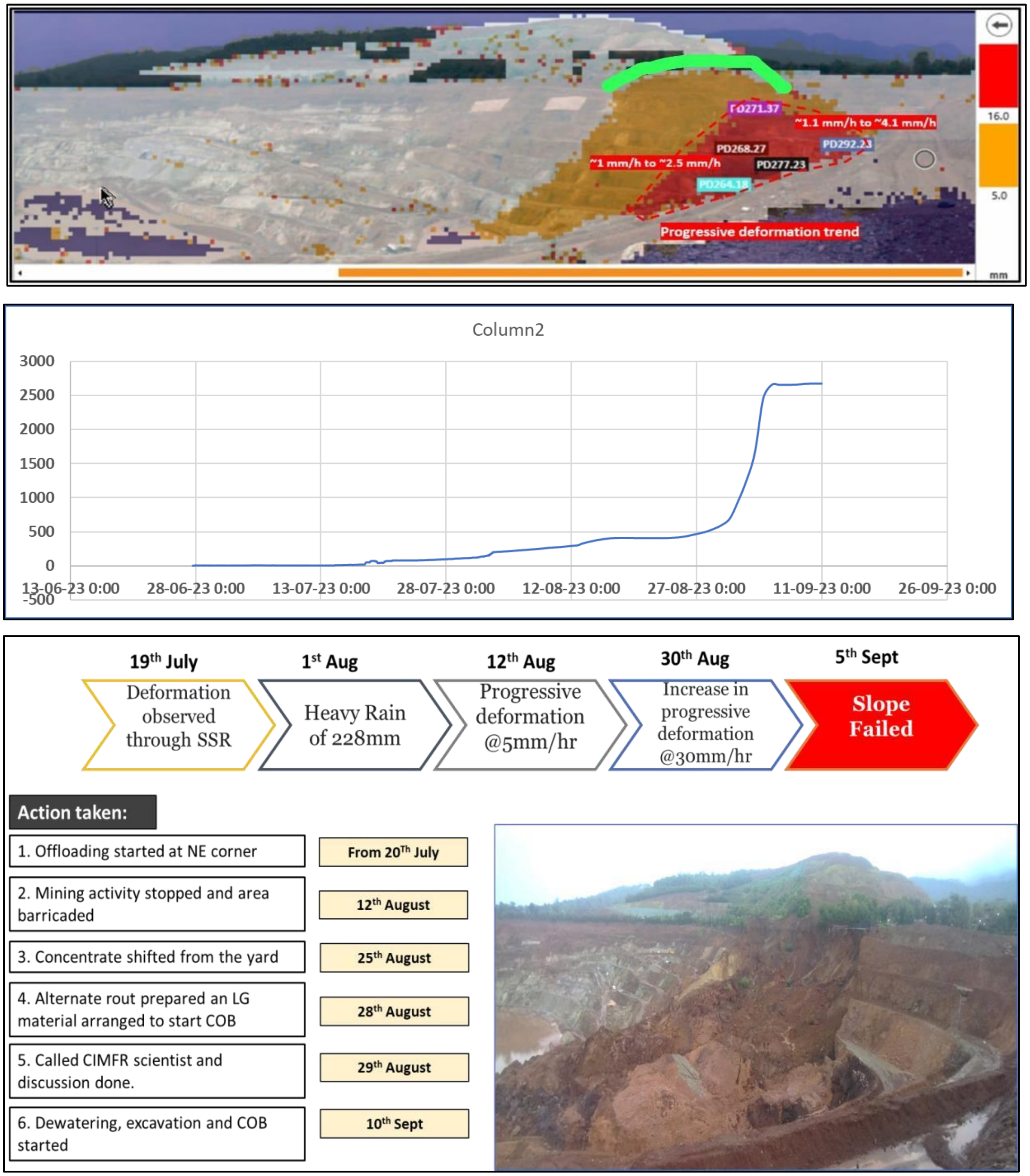
Picture 6: : Surpac Design of Rehandling area at dump

Section 7 just eastern part of the crack zone: In extreme case FOS reaching 1.1



Picture 6: Mining development design using Surpac

4.3 Deformation and Back Analysis:



Picture 7: Deformation graph recorded through Slope Stability Radar (SSR-XT) and the pit failure

4.4 **Back analysis:**

Table 01: Detailed deformation analysis of past failure data w.r.t rock/dump mass category

S. No.	Location	Area(m2)	Starting date of progressive deformation	Cumulative deformation	Max. velocity	Avg. velocity	Failure time velocity	Wall folder name
1	94mRL North- weathered serpentinite	404.823	29.12.2022	149	5	2.33	28.1	221221& 221231
2	80mRL East - Limonite	300	04.01.2023	245	28.1	6.1 - 20.3	28.1	221231
3	90mRL East - Nickeliferous limonite	244	04.01.2023	500		9.4		230104
4	108mRL East - Limonite	85	18.01.2023	31	10.3	0.6		230113
5	90mRL East Away movement - Nickeliferous limonite	200+	24.01.2023	-71	1.8	0.5		230120
6	90mRL East - 112mRL East - Limonite	30.8	14.02.2023	85	12.75	0.1 to 1.4		230208
7	92mRL West - Backfill dump	24.3	14.02.2023	250	24.6	0.1 to 4.5		230208
8	54mRL West – backfill dump	152	12.05.2023	85	4.9	2.4	1.27	230508
9	78mRL East - Serpentinite	95	12.05.2023	250	15	3.2	9.26	230508

10	106mRL, 112mRL East - Brown serpentinite	450	25.05.2023	750	21	7.6		230508
11	118RL West - Ore waste contact zone	172	01.08.2023	50	7.9	0.5-6.8	1.5	230718
12	118RL North - Hard serpentinite	30	01.08.2023	568	3.1	0.2-3.1		230718
13	112RL North - Hard serpentinite	95	01.08.2023	580	2	0.1-2		230718
14	112RL East - Limonite and laterite	90	01.08.2023	425	58	7.2-13.7	3.205, -0.337	230718
15	118mRL East - Limonite	250	01.08.2023	598	58+	0.3-6.3	3.205, -0.337	230718
16	90RL West - Dump mass	1700	01.08.2023	405	NA	0.6-17.5		230718
17	118RL North - Serpentinite	98	01.08.2023	400	1.8	0.1-1.2		230718
18	185RL Boula – Dump mass	200	01.08.2023	563	NA	2.3-8	NA	230718
19	68RL West - Ore waste contact zone	800	01.08.2023	331	8.49	1.3-5	8.49	230718
20	90RL East	207	01.08.2023	393+	58	0.5-3.5	3.205, -0.337	230718
21	90 to 134RL East	378	02.08.2023	393+	58	0.3-6.3	3.205, -0.337	230718
22	114RL West near shotcretin-Dolerite dyke	1171	03.08.2023	158	6.6	0.1-8		230718
23	145RL east - Laterite	113	08.08.2023	393+	58	0.1-5.6	3.205, -0.337	230718

24	78 to 134RL East – Mixed dump mass and limonite	3171	12.08.2023	393+	58	0.8 to 1.2	3.205, -0.337	230718, 230813
25	138 to 90mRL West - Laterite	2900 in the starting	04.10.2023	160+	25+	0.3-2	1.546	231005
26	126 to 90 RL North - Serpentinite	934	05.10.2023	1050	20.015	2	20.015	231005
27	136mRL NE corner - Laterite	118	17.10.2023	285	9.5	0.8 to 1.6	2 & 9.5	231005
28	78mRL West – ore zone	275	27.11.2023	135	2.6	0.5 to 2.6	1.7	231005
29	126mRL NE - Limonite	1073(started from 306.4)	01.12.2023	444+ still continuing	7.2	1 to 7.2		231005

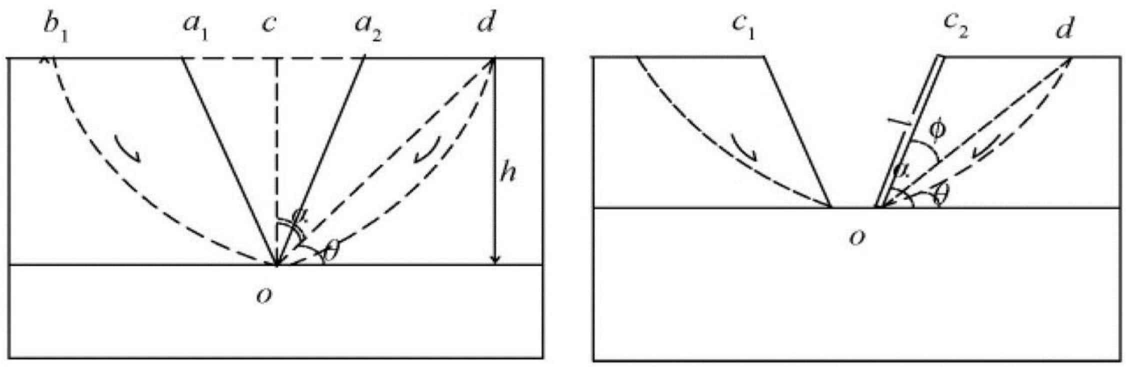
4.4 Material flow analysis:

The failed mass contains- some parts of dump mass, some part of tailing material, some part of pit benches and also a part of backfilling material. Hence the combination of these different materials had a complex mechanism failure. Practically it is impossible to determine the direction of different material and their flowability which resulted into the total mass flow. The distance which was travelled by the combination of these materials were measured through normal survey process. Prediction of the combined mass flow was difficult to analyse, hence the management had decided to stop the complete mining operation for the whole mine. But after failure debris flow mechanism was analyzed to help predicting the future instabilities.

After the development of liquefaction and failure surface in the slope, debris flow can be triggered and the remolded mass during initial failure travels further downslope until the initial stored potential energy is dissipated by friction. The debris flow run-out distance can be estimated using one- or two- dimensional numerical modeling of sediment-laden submarine flow. For this study, the one-dimensional (1-D) model BING assuming one phase flow and "constant volume" constraint. The required input for the simulation includes the bed profile over which the debris mass flow, the initial configuration of the pile of debris slurry, rheological parameters describing the debris slurry and numerical parameters to describe spatial and temporal discretization, run duration and run out distance.

A debris flow is a typical solid–liquid two-phase flow, which commonly causes huge economic losses and casualties every year.

We have used the methodology developed by **Linjuan et al (2020)** as described below—



Picture: 8: Typical section of a failure plane

V01=Δ1cod×L1 ……………………………………………….. eqn (1)
where, V_{01} is the undercut erosion type dynamic reserve, and L_1 is the length of gully bed accumulation.

Dynamic source materials of Lateral Erosional Debris Flow: It is assumed that U-shaped valley slope deposits will gradually collapse from point c_2 to point d and form a debris flow source under the action of flood erosion and flood side erosion; any triangle Δc_2od $\Delta\ c\ 2o\ d$ is the largest possible source area of debris flow dynamic reserves. The area is:

Δc_2od=1/2 c2o·c2d=1/2 l. l ·tgϕ=1/2 l^2·tg(α−θ)………………………………eqn (2)

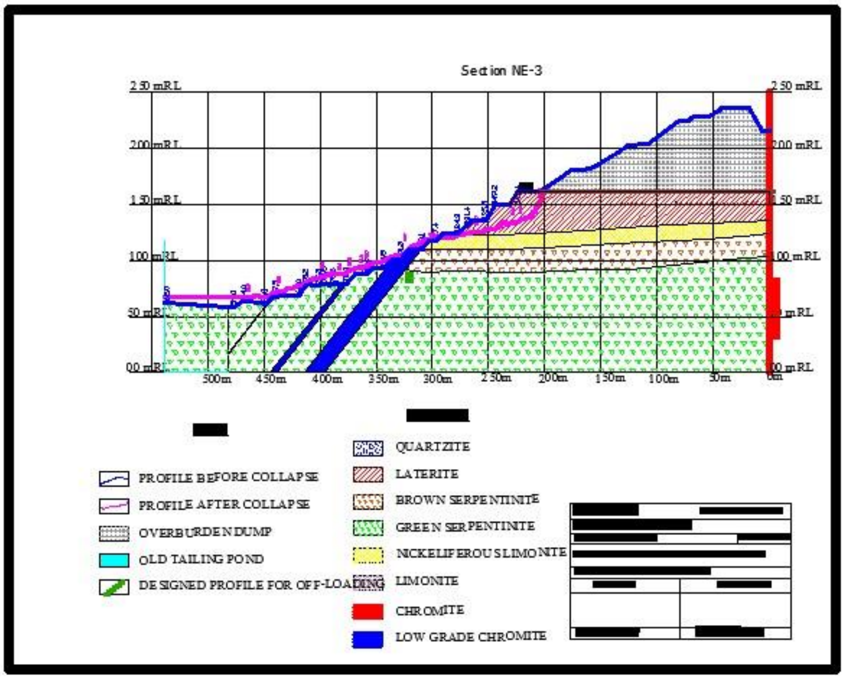
where, θ is the natural angle of repose of the slope, α is the foot of the actually measured accumulation slope, ϕ is the angle between the integration and the natural angle of repose, and $c2o$ = l is the measured slope length.

The volume of dynamic reserves is:

V02=Δc2od×L2 ……………………………………………………………. Eqn (3)

where, V_{02} is the lateral erosion type dynamic reserve and L_2 is the length of the channel stack.

Section NE at Ostapal



Picture 9: Before and after profiles of the failure section

4.6 Runout distance analysis and Preparation of TARP for all future failures:

As per the calculation according to the methodology developed by Linuan et al, the run out distance of different lithos/ masses are as mentioned below. Here run out distance we have calculated as the distance per unit height

Table no 02: Runout distance analysis for different rock/ dump mass type

SN	Material combination	Cohesion	Avg strain rate during failure (mm/hr)	Runout distance (m in m)
1	Dump mass having combination of mixed OB and tailing	60- 100	4.5	8 in 13
2	OB Laterite and limonite material	80-120	8	15 in 27 → 5 in 9
3	OB of Nickeliferous limonite and limonite material	40-60	3	8 in 10 → 4 in 5
4	OB of only Limonite	60-80	35	16 in 18 → 8 in 9
5	OB of Green Serpentinite and brown serpentinite	50-80	3.5	23 in 21
6	OB of Brown and hard Serpentinite	60-100	6	9 in 8

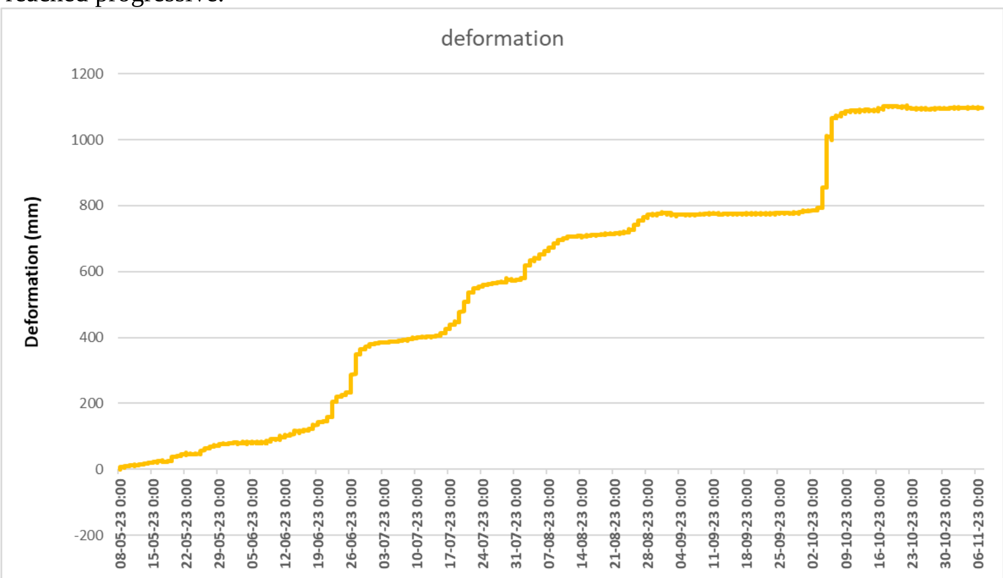
7	Mixed Hard serpentinite/ peridotite	120-160	4	12 in 13

4.7 Backfill dump failure at Western side, next month in Oct-24:

Just after one month another deformation zone we observed on backfill dump which was at the south western corner of the mine, though the real time monitoring instrument. The deformation observed for more than a month.

- Initial 12 days, it was linear
- Then another 15 days it was progressive and
- Last 3-4 days the movement was rapid and ultimately failed.

But now this time we had old analysis data and a proper back analysis with TARP. So this time we didn't stope the total mine premises. We were waiting for the rapid movement. We didn't stop the operation when the movement graph reached progressive.



Picture 10: Deformation of SW corner failure recorded through SSR-XT

4.7 Calculation of Zone of Influence consider material flow analysis of previous failure:

As per the analysis the dump mass had the failure strain rate of 4.5mm/ hour. So we were waiting to reach the movement upto that limit. And the runout distance as per the previous calculation, it was 8 in 13.

This time the height of the movement zone was from RL 145 to RL93= 52m.

So the run out distance we assumed to be = 52/8 * 13 = 84.5m
With 15m margin the zone of influence assumed to be 100m and only that area was barricaded as core zone of the influence and another 100m we took as the buffer zone of influence.
So out of 9 sections, i.e. 900m, our operation stoppage was only within 200m.

5.0 Conclusion:

Monitoring data analysis is a routine task for geotechnical engineers, but accurate failure prediction is critical for miners. Success in this area hinges on the geotechnical engineer's tremendous effort and continuous 24/7 surveillance to detect both progressive and rapid deformation. While progressive deformation is often visible on a total deformation graph, determining the Time of Failure (ToF) and analyzing the failure strain rate are crucial for preventing disasters and saving both personnel and machinery.

- The success rate of prediction has to have 100%. Otherwise, either we have to accept loos of production for a long time by stopping operation whenever we will observe deformation trend, or we have to face the consequences of disaster.
- A case study at the Ostapal Chromite Mine demonstrates the efficacy of predictive analysis. By conducting a back analysis of a major failure involving diverse rock and dump masses, along with several smaller failures, the mine management was able to predict subsequent failures with greater accuracy.
- The use of real-time monitoring instruments, such as the Slope Stability Radar (SSR649XT) at Ostapal, played a critical role in fostering confidence in productive mining operations. By increasing the overall angle and reducing the stripping ratio, the mine, initially slated for closure in 2020, extended its operational life by over three years. This extension enabled the extraction of additional ore safely before failure. Specifically, the monitoring instrument contributed to three key areas: it allowed for the extraction of more than 500,000 tons of additional ore, ensured the safety of personnel and machinery, and facilitated decision-making regarding the zone of influence, thereby minimizing the affected area.
- Obviously before failure the loss of production will be there in between progressive deformation and the failure date but before that the additional extraction of ore is huge, based on building confidence by analyzing the data of real time monitoring instrument. The loss of production for second failure was only 3 days comparing with the previous failure where it was 30 days. In general considering 250 tons of chromite ore production in monsoon, around 7kT production loss having value of more than 9 crore rupees have been saved
- The efficient analysis of zone of influence helped mine management to stop operation only in the core and buffer zone rather than halting the entire mine, as was necessary during the first failure.

7.0 Acknowledgement

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Theme 5: Advancement in Safety, Health, and Environment

NO : 5.1

Identification of personal and occupational injury risk factors in an Aluminum smelter: A case study

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Abstract:

Preventing injuries in high-risk industries like aluminum smelting is essential for maintaining worker safety and operational efficiency. Aluminum smelters are characterized by a complex environment with numerous hazards. These environmental and personnel factors significantly elevate the risk of injuries. Data were gathered from shop floor workers in aluminum smelters, with a total of 600 workers interviewed. Among these, 120 workers had experienced injuries within the past three years. This 1:4 case-control study design enabled a comparative analysis between injured and non-injured workers. Additionally, observations were made to assess workers' exposure to various hazards. The data collection focused on the following risk factors: age, education, number of dependents, hand tools hazard, manual handling hazard, machine-related hazard, and electrical hazard. To determine the association between injury risk factors and injury binary logistic regression was performed. The strength of these associations was further evaluated using the adjusted odds ratio.

The following factors were found to be statistically significantly associated with injury: 25-45 age group (adOR = 0.51, 95% CI = 0.29-0.89, p-value = 0.019), hand tool hazards (adOR = 2.87, 95% CI = 1.74-4.73, p-value < 0.001), manual handling hazards (adOR = 2.63, 95% CI = 1.57-4.40, p-value < 0.001), machine-related hazards (adOR = 4.56, 95% CI = 2.72-7.64, p-value < 0.001), and electrical hazards (adOR = 1.90, 95% CI = 1.12-3.24, p-value = 0.017). However, factors such as education level, number of dependents, and >45 age group were not found to be statistically significantly associated with injury.

Machine-related hazards were identified as having the highest adOR, highlighting the critical need for operational training and the use of personal protective equipment (PPE) when handling hazardous machinery. Identifying injury risk factors in high-risk industries like aluminum smelting is essential for developing effective safety intervention programs. The findings from this study can assist plant management in reducing occupational injuries and fostering a safer work environment.

