CHAPTER 1 INTRODUCTION AND OBJECTIVES OF THE STUDY

1.1 Introduction

1.1.1 Energy scenario and importance of surface coal mining in India

The coal industry contributes significantly to 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. Over 56% of all electricity is produced using coal (Central Electricity Authority, 2021). In recent times, with the ever-growing energy needs, the demand for coal has increased enormously and will continue to be a major source of energy well into the next century. The Indian coal industry has responded magnificently to this hike in demand with the rapid increase in production rate primarily due to the success of open-cast mining.

In India, coal is commonly extracted by surface mining methods. Due to its benefits, including a higher extraction ratio, higher productivity, and fewer safety problems, surface mining is the most widely used for the economical mining of coal. Over the past four decades, there has been spectacular growth in the development of the giant open-cast project. As surface mining technology has advanced, more shallow-depth underground coal mines (up to 300 metres deep) are being converted to surface mining methods in order to boost coal production (Ministry of Coal, Govt. of India, 2021). As of 2021, 225 of India's 454 coal mines are operated using the surface mining method, and 205 are operated using the underground mining method. Figure 1.1 represents statistics on coal extraction in India for the previous ten years by opencast and underground mining (Ministry of Coal, Govt. of India, 2021). The graph illustrates the steadily growing importance of opencast mining in India for the economically successful extraction of coal. This suggests that in order to maximise coal production in India, improved technical and scientific execution of optimised unit operations of surface mining is urgently required. With the advent of large capacity heavy earth moving machinery (HEMM), large diameter blast-hole drills and new explosive technology and blasting practices, it has been possible to maximise coal production successfully in large surface mines.

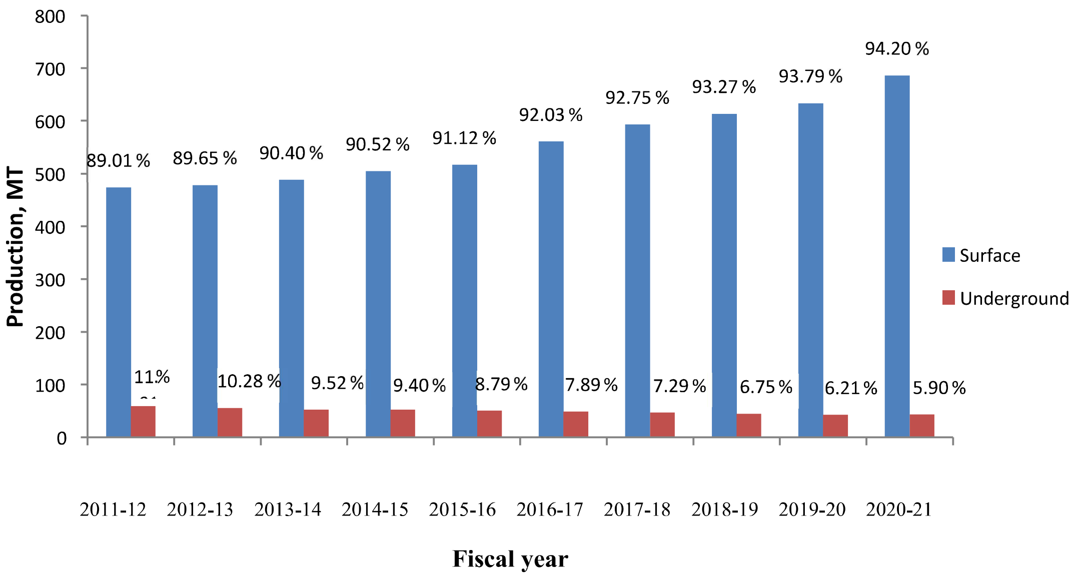

Figure 1.1: Respective shares of surface and underground mining in India's annual coal production over the past ten years.

1.1.2 Overburden removal in surface coal mining

In surface coal mining, overburden (OB) removal is a significant mining operation. All unprofitable material that must be removed in to reach and extract the coal deposit is referred to be OB. According to Jones et al. (2002) and Corke et al. (2006), overburden removal typically makes up more than 60% of the total mining costs in surface coal mines. According to statistics, the average stripping ratio for all surface coal mines in India is above 2.0. As mines become deeper and geo-mining conditions get complex, stripping ratios are anticipated to rise even more.

Figure 1.2 shows the growing significance of the overburden removal trend (in million m^3). 363.76 million m^3 (26.63%) of the 1365.54 million m^3 of overburden handled by heavy earth moving equipment in the 2021-22 year occurred in the Singrauli coalfields area, where the studies were conducted (Ministry of Coal, Govt. of India, 2021). The overburden can be removed with various HEMM like a shovel-dumper combination, dragline and bucket wheel excavator (BWE), etc.

