# THREE-DIMENSIONAL BALANCING DIAGRAM FOR PLANNING OF TANDEM DRAGLINE OPERATIONS IN LARGE OPENCAST MINES

**Thesis submitted in partial fulfilment for the**

**Award of Degree**

**Doctor of Philosophy**

**by**

**Vikram Seervi**

**DEPARTMENT OF MINING ENGINEERING**

**INDIAN INSTITUTE OF TECHNOLOGY**

**(BANARAS HINDU UNIVERSITY)**

**VARANASI – 221005**

**Roll no- 17151501**

**2022**

# CERTIFICATE

It is certified that the work contained in the thesis titled "**Three-Dimensional Balancing Diagram for Planning of Tandem Dragline Operations in Large Opencast Mines**" by **Mr Vikram Seervi** (Roll No. 17151501) has been carried out under our supervision and that this work has not been submitted elsewhere for the award of any degree or diploma.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy, State of Art seminar and Open seminar for the award of Ph.D. Degree.


N. Kishore

**Supervisor**
**Dr. Nawal Kishore**

Mining Engineering Department

Indian Institute of Technology (BHU)

VARANASI-221005

Averma

**Co-Supervisor**
**Dr. Amit Kumar Verma**

Mining Engineering Department

Indian Institute of Technology (BHU)

VARANASI-221005

# DECLARATION BY THE CANDIDATE

I, **Vikram Seervi,** certify that the work embodied in this thesis is a bonafide research work carried out by me, under the supervision of **Dr. Nawal Kishore** and **Dr. Amit Kumar Verma** from July 2018 to December 2022, at the Department of Mining Engineering, Indian Institute of Technology (BHU) Varanasi. The matter embodied in this thesis has not been submitted elsewhere for the award of any other degree or diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not wilfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports, dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date: 27/12/2022

Place: IIT (BHU) Varanasi

Vikram

(Vikram Seervi)

## CERTIFICATE BY THE SUPERVISORS

It is certified that the statement made above by the student is correct to the best of our knowledge.

N. Kishore

**Supervisor** 27/12/2022

**Dr. Nawal Kishore**

Mining Engineering Department

Indian Institute of Technology (BHU)

VARANASI-221005

AKVerma

**Co-Supervisor**

**Dr. Amit Kumar Verma**

Mining Engineering Department

Indian Institute of Technology (BHU)

VARANASI-221005

17/02/2023

**Prof. Suprakash Gupta**

विभागाध्यक्ष/HEAD

The Head

खनन अभियांत्रिकी विभाग

Dept. of Mining Engg.

Department of Mining Engineering

Indian Institute of Technology (Banaras Hindu University)

IIT (BHU) Varanasi

Varanasi-221005

# COPYRIGHT TRANSFER CERTIFICATE

**Title of the Thesis**: Three-Dimensional Balancing Diagram for Planning of Tandem Dragline Operations in Large Opencast Mines

**Name of the Student:** Vikram Seervi

## Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University) Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the ***Doctor of Philosophy***.

**Date:** 27/12/2022

**Place:** IIT (BHU) Varanasi, India

Vikram

**Vikram Seervi**

**Note:** However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for the author's personal use, provided that the source and the Institute's copyright notice are indicated.

# ACKNOWLEDGEMENTS

I take this opportunity to express my heartfelt gratitude towards all those who have contributed to this thesis and supported me in one way or the other. I am indebted to several people who helped me in my research and in compiling the thesis.

At the outset, I extend my deepest gratitude and appreciation to my supervisor, Dr. Nawal Kishore, Assistant Professor, Department of Mining Engineering, Indian Institute of Technology (BHU) Varanasi, India, for his generous guidance, encouragement, direction, and support. I would treasure this enriching experience throughout my life. Apart from the academic training received, other important qualities and skills, like communication skills, and interpersonal skills, were also inculcated in me by you. I have learnt a lot from you, and your valuable suggestions have helped me in completing my PhD research successfully. Thank you very much, once again, for all your help and support.

An immense thank you to my co-supervisor Dr. Amit Kumar Verma. Support and guidance throughout the PhD from you all have been invaluable. I would also like to thank the other members of my supervisory committee, Dr. GSP Singh and Dr. AK Mondel, for their insights and suggestions.