1. Introduction

Safety is paramount in high-risk industries such as aluminum smelters, where workers are exposed to numerous hazards daily. The importance of safety in these environments cannot be overstated, as it directly impacts both human lives and organizational performance. Aluminum smelting involves processes that expose workers to extreme temperatures, hazardous chemicals, and heavy machinery, making it one of the most dangerous industries globally (Young, 2014). Occupational injuries in such high-risk settings can have severe consequences for both employees and organizations. For workers, injuries can lead to physical pain, psychological trauma, loss of income, and in extreme cases, fatalities. Organizations, on the other hand, face numerous challenges when workplace injuries occur. These include decreased productivity, increased insurance costs, potential legal liabilities, and damage to the company's reputation (Leigh, 2011).

Enhancing safety in high-risk industries requires a proactive approach focused on identifying personnel and occupational injury risk factors, followed by the development and implementation of suitable intervention programs. This systematic method allows organizations to address potential hazards before they result in accidents or injuries. The first step in this process involves conducting a comprehensive analysis to identify factors that contribute to workplace injuries. Once identified, these risk factors can be prioritized. In the present study, an attempt was made to identify injury risk factors from a set of predetermined variables: age, hand tool hazards, manual handling hazards, machine-related hazards, electrical hazards, education level, and number of dependents. Each of these factors has been recognized in previous research as potentially contributing to workplace injuries. Age is a significant factor in occupational injuries, with studies showing that both younger and older workers may be at higher risk for different reasons (Ghosh et al., 2004). Younger workers often lack experience and may engage in more risk-taking behaviors, while older workers may have decreased physical capabilities that make them more susceptible to certain types of injuries (Salminen, 2004). Education level can influence a worker's ability to understand and follow safety procedures, as well as their overall risk perception. Workers with higher education levels may be better equipped to recognize and mitigate potential hazards (Gyekye & Salminen, 2009). The number of dependents a worker has may indirectly affect their risk-taking behavior at work. Workers with more dependents might be more cautious due to increased family responsibilities, but they might also be more willing to take risks for financial reasons.

Hand tool hazards are prevalent in many industrial settings, including aluminum smelters. Improper use of hand tools can lead to various injuries (Senapati et al., 2020). Manual handling hazards, such as lifting, carrying, and moving heavy objects, are a major cause of occupational injuries (Senapati et al., 2020). Machine-related hazards are particularly significant in aluminum smelting operations, where workers interact with large, complex machinery. These hazards can result in severe injuries, including amputations and fatalities if proper safety protocols are not followed (Aneziris et al., 2008). Additionally, Electrical hazards are inherent in the aluminum smelting process due to the use of high-voltage equipment. Electrical injuries can range from minor shocks to severe burns and electrocution, making them a critical safety concern (Kowalski-Trakofler & Barrett, 2007). The present study focuses on identifying the crucial risk factors for occupational injuries and helpful for management. By pinpointing the most significant contributors to workplace accidents and injuries, these studies enable the development of targeted interventions that can improve safety outcomes.

2. Materials and Methods

2.1 Data Collection

The study was conducted at an aluminum smelter located in eastern India, a facility that employed approximately 5,000 workers at the time of data collection. The plant's safety department maintained comprehensive injury records, which served as the primary source of information. A total of 171 workers had experienced unintentional bodily harm requiring either first aid or resulting in at least one lost workday over the past three years. Using a random selection process, 120 injured workers were chosen for the study. To establish a robust unmatched case-control design with a 1:4 ratio, four non-injured workers were then randomly selected for each injured worker in the sample. This approach resulted in a final sample size of 600 participants. Personnel injury risk factors such as age, education, and number of dependents were recorded for each worker. The activities of the shop floor workers were observed, and their levels of hazard exposure were documented. Hazard exposure was assessed based on workers' exposure to hand tools, material handling, machinery, and electricity-related hazards. Personnel factors were categorized to facilitate meaningful comparisons and statistical analysis. Age was divided into three distinct groups: under 25 years, 25 to 45 years, and over 45 years. Education level was classified into two categories: less than graduate degree, and graduate degree or higher. Similarly, the number of dependents was categorized into two groups: fewer than or equal to five dependents, and more than five dependents.

2.2 Statistical Analysis

Logistic regression

Logistic regression is a statistical method used to analyze and model the relationship between a binary outcome variable and one or more predictor variables. One of the key outputs of logistic regression is the odds ratio, which provides a measure of the association between an explanatory variable and the outcome. The odds ratio represents the change in odds of the outcome for a one-unit increase in the predictor variable, holding all other variables constant. An odds ratio greater than 1 indicates that as the predictor variable increases, the odds of the outcome occurring also increase. Conversely, an odds ratio less than 1 suggests that as the predictor variable increases, the odds of the outcome occurring decrease. This interpretation makes odds ratios particularly useful in risk assessment and decision-making processes, as they provide a clear, quantifiable measure of how changes in predictor variables affect the likelihood of the outcome of interest (Szumilas, 2010).

3. Results and Discussion

In the present study, we employed logistic regression to identify factors significantly associated with occupational injuries in an aluminum smelting plant. This statistical approach is particularly suitable for analyzing binary outcome variables, such as the occurrence or non-occurrence of an injury. Table 1 shows the percentage of injured workers for each group of explanatory variables.

Table 1: Percentage of injured workers for each group of explanatory variables

Factors	Percentage of injured workers
Age	
<25 years	65.83%
25-45 years	30.83%

>45 years	3.34%
Education	
Less than graduate-level	49.16%
More than or equal to graduate-level	50.84%
Number of dependents	
Less than or equal to five	63.33%
More than five	36.66%
Hand tools-related hazard	
Exposed	37.5%
Not Exposed	62.5%
Material handling-related hazards	
Exposed	37.5%
Not Exposed	62.5%
Machinery-related hazard	
Exposed	25.83%
Not Exposed	74.14%
Electricity-related hazards	
Exposed	27.5%
Not Exposed	72.5%

The result of binary logistic regression is shown in Table 2. Results indicate that the 25-45 age group is significantly associated with a lower risk of injury compared to other age groups (adOR = 0.51, 95% CI = 0.29-0.89, p-value = 0.019). This finding suggests that workers in this age range have approximately half the odds of experiencing an injury compared to those less than 25 years old. This protective effect could be attributed to a combination of physical capability and accumulated experience. Workers in this age group may have reached a balance between the physical resilience of youth and the wisdom gained from years of experience (Salminen, 2004). Interestingly, the age group over 45 did not show a statistically significant association with injury. The lack of significance in our study might be due to skewed data, as only 3.34% of injured workers fall into this group.

Table 2: Association of individual and occupational factors with occupational injury: adOR and 95% CI

Factors	adOR[#]	95%CI	p-value
Age			
<25 years			
25-45 years	0.513	0.294-0.896	0.019
>45 years	1.077	0.256-4.527	0.919

Education	1.143	0.696-1.878	0.598
Number of dependents	0.921	0.532-1.594	0.769
Hand tools-related hazard	2.871	1.742-4.734	<0.001
Material handling-related hazards	2.637	1.578-4.405	<0.001
Machinery-related hazard	4.567	2.278-7.645	<0.001
Electricity-related hazards	1.124	3.242	0.017

Adjusted odds ratio

The noteworthy findings of our study relate to the various hazards present in the aluminum smelting environment. All four hazard types examined - hand tool hazards, manual handling hazards, machine-related hazards, and electrical hazards were found to be significantly associated with increased injury risk.

Workers exposed to hand tool hazards had nearly three times the odds of experiencing an injury compared to those not exposed (adOR = 2.87, 95% CI = 1.74-4.73, p-value < 0.001). This substantial increase in risk underscores the importance of proper training in tool use and maintenance, as well as the need for ergonomic tool design. Similarly, exposure to manual handling hazards was associated with more than double the odds of injury (adOR = 2.63, 95% CI = 1.57-4.40, p-value < 0.001). This finding aligns with the well-established link between manual handling tasks and musculoskeletal injuries in industrial settings (Marras et al., 2000). The result emphasizes the need for proper lifting techniques, mechanical aids, and ergonomic workplace design to mitigate these risks.

Of all the factors examined, machine-related hazards showed the strongest association with injury risk. Workers exposed to these hazards had more than four and a half times the odds of experiencing an injury compared to those not exposed (adOR = 4.56, 95% CI = 2.72-7.64, p-value < 0.001). This finding highlights the critical importance of machine safety in aluminum smelting plants. The high odds ratio suggests that interventions targeting machine-related hazards could have a substantial impact on overall injury rates. This result is consistent with previous studies that have identified machinery as a major source of severe injuries in industrial settings (Aneziris et al., 2008). Exposure to electrical hazards was associated with nearly double the odds of injury (adOR = 1.90, 95% CI = 1.12-3.24, p-value = 0.017). While the odds ratio for electrical hazards is lower than for other hazard types, the potential severity of electrical injuries makes this a crucial area for safety interventions. The significance of this factor aligns with the known risks of electrical work in industrial settings, particularly in environments with high-voltage equipment like aluminum smelting plants (Kowalski-Trakofler & Barrett, 2007).

Contrary to some previous research, our study did not find statistically significant associations between injury risk and education level or number of dependents. This lack of significance does not necessarily mean these factors are unimportant, but rather that their influence may be less pronounced in this specific context. The number of dependents sometimes used as a proxy for a worker's level of family responsibility, also showed no significant association with injury risk.

Based on the odds ratios obtained from our logistic regression analysis, we can identify the most crucial factors for targeted safety interventions. Machine-related hazards emerge as the most critical area for improvement, given the high odds ratio associated with this factor. Implementing comprehensive machine guarding systems, enhancing operator training programs, and ensuring strict adherence to lockout/tagout procedures could significantly reduce injury risk. Hand tool and manual handling hazards also present significant opportunities for risk reduction. Interventions in these areas might include ergonomic tool design, regular tool maintenance programs, training in proper handling techniques, and the introduction of mechanical aids for heavy lifting tasks. While electrical hazards showed a lower odds ratio compared to other hazard types, the potential severity of electrical injuries warrants serious attention. Enhancing electrical safety protocols, improving insulation and grounding systems, and providing specialized training for workers dealing with electrical systems could help mitigate these risks.

4. Conclusion

This study has identified several crucial risk factors for occupational injuries in an aluminum smelting plant, with machine-related hazards emerging as the most significant concern. The findings provide a strong evidence base for developing targeted safety interventions. By focusing on the most crucial factors identified through odds ratios particularly machine-related, hand-tool, and manual handling hazards, plant management can allocate resources more effectively to create a safer work environment. Furthermore, the protective effect observed in the 25-45 age group suggests potential benefits in leveraging the experience of these workers in safety programs. Ultimately, the insights gained from this logistic regression analysis offer a valuable tool for enhancing occupational safety in high-risk industries. By addressing the identified risk factors, organizations can work towards reducing injury rates, improving worker well-being, and enhancing overall operational efficiency.

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NO : 5.2

Possible remedies on musculoskeletal disorders of HEMM operators under smart mining technologies

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Abstract:

Introduction: HEMM Operators frequently experience musculoskeletal diseases (MSDs), which are brought on by extended sitting, unpleasant postures, and repetitive movements. These conditions can cause serious physical discomfort as well as long-term health effects.

Objective: The present study aimed at evaluating the prevalence of work-related musculoskeletal disorders among HEMM Operators of mining sector.

Method: The study was conducted on 10 HEMM Operators (age:45.0±9.88years) to evaluate their postural stress using a modified Nordic musculoskeletal questionnaire, Body Part Discomfort (BPD) scale, Ovako working posture analysis system (OWAS),and Rapid Upper Limb Assessment (RULA).

Results: Analyzing the data, we found that while 50% of the HEMM Operators reported about musculoskeletal discomfort in lower back with BPD Scale 5.1, 50% of participant have buttock pain with BPD scale 6.2. The lower back, neck, and shoulder were the area most commonly afflicted. An uncomfortable seated position was the main risk factor for back and neck pain.

Applicability: The study on HEMM Operators' ergonomic challenges applies directly to smart mining technologies. Issues like prolonged sitting, repetitive motions, and poor postures affect mining operators and monitoring personnel. Tools like the BPD scale, OWAS, and RULA can assess and mitigate musculoskeletal lrisks. Implementing ergonomic interventions based on these findings can enhance health, safety, productivity, and operational efficiency in smart mining.

Conclusion: HEMM operators in the mining sector face substantial musculoskeletal discomfort, particularly in the lower back, neck, and shoulders, attributable to prolonged sitting and poor posture. Tools such as the BPD scale, OWAS, and RULA are essential for assessing and mitigating the risks. Implementing ergonomic interventions informed by these findings is crucial for improving health, safety, and productivity in smart mining operations.

Keyword: HEMM Operators, musculoskeletal pain, BPD scale, RULA.

1.Introduction:

Work-related musculoskeletal disorders (WRMSDs) involve repeated movements, uncomfortable postures, aggressive efforts, and other physical stressors experienced at work that are usually associated with different types of illnesses. Among other regions, WRMSDs can have an impact on the back, neck, shoulders, arms, wrists, hands, hips, and legs. Examples of musculoskeletal disorders include Rheumatoid arthritis, Tendonitis, Carpal tunnel syndrome, Herniated disc, Scoliosis, Sprains and strains, Osteoporosis.

Work-related musculoskeletal diseases (WRMSDs) can be caused by a number of factors, like without enough rest or inadequate recovery time, performing repetitive tasks can cause muscle tension, tiredness, and pressure on the musculoskeletal system. Long-term holding of unpleasant or incorrect positions can put unnecessary strain on the muscles and joints, resulting in WRMSDs. When bending, pushing, tugging, or carrying heavy objects, using excessive force might strain the musculoskeletal system and raise the risk of WRMSDs. WRMSDs can be brought on by prolonged exposure to hand-arm or whole-body vibrations, such as those that come with using power tools or working around heavy machinery. WRMSDs can develop as a result of stress on the musculoskeletal system caused by doing tasks that require uncomfortable or unnatural movements. Working in a setting with poor ergonomic design, such as one with misaligned workstations, uncomfortable seating, or insufficient tools and equipment, can increase the risk of developing WRMSDs.

WRMSD risk can be increased by using improper lifting techniques, carrying significant loads without appropriate training, or using too few mechanical aids. WRMSDs may be brought on by a lack of training in safe work procedures, ergonomics, and correct lifting techniques. Without variation or breaks, regularly doing tedious manual handling jobs can cause muscle tension and fatigue, which raises the risk of WRMSDs. The musculoskeletal system can become overstressed through insufficient rest times or from not providing enough time for recuperation between tasks, which makes it more vulnerable to WRMSDs. Occupational musculoskeletal disorders (WRMSDs) can affect people differently, as well as the workplace. Common impacts include the following:

WRMSDs frequently cause persistent pain, discomfort, and stiffness in the muscles, joints, tendons, or ligaments that are afflicted. Individual's quality of life and capacity for carrying out daily tasks, both at work and at home may be greatly impacted by this.

WRMSDs may result in less efficiency and productivity at work. An individual's capacity to accomplish jobs effectively and efficiently might be hampered by pain and physical constraints, which can result in lower production and more mistakes.

WRMSD sufferers could need time off work for doctor's appointments, treatments, or recuperation. People who experience chronic pain and discomfort may need to take time from work to treat their symptoms or recuperate after flare-ups, which can increase absenteeism.

Work restrictions or the necessity for task adjustments may be necessary as a result of severe WRMSDs. Some people might find it challenging to complete specific jobs or need accommodations to keep functioning. Due to the influence of WRMSDs, people may occasionally need to switch job responsibilities or even quit their current jobs.

Physical limits and ongoing pain can take a serious emotional and psychological toll. Due to their condition and the restrictions it places on their everyday life and employment, people may suffer increased stress, irritation, worry, and even depression.

Due to the requirement for medical consultations, diagnostic testing, treatments, medications, physical therapy, and potential surgical procedures, WRMSDs can result in higher healthcare expenses. This may have an effect on the patient as well as the healthcare system as a whole.

Workers' compensation claims resulting from severe WRMSDs may have a costly impact on employers. Medical bills, disability benefits, and probable legal fees are all possible components of compensation claims.

HEMM operators significantly influence the nation's citizens' access to essential resources through efficient management of heavy machinery. Musculoskeletal diseases among HEMM operators can profoundly affect both their health and the operational efficiency of heavy equipment fleets. Upadhyay et al. (2021) conducted a case-control study on WBV exposure and MSDs among dumper operators, revealing a higher prevalence of upper and lower back pain, knee, and leg pain among operators compared to office workers. Their study called for regular evaluation and reduction of WBV exposure to mitigate MSD risks. According to Dev and Gangopadhyay (2008), low back pain (LBP) emerged as the most predominant musculoskeletal disorder (MSD), demonstrating a highly significant association with occupational exposure ($P<0.001$). This could lead to a reduced productivity, increased absenteeism, and potential disruptions in the operation of heavy equipment fleets.

2. Significance of studying WRMSDs in HEMM operators:

HEMM (Heavy Earth Moving Machinery) operators are essential to our civilization because they operate machinery crucial for mining, construction and infrastructure projects, facilitating efficient earth-moving tasks. By contributing to development and maintenance projects, they ensure that communities have the necessary infrastructure for growth and connectivity. HEMM operators prioritize safety protocols, provide operational expertise, and engage with local communities, enhancing project outcomes. Their role supports sustainable development, drives economic progress, and enhances overall efficiency in various sectors of our society.

Studying work-related musculoskeletal disorders (WRMSDs) among HEMM operator is significant for several reasons:

Understanding the causes, risk factors, and impact of WRMSDs on HEMM operators' health and well-being is essential. It helps identify preventive measures and interventions to mitigate the risk of developing musculoskeletal disorders. By promoting HEMM operator health, we can enhance their overall quality of life, reduce pain and discomfort, and improve job satisfaction.

HEMM operators face specific occupational hazards related to prolonged sitting, repetitive motions, and exposure to vibrations. By studying WRMSDs, we can identify ergonomic issues, evaluate workstations, assess seating arrangements, and recommend ergonomic modifications to minimize the risk of injuries. This helps create a safer working environment for HEMM operators and reduces the likelihood of work-related musculoskeletal disorders.

WRMSDs can have a direct impact on the functioning and efficiency of heavy earth moving machinery (HEMM) operations. If a significant number of HEMM operators are affected, it can lead to workforce shortages, reduced operational quality, and disruptions in project timelines. By studying and addressing WRMSDs among HEMM operators, we can minimize these impacts, maintain reliable machinery operations, and ensure the smooth progress of construction and infrastructure projects.

WRMSDs can result in increased healthcare costs, workers' compensation claims, and productivity losses for mining companies. Understanding the economic implications of these disorders can help decision-makers recognize the financial benefits of implementing preventive measures. By investing in HEMM operator health and ergonomics, companies can potentially reduce costs associated with injuries, absences, and turnover.

Research on WRMSDs among HEMM operators helps identify effective preventive strategies and interventions. This may involve training programs, ergonomic adjustments, exercise regimens, rest breaks, and policies promoting healthy work practices. Implementing these measures can reduce the occurrence and severity of musculoskeletal disorders, improving the long-term health and sustainability of HEMM operators' careers.

We can improve operator health and well-being by increasing workplace safety and ergonomics, maintaining effective heavy earth moving machinery (HEMM) operations, considering economic ramifications, and by developing efficient preventive measures through investigating WRMSDs among HEMM operators. The end result of such study is the enhancement of construction and infrastructure projects as a whole as well as healthier and more sustainable working conditions for HEMM operators.

