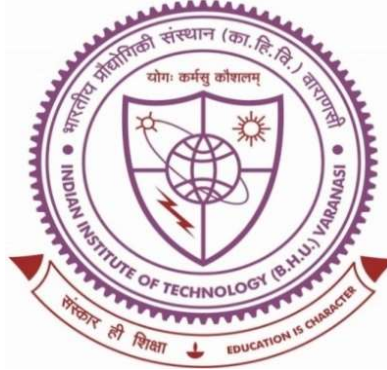


**Impact of Surface Miner on Production and Productivity with  
Special Reference to Coal Mining**



**Thesis submitted in partial fulfilment for the  
Award of Degree**

*Doctor of Philosophy*

by

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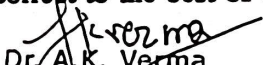
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## ACKNOWLEDGEMENT

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Reflecting on the culmination of dedicated efforts and exploration, I am filled with profound gratitude for the journey that brought me to this moment. Deep appreciation goes to the pious seat of learning, Indian Institute of Technology (Banaras Hindu University), Varanasi – the institution founded by the Bharat Ratna “Mahamana”, Pt. Madan Mohan Malviya is a testament to his educational commitment.

Indebtedness goes to the esteemed Department of Mining Engineering, IIT (BHU), for providing a nurturing environment and steadfast support, which was instrumental in shaping my academic path. I appreciate this distinguished department for fostering a space conducive to scholarly pursuit and research.

My sincere gratitude goes to my supervisor, Dr. Nawal Kishore, whose constant mentorship, consistent support and impeccable expertise have shaped my research journey. I am equally thankful to my co-supervisor, Dr. Amit Kumar Verma, for his thoughtful supervision, enduring support and unique perspective, which have immensely contributed to my research journey. Their guidance has kept me motivated and focused to achieve my research goals.

I am expressing my earnest gratitude to Prof. Rajesh Rai, Head of Department and Prof. Suprakash Gupta, former Head of Department, Department of Mining Engineering, IIT(BHU), for providing essential resources, enriching environment and staunch support.

I am incredibly grateful to the research progress evaluation committee members, Prof. Aarif Jamal and Dr. Girija Shankar Mahobia, for their moral support, encouragement, and valuable suggestions, which helped me complete this research work.

My heartfelt regard goes to Prof. Sanjay Kumar Sharma, Prof. Piyush Rai and Prof. Gauri Shankar Prasad Singh for their generous guidance and valuable expertise, which have greatly enriched my learning experience.

I offer my sincere thanks to Dr. Ashok Jaiswal, Dr. Sanjay Kumar Palei, Dr. Tarun Verma and Dr. Amrendra Kumar for their incitement and assistance, which have significantly enhanced my educational journey.


I thank all supportive lab associates and office staff at the Department of Mining Engineering, IIT(BHU), for their invaluable help in facilitating my research endeavours across various academic and non-academic domains. I offer special thanks to my lab mate, Dr. Vikram Seervi, for consistent discussions, encouragement, and support. I am genuinely thankful to all my seniors and joyful friends for their camaraderie and collaborative spirit. Their faith in me kept me going through difficult times.

My warm gratitude goes to the Ministry of Human Resource Development, India and the Science and Engineering Research Board, India, for their financial support, which enabled me to pursue my research ambitions.

I am indebted to my beloved family, Urmila Singh, Rama Shankar Singh, Devesh Pratap Singh, Neetu Singh, Sangeeta Singh and Preyanshi Singh, for their unwavering love, empathy, patience, encouragement, and sacrifices, which have been the cornerstone of my success. I am grateful to have them by my side and for always believing in me.

Lastly, I humbly thank Lord Vishwanath for instilling the courage and determination to overcome challenges. I am forever grateful for your presence in my life.