I want to express my gratitude to Prof. S. Gupta, Head of the Department and Prof. Piyush Rai, former Head of the Department of Mining Engineering at IIT BHU for providing essential resources, permissions, and support. Dear Prof. Piyush Rai, I am very grateful for your support and advice.

I wish to express my profound thanks to Prof. S K Sharma, former Head of the Department of Mining Engineering at IIT BHU. Dear sir, thank you for your guidance and motivation during my PhD research. I am truly grateful for your support.

Dear Prof. Aarif Jamal (former Head of the Department) and Dr. Ashok Jaiswal, thank you sir for your guidance during my PhD research. Your support has been invaluable in helping me to achieve my research goals.

I would like to express my sincere gratitude to Dr. BS Choudhary, IIT (ISM) Dhanbad, for his support and encouragement in pursuing my PhD. His guidance has been instrumental in helping me stay motivated and focused on my goals.

I am extremely grateful to Prof. Sheo Shankar Rai, at IIT (ISM) Dhanbad for his guidance and help in understanding critical dragline operation and simulation concepts. I am very grateful for his support and advice.

I would like to extend my heartiest gratitude towards Mr. Rahul Kumar, senior manager of technical services at Sasan Coal mines, who has helped me a lot to understand the dragline operation. He has guided me in the right direction. I am very thankful to him for his help and support.

The valuable help rendered by various officers of NCL Mr. PD Rathi, Mr. SB Sindhur, Mr. Piyush Pandey, Mr. RK Shukla, Mr. Ankit Gupta, and Mr. Harshit Baranwal in collecting the field data and the knowledgeable discussions is sincerely acknowledged.

My special thanks go to my dear lab mate Nilesh Pratap Singh for all the discussions, encouragement, moral support, help, and happy moments I received during these years. His faith in me kept me going during difficult times. I will always cherish our friendship.

I am extremely grateful to my friend Vaibhav. He has provided me with a great deal of support in the development of computer program. Without his help, I would not have been able to make the progress I have.

I am very thankful to my friends from graduation, Maneeb Masood and Charchit Jain, who have supported me throughout my PhD journey. Thank you for being there for me, and I look forward to continuing our friendship in the future.

I would like to express my gratitude to my joyful friend Rajeev Verma. Your support and encouragement have been invaluable. I am also thankful for the many laughs we have shared. You have made this PhD process a lot more enjoyable.

I would like to express my gratitude to my friend, Dr Vineeth Balakrishnan, senior scientist at CIMFR Dhanbad, for his support and encouragement throughout my PhD journey. His belief in me kept me going when things got tough.

Special acknowledgement to my senior, Saurabh Jain, from VNIT Nagpur, who has helped and supported me throughout my PhD journey and college life. Thank you for your constant guidance, encouragement, and motivation. You have been an invaluable source of strength and inspiration, and I am truly grateful for all your support.

I am also thankful to my fellow research scholars Ankush Galav, Gagan Gupta and Anupam Chaturvedi for their valuable suggestions during the research that encouraged me and helped me make the journey more sustainable.

I am also grateful to my friend and senior, Dharmendra Kumar, for their continuous support during my PhD studies. I would also like to thank him for providing valuable feedback on my work.

Many people have contributed to this thesis indirectly or directly, even though their contributions may not be visible. I want to thank all those who helped me throughout this process.

My sincere appreciation goes to avail this opportunity to express my deep gratitude, love and respect to my family for their support during my PhD studies. I would especially like to thank my parents for their patience and understanding during this process. Additionally, I would like to thank my younger brother and friend Suraj and sister Sandhya for their encouragement and enthusiasm for their love, care, encouragement, and support throughout my entire life.

I would like to express my gratitude to my wife, Suman, for her immense support and patience throughout my PhD journey.  She has been my pillar of strength and motivation, always pushing me to do better. I am truly grateful to have her by my side and for always believing in me.

Finally, I thank "Lord Shiva", for being with me and respond to all my silent sincere prayers.