3. Review of literature:

The study of musculoskeletal disorders (MSDs) among Heavy Earth Moving Machinery (HEMM) operators under smart mining technologies has been extensive and multifaceted, addressing various ergonomic and occupational health challenges. Ergonomic interventions, such as Ergonomic Work Rest Scheduling (EWRS), have been pivotal in enhancing productivity and reducing metabolic energy costs for miners, as evidenced by Netai Chandra Dey et al. (2017). Their research demonstrated a significant decrease in Average Working Heart Rate (AWHR), Net Cardiac Cost (NCC), and Relative Cardiac Cost (RCC) following the implementation of EWRS, leading to reduced physiological job stress and increased efficiency. Whole-body vibration (WBV) remains a critical occupational hazard, particularly in the mining industry. Duartea et al. (2020) highlighted the adverse health effects of prolonged WBV exposure, such as low back pain and spinal degeneration. Their systematic review identified various mining equipment contributing to WBV and emphasized the need for improved cabin design and seating to mitigate these risks. Similarly, Atal et al. (2020) investigated WBV exposure among dumper operators in Indian opencast coal mines, finding that most operators experienced vibration levels exceeding the Health Guidance Caution Zone (HGCZ) as per ISO 2631-1:1997 standards. Their study employed Bayesian Network modeling to predict WBV risk factors and prioritize human health risk assessment, underscoring the need for targeted interventions. Sandeep Kumar et al. (2020) evaluated WBV exposure in operators of seventeen types of HEMM, noting severe vibration levels in specific machinery such as shovels, loaders, drills, graders, and water sprinklers. Their findings indicated that the vertical (Z-axis) direction was the most prominent axis for WBV, necessitating ergonomic improvements in machinery design and operator seating. Kaviraj Ramar et al. (2021) further explored the physiological impact of WBV on dumper operators during different operational phases. Their research revealed significant discomfort during material loading and unloading tasks, with WBV levels frequently exceeding HGCZ limits. The study highlighted the combined effect of WBV and asymmetric posture, leading to increased musculoskeletal strain and the need for frequent posture changes. Tiemessen et al. (2007) developed an intervention program focusing on behavior change to reduce WBV exposure among vehicle drivers. Their approach, based on the ASE model, aimed to enhance knowledge and skills related to WBV determinants, thereby reducing exposure and associated lower back pain over time. Bekal Kar (2023) utilized structural equation modeling (SEM) to analyze the influence of personal, habitual, and work-related factors on the occurrence of work-related musculoskeletal disorders (WRMSDs) among dumper operators. The study found significant correlations between WRMSDs and personal and work-related factors, highlighting the need for comprehensive ergonomic interventions. Vanerkar et al. (2007) conducted a cross-comparison of WBV exposure in operators across different types of metalliferous mines. Their findings indicated that WBV exposure was not dependent on the type of mine but rather on the working conditions and type of HEMM in operation, stressing the importance of selecting equipment based on vibration hazard potential. Mandal and Sishodiya (2023) emphasized the need for pre-introduction vibration surveys of mining equipment to ensure safety standards. Their research revealed significant health risks associated with high WBV levels, particularly in backhoes and shovels, advocating for stringent procurement and deployment guidelines. Upadhyay et al. (2021) conducted a case-control study on WBV exposure and MSDs among dumper operators, revealing a higher prevalence of upper and lower back pain, knee, and leg pain among operators compared to office workers. Their study called for regular evaluation and reduction of WBV exposure to mitigate MSD risks. Rahul Upadhyay et al. (2024) introduced a fuzzy-based approach to prioritize safety measures for reducing MSD risks among dumper operators. Their study identified poor work posture, WBV exposure, and inadequate seat design as significant risk factors and recommended practical interventions like ergonomic seat design and scheduled maintenance practices. Sharma et al. (2020) provided a comprehensive review of WBV exposure effects on HEMM operators, advocating for long-term monitoring to better understand and mitigate the adverse health effects. Their findings aligned with the need for sustained ergonomic interventions to ensure operator safety. Lastly, Anand Sharma et al. (2021) assessed WBV exposure among HEMM operators, emphasizing the biochemical and biodynamic alterations caused by prolonged exposure. Their study reinforced the critical need for ergonomic assessments and interventions tailored to operator-specific parameters and work conditions.

The purpose of this paper revie is to systematically evaluate and address musculoskeletal disorders among HEMM operators, with the goal of improving HEMM operators' health, safety, and job satisfaction, as well as enhancing the overall functioning of mining sector. Assessing, detecting, analyzing, and recommending strategies to address musculoskeletal diseases among HEMM operators are among the goals of this research. The initiative aims to improve the overall performance and quality of the mining sector, as well as promote the health, safety, and job satisfaction of HEMM operators.

4. Methods and materials:

4.1 Subjects: Ten male HEMM operators (age: 45.0±9.88 years) were taken as subjects from one mine of Asansol, West Bengal. The subjects were free from any chronic diseases and having at least six months of experience in the

HEMM operating job. Subjects were categorized into two groups based on years of work experience (0-5 years of work experience and >5 years of work experience).\

Picture: HEMM Operators

4.2 Daily work schedule: They work 6 hours daily. Attendance and job allocation require an additional 2 hours with a total an 8-hours commitment.

4.3 Anthropometric parameters: The height and weight of the subjects were measured using a Martin anthropometer and a digital weighing machine, respectively. The body mass index (BMI) (Weisell et al., 2002) of all subjects was calculated using the following formula:

$$BMI = \text{Weight in Kg}/\text{Height in m}^2$$

4.4 Questionnaire Study: A modified Nordic musculoskeletal questionnaire was applied to evaluate the postural stress of HEMM operators (Kourinka et al., 1987). The questionnaire comprised of a series of questions with multiple-choice responses regarding working conditions and physiological health. Working environment and duration of work of the workers was assessed using the questionnaire.

4.5 Subjective rating of discomfort: The discomfort/pain intensity in different body parts were evaluated by Body Part Discomfort (BPD) scale (Jacquelin et al., 1994). This scale is marked as '1' to '10' where '1' indicates 'noticeable discomfort' and '10' indicates 'intolerable discomfort'. A 'zero' in the scale means no discomfort at all.

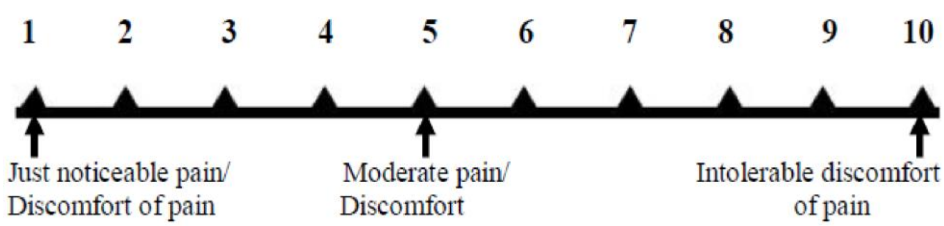


Figure: BPD Scale

4.6 Working posture analysis: Still photograph and video recordings of different working activities of the HEMM operators were taken. Various methods of working posture analysis were tested. Ovako working posture analysis system (OWAS) (Karhu et al., 1977) was applied to evaluate the postural stress of the workers. Rapid upper limb assessment (RULA) (McAtamney and Corlett, 1993) was done to evaluate the postural stress on the upper extremities of the workers.

4.7 Statistical analysis: Data were represented as mean ± standard deviation. Chi square test was done to compare association between pain in different body parts and years of work experience. Statistical significance was considered as $p < 0.05$

5. Results:

Table: 1: Anthropometric parameters of the HEMM operators (N=10)

Age (Years)	Weight (Kg)	Height (m)	BMI (Kg/m^2)
45.0±9.88	62.4±8.66	1.64±0.66	23.07±3.58

Table: 2: Discomfort/pain in different body parts of the HEMM operators (N=10)

Pain in different body parts	Number of subjects (N=10)	Percentage (%)
Head	01	10
Neck	04	40
Shoulder	04	40
Arm	03	30
Upper back	03	30
Lower back	05	50
Leg	03	30
Thigh	02	20
Feet	01	10
Buttock	05	50

Figure: 1: Body parts discomfort (BPD) scaling of different body parts of HEMM operators (N=10)

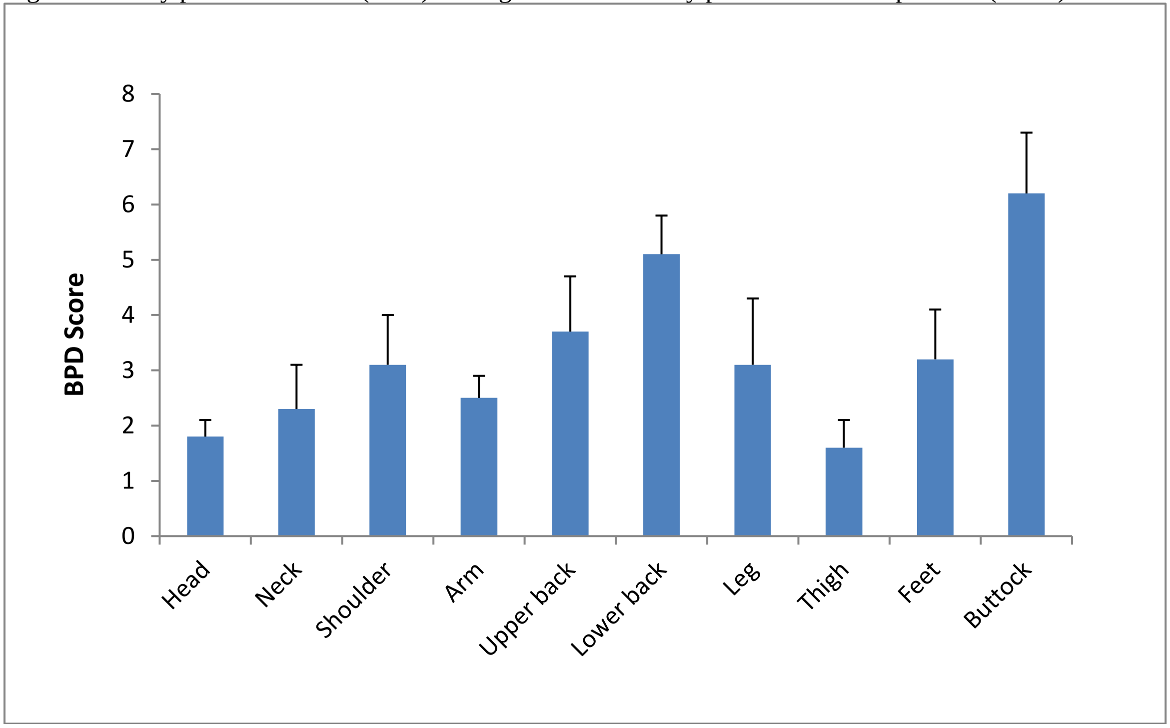
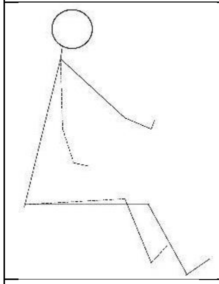
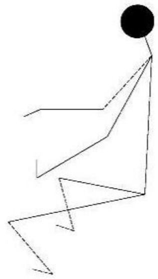
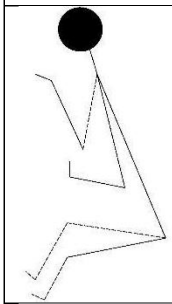
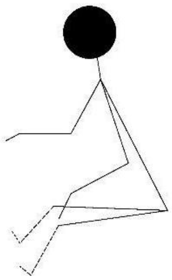
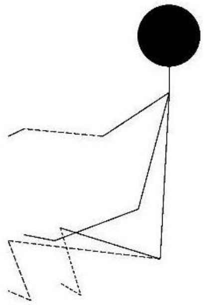


Table: 3: Working postural analysis by Ovako working posture analysis system (OWAS) and Rapid upper limb assessment (RULA) (N=10)

Stick Diagram	Owas Position	Owas Score	RULA Score	Rula Remark
	2111	5	7	Very high risk, changes are required immediately
	1111	4	7	Very high risk, changes are required immediately
	1211	5	5	Medium risk, investigation and changes are required.
	1111	4	7	Very high risk, changes are required immediately
	1111	4	7	Very high risk, changes are required immediately

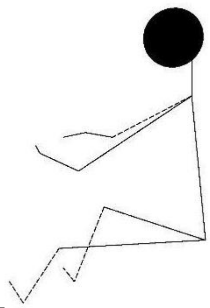
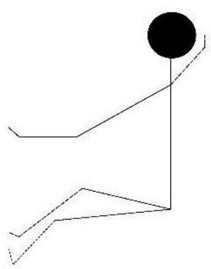
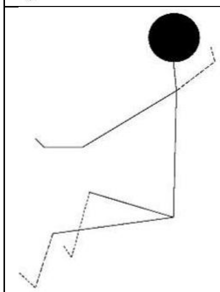
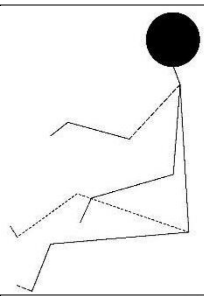
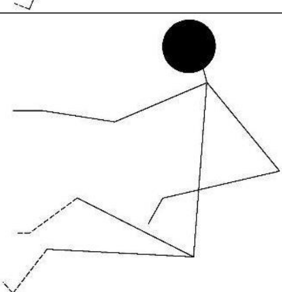
	1111	4	7	Very high risk, changes are required immediately
	1111	4	7	Very high risk, changes are required immediately
	1111	4	7	Very high risk, changes are required immediately
	1111	4	7	Very high risk, changes are required immediately
	1111	4	7	Very high risk, changes are required immediately

Table 4: Relation between pain intensity in different body parts and years of experience of the participants (N=10)

Pain in different body parts	Response	0-5 years (n=06)	>5 years (n=04)	Chi-square	p value
Head	Yes	1	0	8.28	0.003*

	No	5	4		
Neck	Yes No	4 2	0 4	0.47	0.49
Shoulder	Yes No	2 4	2 2	0.05	0.81
Arm	Yes No	2 4	1 3	0.06	0.80
Upper back	Yes No	3 3	0 4	0.17	0.67
Lower back	Yes No	4 2	1 3	3.87	0.04*
Leg	Yes No	2 4	1 3	3.91	0.04*
Thigh	Yes No	2 4	0 4	0.61	0.43
Feet	Yes No	1 5	0 4	0.02	0.88
Buttock	Yes No	4 2	1 3	8.28	0.003*

Note:* $p<0.05$

Table 1: The HEMM operators in the study had a wide age range, with an average age of 45.0 years (SD = 9.88). They also have variation in body weight, with an average weight of 62.4 kg (SD = 8.66). Heights varied within the sample, with an average height of 1.64 meters (SD = 0.66). The calculated average BMI was 23.07 kg/m² (SD = 3.58), indicating diversity in body composition among the participants.

Table 2: The table represents the number and percentage of HEMM operators who experience the discomfort or pain experienced in different body parts. The findings indicate that 10% of individuals reported discomfort in their head, 40% in the neck, 40% in the shoulder, 30% in the arm, 30% in the upper back, 50% in the lower back, 30% in the leg, 20% in the thigh, 10% in the feet, and 50% in the buttocks. Finally, lower back pain and the buttocks discomfort had the highest percentage of participant (50%) discomfort.

Figure 1: The graph illustrated Body Part Discomfort (BPD) scores for various body parts, ranging from relatively low discomfort in the head (1.8) to significant discomfort in the buttock region (6.2). It demonstrates varying levels of discomfort across different body areas, with the lower back (5.1) and upper back (3.7) showing notable discomfort as well. The lower back follows with a higher score of 5.1, indicating a significant level of discomfort in that area. Lastly, the buttock region shows the highest BPD score on the graph, with a value of 6.2. This high score suggests a substantial level of discomfort in that area.

Table 3: This table provides a comprehensive overview of different HEMM operators positions, including, stick diagrams representing body postures, OWAS scores ranging from 4 to 5, RULA scores which are 5-7, and recommendations to improve ergonomics and reduce the risk of discomfort or injuries.

Table 4: This table indicates the relation between pain intensity in different body parts and years of experience of the participants. Significant association was found between pain intensity in leg, lower back and buttock and an increase in years of work experience.

6.Discussion:

Awkward and prolonged working positions are closely associated with the onset of musculoskeletal disorders (MSD) (Dev & Gangopadhyay, 2008). Musculoskeletal disorders (MSDs) can manifest in many ways based on a person's physical development, health, and physical and mental burden.

In order to have a more thorough picture of the issue, future research should look into the same risk variables in non-respondents or other occupational groups. It's also likely that people with pre-existing issues were more willing to come forward and participate in the current study. The results also showed that a large proportion of these complaints have been for more than 1 year, with many participants experiencing prolonged discomfort of five years or more. The majority of people who experienced discomfort could still work, though. Overall, the findings on how this discomfort affected work and recreational activities as well as the statistics of medical care received were consistent in reflecting a generally persistent but moderate-to-mild nature of the symptoms, and in some cases disorders.

Future studies may consider a longitudinal or prospective approach to examine different cohorts of workers over a period of time, in order to determine whether their pains were started before or after they join this line of work. The previous study, it was observed that the majority of participants experienced lower back and neck pain. However, in the present study, 50% of HEMM operators reported lower back pain with BPD score 5.1 indicating a significant prevalence. Additionally, there was an increase in buttock pain, with 50% of the subjects experiencing discomfort in that area with BPD scores 6.2.

The high prevalence rates of musculoskeletal pain in the knee, back, neck, and shoulder regions may be linked to work-related issues that place undue strain on various body parts. The numbers for the self-perceived risk variables matched the different types of pain well. This could indicate that the participants had a solid understanding of the potential strain or stress that the physical risk factors might impose on the body, or it could be a good projection of the actual biomechanical exposure of this activity. The analysis of stepwise logistic regressions further confirms this notion, as prolonged sitting was shown to be the only significant high-risk factor identified by OWAS and RULA. HEMM operators work for 6 hours per day. The impacts of low-load continuous vibration may also cause more "creep" in the soft tissues, according to biomechanical understanding and previous research evidence. Prolonged sitting increases biomechanical strain on the intervertebral discs in the lumbar area (Chaffin et al., 1999; Magnusson et al., 1996). These elements would probably speed up the degenerative process in the lumbar spine. Additionally, it is noted that when the spine is stressed axially for an extended length of time, the back muscles and discs become compressed (Lyons, 2002). If there is any abrupt applied force, such as a rapid halting of the car, there may be an increased chance of suffering major spinal injuries because they are not in a better position to support bigger weights. Additionally, static muscle activity in the cervical and lumbar spine, as well as in the major joints such the shoulders, hips, and knees, are needed for sustained posture when using the steering wheel and control pedals. The results of this study indicate that HEMM operators work constantly for a significant amount of time, and that their heavy workload may have contributed to the onset of buttock, lower back, arm, leg pain.

7. Conclusion:

HEMM operators' lengthy shifts, uncomfortable seating for extended periods of time, and high levels of stress at work all contribute to musculoskeletal problems, especially in the buttocks, lower back, arms, and legs, which negatively affects their health and overall productivity.

8. Recommendation

The discomfort and pain experienced by HEMM operators in various body parts necessitate interventions to reduce the risk of musculoskeletal disorders (MSDs) among them. To address this issue and enhance HEMM operators' wellbeing, recommendations include offering thorough ergonomic training programs to teach operators optimal lifting techniques and posture. In HEMM, installing seat cushions and lumbar support can increase comfort and ease pressure on the buttocks and lower back. Regular pauses and the use of stretching exercises that target particular muscle areas can reduce stress and discomfort. While routine health checks can reduce the MSDs and delay onset of fatigue.

9. Limitations:

The present study has a number of limitations. The study was limited to only male respondents. This study was cross-sectional, so it is impossible to determine cause and effect. Since exposures and outcomes are typically examined concurrently in study participants, self-report bias is a possible issue in many job strain studies. Further finite element analysis may prove to be a better solution to these MSD-based problems. The information supplied here is based on sampling of only one mine; however, collection of more data can provide better and precise result.

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NO : 5.3

Development of a Multi-Channel Cost-effective Arduino-based System for Segmental Whole-Body Vibration Assessment

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Abstract:

Background: Prolonged exposure to whole-body vibration (WBV) is a recognized risk factor for musculoskeletal disorders (MSDs). There is a need for efficient, accessible methods to measure and analyse WBV.

Aim of the study: This study aims to develop a cost-effective, Arduino-based, multi-channel, multi-point vibration analysis system to assess WBV exposure.

Method: The prototype system utilizes ADXL-345 accelerometers and an Arduino Uno microcontroller, prioritizing affordability and ease of implementation. Seven accelerometers capture multi-segmental WBV data to investigate vibration transmission across different body regions. Data is stored on an SD card or transferred through Wi-Fi for further analysis.

Result: The system successfully captured and stored comprehensive WBV data, facilitating detailed analysis of vibration exposure patterns across various body regions.

Conclusion: This research presents an accessible, user-friendly tool for assessing WBV, addressing a critical need in occupational health research and practice. The system's affordability and ease of implementation make it suitable for various settings.

Keywords:*Whole-body vibration, Multi-channel, Body segmental, cost effective, Arduino based.*

1. Introduction:

Whole-body vibration (WBV) exposure is a prevalent concern in occupational settings, posing various health risks depending on the duration, intensity, and frequency of the vibration. While WBV may have potential benefits in certain contexts, prolonged or high-intensity exposure can adversely affect the musculoskeletal system. Research has shown a strong correlation between chronic WBV exposure and an elevated risk of musculoskeletal disorders (MSDs), such as low back pain, muscle fatigue, and discomfort (Bovenzi & Gosselin, 2003). Furthermore, high-intensity WBV increases compression forces on vertebral discs, potentially leading to spinal disc degeneration and related back problems. Long-term WBV exposure has also been linked to circulatory, digestive, and nervous system complications (Mansfield, 2004). A systematic review by Shaikh et al. (2022) identified significant risk factors for WRMSDs, including exposure to whole-body vibration, poor posture, repetitive movements, lifting tasks, and applied force/load, along with personal factors such as age, BMI, experience, and gender. The studies have found that the body parts most affected by musculoskeletal disorders includes the neck, shoulder, upper back, lower back, knees, pelvis, and abdomen (Demissie et al., 2024; Rahman & Hossen, 2018). Thus, accurately measuring WBV is crucial for understanding and mitigating its adverse health effects. Developing numerical representations and predicting vibration features through analytical studies can be challenging in empirical scenarios. The advent of the piezoelectric accelerometer, pioneered by Bruel and Kzear (Denmark), Columbia Research Laboratories (Woodlyn), Gulton Manufacturing (Metuchen), Endevco (Pasadena), and Kistler Instruments (Buffalo), marked a significant milestone. Brüel & Kjær's release of their first commercial piezoelectric accelerometer (model 4303) in 1945, followed by the first shear accelerometer in 1972 (model 8307), and the introduction of a LASER transducer based on the Doppler Effect for non-velocity measurement in 1980 (Nakamura et al., 2018), set the foundation for modern vibration measurement. Various accelerometers like ADXL-335, ADXL-345, and ADXL-555 are now commonly used for vibration measurement. Companies like Adafruit and SparkFun have developed a wide range of accelerometer boards, piezoelectric sensors, gyroscopes, and Arduino-based vibration sensors (Liu et al., 2017).