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*Dedicated to Cheeku  
and Peehu*



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## LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AAI	Average Annual Investment
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
BEPF	Bivariate Exponential Production Function
BOCM	Bhubaneswari Opencast Coal Mine
CAGR	Compound Annual Growth Rate
CCA	Correlation Coefficient Analysis
CCL	Central Coalfields Limited
CIL	Coal India Limited
CMPDI	Central Mine Planning and Design Institute Limited
CPDF	Cobb-Douglas Production Function
CRS	Constant Return to Scale
D	Cutting Depth
DEA	Data Envelopment Analysis
DRS	Decreasing Return to Scale
EHMR	Engine hour meter reading
FOG	Filter, Lubricating oil, and Grease
FY	Fiscal Year
GDP	Gross Domestic Product
GOCM	Gevra Opencast Coal Mine
IRS	Increasing Return to Scale
JOCM	Jayant Opencast Coal Mine
LB	Larger-is-Better
LOCM	Lakhanpur Opencast Coal Mine
L&T	Larsen and Toubro
MCL	Mahanadi Coalfields Limited
MLF	Machine Load Factor

MLP	Multi-layer Perceptron
MLR	Multiple Linear Regression
MSK	Machine Shift Cost
MST	Machine Shift Time
MSL	Mean Sea Level
Mt	Million Tonnes
NCL	Northern Coalfields Limited
NB	Nominal-is-Best
NOCM	Nigahi Opencast Coal Mine
OB	Overburden
OMS	Output per Man Shift
O&O	Ownership and Operating Costs
PCA	Principal Component Analysis
PEKB	Parsa East and Kanta Basan opencast coal mine
Q	Coal Production
R	Coefficient of Correlation
R <sup>2</sup>	Coefficient of Determination
RMSE	Root Mean Square Error
ROCM	Rajmahal Opencast Coal Mine
SB	Smaller-is-Better
SECL	South-Eastern Coalfields Limited
SM	Surface Miner
SMPI <sub>C</sub>	Surface Miner Productivity Index for Coal
S/N	Signal-to-Noise
SOCM	Samaleswari Opencast Coal Mine
SSE	Sum of Squared Errors
UCS	Uniaxial Compressive Strength
V	Cutting Speed
VIF	Variance Inflation Factor
$v$	Drum Speed
bcm	Bank cubic meter

## PREFACE

Coal remains a cornerstone of India's energy portfolio, fulfilling 51.65% of nation's total energy demand. Despite consistent growth in domestic coal production, the country's coal demand continues to surpass supply. The persistent supply-demand gap highlights the challenges of meeting production targets, particularly in opencast coal mines that contribute 95% of India's total coal output. Surface miner (SM), as state-of-the-art technology, is introduced to address this challenge and has gained significant traction in India's opencast coal mines over the past two decades due to its continuous, selective, cost-effective and eco-friendly coal mining capabilities. It is a crawler-mounted machine equipped with a cutting drum having multiple conical picks as cutting tools to cut coal into specified sizes.

The energy consumed for coal cutting dominates the total energy consumption in opencast mines. In consequence, machine selection becomes important in reducing the energy consumed. In this study, five SM models, namely, KSM 303 (Machine A), KSM 304 (Machine B), KSM 403 (Machine C) from L&T and 2200 SM (Machine D) and 2200 SM 3.8 (Machine E) from Wirtgen are selected to facilitate meaningful comparisons across SM models based on energy productivity. Energy productivity, defined as the ratio of rated production to the energy consumed during coal cutting in a fixed period is analysed for various cutting depths to select the most productive machine in term of energy.