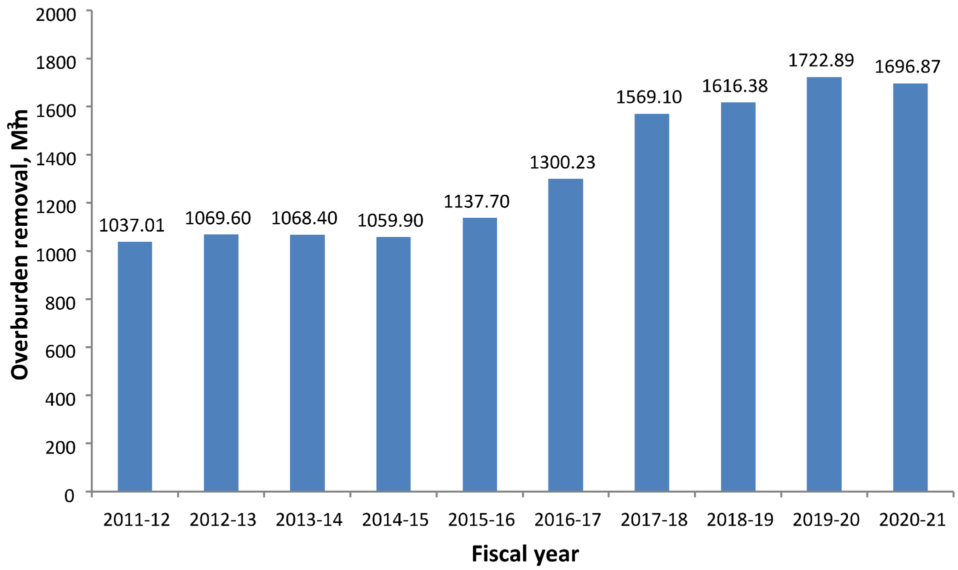

Figure 1.2: Annual removal of overburden in India.

1.1.3 **A comparison of** overburden removal **with various HEMM**

In a typical application where the choice of shovel truck or dragline systems may be considered, operating costs will be less with the dragline, but a higher initial investment will be required. But where overburden must be moved a considerable distance, truck transportation has been generally favoured over conveyors because of greater flexibility and lower investment cost. Modern high-production equipment systems that transport overburden employing high-capacity dump trucks (dumpers) and large shovels for loading are unable to fully compensate for the challenging working circumstances at greater depths. It is, therefore, required to modify the technological parameters of equipment systems, one of which is the high bench strip mining operations using draglines (Kovalev and Fedotenko, 2015). In a shovel-dumper mining system, OB transport costs may account for one-third or more of the total operating costs (Zhang et al., 2013).

The use of Bucket wheel excavators with round-the-pit conveyor systems has been widely studied but application to date has been limited because of the high investment cost and limited flexibility. Most draglines have been applied to deposits where the average overburden or interburden depth does not exceed 40 m, and the material may be overcast by the machine to expose a strip of coal seam for excavating by other methods – usually shovel or loader with truck transportation of the coal (Learmont, 1975**).**

From the foregoing discussions, it is clear that the role of surface mining with dragline stripping is vital in maintaining and enhancing energy production through increasing coal productivity. Dragline equipment systems can excavate, transport, and dump all by one machine. The system is characterized by a smaller fleet, higher operating efficiency, lower production costs, bigger capacity, and higher reliability (Zhang et al, 2013).

Figure 1.3 A dragline machinery. (Source: https://mining.komatsu/en-in/product-details/p-h-9020c)

1.1.4 Global dragline production

A global statistic of productions from dragline-operated coal mines is presented in figure 1.4. In India, over 150 Mt. of coal is produced annually from dragline-operated coal mines. Singrauli coalfields of India, which produce over 120Mt coal per year, deploy more than 25 draglines for overburden removal (Ministry of Coal, Govt. of India - 2021).