Measuring segmental whole-body vibration in vehicle operators is a crucial research task for understanding vibration generation, propagation, and its impact up to the head (Linessio et al., 2016). This comprehensive review underscores the importance of WBV measurement in evaluating its adverse health effects, especially among vehicle operators. Advances in accelerometer technology and sensor integration allow for deeper exploration of WBV exposure and its implications for musculoskeletal health. Continued innovation in WBV measurement and analysis methodologies is essential for enhancing occupational safety and mitigating the risks associated with prolonged vibration exposure. This paper focuses on measuring segmental whole-body vibration at multiple locations simultaneously, using a setup comprising multiple ADXL-345 triple-axis accelerometers, a Wi-Fi enabled Arduino Uno, an I2C multiplexer, an RTC module, an SD card module, an SD card, and a GPRS GSM module with a SIM card.

2. Methodology and Design:

2.1 Methodology: Vibration is a ubiquitous phenomenon encountered in various activities such as operating heavy machinery, including tractors, forklifts, mining machinery, and construction equipment, which expose drivers to whole-body vibration (WBV) due to constant movement over uneven terrain. Pilots and passengers experience WBV during take-off, landing, and turbulence. Activities like running, jumping, or using exercise equipment like treadmills or vibrating plates can also induce WBV, characterized by the oscillatory motion of an object relative to its equilibrium state (Mansfield, 2004). This study outlines the methodology and design considerations for developing an Arduino-based, multi-point accelerometer system capable of measuring vibration and acceleration along three axes (X, Y, and Z). This system can measure vibration data at seven different locations simultaneously.

Understanding the fundamental principles and operation of the components used in the system is crucial for its successful implementation. The basic scheme involves integrating the Adafruit ADXL-345 accelerometer with an Arduino microcontroller to capture vibration and acceleration data. The Arduino processes the data, stores it on an SD card module, and sends the data to an external server via the internet through a GSM module for real-time monitoring and analysis.

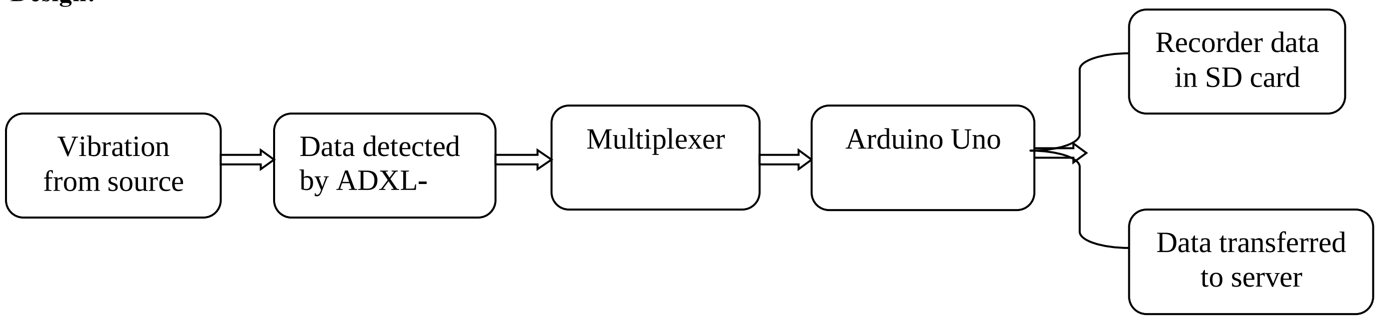
The development and implementation of an Arduino-based, multi-channel, multi-point accelerometer system for WBV and acceleration measurement require a systematic approach, including component selection, system specification, and methodological considerations. By adhering to established principles and design practices, the resulting system can effectively monitor and analyse vibration parameters in various applications, contributing to an enhanced understanding and management of dynamic motion phenomena.

2.2 Specification: The transducer employed is the Adafruit ADXL-345 Accelerometer, capable of measuring frequencies up to 3200 Hz and acceleration within a range of 10000g (both powered and unpowered) along any axis. The system boasts an accuracy of ±4.6% and operates under varying conditions with an operating voltage of 2 to 3.6V and an operating temperature range of -40°C to +85°C. Power is supplied at +5V, with the overall weight of the system at 450 grams.

Specification:

- Transducer: Adafruit ADXL-345 Accelerometer.
- Micro Controller: Wi-Fi enabled Arduino Uno
- Time Record: Real Time Clock (RTC) Module.
- Data storage: SD card and SD card module
- Data transfer: GPRS GSM module/ Wi-Fi enabled Arduino Uno
- Parameters: Time, acceleration.
- Measuring range: Frequency 3200Hz, Acceleration unpowered 10000g, Powered 10000g (any axis).
- Accuracy: ± 4.6%.
- Operating condition: Operating Voltage 2 to 4.5V, Operating Temperature -40ºC to +85ºC.
- Power supply: +5V.

2.3 Design:



ADXL-345 data senses through a sensor and microcontroller process the data and store it to a SD card via SD card module as well as send the data to server through GSM module or Wi-Fi. Finally, the raw data from SD card or from server can be taken for further analysis. The recorded data then analysed to calculate the RMS acceleration values.

2.4 Modelling of the System:

- Connection with Arduino and multiplexer.
- Making serial communication between ADXL-345 accelerometer sensors and Arduino Uno via Multiplexer.
- Connecting Real Time Clock (RTC) module to Arduino Uno.
- Connection between SD card module and Arduino Uno.
- GPRS GSM module is connected to Arduino Uno.
- Power supply connection to Arduino Uno then other units.
- Record data to the SD card via SD card module or send the data to server via GSM module/Wi-Fi enabled Arduino for further analyse.
- Finally, the data is compared with the standard Vibrometer.

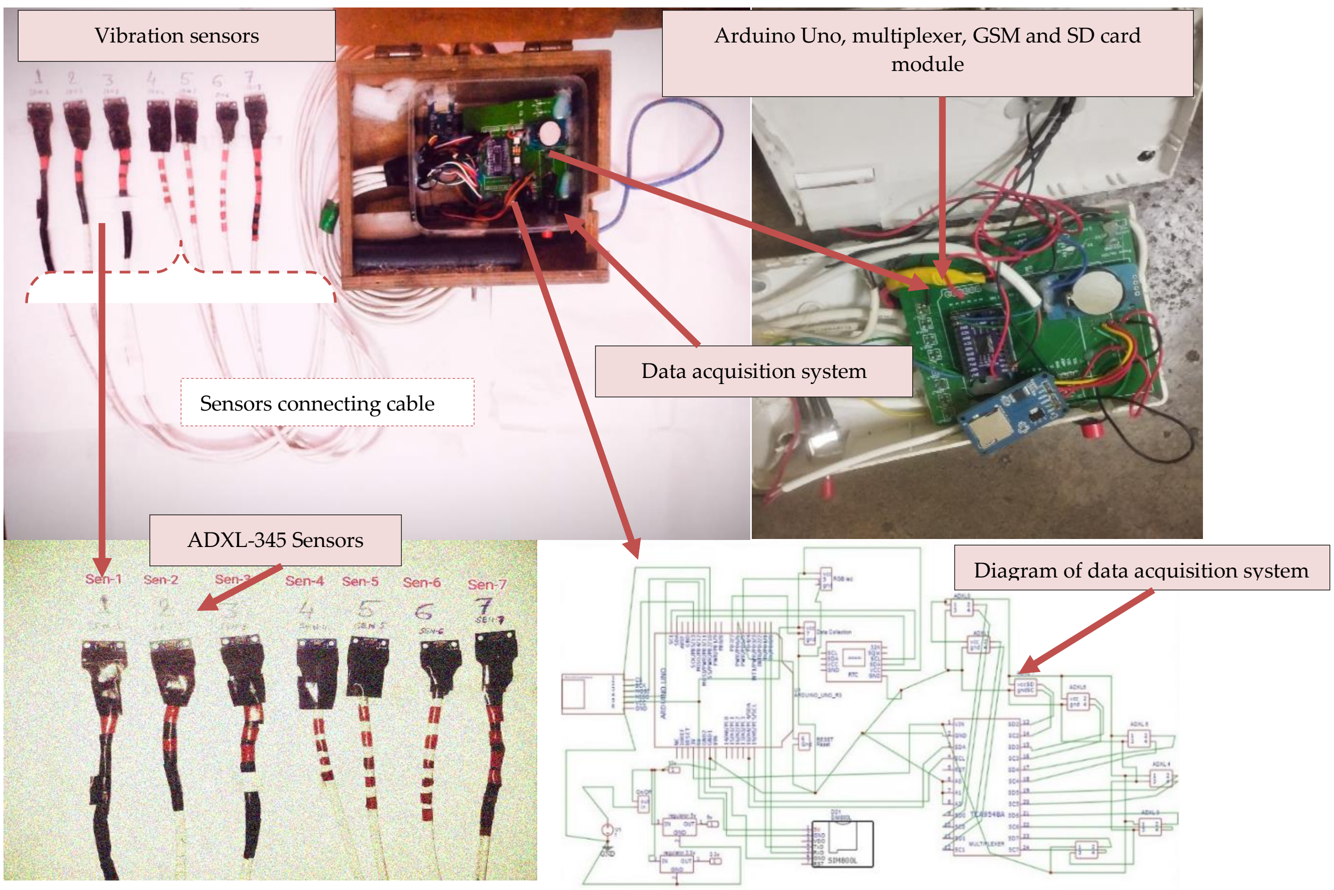
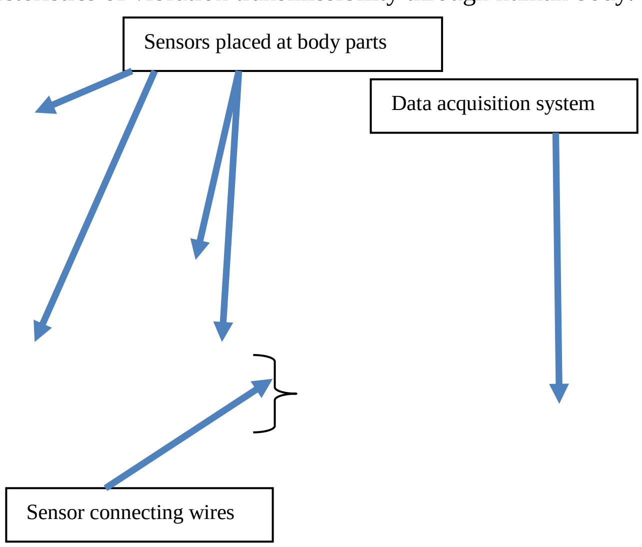


Fig. 2: Experimental setup of data acquisition system with ADXL-345, Arduino Uno, Multiplexer, GSM and SD card Module

Fig.3: vibration measuring of a seated shuttle car operator

3. **Result:** The meticulous implementation process of the ADXL-345 accelerometer, alongside the seamless integration between the Arduino Uno and ADXL-345, as well as the method for transferring sensing data, are detailed below:

3.1 Data Collection: Upon configuring the device, the experimentation phase commences. Vibrational data, encompassing both time and acceleration metrics, is gathered from six distinct locations (pelvis, abdomen, lumber, thoracic, shoulder and head) on a seated shuttle car operator within an underground mine for experimental validation. Typically, the initiation of a shuttle car engine induces vibration, which may intensify due to various factors such as suboptimal motor mounts, uneven road profiles, vehicle aging, speed, and disconnected hoses. Furthermore, these seat-induced vibrations, upon transmission through the human body-seat interface, propagate across different anatomical regions. The amplitude of transmitted vibrations varies based on factors like occupant demographics (age, weight, height), posture, experience, frequency, and input excitation at the seat. Here, the measured data is not the absolute value, rather it helps to know the characteristics of vibration transmissibility through human body.



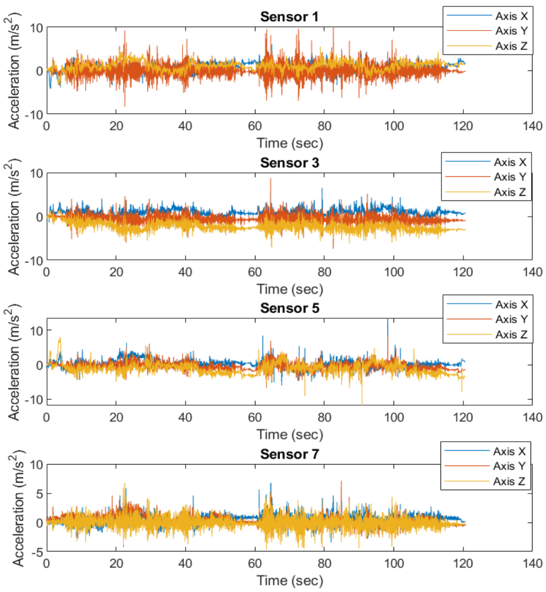


Fig.3: Acceleration data of X, Y, Z axis of seven sensors

3.2 Data Storage to SD Card: In the data acquisition phase, all ADXL-345 sensors are interfaced with the Arduino Uno. Both the Arduino and the SD card module are powered by an external 5V supply. Acceleration data along the x, y, and z axes is recorded onto the SD card through the SD card module, structured as time (seconds) versus acceleration (m/s^2).

3.3 Data Transmission to Server: In addition to local storage, an alternate data transmission route involves the integration of a GSM module with the Arduino board or utilizing a Wi-Fi enabled Arduino board for wireless data transmission. Through wireless connectivity, the GSM or Wi-Fi module facilitates the transmission of data to the designated server.

3.4 Analysis of Acceleration Data: The stored acceleration data, whether retrieved from the SD card or obtained from the server, undergoes comprehensive analysis. Utilizing both time and frequency domain techniques, depicted in fig. 6 and fig.7 respectively, enables the measurement of key vibration parameters including acceleration, frequency, and root mean square (RMS) acceleration.

For a running vehicle (shuttle car), acceleration data is taken from this device at seven different locations including seat, pelvis, lumber spine, thoracic spine, abdomen, upper torso and head. This data is the real-time acceleration value for ADXL-345 for the three-axis of x, y, z axis shown in graph (fig.6 and fig.7) for acceleration vs time graph where the x-axis direction is for time and y-axis acceleration.

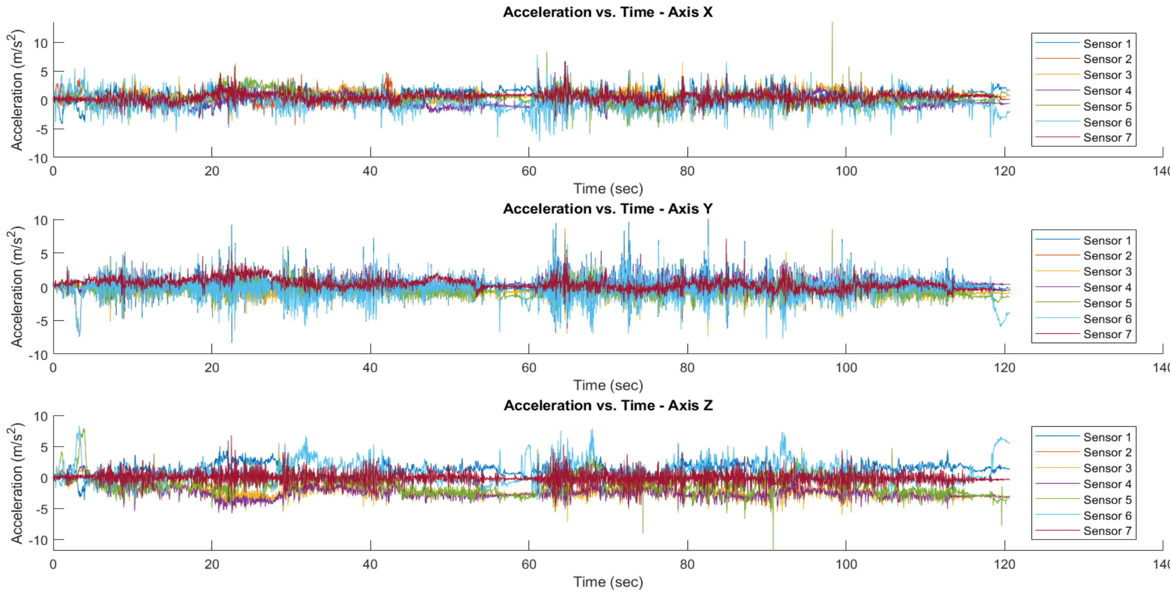


Fig. 4: Acceleration data of X, Y, Z axis of seven sensors

From the graph, the highest value of acceleration can easily be observed at what time it appeared (in second) as the graph shows separate acceleration value for every second. From the graphs in Fig.3 and Fig.4, it is observed that in the x- axis graph the highest acceleration is 8.17 m/s^2 in 64.8 sec, 7.19 m/s^2 in 64.8 sec, 11.8 m/s^2 in 90.85 sec, 5.2 m/s^2 in 64.8 sec, 7.19 m/s^2 in 64.8 sec, 6.22 m/s^2 in 64.8 sec and 7.18 m/s^2 in 91.9 sec for seven sensors respectively. In the y-axis graph, the highest acceleration is 4.64 m/s^2 in 64.85 sec, 6.55 m/s^2 in 79.35 sec, 13.5 m/s^2 in 98.25 sec, 6.66 m/s^2 in 64.6 sec, 6.55 m/s^2 in 79.35 sec, 4.06 m/s^2 in 79.35 sec and 7.86 m/s^2 in 61.65 sec for seven sensors respectively.

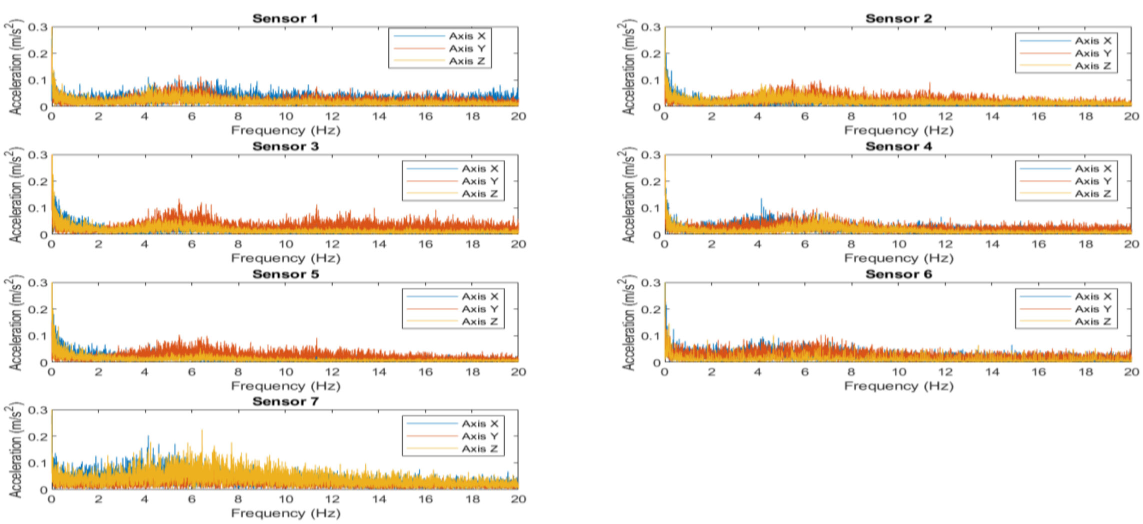


Fig.5: Frequency vs acceleration in three directions (X, Y, Z) of seven sensors

Similarly, in the z-axis graph, the highest acceleration is 9.5 m/s^2 in 63.4 sec, 8.75 m/s^2 in 64.52 sec, 6.98 m/s^2 in 64.52 sec, 5.29 m/s^2 in 64.35 sec, 8.75 m/s^2 in 64.52 sec, 5.23 m/s^2 in 64.52 sec and 7.57 m/s^2 in 64.52 sec for seven sensors respectively.

Without graph plotting, it is very difficult to detect the proper rate of acceleration or frequency visualization for comparing with some standards. The intensity of vibration frequency is shown in the figure (Fig.5 and Fig.6) (magnitude vs frequency graph) in which, the quantity of vibration in respect of frequency is visualized.