However, industries may not have financial resources to acquire productive machines. Thus, an improvement of energy productivity becomes necessary at the level of existing machine. In this study, Taguchi method is used to optimise the control factors of machine E, namely, cutting depth (D), cutting speed (V) and drum speed ( $v$ ) by serving energy productivity as a characteristic response. Taguchi L25 orthogonal array is utilised to statistically analyse the effect of control factors on energy productivity. The optimal

control factor settings are found to be D as 0.35 m, V as 30 m/min, and v as 60 rpm at minimum tensile strength (1.5 MPa); D as 0.30 m, V as 25 m/min, and v as 65 rpm drum speed at mean tensile strength (2.6 MPa); and D as 0.20 m, V as 10 m/min, and v as 70 rpm at maximum tensile strength (3.7 MPa) for machine E. A confirmation test validated that 29% of overall energy productivity is improved for machine E operating on a coal seam present at Bhubaneswari opencast coal mine by practicing optimum control factor settings as compared to the initial setting of control factors during coal cutting.

Energy productivity models are developed based on control factors using Taguchi, multiple linear regression (MLR) and artificial neural network (ANN) techniques at significance level of 0.05. A confirmation test revealed that Taguchi method provided a better outcome with minimum deviation. Meanwhile, cutting speed is identified as the most contributing control factor using ANOVA, emphasising a substantial contribution of 66% in the variability of energy productivity. Empirical models are also developed to predict cutting speed at specified cutting depths for machine E, indicating that cutting speed followed an exponential decline with increased coal tensile strength.

The prediction of key productivity indicators of an excavator can prevent the excessive material consumption. Coal, machine and operational parameters affect key productivity indicators of SM, namely, machine productivity, pick consumption and diesel consumption. A dataset of 39 field-scale SM coal production trials is observed to select critical factors affecting key productivity indicators based on correlation coefficient and principal component analysis. Seven critical factors are selected out of eleven identified influencing factors, namely, uniaxial compressive strength, tensile strength, ash content, moisture content, cutting width, cutting depth, cutting area, cutting speed, rated power for cutting drum, face length and machine utilisation for better imitation of all the interacting parameters in predicting key productivity indicators of SM.

MLR models are developed to predict key productivity indicators based on selected critical factors. The performance of these models is validated using coefficient of determination between actual and predicted values and standardised residual analysis for normal distribution of residuals with zero mean and constant variance. To simplify the relationships within the MLR models, a unified index, termed as Surface Miner Productivity Index for Coal (SMPI<sub>C</sub>) is developed as a composite of coal, machine and operational parameters to predict key productivity indicators. Empirical models based on SMPI<sub>C</sub> index are validated using 6 field-scale SM coal production trials dataset.

In summary, MLR models and SMPI<sub>C</sub> index-based models are found to be statistically significant to predict key productivity indicators at 0.05 significance level. These models are successfully verified outside the statistical domain using ANN technique. A confirmation test based on the sum of squared errors (SSE) validates that the developed key productivity indicators prediction models using ANN technique are found to be the most significant as compared to MLR models and SMPI<sub>C</sub> index-based models. However, ANN models based on selected critical factors reveals the compatibility between statistical and ANN approach.

Lastly, SM coal production in a 24-hour scheduled shift is aggregated on monthly basis as an output, to examine whether it follows the Cobb-Douglas production function (CPDF) with respect to the production factors, *i.e.*, machine shift time (MST) as a ‘labour’ input and machine shift cost (MSK) as a ‘capital’ input. A confirmation test based on root mean squared error (RMSE) concludes that the CDPF model is more significant as compared to model based on bivariate exponential production function (BEPF) at significance level of 0.05. Meanwhile, isoquant curves representing a unique production level for each curve are developed to categorise SM coal production based on SM total factor productivity.

In addition, the output elasticities of labour ( $\alpha$ ) and capital ( $\beta$ ), i.e., 1.7162 and 1.2537, gauge the utilisation intensity of MST and MSK, respectively. A higher value of  $\alpha$  than  $\beta$  suggests that SM leans towards the MST-intensive technology. Moreover, the sum of  $\alpha$  and  $\beta$  exceeds unity, indicating an increasing return to scale economy, highlighting the need for mine managers to exercise caution while utilising MST and MSK as production factors to avoid irregularities and cost overruns during SM coal production, since, doubling either or both factors shall increase the coal production for more than double.