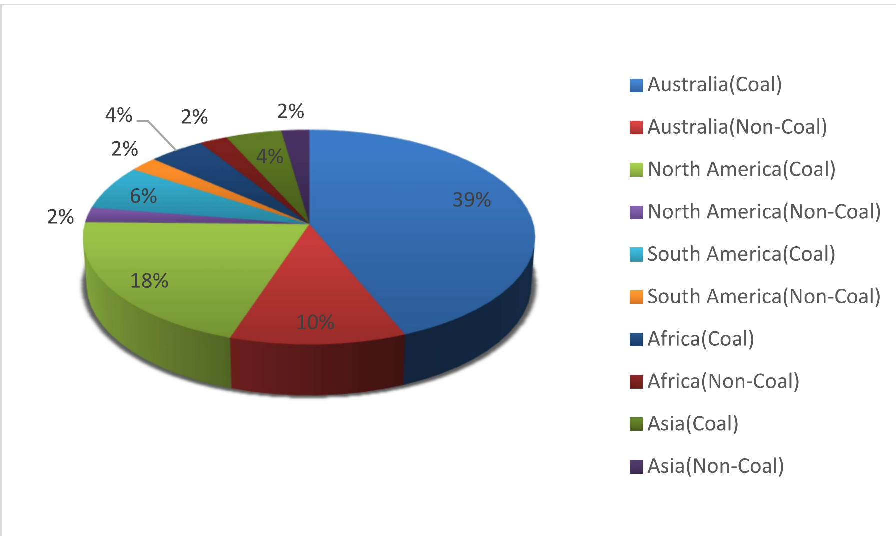

Figure 1.4: Global production statistics of draglines. (Dragline Dictionary, 4th Edition, PwC)

1.1.5 History and assessment of dragline mining methods in India

Dragline mining was introduced in India in the early ‘60s, with the commissioning of walking dragline ('PAGE' Model 754) of bucket size of 11.47 cum at Khrasia in 1961. This was followed by the introduction of many other draglines, primarily of U.S. and Russian make.

To understand the prevalent dragline mining techniques used across various mines with different geo-mining conditions, a thorough survey of dragline mining techniques in India was conducted. The survey of dragline mining methods is shown in table 1.1. Although, detailed information about all the dragline operated Indian mines could not be found. The table indicates that just a few dragline mining methods are now being used in India in various surface coal mines located throughout different coalfields. The extended bench method is the most popular of them. There are 39 draglines in India. The typical dragline sizes range from 10 to 30 m^3 in bucket volume and 70 to 100 m in boom length. The most typical dragline model is a 96-meter boom and a 24-meter bucket. In India, there is no multi-seam dragline operation. 22 of the 39 draglines used in India's surface mines are currently working in the Singrauli coalfields alone, assisting in the removal of overburden and contributing to a significant amount of coal production (122.43 MT) (Provisional Coal Statistics, 2021).

Northern Coalfield Limited (NCL) is the only subsidiary company of Coal India Limited, where the entire coal production is mined by opencast mining method. Another unique feature of the company is that about 40% of the large volume of excavation is done with the help of large walking draglines. The major work done by the author for this study to prepare the thesis is for tandem dragline operation only. The tandem method can be broadly divided into horizontal and vertical tandem methods. In NCL, most of the draglines work in tandem methods.

Table 1.1: Assessment of dragline mining methods in India (Rai and Singh, 2021).

Sl. no.	Project Name & Coalfields	Geological & Mining Conditions						Dragline Fleet and Configurations							Mining Methods
		Coal Production (Mt per year)	Strike Length (km)	No. of coal seams	Thickness of coal seams (m)	Thickness of overburden (m)	Cut Width (m)	No. of Dragline operating	Bucket Size (m^3)	Boom Length (m)	Operating Radius (m)	Boom Angle (°)	Dumping Height (m)	Digging Depth (m)	
1	Amlohri (NCL) Singrauli Coalfields	10	2.6-3.1	5	12-18	55-66	70-80	4	24	96	88	30	38	46	Horizontal tandem method having central entry with 70-80m strip width and 30-40m depth
2	Dudhichua (NCL), Singrauli Coalfields	15	3.2-3.6	5	16-25	50-63	75	4	24	96	88	30	38	40	
3	Jayant (NCL) Singrauli Coalfields	15	3.4	5	14-24	46-66	70-80	3	24	96	88	30	38	46	
4	Jayant (NCL) Singrauli Coalfields	15	3.4	5	14-24	46-66	70-80	1	15	90	83	30	37	42	
5	Khadia (NCL) Singrauli	10	4.1	5	19-22	55-60	70-80	2	20	90	83	32	38	43	

	Coalfields														
6	Nigahi (NCL) Singrauli Coalfield	15	3.5	5	12-19	52-59	70-80	2	24	96	88	30	38	46	
7	Nigahi (NCL)	15	3.5	5	12-19	52-59	70-80	2	20	90	83	32	38	43	
8	Bina (NCL)	6	2.0 - 2.3	5	13-22	42-50	70-80	2	10	70	67	30	28	35	Vertical Tandem Method
9	Bina (NCL)	6	2.0 -2.3	5	13-22	42-50	70-80	2	24	96	88	30	38	46	
10	Dhanpuri (SECL) Suhagpur Coalfields	1.30	1.0	2	8.0	60	60	1	20	90	-	-	47	42	Extended bench method
11	Block-II (BCCL), Jharia Coalfields	1.80	0.60	4	25	30	60	1	24	96	88	30	38	46	Extended bench method
12	Sonpur Bazari (ECL), Raniganj Coalfields	5.00	1.00	10	4.0	28-30	60	1	24	96	88	30	38	46	