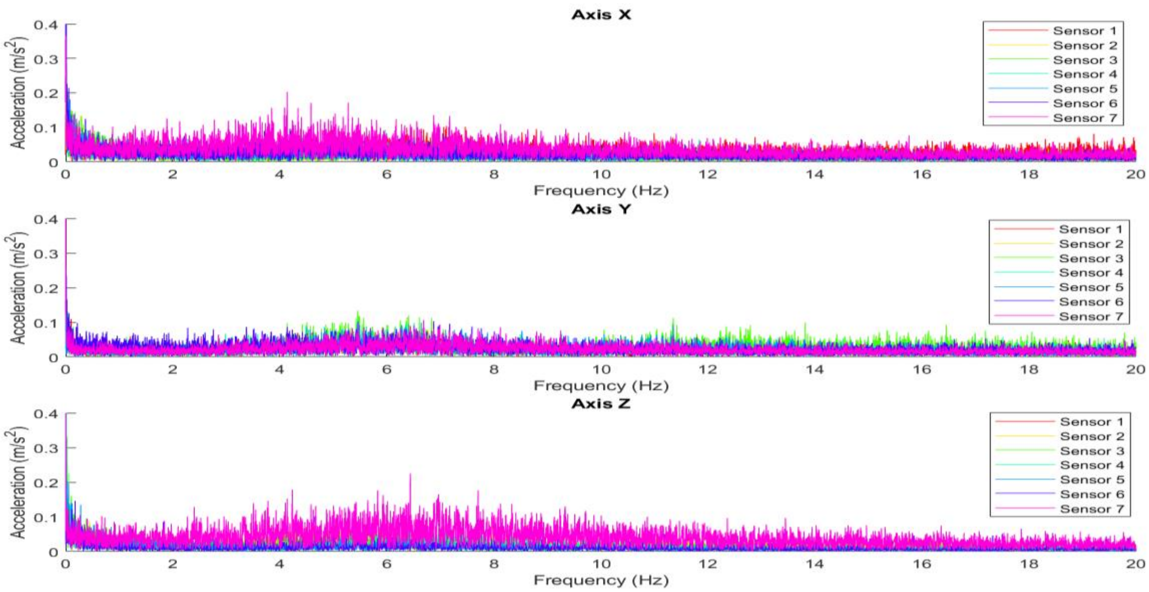


Fig.6: Frequency vs acceleration in X, Y, Z directions of seven sensors

4. **Discussion:** The human segmental body parts subjected to vibration has its own resonating frequency. This resonating frequency primarily depends upon some factors like occupant's age, weight, height, posture, experience, frequency and the input excitation at seat. The forcing frequency of the structure should be always away from resonating frequency in order to avoid mechanical resonance.

In Fig.3 and Fig.4, the acceleration data of x, y, and z-axis values of seven sensors are shown in respect of time and in Fig.5 and Fig.6, the acceleration data of x, y, and z-axis is shown in respect of frequency with the seven ADXL-345 accelerometers.

4.1 Comparison with the existing system: The proposed model presents significant advantages in terms of cost-effectiveness and user-friendliness when compared to existing systems. Despite the availability of numerous expensive vibrations measuring devices in the market, this model offers distinct advantages, as delineated in Table I below. Employing a GSM module, the model can efficiently record data and transmit it to a server via the internet. Alternatively, the utilization of a Wi-Fi module allows for data transmission to an external local server, albeit with limitations imposed by the Wi-Fi coverage range. A detailed comparative analysis between the proposed model and existing systems is presented in Table I.

Table I: Comparisons between proposed and existing accelerometer system

Proposed accelerometer	Existing Accelerometer
In this research tri-axial ADXL 345 accelerometer uses.	Most of the vibrometer uses a novel optic accelerometer like Nor1286/1287 Vibrometer.
The sensors are open and placed as per required place to measure the value.	A build in sensor is inside the Vibrometer which sense the vibration.
Real time vibration measurement process.	Similar way measures the vibration in real time basis.
Store the accelerometer data in SD card, also can transmits the data with the help of Wi-Fi/GSM module for analysis.	Store the accelerometer data in SD card. There is no data transferring module in it
Frequency sensing level is 3200Hz.	Frequency level is about 10Hz to 1KHz.
Accuracy is ±4.5%	Accuracy level is near to ±5%
Data transferring rate is fast.	There is no option to transfer data in this Vibrometer.

4.2 Impact of the Proposed Model: The design prototype of the segmental vibration measuring device harbours considerable potential for augmenting safety protocols through precise measurement of vibration data concerning both human bodies and objects. By discerning the effects of vibrations on various body segments or machinery components, potential hazards can be promptly identified, thereby averting machinery accidents and mitigating the onset of musculoskeletal disorders in humans. Real-time monitoring of vibration acceleration and frequency patterns facilitates swift detection of anomalies, be it in machinery operations or human body dynamics. The device's ability to pinpoint resonant frequencies or faults in human bodies or machinery ensures timely preventive measures or maintenance, thereby bolstering overall safety protocols.

5. **Limitations and Future Enhancements:** Despite the objective of the proposed model to achieve thorough vibration measurement at multiple points and analysis utilizing the ADXL-345 triple-axis accelerometer, it is crucial to acknowledge inherent limitations that prompt consideration for future enhancements. Transitioning to a Raspberry Pi platform holds promise for enhancing data processing speed and facilitating seamless data transfer to servers.

6. **Conclusion:** The proposed model signifies a notable leap forward in vibration measurement technology, addressing the needs of both mechanical acceleration and whole-body vibration analysis for safety and occupational health considerations. Harnessing the capabilities of accelerometer technology, this device provides precise data with minimal margin of error, outperforming traditional measurement instruments in terms of accuracy and cost-effectiveness. Moreover, its wireless data transfer feature ensures robust safety standards alongside economic benefits. Nevertheless, ongoing research and development endeavours are imperative to tackle current constraints and bolster the device's versatility and effectiveness across various environments.

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Integrated strategies for managing heat index in Opencast mines to enhance worker safety and operational efficiency

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Abstract:

The rising global temperatures and demanding environmental conditions of opencast mines present significant challenges to worker safety and operational efficiency. This technical paper presents integrated strategies for managing the heat index in opencast mining environments, focusing on enhancing worker safety and maintaining operational efficiency. Key strategies discussed include the implementation of adaptive work-rest schedules, deployment of advanced cooling technologies, and utilization of real-time monitoring systems for environmental and physiological parameters. The paper examines the effectiveness of these strategies through detailed case studies from various mining regions, demonstrating their impact on reducing heat-related illnesses and improving overall productivity. Additionally, it explores the role of data analytics in predicting heat stress and optimizing operational protocols. The findings indicate that a holistic approach, combining technological innovations with proactive health and safety measures, can significantly mitigate the adverse effects of high temperatures in opencast mines. The paper concludes with practical recommendations for industry stakeholders, emphasizing the need for collaborative efforts and policy support to ensure sustainable and safe mining operations.

Keywords: Heat index; opencast mines; Heat stress; Heat Index Modeling; adaptive management practices

1. Introduction

Humans are warm-blooded, so in industries or workplaces where employees are working under an open sky in the presence of the sun in the summer, they experience discomfort, stress, and anxiety due to the surrounding hot environment. As a result, their productivity decreases [1]. This problem is also noticed in the mining industry, especially in opencast mines. In the summer, a comparable reduction in production is observed. Nowadays, increasing global warming and rapid heatwaves make it a more serious matter [2]. Effective measures must be taken to ensure workers' health and safety and achieve the desired optimum production. This paper aims to highlight the consequences of heat in terms of heat index in opencast mines and possible solutions to deal with this problem.

2. Heat Index

The heat index is a metric that gauges how hot it feels on the body by combining relative humidity and air temperature. This measurement, often known as the "apparent temperature," considers how humidity affects the body's capacity to expel heat through sweat. This process can be hampered by high humidity, which causes the air to seem much hotter than it actually is [3].

In summer or hot climates, the heat index is especially significant since high values might signal hazardous situations that could result in heat-related diseases including heat exhaustion or heat stroke. The heat index is a common tool used by meteorological organisations like the National Weather Service (NWS) of USA to issue public health recommendations. Complex polynomial equations are used in the formula to get the heat index. Nonetheless, there are charts and online calculators that make the procedure easier by letting one enter humidity and temperature readings to obtain the heat index instantly. A Heat Index Chart used by NWS is shown in **Error! Reference source not found.**.

3. Effects of Heat Index

Relative Humidity %	Temperature °C																
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	28	29	30	31	32	34	35	37	39	41	43	46	48	51	54	57
45	27	28	29	30	32	33	35	37	39	41	43	46	49	51	54	57	
50	27	28	30	31	33	35	36	38	41	43	46	49	52	55	58		
55	28	29	30	32	34	36	38	40	43	46	48	52	54	58			
60	28	29	31	33	35	37	40	42	45	48	51	55	59				
65	28	30	32	34	36	39	41	44	48	51	55	59					
70	29	31	33	35	38	40	43	47	50	54	58						
75	29	31	34	36	39	42	46	49	53	58							
80	30	32	35	38	41	44	48	52	57								
85	30	33	36	39	43	47	51	55									
90	31	34	37	41	45	49	54										
95	31	35	38	42	47	51	57										
100	32	36	40	44	49	56											

Caution | Extreme Caution | Danger | Extreme Danger

Source: Calculated °F to °C from NOAA's National Weather Service *Source:* NDMA Heat Guidelines (2016)

Figure 8: Heat Index Chart

3.1. Influence of the heat index on human comfort and health

The heat index can significantly impact human health and comfort, particularly in hot and humid conditions. Various heat index levels affect people in different ways. When the heat index is medium (80-90°F / 27-32°C), people may start to feel discomfort, and prolonged exposure or physical activity can lead to fatigue. At high levels (90-103°F / 32-39°C), heat cramps and heat exhaustion are possible with prolonged exposure or physical activity, along with an increased risk of dehydration. When the heat index is very high (103-124°F / 39-51°C), heat exhaustion is likely, and heatstroke is possible with prolonged exposure or physical activity. Individuals are at a high risk of heat illness, experiencing symptoms such as weakness, dizziness, fainting, and profuse sweating. At extreme levels (125°F / 51°C and above), heatstroke becomes very likely if exposure continues, posing a significant risk of life-threatening heat illness, requiring immediate medical attention if symptoms occur [4].

3.2. Specific health effects

Specific health effects include heat cramps, which are painful muscle spasms usually occurring in the legs, arms, or abdomen due to prolonged physical activity in hot conditions. Treatment involves stopping the activity, moving to a cooler area, and drinking fluids. Heat exhaustion presents symptoms such as profuse sweating, weakness, chills, pale clammy skin, a rapid and weak pulse, nausea or vomiting, and fainting. This condition can develop after several days of exposure to high temperatures and inadequate or unbalanced fluid replacement. Treatment includes moving to a cooler environment, lying down, and drinking fluids.

3.3. Impact on productivity in opencast mines

High Heat Index values increase the risk of heat-related illnesses among workers, affecting both cognitive and physical performance, leading to slower reaction times, reduced concentration, and higher error rates. Frequent breaks and hydration are necessary, reducing effective work time [5]. High ambient temperatures also impair equipment performance, leading to more frequent maintenance and repairs [6]. The heat index varies within an opencast mine due to factors like topography, shade, direct sunlight, wind, surface materials, water presence, human activities, and temporal variations [7-9]. Different mine areas experience different temperature and humidity levels due to these factors.

4. Heat Index Modelling and Risk Assessment

4.1. Heat Index Modelling

Continuous temperature and humidity measurements should be taken using weather stations or portable monitors across various mine sections, integrating local forecasts and historical data to predict future heat index values. Charts, online calculators, and software like MATLAB, Python scripts, or proprietary tools for dynamic heat index calculations should be used. Predictive models should be developed to simulate heat index over different timescales and future conditions and their operational impacts have to be assessed.

4.2. Risk Assessment

Workers most exposed to high heat conditions should be identified and machinery affected by high temperatures and humidity should be assessed. Workers' susceptibility to heat-related illnesses should be evaluated and understand how high heat affects operations, including equipment failures and reduced productivity. The likelihood and impact of heat-related incidents should be estimated using historical data and forecasts, prioritize risks using a risk matrix, utilize heat index monitoring devices for continuous assessment, and implement automated alerts for dangerous heat levels. Establish and train workers on procedures for heat-related incidents. Physical changes like shade structures, cooling systems, and proper ventilation should be implemented, work schedules should be adjusted, hydration breaks should be enforced, workers should be trained to recognize heat stress symptoms, and PPE should be provided to keep workers cool.

4.3. Tools and Technologies

4.3.1. Heat Index Monitoring Devices

The Kestrel 5400 Heat Stress Tracker with LiNK by Nielsen-Kellerman measures heat index, temperature, and humidity, and features Bluetooth LiNK for real-time data transmission, making it portable and rugged for harsh mining environments. The Extech RH300-CAL with Wireless Data Logging by Extech Instruments measures heat index, temperature, and humidity, supports wireless data logging with USB for real-time monitoring, and is ideal for remote data access. The PCE-WB 20SD Heat Stress Meter with Data Logging by PCE Instruments measures heat stress, temperature, humidity, WBGT, and heat index, includes SD card data logging, and can transmit data wirelessly, making it robust for continuous industrial monitoring.

4.3.2. Weather Stations

The Davis Instruments 6830 by Davis Instruments measures heat index, temperature, and humidity, and provides wireless data transmission to cloud systems, ideal for permanent monitoring stations in open-cast mines. The Ambient Weather WS-2902C Osprey WiFi 10-in-1 by Ambient Weather measures heat index, temperature, humidity, and other weather parameters, includes WiFi connectivity for real-time transmission, and is suitable for comprehensive weather monitoring with remote access. The AcuRite 01540M Atlas Weather Station by AcuRite measures heat index, temperature, humidity, and additional weather variables, equipped with WiFi for real-time updates to the My AcuRite platform, and is suitable for extensive area monitoring in open-cast mines.

4.3.3. Software and Modeling Tools:

MATLAB provides advanced heat index modeling and simulations, Python with libraries like Pandas and NumPy aids in data analysis and heat index calculations, and proprietary software from environmental monitoring companies offers real-time data integration and risk assessment.

Data Integration Platforms: SCADA Systems integrate heat index data with operational parameters, and IoT platforms enable real-time monitoring and alerts using wireless sensors and cloud-based analytics.

Implementation Steps: Set up monitoring infrastructure by installing devices and weather stations across the site, develop predictive models using historical and forecast data, link monitoring devices and models to management systems for tracking and alerts, regularly evaluate heat-related risks, apply engineering and administrative controls, and continuously monitor and review the effectiveness of measures, adjusting as needed.

5. Mobile shades for opencast mines

Mobile shades are essential for opencast mines due to harsh environmental conditions. Traditional methods such as natural shade and stationary structures made from wood and thatch have limitations like scarcity, non-durability, and the need for frequent relocation and reconstruction. Mobile shades provide a practical solution.

5.1. Concept

Mobile shades are portable structures designed to be easily moved and positioned close to active work areas. They provide immediate relief from the sun and harsh weather conditions, enhancing worker comfort and safety.

5.2. Design and materials

A robust and durable steel frame forms the structure's backbone, ensuring longevity and stability. The shade canopy is made from heat-reflective materials, reducing the temperature under the shade.

5.3. Optional features

a) Chilled water and electrolyte beverages to prevent dehydration and heat stress.
b) Cooling systems like hand or mechanical fans to improve air circulation.
c) First aid kit for immediate medical attention.

5.4. Mobility and flexibility

Mobile shades can be designed in various forms:

a) *Tyre-Mounted:* Shades mounted on wheels for easy relocation.

b) *Foldable Canvas Tents or Yurts:* Lightweight and collapsible structures offering flexibility in positioning and storage.

A prototype of mobile shade is shown in Figure 9.

Figure 9: Tent type mobile shade

5.5. Advantages

The advantages of this system include proximity to work areas, durability, no reconstruction required, and enhanced worker comfort and safety, while implementation considerations involve determining dimensions based on worker numbers and available space, selecting a mobility mechanism for easy relocation, and ensuring regular maintenance of the shade structures for continued effectiveness and safety.

6. Air Velocity Amplifier

6.1. Effect of air velocity on heat index

Air velocity significantly affects the heat index by influencing heat perception and the body's cooling efficiency.

6.1.1. Mechanism of cooling

Evaporative cooling is enhanced by increased air movement, which raises the rate of sweat evaporation and disperses moisture around the skin, reducing local humidity and allowing more sweat to evaporate. Convection cools the body by removing heat from the skin's surface and mixing warmer air near the body with cooler ambient air, lowering the perceived temperature.

6.1.2. Impact on heat index calculation

Although wind speed is not included in the standard heat index calculation, higher wind speeds generally lower perceived heat stress. The effects are considered in the concept of "apparent temperature" or "feels-like temperature." Practical Implications in Opencast Mines: Enhanced air velocity improves worker comfort and reduces the risk of heat-related illnesses, while fans or ventilation systems can create localized areas with higher air velocity, providing relief in high-heat zones.

6.1.3. Operational adjustments

Installing and optimizing ventilation systems to increase air movement, and using windbreaks and barriers strategically to enhance airflow and cooling in hot conditions.

6.2. Description of the air velocity amplification structure

Structures based on the principle of fluid flow continuity with adjustable funnel-like cones can be used to manage high heat index areas in an opencast mine [10]. This structure could potentially enhance airflow and reduce localized heat stress by increasing air velocity through the use of Venturi effects. Here's a detailed explanation of how this system could work and the principles behind it:

6.2.1. Principle of continuity

The continuity equation for incompressible fluids states that the mass flow rate must remain constant from one cross-section of a pipe to another. Mathematically, it is expressed as $A_1V_1=A_2V_2$; where, A is the cross-sectional area and V is the fluid velocity.

When air flows through a funnel, as the cross-sectional area decreases, the velocity of the air increases [11].

6.3. Structure design and function

6.3.1. Components

Funnels (Cones): The structure consists of multiple funnel-like cones. These cones are horizontally placed and have two openings: a smaller opening and a larger opening. The small opening faces the place with the high heat index.

Changeable Area Mechanism: A shutter arrangement consisting of a rack and pinion mechanism allows the cross-sectional area between the two openings of each cone to be adjusted.

Vertical Placement: The structure is vertically placed with the cones starting from 1.5 meters above the ground on a heavily weighted base. The structure is further supported by four legs anchoring into the ground.

Mobility: The structure is capable of moving but is designed to effectively stand still once positioned.

6.3.2. Design

A conceptual design of the air velocity amplification structure is shown in Figure 10 and the components of the structure are mentioned in Table 2.

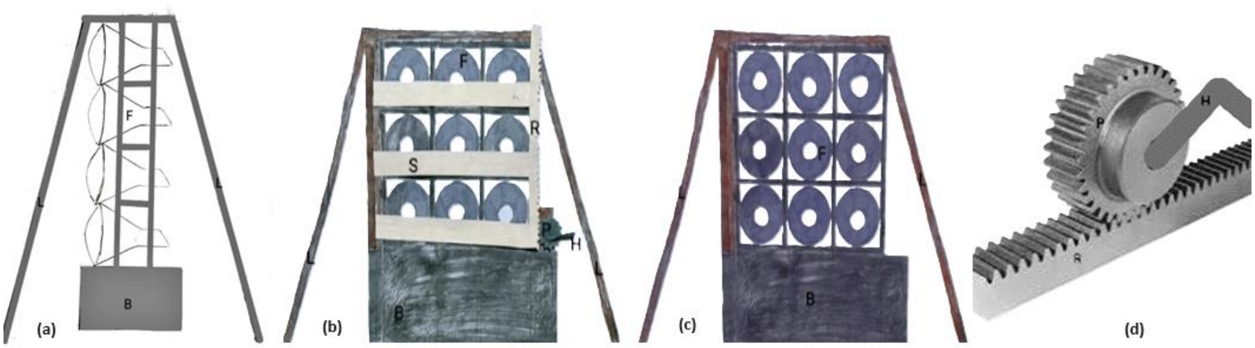

Figure 10: (a) Side view of the structure; (b) Front view of structure with shutter arrangement; (c) Front view of structure without shutter arrangement and (d) Rack and pinion mechanism with handle

Table 2: Components of the air velocity amplification structure

Alphabetical symbols	Components name
F	Funnels
L	Legs
B	Base
S	Shutters
R	Rack
P	Pinion

H	Handel

6.3.3. **Function**

a. Airflow Enhancement: By narrowing the openings, the structure can increase the velocity of air passing through the funnels, thereby enhancing cooling through increased airflow.

b. Dust Management: Placing the structure 1.5 meters above the ground minimizes surface dust disturbances while improving air movement at worker height. Additionally, fine wire netting is used to prevent the ingress of dust through the large opening.

6.4. Implementation steps

For site selection and setup, high heat index areas in the mine should be identified and stable ground should be ensured to securely place the structure. The frame should be constructed from durable materials and adjustable cones should be installed with manual shutters. During installation, the structure should be placed in the selected high heat index area, adjusting height and orientation for optimal airflow. In operation, the funnel openings should be narrowed during high heat periods to increase air velocity, performance should be monitored and adjustments should be made as needed to maximize cooling.