Vikram

Date:  27/12/2022

Place:  Varanasi                                                                                          Vikram Seervi

*Dedicated to my Beloved*

*Niece, Jigyasa*

# CONTENTS

# LIST FO FIGURES

# LIST FO TABLES

# ABSTRACT

The coal industry plays a significant role in the development of the Indian economy. Coal is the most important and abundant fossil fuel in India due to the limited availability of oil and gas. In recent years, with the ever-growing energy needs, the demand for coal has increased drastically and will continue to be a major source of energy well into the next century. Coal is commonly extracted through surface mining methods due to its benefits, including a higher extraction ratio, higher productivity, and fewer safety problems. In surface coal mining, overburden (OB) removal is a significant mining operation and calls for efficient and careful planning for the best utilization of the system.

Overburden removal typically makes up more than 60% of the total mining costs in surface coal mines. The amount of overburden removal and coal production are directly proportional to each other. Over the past four decades, draglines have become increasingly popular for overburden handling because of their flexibility and high production rate. As mines expand and demand higher outputs, either higher capacity draglines with larger bucket sizes and radii or tandem operation of draglines are becoming more common.

In recent years, there has been an increased focus on operating draglines in tandem. This involves using two draglines to work together, either in horizontal tandem or vertical tandem, in order to maximize overburden removal and coal exposure while minimizing rehandling. This helps to make better use of these capital-intensive pieces of equipment. To get the most out of such tandem operation, it is extremely important to identify the key operational parameters that increase the rate of coal exposure and reduce the percentage of rehandling. There are two main aspects that have been identified to

improve the rate of coal exposure, considering geo-mining and machine specification parameters to be constant. The first step to increasing the productivity of draglines is to increase availability and utilization. The second step is to develop efficient and careful pit planning and design. The planning process helps identify operational parameters and how to best utilize resources. It is a blend of engineering and economics. It is good practice for planning engineers to assess the productivity of equipment in a given situation before making further operational plans. This will help ensure more meaningful results.

The current study has looked at the planning and design aspect of tandem dragline operation, taking into account the average annual productivity of draglines based on an actual field study. The key dragline performance and efficiency statistics have been gathered to get the average productivity of different capacity draglines, which is needed for further analysis.

Different seating arrangements of draglines are presented in the form of balancing diagrams to help determine the most effective way to utilize the draglines and minimize rehandling. The diagrams are based on synchronized linear advancement of both draglines and show the dragline cut spoil geometry in two dimensions, as well as bench division in horizontal and vertical tandem operation.

The draglines must be correctly deployed using the balancing diagram for draglines running in tandem. However, regularly drawing balancing diagrams by manually could become expensive, time-consuming, and even inaccurate. In order to quickly and accurately calculate the rate of coal exposure, % rehandle, area of cuts, synchronized linear advancement of each dragline, and stripping bench division; computer graphics are most suited for this task.

The purpose of this study is to conduct parametric and field studies of dragline operations in horizontal and vertical tandem configurations to evaluate the importance of various geo-mining, machine, and operative parameters on annual productivity and to offer suggestions for productivity enhancement.

With the aim of simplifying complex tandem dragline operation, an interactive, graphics-based program was developed in C++ language using OpenGL graphics API to help in generating three-dimensional balancing diagrams for draglines operating in horizontal and vertical tandem. This graphics program can be adopted for all decision-making situations, such as deciding the bench height for stripping, the width of cut, rate of coal exposure, percentage rehandle, and linear advancement of each dragline in tandem dragline operation. The computer graphics technique has been deployed as a tool to speed up the tedious procedure of manually drawing the balancing diagram, which is not amenable to repeated reiterations. This program can be used to create balancing diagrams for careful analysis and planning of tandem dragline operations. The computer graphics program produces precise and reliable results.

Field studies were conducted on four different mines of Northern Coalfields Ltd., Singarauli, a subsidiary of Coal India Ltd. Different draglines with different modes of operation and under different mining conditions. The draglines had capacities ranging from 10 to 24 $m^3$, cut widths ranging from 70 to 90 m, and stripping bench heights of 27 to 45 m. The modes of operation encountered in the field study were horizontal tandem (in the Jayant, Nighai and Dhudhichua mines), and vertical tandem (in Bina mine).

At the end of this thesis, there is a list of references that were mentioned throughout the thesis. The thesis is approximately 312 pages long and includes figures and appendices.

**Keywords:** Opencast coal mining, overburden removal, HEMM, dragline, tandem dragline methods, horizontal and vertical tandem, dragline planning in opencast coal mines, pit optimization, software development, three-dimensional balancing diagram, field studies, dragline performance and cost analysis, parametric analysis.