6.5. **Potential benefits**

The implementation of this system enhances airflow by increasing air velocity through the Venturi effect, improving evaporative cooling, and reducing perceived temperatures. Its flexibility and mobility allow it to be easily moved to provide targeted cooling in different mine areas. This system significantly reduces the heat index, enhancing worker comfort and safety by reducing the risk of heat-related illnesses. Additionally, it manages dust without excessively disturbing surface particles, with the option to use water sprinkling to reduce ground heat if dust is generated.

Additionally, this proposed system offers several advantages, primarily in cost efficiency, environmental friendliness, and safety improvements. Cost Efficiency includes lower operational costs and minimal maintenance due to durable materials, leading to significant energy savings as the system requires no electricity. Reduced downtime results in increased productivity and prevents equipment overheating, reducing maintenance costs and extending machinery lifespan. Environmentally friendly benefits stem from passive cooling without energy consumption, leading to lower greenhouse gas emissions. The system is designed to minimize dust disturbance and improve air quality without using chemicals or emitting pollutants. Safety Improvements involve effective heat stress mitigation, preventing heat-related illnesses, and reducing the risk of accidents from heat-induced fatigue. The structure’s secure placement and mobility ensure it remains stable while allowing targeted cooling in high-heat areas. Additionally, its quick relocation capabilities and sensor-equipped real-time monitoring provide responsive heat management and proactive risk mitigation.

6.6. **Monitoring and feedback**

Real-time monitoring is facilitated by equipping the structure with sensors for temperature, humidity, and airflow, providing data for performance optimization. An alert system can be implemented for necessary adjustments. Regularly worker feedback on the structure's effectiveness should be gathered and design and operational adjustments be made based on this feedback and data.

6.7. Additional Considerations

Implementing this system requires several additional considerations to maximize effectiveness and integration. Worker Training is crucial; workers should be trained on how to adjust and optimize the structure for maximum effectiveness and safe handling. Integration with existing systems can complement current ventilation and cooling systems, creating a comprehensive heat stress management strategy when combined with other safety measures. Scalability allows the system to meet specific needs of different mine areas, providing flexible cooling solutions as required. Adaptability ensures the system can be adjusted based on weather conditions and operational requirements, offering year-round cooling solutions.

7. Results and Discussion

This theoretical study explores integrated strategies for managing the heat index in opencast mines to enhance worker safety and operational efficiency. Although empirical data is unavailable, potential outcomes based on literature review and theoretical models are discussed:

Heat Index Model Development: A theoretical model was proposed, integrating data from temperature and humidity sensors placed across the mine. Using MATLAB and Python, the model predicts heat index values dynamically and allows for scenario analysis.

Cooling Technologies Implementation: Suggested technologies include air-conditioned cabins, misting systems, and heat-reflective coatings. Theoretical assessments show that mobile shades and air velocity amplifiers could significantly reduce localized heat index values.

Data-Driven Decision Support Systems: A conceptual decision support system provides real-time alerts and recommendations based on predicted heat index values, integrating weather station data and predictive models. Theoretical heat maps identify potential hotspots, guiding targeted interventions.

Health Monitoring and Behavioural Approaches: Protocols include regular health checks and wearable devices for tracking vital signs. Training programs educate workers on recognizing and responding to heat stress, supported by a buddy system for mutual monitoring.

Economic Impact Analysis: Theoretical analysis predicts reduced heat-related incidents, lowering medical costs and enhancing productivity. Improved equipment performance and reduced maintenance costs from cooling technologies contribute to overall savings.

8. Conclusion and Future Scope

This theoretical study outlines a comprehensive approach to managing heat index in opencast mines, integrating advanced heat index modeling, cooling technologies, and health monitoring protocols. The models suggest significant benefits, including reduced heat-related incidents, improved worker health and productivity, and economic savings.

Future empirical research should focus on:

1. Validation of Heat Index Models: Conduct field studies to collect real-time data and validate the heat index model.
2. Testing of Cooling Technologies: Deploy and test cooling technologies in real mining environments to assess effectiveness.
3. Development of Decision Support Systems: Develop and implement a functional decision support system, evaluating its impact on efficiency and safety.

4. Health Monitoring and Training Programs: Implement health monitoring and training programs using wearable devices to analyse effectiveness in managing heat stress.
5. Economic Analysis: Conduct detailed economic analysis based on empirical data to evaluate long-term benefits.
6. Scalability and Adaptability: Explore the scalability of strategies to different mining operations and climates, adapting models and technologies as needed.
7. Policy Recommendations: Develop policy recommendations based on empirical findings and advocate for industry-wide adoption of heat index management strategies.

Overall, while this study provides a promising framework, empirical research and practical implementation are crucial for realizing the full potential of these strategies. Continuous refinement and validation can significantly contribute to safer and more efficient mining operations.

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Work posture assessment of equipment operators and industrial workers – a review

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Abstract:

Adoption of awkward postures, while operating heavy equipment/machine, can lead to musculoskeletal disorders (MSDs). The MSDs can cause discomfort and agony. Therefore, posture evaluation examines the static posture to identify imbalances that are producing discomfort and suffering in the human body. This review paper aims to evaluate the studies, mainly published in last two decades, focusing on adoption of awkward postures at workplaces in various industries. The present review includes studies on posture assessment using rapid upper limb assessment (RULA), rapid entire body assessment (REBA), Ovako working posture assessment (OWAS). Most of the studies reported lower back pain as the most common MSDs followed by upper back pain experienced by the workers who adopted poor/awkward posture during their work. From the studies, it can be clearly observed that irrespective of industry, in most of the cases the posture adopted by the operators/workers are generally not ergonomically safe. This review paper also discusses postural risk assessment of a shovel operator deployed in an opencast mine using tools such as RULA and REBA. It is recommended that poor and awkward postures should be modified by good postures through ergonomic design of workplaces and work environment, considering the physical and psychological capabilities of the available work-force (e.g., operators and workers) to avoid MSDs.

Keywords**:** RULA; REBA; OWAS; Postural assessment; Musculoskeletal disorders.

1. INTRODUCTION

In the modern era, the emphasis on using sophisticated and large machines to expedite tasks and meet industrial demands has led to the integration of a man-machine interface to accomplish work efficiently. For successful accomplishment of any given task, the equipment operators has to often adopt various kinds of awkward postures and repetitive movements depending on the required work profile [1]. The adoption of poor and long-term work postures can lead body parts to exert extra effort, negatively impacting both work performance and labour productivity. If these awkward postures are adopted over a long period of time, it results in work-related musculoskeletal disorders (MSDs). The MSDs refer to injuries or pain in the joints, ligaments, muscles, nerves, tendons, and supporting structures of the neck, back, and limbs. Most of these disorders are caused by poor ergonomic working conditions and poor/awkward postures of equipment operators while performing their activities [2]–[4]. To minimize these hazards, the workplace along with working postures should be ergonomically designed. It will not only help to reduce risk of MSDs, but also to improve workers' health conditions and work efficiency [5].

Assessment of the posture is carried out to understand whether a working posture is free from the risk of MSDs [6], [7]. It is performed by evaluating the ergonomic impact of the activities on the equipment operators and workers. This involves the examination of body posture, joint angles, and muscle engagement while performing their assigned tasks. Effective postural assessment incorporates the utilization of advanced tools and technologies, such as rapid upper limb assessment (RULA) [3], rapid entire body assessment (REBA) [8], [9], Ovako working posture assessment (OWAS) [10], and National institute for occupational safety and health (NIOSH) lifting equation [11]. These examinations give useful information about possible dangers linked with poor posture, such as back discomfort, neck strain, and decreased postural stability. These evaluation approaches can provide useful information about the occurrence of MSDs, even on a specific region of the body. Therefore, the present aim of the review paper is to evaluate the studies focusing on adoption of awkward postures at workplaces in various industries. A case study example of RULA & REBA methods for shovel operator in mining industry.

2. METHODOLOGY

The literature related to postural assessment was compiled from both available hard copy resources like books and through online resources such as journals from various libraries and from electronic databases like scopus, sciencedirect, web of science and google scholar. The research is totally centered on the keywords such as posture, musculoskeletal disorders, and equipment operators. The main keywords/searches are inserted in the databases like sciencedirect and researchgate with a combination of "postural assessment + musculoskeletal disorders + equipment operators" with a time reference of last two decades. A few relevant papers were also included directly from the google search.

After the initial search, the collected literature was screened based on various inclusion or exclusion criteria (e.g., language, year of publication, relevance to current review). Inclusion criteria were defined to ensure capturing of relevant literature. The title and abstract of each study were used to determine whether or not it was included in this study. Only peer-reviewed journal articles dealing with posture assessment leading to various work-related MSDs were included. This includes literature dealing with factors affecting work postures of the workers and operators while driving heavy machinery. A total of 12 studies have been selected for this peer review. Out of these 12 studies, six are based on RULA, one is based on REBA, two are based on OWAS, two studies use both RULA and REBA, and one study assessed through RULA, REBA and OWAS.

3. LITERATURE REVIEW

There are numerous tools for postural risk assessment. However, most of the researchers have adopted tools such as RULA, REBA, OWAS, Revised NIOSH lifting equation, Rodgers muscle fatigue analysis, and quick exposure check, for postural assessment. In this paper, the review is confined to RULA, REBA and OWAS assessment and these methods are explained in detail since these are popularly used for postural assessment in various industries. Some of the studies carried out for postural assessment in various industries using various tools/methods are presented in Table 1.

Table 1. Summary of the studies conducted on postural assessment

Study	Year	Country	Industry	Sample Size	Method Used	Software/ Worksheet	Inference with respect to MSDs
Sakinala et al [12]	2023	India	Mining	4	OWAS	OWAS worksheet (Nordic questionnaire)	Most of the postures undergone by operators are slightly harmful to distinctly harmful.
Rasoulivalajoozi et al [13]	2023	Canada	Agriculture	33	OWAS	Nordic questionnaire	Findings of the study revealed that the back, waist, and shoulder had highest prevalence of pain among bee keepers.
Singh et al [1]	2022	India	Mining	5	RULA	ErgoMaster	Most of the operators are exposed to medium to high-risk leading to MSDs.
Mitchelle et al [14]	2022	Malaysia	Hospital	7	REBA	Xsens Based Automated WMSDs ergonomic assessment system	Motorized patient transfer device significantly reduced the mean peak REBA score by 4.21 (95% CI [3.77, 4.65], p < 0.001).
Upadhyay et al [15]	2021	India	Mining	100	RULA	ErgoMaster	All dumper operators had one or more body areas that were subjected to uncomfortable posture, which might lead to medium to high MSD risk.
Kee et al [16]	2020	South Korea		16	RULA, REBA, OWAS	Worksheet	RULA was better for assessing postural loads under the conditions of the study because the grand score and maximum holding times more precisely reflected the effects of four independent variables (hand position, trunk rotation, angle, and external load) adopted in the experiment than did the OWAS action category and REBA score.
Aminuddin et al [17]	2018	Indonesia	Chemical	12	RULA	RULA Worksheet	Operating the valve with squatting position and bending has the highest risk level.
Norhidayah et al [18]	2016	Malaysia	Mining	18	RULA, REBA	Worksheet	Subjects were exposed to all the physical risk factors such as neck, trunk, and upper extremities. REBA shows wet screening task was at very high-risk level
Ansari & Sheikh [19]	2014	India	Small scale industry	15	RULA, REBA	Worksheet	Significant proportion of the workers are working in uncomfortable and painful postures.
Mohamad et al., [20]	2013	Malaysia	Packaging Industry	1	RULA	CATIA P3 V5R14 software	Further improvement need to be conducted on the manual material handling at department to avoid discomfort.

Study	Year	Country	Industry	Sample Size	Method Used	Software/ Worksheet	Inference with respect to MSDs
Sharan & Ajeesh [21]	2012	India	Information Technology professionals	620	RULA	Worksheet	Postural analysis found that 30% of the participant's posture need to “modify soon” and 15% need to adjust “immediately”.
Massaccesi [2]	2003	Italy	Driving industry	77	RULA	Worksheet	Substantial correlation observed between trunk and neck scores, and all self-reported pains, aches, or discomforts in the trunk or neck areas in all individuals.

Note: RULA = rapid upper limb assessment, REBA = rapid entire body assessment, OWAS = Ovako working posture assessment, MSD = musculoskeletal disorder.

From Table 1, it can be clearly observed that irrespective of any industry, in most of the cases the posture adopted by the workers generally are not safe and most of them are awkward postures which may be responsible for occurrence of various kind of MSDs to equipment operators and workers.

4. METHODS OF RULA AND REBA

There are many methods/tools used in the literature for postural assessment. RULA & REBA are used by most of the researchers for posture assessment and corresponding modification in posture to reduce the MSD.

4.1 Rapid Upper Limb Assessment (RULA)

RULA was created to quantify individual worker's exposure to ergonomic risk factors linked with the upper extremities of MSD. RULA records the common posture of individual operator, with a focus on the neck, trunk, and upper limbs. It may analyze several risk factors connected with the body's posture, muscular usage, and load, which are presented as a posture score. A single page worksheet is used to assess the desired body positions, repetition, and force. Based on the evaluation, the scores acquired from each body component, namely the arm and wrist in Group A and the neck and trunk in Group B, are indicated [2]–[5], [21]. Once the data is gathered, tables on the RULA worksheet are used to quantify the MSD risk score. The approach used for RULA is as follows.

- Monitor workers many times to ascertain their cycle of operation and time.
- Determine which positions on the right and left sides will be reviewed.
- Identify the most static and recurring positions.
- Individual posture scores are obtained using the RULA stages (1–15).
- Compare the final score to the MSD risk level and take appropriate action.

To understand the RULA method more effectively, a case study example of a shovel operator from an opencast coal mine is illustrated in Figure 1. By following the above-mentioned steps, the assessment is carried out. Initially photographs of operator were assessed to identify the most repeated posture as well as mostly adopted posture. Thereafter, RULA worksheet is used for the assessment.

Figure 1. Postural assessment of shovel operator

From Figure. 1, it can be seen that the shovel operator's upper arm position is between 45^o to 90^o (arm is supported) which gives the postural score of 2. The lower arm position is 90^o or less than 90^o (arm is outside of the body) which gives the score of 2. The wrist position is less than or equal to 15^o which makes the score 3. The wrist is twisted at or near end range that makes the postural score 2. This provides the arm and wrist combined posture score as 3. Moreover, the muscle use score is 1. Therefore, in Group A, the final wrist and arm score becomes 4. The neck position is flexed between 10^o to 20^o when the neck is side bending and making a score value of 3. The trunk position is erected or seated in extension (supported) making the score 2. The legs and feet position are supported and balanced making the score value of 1. The combined neck, trunk and legs posture score is 3. Moreover, the trunk muscle use score is 1. Thus the final neck, trunk and legs score value is 4 in Group B. Therefore, final RULA score, after combining Group A and Group B scores from Table C of RULA worksheet, becomes 4. This score indicates that the posture of the shovel operators is at low risk.

4.2 Rapid Entire Body Assessment (REBA)

The REBA was created to quantify individual worker's exposure to ergonomic risk factors linked with entire body extremities. REBA records the common posture of individual operators, with a focus on the neck, legs, trunk, and upper limbs. It may be used to analyze several risk factors connected with the overall body's posture, muscular usage, and load, which are presented as posture score. A single page worksheet is used to assess the required body position, repetition, and force. Based on the evaluation, the scores acquired from each body component, namely the arm and wrist in Group A and the neck and trunk in Group B, are indicated [4], [5], [8], [19], [22], [23]. Once the data is gathered, tables on the REBA worksheet are used to quantify the MSD risk score. The approach used for REBA is similar to RULA method. The case study of the shovel operator is also used for better understanding of the REBA method. The initial procedure is same as RULA method, as explained earlier, except the REBA scores are calculated for the entire body including leg positioning and coupling movement.

From Figure 1, it can be observed that the neck position is flexed between 0º to 20º when the neck is side bending and making a score of 1. The trunk position is erect or seated in extension (supported) making the score value of 2. Position of both the legs was down making its score value of 1. This makes the neck, trunk and legs combined posture score of 4. In addition, the force/load score is zero. Therefore, it makes the final score of 4 in the Group A. The upper arm position is between 45º to 90º (arm is supported (-1) which gives the value of 2. The lower arm position is placed between 0º to 60º which gives the value of 2. The wrist position is 15º -15º with the wrist is bent from twisted which is evaluated as score 2. Now the arm and wrist combined posture score is 3. The steering is well fitted in the hand with fair grip, making the coupling score zero. The final wrist and arm score in Group B becomes 3. Thus the final score becomes 4, as observed from Table C of REBA worksheet [9]. Thereafter +1 is added as the activity score to the final score obtained from Table C since the posture repeats small range of actions making the final REBA score 5. This score indicates medium risk, which demands further investigations to modify the posture to reduce the risk of MSDs.

5. CONCLUSION

This systematic review was carried out to understand the effect of postural assessment leading to various kind of MSDs. Adoption of awkward posture at workplace has adverse health effects which results into MSDs depending on the duration of exposure and the causal influence of man-machine interaction factors. In most of the studies, it was observed that operators/workers had to adopt awkward posture in order to complete their respective tasks. It is also revealed that workers deployed across various industries adopted awkward postures which affect their musculoskeletal system, usually manifested as pains in lower back, neck, hand, and shoulder. Moreover, it is observed from the literature that most of the studies preferred to use RULA, REBA, NIOSH lifting equation and OWAS as their risk assessment tools. This review paper also demonstrated about postural risk assessment with a case study to understand the postural risk of a shovel operator deployed in an opencast mine using RULA and REBA.

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An advance global investigation on electrical safety for removing electrical hazard for daily life and post disaster renovation work

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Abstract:

Electrical risks, which have a significant negative influence on residential, business, public, and human health, have greatly exaggerated the current power market around the world. To avoid hazard critical awareness are required in everyday life as well as post disaster reconstruction jobs. Throughout this article highlighted the severe disasters associated with electrical hazards (EH) and Electrical Safety and Precautions (ESP) to the daily user as well as electricity worker for repair and maintenance as post operative EH circumstances in different locations. Generalized analysis has been highlighted to collect some raw data from all over the world. After thorough analysis, a graphical report has been made on different kinds of fatal and nonfatal electrical injuries that highly impact human life as well as animal life. A wide range of subjects are covered in this comprehensive overview of the literature, such as risk assessments in the energy sector, methodical approaches to EH regulation, ESPs at different voltage levels, and the harmful effects of EHs on human life. This safety suggestion aims to eradicate deaths resulting from electrical hazards. This paper has been helpful for the new researcher to identify the problem associated with EHs and create an EH free environment. The World Health Organization states that an electric shock could result at voltage levels higher than 250 volts, and that radiation from high-voltage power lines can cause sleeplessness, anxiety, headaches, and burns on the skin, exhaustion, and muscle soreness at voltage levels higher than 33000 volts. In order to minimize the risk of accident or fatal injuries the compliance of OSHA and NEC standard is mandatory. According to the literature survey report in year 2003 to

year 2011, around 47.8% of all types of injuries (nationwide) take place due to human negligence, which can be reduced by awareness programme periodically. When it comes to household and post-disaster restoration work, the results of this survey will be helpful to the electricity workers as they produce useful suggestions for avoiding dangerous situations. Proper electrical installed setup and correctly installed and maintained strategy are able to save life.

Keywords - Electrical hazard (EH), Electrical safety, awareness, hazard protection and precautions.

1. INTRODUCTION

Presently countless electrical hazards [1] like burns, shocks, falls etc. that may cause potential or actual threat to the well being of people, machinery or surroundings. Electrical safety is required everywhere to manage electrical hazards and decrease the risk level. Electrical protection is more significant for the reason that each equipment has some specific limit of tolerance. Another concern, it is very difficult to identify at a quick look whether a conductor is live or dead in case of a simple cable or a bare conductor. This manifestation may possibly misguide electrical workers as well as users. Furthermore this is the source of the majority of electrical mishap. Any kind of electrical disaster or mishap is an unexpected incident causing defeat of living or physical damage and defeat of assets is an unexpected incident which hampers the procedure of manufacture as well. It can take place either due to an unsafe act or risky action of work or mutually. Safety measures revenue to severely track the prearranged regulations for safety of person or otherwise chance of electric shock or hazards may perhaps. There are different concerns which are related with electrical safety systems such as ensuring proper insulation, high-quality earthing system and approval of sufficient protection and control systems. For illustration, arc flash is a dangerous hazard that involves current flowing throughout the air between phase conductors, or linking phase conductors and the ground—fundamentally, an unanticipated electrical short-circuit that creates an arc of electricity and can cause important damage, including fatality [1].

Traditional electrical grids or networks are very complex networks which are connected with national and international grid. Multiply overhead and underground cables are connected to transmit and distribute the power through the generating station to the consumer end. Electrical hazards may happen due to any kind of natural calamities or natural disasters [2] like earthquakes, thunderstorms etc. Chakrabarty et al [3] have addressed multiple electrical hazards which impact on human life on a daily basis, along with that, highlighted all the electrical hazards that happened all over the world in 2011-2019 based on the amount of severity. There are some solutions [4-7] to solve the electrical hazard at emergency condition using Floyd–Warshall Shortest Path Algorithm [4], Multi-Constraints Priority-Based Dijkstra's Algorithm [5], an Interactive Partitioning Algorithm-Based Electrical Power Crisis Management [6]. Chen et.al have been focused on newly introduced safety programs to improve the environment safety [8] based on the suggestion report of 71 top executives, 229 side management personnel & 350 field workers can be victimized for it. Recently there have been huge fatalities & infrastructure losses in our society [9]. In [10] it has been recorded that several incidents happened in the year 2020 related to fatal electrical injuries happening in residential environments to workplaces and people of different ages.

2. ELECTRICAL HAZARDS

Electrical hazards [7] can be classified in two categories: fatal type electrical injuries and non-fatal type's electrical injuries.

Fatal electrical injuries:

- Fatal electrical injuries can be explained when high amounts of current pass through the body which may have an instant or immediate impact on human life and may cause life threatening incidents due to electrical hazards.

Non-fatal electrical injuries:

- Non-fatal electrical injuries can be explained when a small amount of current passes through the body which may have comparatively less impact on human life where severity of this kind of electrical hazards is less than the fatal electrical injuries.

There are several cause may impact on the daily life like our household activity to workplace like any kind of defective or scratched wiring, overfilling or overloading the power line in a network or socket, loose connection of extension cords and fitting plugs or any equipment, water spill on electrical equipment or touch electrical equipment with wet hands, inappropriate grounding, wrongly located electrical cords, improper use of safety equipment like fuses. Most of the cases electrical hazards are affected to the safety workers, engineers, electricians, those who are dealing with overhead lines; installation, repairs, inspection and maintenance of electrical equipment as well as agricultural workers are also suffering because most of the machinery is able to get in touch with overhead power lines on farmland. Basically, electrical hazards [15] can be classified as: 1. Electrical shock. 2. Electrical burns. 3. Arc flash or arc blast.

2.1. EFFECT OF ELECTRIC CURRENT ON HUMAN BODY

Electric current may be defined as the time rate of net motion of an electric charge across a cross sectional boundary. A random motion of electrons in a metal does not constitute a current unless there is a net transfer of charge with time. Fig 1 has shown the flow of electrical current.

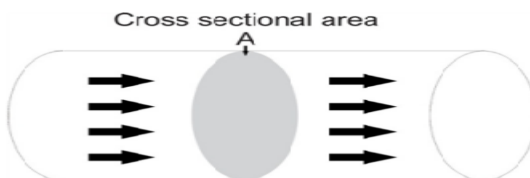

Fig. 1 Flow of electrical current

When electrons flow through a material due to electricity, it finds a resistance, its effects shown in the form of heat. If an excessive amount of heat is produced, the human body is badly affected by it like internal tissue or organs may be burnt without external evidence. Fig 2 has shown the overall impact in the human body due to electrical hazards.

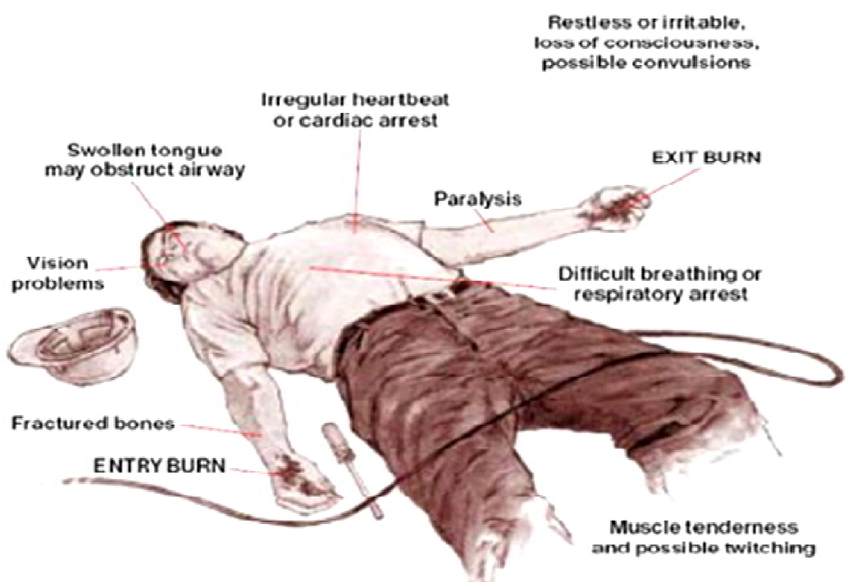

Fig. 2 Overall impact in the human body due to electrical hazards

2.2. DANGERS OF ELECTRIC SHOCK

The amount of electrical current and the length of time it spends in the human body determine how dangerous an electrical shock accident will be. For instance, merely 2 seconds of 0.1A of electricity flowing through the body is enough to kill. Muscles in the body can become immobile or "freeze" at current levels above 10 mA. An individual is unable to release his hand-held equipment or other attachments while this "freezing" takes place. In fact, due to the large amount of current, the handheld equipment may even be held even more tightly for extended periods of time. Handheld tools that provide an electrical shock can therefore be extremely dangerous.Respiratory paralysis may result from the prolonged passage of electric current through the body if you are unable to release the gadget. Your respiratory issues have been bothering you for a while. When electrocuted with electrical currents between 48 and 50 volts, some have experienced breathing difficulties. It typically takes 30 mA of electricity to paralyze the respiratory system. Ventricular fibrillation is caused by a current flow of more than 75 mA. The victim will experience death as a result of this situation within a few minutes, although it can be prevented by utilizing a defibrillator. More than 4 amps of electricity will paralyze the heart and render it incapable of pumping at all. Currents larger than 5 amps are used to burn tissue [8]. Greater currents result from higher voltages. Higher voltages provide a larger threat. Current is hampered by resistance. The current will be stronger the lower the resistance is. Skin that is wet significantly lessens resistance. Wet skin makes it simple for current to enter the body and deliver a powerful shock. Stronger shocks result from reduced resistance, which occurs when greater force is applied to the contact point or when the contact area is larger [29]. The various types of protection needed to shield the human body against electrical shock are covered in Table 1.

3. IMPACT ON THE HUMAN LIFE DUE TO ELECTRICAL SHOCKS

Depending upon the amount of electrical current flow through the human body it may cause severe impacts [7]. Table 1 has mentioned several impacts on human life due to electrical shocks.

TABLE 1
Multiple impacts on human life due to electrical shocks

Sl no.	Current (mA)	Impact on human body
1	1	Small tingling feeling
2	2-9	Little shock
3	10-24	Muscles contract causing you to freeze
4	25-74	Respiratory muscles can become paralyzed, pain, exit burns often visible
5	75-300	Usually fatal; ventricular fibrillation; entry & exit wounds visible
6	>300	Certain death; if survive will have badly burnt organs and probably require amputations

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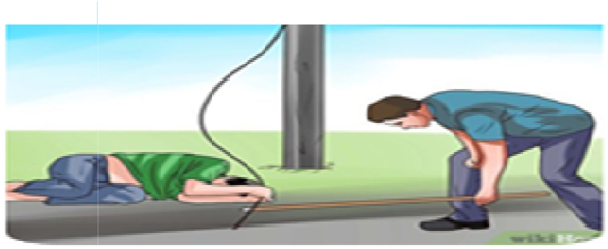


Fig. 3 Impact on electrical shock

3.1. *IMPACT ON THE HUMAN LIFE DUE TO ELECTRICAL BURNS*

The epidermis, dermis, and hypodermis are the three layers that make up the skin. The epidermis, which is the skin's top layer and primarily composed of keratinocytes for pathogen defense, is the skin's outermost layer. Dermis, the second layer, is composed of vascular, nerves, and glands. This layer's primary function is to give the skin flexibility and tensile strength. The last layer of skin, or hypodermis, contains tissues that are physically related to bones and muscles. The degree of the wound and the impact on the skin layer describe the burn severity. Only the epidermis is affected by burns of the first degree, the top half of the dermis by burns of the second degree, and the hypodermis by burns of the third degree. Basically, a third-degree burn ruined the vasculature and caused the victim to lose selfregenerate capacity of skin [28]. Fig 4 has shown the overall impact in the human skin layers due to electrical hazards.

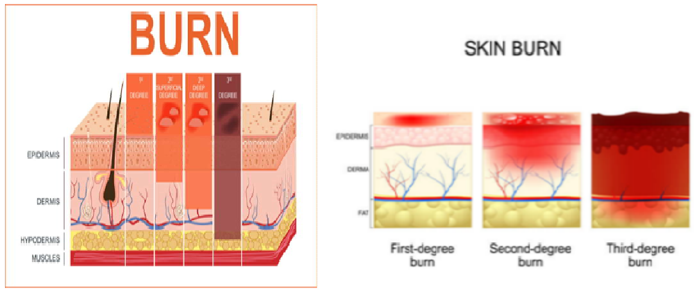


Fig. 4 Layers of Skin and Skin burn[23]

In the human body skin resistance is very high; a small amount of current flow in a short duration causes skin burns [18]. Table 2 has addressed normal resistance of the human body considering different skin types. In [22] have been highlighted to treat a victim of electrical burns.

TABLE 2
Body resistances of different kind of human skin

SL. No.	Type of Resistance	Resistance Values
1	Dry Skin	100,000 to 600,000 Ohms
2	Wet Skin	1000 Ohms
3	Hand to Foot	400 to 600 Ohms
4	Ear to Ear	100 Ohms

of the human body, especially the heart, nervous system loses all functional excitability when high amounts of currents pass.

3.2. IMPACT *ON THE HUMAN LIFE DUE TO ELECTRICAL ARC FLASH AND BLAST*

Arc flashes are a phenomenon where flash over leave their right path and flow through air from one to another conductor. It causes many fatal injuries even death and non-fatal injuries also like hearing loss, blast, eye injury, lung damage etc. Fig 5 has shown the arc flash impact in the human due to electrical hazards.


Fig. 5 Arc flash impact[21]

3.2. PREVENTION

1. Disconnect the power supply. To relocate the source away from you and the injured person, if at all possible, use a dry, non-conductive substance like cardboard, plastic, or wood.
2. Perform CPR (Cardiopulmonary Resuscitation) if the person is not breathing, coughing, or otherwise demonstrating indications of circulation. Check to make sure the injured individual doesn't become cold.
3. Avoid attempting to clean up the burnt area. Any burned areas should be covered with a clean cloth or sterile gauze bandage. Use neither a blanket nor a towel as the loose fibers could adhere to the burns.
4. Wear PPE (personal protective equipment) correctly, such as arc-rated long sleeve clothing, safety eyewear, ear canal inserts, gloves, and leather protectors.
5. Educate the workforce on how to handle arcs or blast.
6. Arc flash is very dangerous up to 6 meters, so keep a minimum safe distance.

7. Power down any electrical equipment when the equipment is not in us.

4. RISK ANALYSIS RELATED WITH ELECTRICITY SECTOR

There are two major assessment involved with the electricity sector i.e. (i) Electricity risk assessment estimation (ii)process to control the risk management. Initially the electricity risk assessment estimation has been focused on types of electricity hazard identification, established content, types of risk involved with this and level of risk involved with it. Finally the electricity risk assessment estimation has been focused on evaluation of the risk and control of the risk. Evaluation of the risk has been segregated the rank of risk and checked the tolerable point etc. and control of the risk has been identified as the best available solution scheme for mitigating the risk [24].

According to ISO 14001:1996, an environmental element is a component of a company's activity, product, or service that has a connection to the environment. The surroundings in which a concern operates are described as the environment, which includes the air, water, land, natural resources, plants, fauna, humans, and their interactions. When environmental factors are acknowledged, they can include things like air emissions, water and land discharges, raw material consumption, waste generation, depletion of natural resources, and biodiversity impacts. The process of aspect marking is crucial in this regard because it aids in identifying how the organization's operations, services, and goods have an impact on the environment.
Any Risk assessment is a sequential procedure with linked but separate components. Therefore, before the aspect is identified, the context must be defined. The same is true for the estimation of the danger stage, which cannot begin until the aspect stage's identification has been completed. Establishing the context, recognizing the risk, estimating the risk, evaluating the risk, and controlling/responding to the risk are the five stages of risk assessment. The process utilized for aspect identification and risk assessment at the study's environment is highlighted in the steps that follow.

The overall methodology use for risk analysis due to electrical hazards has been explained in this above section.

Fig.6 Methodology use for Risk analysis

4.1. SYSTEMATIC ARRANGEMENT FOR CONTROLLING ELECTRICAL HAZARD

John J. Kolak [25] has addressed necessary environmental aspects and impacts of electrical hazard to systematize efficient electrical planning. An effective action plan such as preparing a hazard control scheme after analysing the past record, preparing the proper guideline for training, maintenance and operational safety will help to minimize the electrical hazard. Table 3 has highlighted the multiple aspects for controlling electrical hazard in a systematic way.

TABLE 3
Systematic arrangement for controlling electrical hazard with the precautions guideline

ASPECT 1 Active Behavior Plan	Plan the proactive activities framework
	Types of Hazard analysis
	Hazard mitigation plan
	Planned proactive actions schedule
ASPECT 2 MAKING THE GUIDELINE FOR THE ISSUE OF TRAINING AND EVALUATION	Design the Technological
	guideline Safety security & protection training
	Expertise training
	Testing & Evaluation
	Meetings
	Crisis recovery guideline
	Consciousness and situation handling guideline
ASPECT 3 LOGS ALL TRANSACTIONS	Safety rules
	Electrical operating practices
	Disaster planning
	Equipment-specific procedures
	Auditing procedures
ASPECT 4 MAINTENANCE routine	General maintenance
	Electrical maintenance
	PPE
	Tool maintenance
ASPECT 5 OPERATIONAL SAFETY	Consciousness and self-control monitoring
	Tracking corrective measures
	Inspections
	Hazard reporting
	Contractor safety
ASPECT 6 Management commitment and leadership employee participation duties	Management leadership & commitment
	Employee involvement
	Roles and responsibility
	Performance planning
ASPECT 7 REACTIVE MEASURES	Accident investigation
	Emergency response

The overall record of non-fatalities in U.S. Private Industry from 1992 to 2020 has been analyses in [11]. Fig 7 shows the non-fatal injuries that happened from 1992 to 2020.

As of the year 2020, fatalities in the construction and extraction industries affect 44% of workers, fatalities in the installation, maintenance, and repair industries affect 20% of workers, fatalities in the building and ground cleaning industries affect 13% of workers, and fatalities in the transportation, material moving, and farming, fishing, and forestry industries affect 6% and 3% of workers, respectively.

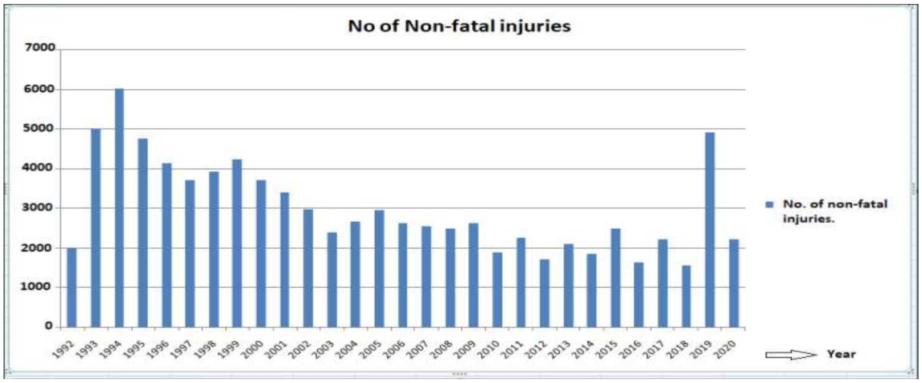


Fig. 7 Non-fatal Electrical Injuries from 1992 to 2020

Below mentioned pie chart Fig 8 has shown the overall recorded fatalities in U.S., Private Industry[11] from 2011 - 2020.

Fig.8 Statistical report for fatalities electrical injuries by event, all ownership2003 - 2020

5.1. *OVERALL ANALYSIS REPORT ON DIFFERENT AGE'S PEOPLE*

Consider the following statistics from a report based on the year 2020: 7% of workers aged 20 to 24 suffer fatal work injuries as a result of exposure to electricity, compared to 33% of workers aged 25 to 34, 21% of workers aged 35 to 44, and 18%, 17%, and 5% of workers aged 45 to 54, 55 to 64, respectively [10].

Fig 9 has been shown the overall pie chart of the victim for fatalities of different age groups recorded in U.S., Private Industry from 2011 - 2020.

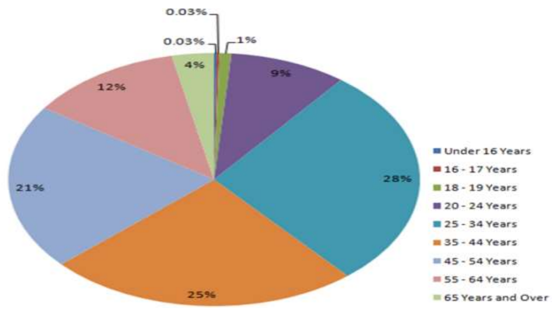


Fig. 9 Pie Chart for ages under 16 years to 65 years and above

5.2. OVERALL ANALYSIS REPORT ON DIFFERENT WORKPLACES

Take a look at the report based on the year 2020. According to the survey, 33% of fatal electrical injuries happened in private homes, 31% happened in industrial settings, 13% happened on streets and highways, and 14% happened at farms and other places. The bar graph in Fig. 10 compares self-employed individuals, wage and salary workers, and the years 2011 to 2020.

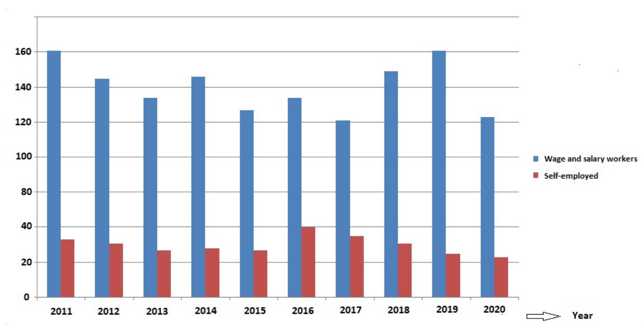


Fig.10 Bar graph between wage and salary workers, self employed and years from 2011-2020

5.3. STATISTICAL INDIA REPORT

The Indian national grid or central grid has been divided into five regional grids like Northern grid, Southern grid, Eastern grid, Western grid and North Eastern grid. There are several reasons for the Indian national grid also experiencing multiple electrical accidents here statistical analysis have been made in the year 2013 to 2021[72].The overall analysis data has been collected from the Government of India Ministry of Power Central Electricity Authority.

Western region states of India basically are Madhya Pradesh, Maharashtra, Gujarat, Goa, Chhattisgarh and Mumbai. So according to the data from the year 2013 to 2020 of the western India it has been shown the Fig 11 observed that some details associated with the fatal and non fatal electrical injuries happened to the human and the animals life.

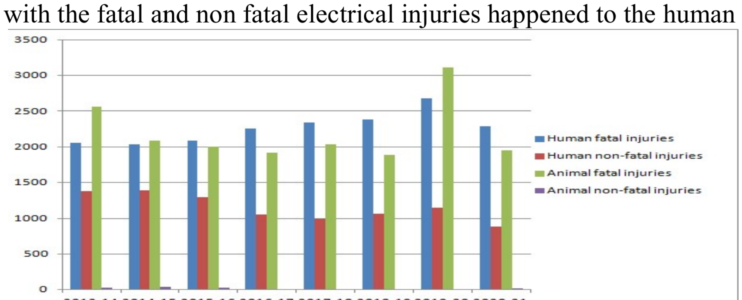


Fig. 11 Fatal and non fatal electrical injuries bar graph in 2013 to 2021 for Western Region

It has been seen that in the year of 2019 the number of fatal injuries of humans were the most, that is 2676 cases and in the year of 2014 the human fatal electrical injuries were the least that is 2035 cases. And in the year of 2014 the human non-fatal electrical injuries was the most that is 1390 cases and in the year of 2020 the non fatal electrical injuries of humans were the least that is 882 cases and the other corresponding cases with respect to the years also been observed. Animal fatal and non fatal electrical injuries are also shown, in the year of 2019 the fatal animal injuries were the most, that is 3111 cases and in 2018 the fatal animal injuries that were 1186 cases are the least. And in 2014 the non fatal animal injuries were the most and in 2016 were the least. In 2015 the non fatal animal injuries were approx 179 cases and in 2016 and 2017 were low.

Similarly the data of other regional grids like southern region, north eastern region, eastern region and northern region has been collected on fatal and non fatal electrical injuries and overall analysis shown in Fig.12, 13, 14, 15 respectively in a bar graph representation.

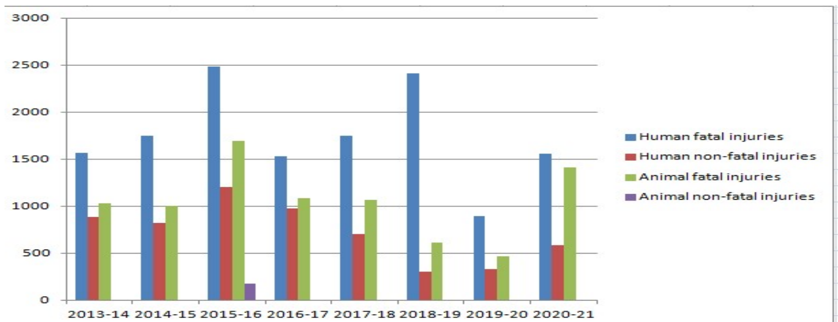


Fig. 12 Fatal and non fatal electrical injuries bar graph in 2013 to 2021 for Southern region

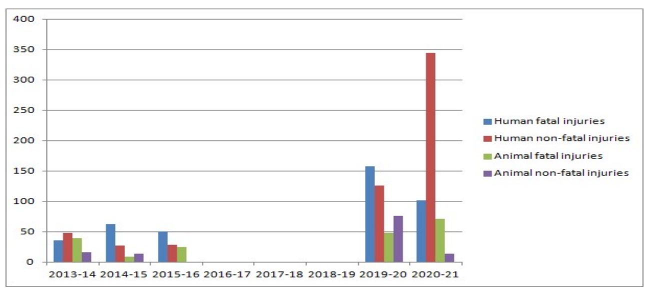


Fig.13 Fatal and non fatal electrical injuries bar graph in 2013 to 2021 in North Eastern region

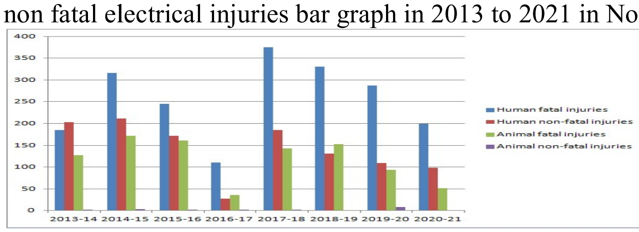


Fig. 14 Fatal and non fatal electrical injuries bar graph in 2013 to 2021 for Eastern region states

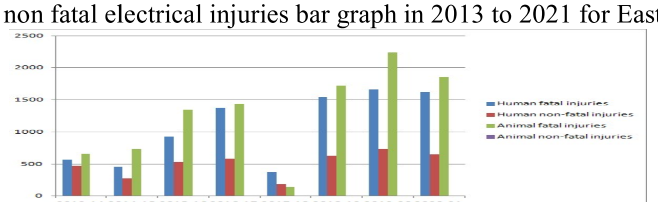


Fig. 15 Fatal and non fatal electrical injuries bar graph in 2013 to 2021 for Northern region states

6. CHALLENGES RELATED THROUGHOUT ELECTRICAL HAZARD RECONSTRUCTION WORK

There are multiple reasons behind the post disaster reconstruction activity. Initially identifying the faulty zone otherwise it will affect the electricity workers. Providing a safe environment to the workers is a very important task[9].Several times due to earthquakes or natural calamities such as lightning, thunderstorms, wind flow etc can destroy the electrical network as well as constructive activity like road construction; underground cable repairing work, etc are also responsible for creating severe electrical hazard or power blackout conditions. After the electrical hazards, reconstructive activities have been required to mitigate the faulty area as early as possible. These reconstructive activities are called post disaster activities.

Post disaster reconstruction safety mainly deals with the flowing collaborative work. They are known as high level management, medium level management and workers. Fig 16 has segregated different levels of classification for post disaster reconstruction works.

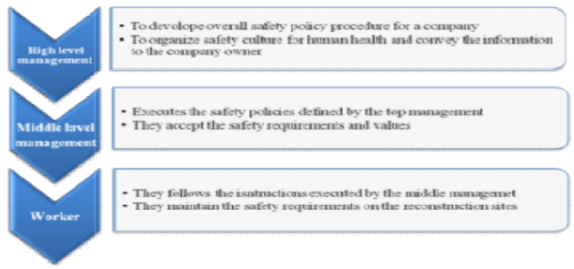


Fig. 16 Classification of post disaster reconstruction safety

TABLE 4
Segregating the responsibilities list for multiple section

Categories	Responsibilities [High Management]	Responsibilities [Middle Management]	Responsibilities [Worker]
Electrical Hazards	-Provide standard instructions -Provides low voltage testing equipment	-To allow only properly trained workers. -To inspect the electrical lines before repairing	-Avoid coming into direct contact with power lines. Always wear sufficient body protection when working on any electrical equipment, check to see if the power lines are down, and utilize electric tools or appliances to turn on and off the power supply.
Structural dangers or hazards	-Solid structural work is requered to avoid the falls	-Inspection and identification of damaged structures, as well as safety	-Away from the damaged structures that could collapse at any time, inspect the damaged structure in the repair area.
Chemical risk or hazards	- Check the local water and debris for any chemicals. -The atmosphere in the area is also examined	-Should not close any area adequately, there must be sufficient venting	-Should be available of venting if any kind of generators or electric compressor are employed.
Carbon monoxide Hazards	-Provides battery powered detectors and are checked twice annually.-For prevention of any kind of fatal incident, to create awareness not to use any generators, propane or natural gas or charcoal-burning devices in enclosed spaces. -To provides CO detector	-While using generators battery powered CO detectors are provided -Never use a generator, pressure washer or any kind of gasoline-powered engine in any enclosed area	-Never leave any running generators or compressors in the enclosed area
Fire Hazards	-Be ready with a proper and sufficient number of	-Examine if any structure has a gas	-All the fire exits and the extinguishers must be

Most important post-disaster [20] activity is to clean up the affected area. Safety management plans post-disaster can reduce many hazards. Initial concern is to consult utility companies before installation of power generators, as it can reduce CO &chemical hazards. Next is a step to clearly identify & mark dangerous areas to reduce electrocutions. Disasters can immediately destroy societies.

Number of electrically-related fires in England between 2015 and 2016 Out of a total of 28,350 fires, electricity was to blame for 15,432 of them, or 54.4% of all fires in England. The main contributing factor was improper usage of tools or appliances [19]. On 17 of the 15,432 fires, 80.5% (excluding undefined in the raw dataset) were caused by items and appliances, and 2.920 were 18.9% by electrical distribution. Cooking appliance electrical fires caused by major goods accounted for 8,759 of the fires in England in 2015–16.Below mentioned Fig 17 shows the home electrical fire caused by electrical equipment in England. (Electrical safety first core data, 2016)

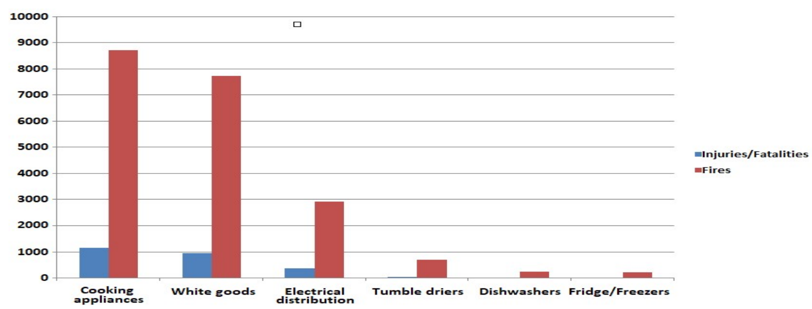


Fig. 17: Bar graph for electrical fire injuries

6.1. SAFETY PRECAUTIONS

Electrical safety means to take precaution on the electrical hazards and all kinds of electrical faults that are responsible for the death of many human lives. There are some of the basic household safety tips that should be maintained to prevent electrical injuries [12]. Safety tips for domestic and multiply commercial users:

(i) Repair or replacing damaged electrical equipment, electrical power cords etc.
(ii) Keeping the electrical devices away from water or any kind of moisture surface to prevent electrical shocks.
(iii) By avoiding overload outlets in the households.
(iv) The unused equipment should be unplugged when not in use to prevent overheating.
(v) Never use any electrical equipment of improper wattage.

On the other hand several safety protocols have to be taken for post disaster reconstruction work. In [9] have been addressed some safety tips which is mention below

1. To properly train all workers before allowing them to repair any electrical equipment.
2. Never turn any electrical equipment on or off when there is any contact with water or any conductor body.
3. Before repairing any power lines to wear protective shoes, gloves etc. Make sure the generator is off before re-supplying [9].
4. To inform and consult the utility company before installing any generators.

6.2. ELECTRICAL SAFETY PREQUATION AT VARIOUS VOLTAGE LEVELS

There are multiple consequences like a small tingling feeling to instant cardiac arrest due to electric shocks within a second. The harshness depends on the subsequent point [15], like current flow capacity of a path, time duration for body contact with the live line, amount of current level etc.
Table 1 has highlighted [25] the multiple severity record in the different voltage levels along with the precautions guideline. Indian standard electricity rules and regulation policy if voltage level goes beyond the range mentioned below table it may cause different kinds of electrical injuries. If voltage levels exceed 250 volt it may cause an electric shock that is dangerous because it can cause electrocution and fatal injuries even though there are no visible signs of external injury. According to the research of the World Health Organization, if voltage levels exceed 33000 volt it may cause insomnia, anxiety, headache, skin burns, fatigue, and muscle pain because of radiations from HV power lines. Table 5 has addressed some of the precautions guideline for multiply injuries at the different voltage levels.

In [26], some of the electrical safety related issues are serious for the manufacturing industry or other workplace in the USA where lives are lost owing to accidents that might have been barred with appropriate education and alertness of place of work hazards. In [27] has been addressed some necessary moves toward an electrical safety evaluation in RMG Industries for improvement of Electrical Hazards. Some safety methodology is made for audit planning which helps to minimize the cost of energy and also consider improved production, better quality, higher profit and most important satisfaction of heading towards developing electrical hazards.

TABLE 5
Injuries details and guideline

Safety Synopsis	Range	Injuries	Precautions	PPEs to be used
Low-Voltage	Not exceed 250V	Electric shock, electrocution and fatal injuries	Safety Shoes, Helmet, Goggles	8.5 ~ 9 Calories /cm2 ATPV LV Arc flash suit, 12 Calories /cm 2 ATPV Hand gloves, 12 Calories /cm 2 ATPV Arc Face Shield
High Voltage	Not exceed 33000V	Insomnia, anxiety, headache, skin burns, fatigue, and muscle pain	Safety Shoes, Helmet, Goggles, Double layer switching coat, Hand gloves (Inner & Outer), Hard Hat is included in the HT Kool Coat Kit)	40 Calories/ cm2 ATPV HT Kool coat

to prevent any kinds of injury to themselves and others. Many users of electricity are not well informed or aware about electricity hazards and safety measures [16]. To prevent this people have been gone through with proper training and awareness about the workplace hazards. Enhancing the training methods that are activated and interactive for electrical safety training for all construction workers and reduce accidents and fatalities caused by the electrical shock. Virtual Environment (VE's) simulations [16] are used mainly for successful safety training within the construction industry. This training improves the psychological ability and awareness that generally improves the customer capacity of training material. The main purpose of this study is to assess the level of electrical hazards and safety measures awareness among electricity worldwide [14].

1. Increase the awareness to improve the potential of electrical hazards.
2. Thinking in such a way to eliminate, remove, and prevent electrical hazards in the workplace.
3. Having some knowledge about electrical accidents.
4. Never pull a plug by its cord.
5. Stay away from power lines which are broken.

The electricity users are aware of the following electrical Hazards such as (i) damage Electrical Appliance and Equipment and (ii) improper Electrical Installation are not aware of the following as electrical hazards [14].
1. Un-grounded circuit and equipment.
2. Coiled extension leads.
3. Covered ventilation holes in electrical equipment.

The safety measures awareness has been followed by some do's and don'ts by the electricity users [14].

TABLE 6
Do's and don'ts by the electricity users

Do's	Don'ts
Proper electrical insulation	Uncoiled extension cord on the drum.
How to treat a victim of electrical shock	Uncovered slots of electrical machine and equipment.

7.1. SAFETY GUIDELINES BY RCD FOR SAFETY AWARENESS

The full form of RCD is Residual Current Device. Some safety guidelines have been mentioned by RCD for safety protection in the commercial industry, agricultural and residential prospective. If equipment is operating at 230 volts or higher than 230 volts, a residual current device must be used to provide additional safety for the equipment. RCD device uses residual current for its operation at rated 30 mA or less, it offers many protections against the electrical hazards from interaction with live parts. An RCD [15] is a device which can detect some faults, but cannot detect all kinds of faults in the electrical system and immediately switches off the power supply. The best place for installing an RCD is into the main switchboard or the socket outlet, by using the RCD device we can permanently protect the supply cables. There are multiple reasons to fall in fault which includes (i) improper maintenance, (ii) insulation fault, (natural tear and wear) (iii) carelessness (iv)water immersion and (v) unintentional touching. This rapid tripping device identifies the residual currents to the earth and separates the power supply automatically in order to protect human or animal lives. RCD guidelines have been mentioned below:
1. An RCD is a useful safety device. It should never be bypassed.
2. If it trips, it indicates that there is a fault, so for this reason we must check the system before using it again.
3. If it trips intermittently and no fault can be detected in the system, contact with the manufacturer of the RCD and the RCD has a test button to check that its mechanism is free and functioning.

8. RECOMMENDATION AND RESCUE TECHNIQUES FOR HAZARDS AND SAFETY

Some electrical guidelines and approaches are discussed in [14] and are listed below:
1. The government, non-governmental organizations, electrical power companies, and manufacturers of electrical devices should educate all electricity users on the risks associated with using electricity and should do so solely through television, radio, posters, news, and other forms of communication.
2. Through safety posters, news, and other forms of communication, electricity users should be well-informed of the safety precautions that will assist protect their lives and property.

Some electrical rescue approaches are discussed in [15] and are listed below:
1. **Moving closer to the accident scene:** Avoid running into an accident scene immediately. As soon as you can, call the members of the medical team. Get the assistance of trained electrical workers if at all feasible. Be cautious as you approach the accident scene.
2. **Inspect the surroundings:** Virtually inspect victims to see if they have come into contact with the energized wires. The soil itself, nearby metal items, or metal surfaces may all be electrified. If you come in contact with an energized person or conductive surface, you could become a victim. When they are energized, avoid touching the victim or conductive surfaces. Electrical circuits should be de-energized if at all possible.
3. **Understand how to de-energize:** The small electrical equipment is powered by an extension cable or power cable. To cut electricity, disconnect the little electrical apparatus. To de-energize the stationary electrical equipment, we should open a cutoff circuit or circuit breaker.

For the general safety of human body parts to prevent electrical risks in the workplace, some protective equipment is listed in Table 7 as necessary.

TABLE 7

Protecting equipment for our different body parts

Body part	Protecting Equipment	Body part	Protecting Equipment
Eye	Safety glasses	Hands	Gloves
Head	Hard hat	Respiratory system	Masks & respirators
Face	Face shield	Bodies	Vests
Hearing	Earmuffs, earplugs	Feet	Safety shoes

9. OVERALL STRATEGIES PLANNING

A literature survey of several publications in electrical hazard and safety strategies has been classified in different division. Various research approaches which are outlined in Table 8.

TABLE 8

Literature survey of existing Electrical hazards and Safety protection

Sl no	Categories	Paper no
1	Electrical safety	[1,8,18,25,29-31]
2	Post-Disaster Reconstruction Safety	[9,20]
3	The effects of electrical hazards	[7]
4	Electrical Safety hazards awareness	[14-16,19]
5	Fatal Work Injuries	[10]
6	First aid and treatment	[17,22]

Summary of previous studies related to the implementation of the Solving the electrical hazard in last few years

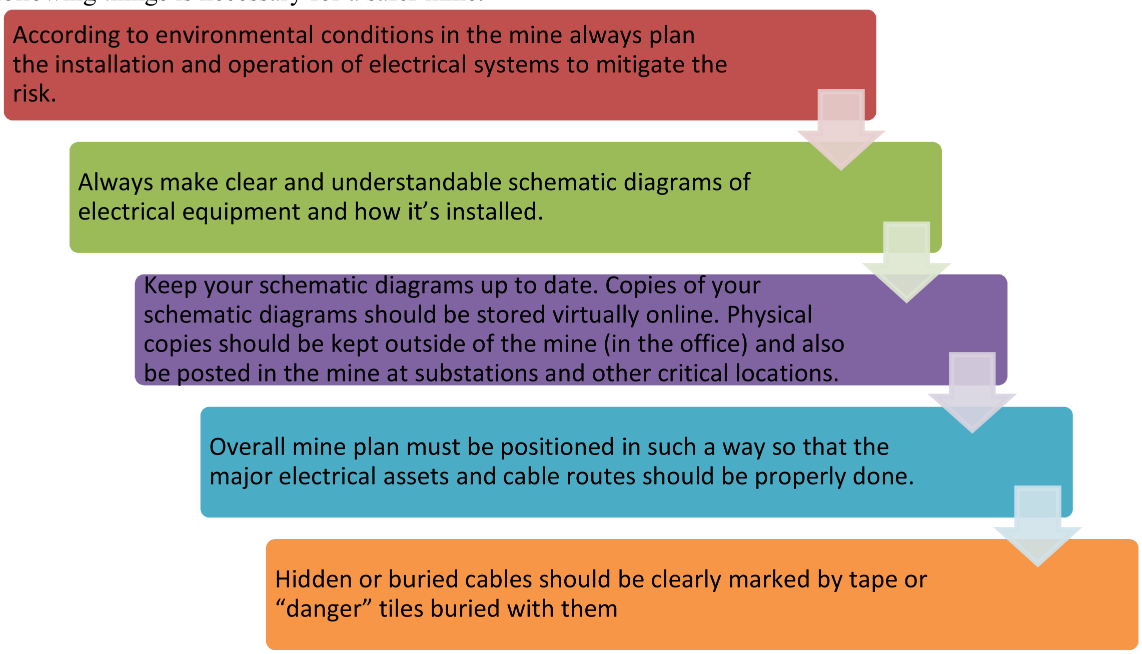
References	Optimization technique	Objective
Dong Zhao et al [16]	An analysis of construction industry	Control measures of electrical hazards
M. Chakrabarty et al [5]	An Interactive partitioning algorithm-based electrical power crisis considering post disaster condition	service restoration with existing black-start resources considering load priority
Moja et al [24]	environmental risk assessment in the electricity sector	Aspect identification and environmental risk assessment
Zhao et al [26]	Virtual reality simulation	construction safety promotion
Hossain et al [27]	Assessment in RMG Industries	Development of Electrical Hazards
Abdel-Sayed et al [28]	Cell therapies for skin regeneration	Cell therapies for skin regeneration
Floyd, L et al[32]		Home electricity safety

...omes out along ... accident. Damp and wet conditions add additional factors of complications for risk of fire and accident. Safety protocol will start when planning for the mining is properly done.

10.1. PLANNING FORMINEING SAFETY

Mine safety is always important and it is carefully done with utmost planning to power the mines. In order to achieve certification from the United States Depart of Labor's Mine Safety and Health Administration, designing along with specifications for electrical equipment and accessories should be carefully submitted through a written application. It is then reviewed and evaluated according to MHSA's standards and regulations to produce a compliance report.

The following steps should be taken as precautionary measures for Electrical system installation:.
1. Ground the electrical system properly
2. Ensure that the system being used should have automatically power cut off system when fault occurs. In addition, always install a back-up power supply including environmental monitoring equipment, control rooms, ventilation fans etc.
3. Don't ever make changes to any part of your system without carefully thinking them through and determining the impact to the overall system.
4. Always use cables and equipment tested and approved for use in mines according to MSHA, cables and cords used in mining must follow the standards created by the Insulated Power Cable Engineers Association (IPCEA). The following things is necessary for a safer mine.



Safety tips for using electrical equipment in mines.
1. Always select and use equipment that is fully compatible otherwise leading cause of mine accidents and injuries.
2. If there is any chance that unrelated plugs or sockets could be coupled together, take precautions to prevent this by using keyway coding, padlocking, or clearly marking the switchgear, plugs, and sockets.
3. Any electrical equipment used in areas that could potentially have flammable dusts or gases should be certified for use in these types of areas.
4. Only use low-voltage handheld equipment in mines (at or below 50VAC or 120VDC).
5. Traction batteries should only be changed at designated charging or transfer stations that are adequately equipped for doing the job.
6. Use spider boxes and other temporary power supply sources designated for mine.
7. Always double check that cable coverings, protective devices, and conducting screens are securely attached to equipment and properly sealed.
8. Flexible cables attached to tools should always be placed in secure locations where they can't be damaged.
9. To keep unauthorized workers from making system changes to operate their equipment.

11. CONCLUSION

This overall analysis has been very useful for academics, researchers and decision makers to minimize the risk associated with the electric hazards. Electricity is an essential in human life but improper use of it can have a deadly impact on society. The conclusion of this survey work will help the electricity workers while concerned in household and post-disaster reconstruction work and will help them in developing practical guidelines for avoiding unsafe hazards. Proper electrical installed setup and correctly installed and maintains strategy be able to save life.Using the right equipment correctly can help reduce the number of electrical-related accidents, injuries and deaths that happen in mines. Safety is something that should be considered from the beginning to keep it hazardless.

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