13	Ramagundam-1 (SCCL), Godavari Valley Coalfields	3.31	2.0 – 2.5	6	10	26	60	1	24	95.6	88	30	39.6	46	Extended Bench Method for 3 Seam and Spoil Bench Method to expose 4 Seam by removing 10m OB
14	Ramagundam-3 (SCCL), Godavari Valley Coalfields	6.3	2.0-2.5	6	10	23	60	1	30	93	81	37.8	44	50	
15	Moher, Sasan Power Ltd.	18.00	4.10	2	18	55	60 - 77	2	63	100	90	32	46	48	Extended Bench Method

1.1.6 Tandem dragline operation

The major investment required by a single large dragline, utilized as the primary stripper, can be reduced by the employment of two or more smaller draglines. Not only are there savings associated with the initial acquisition, but these benefits continue during ongoing operations. Equipment optimization may be defined as finding the most favourable way to achieve a given result. When selecting draglines, this would translate into minimizing cost and risk while maintaining flexibility. The draglines are deployed to strip both single seam and multiple seams. The overburden may be excavated either by a single dragline or two draglines in tandem, or more draglines in conjunction.

Recently with the expansion of mines for higher rated outputs, the concept of tandem dragline operation has evolved, especially on longer face lengths, to maximize the coal exposure and minimize the rehandling percentage because a single dragline does not meet the required rate of coal production and creates problem with the extended bench method.

The use of two draglines in tandem operation makes it possible to raise the production capacity and utilization of the draglines (Rai, 2000) and, therefore, the mineral capacity of the mine (Rzhevsky, 1987).

The inherent advantages of tandem operation of draglines are described by many researchers (Learmont, 1989; Fisher and Chironis, 1986). There are mainly two modes of tandem operation, i.e., horizontal or real tandem and vertical tandem. In the horizontal tandem operation, both the draglines are deployed in the same bench whereas, in the vertical tandem operation, one of the draglines is deployed on the upper (advanced) bench and the other dragline on lower (main) bench in synchronism for fast rate of mining advancement and coal exposure (Lal *et al.*, 1988; Erden & Celebi, 1999). From the foregoing discussions, it is quite clear that tandem dragline operation is an innovative operational method which provides higher rated outputs with the expansion of mines.

1.1.7 Planning of tandem dragline operation

For effective planning and utilization of draglines, the draglines deployment schemes are presented on graph paper through balancing diagram or other means in the plan and in some typical geological sections (cut sections or range diagram) to calculate comprehensively and accurately the cut sections area, percentage rehandling, rate of coal exposure (production), rate of linear advancement of draglines etc. (Rzhevsky, 1987; Pundari, 1981). Calculations and analysis of technological complexes and excavation schemes and design solutions of elements of the mining system. are considered by these balancing diagrams (Morey and Lee, 1979; Rai, 1997). The balancing diagram (cross-sections) for the draglines operating in tandem is most essential tool to deploy the draglines successfully.

The procedure involved in the manual design and planning of dragline pit optimisation through balancing diagram requires a number of trials before a final decision is selected. The different alternatives are evaluated, involving too many hand calculations and preparing sections in plans for different alternatives. As the number of input parameters is many, the evolution of each of these individually as well as jointly becomes difficult for manual determination. Moreover, every input involved in the design has a range, so it is impractical to manually evaluate the exact value of the input parameter for the best design of the pit. Hence doing this job manually on a regular basis could become time-consuming and expensive.

1.1.8 Planning of dragline operations using computer

The use of computers to act as high-speed data processors has added a new dimension to mine planning. Although the same well-proven manual method is adopted as a basis, the use of a computer makes a complete revamp of the plan a mere formality. As such, it is possible to optimise a plan such that all sensitivities are critically examined and weighted and the "best" plan adopted. Dragline planning can be accomplished by applying computer methods at a relatively low cost and in a timely manner (Pundari, 1981).

Hence, quick and accurate calculation of the parameters affecting dragline operation is essential for effective planning and utilization of draglines. Over the years, there has been significant technological advancements in the field of computer application in dragline operations (Chatterjee et al., 1977; Bandopadhyay and Ramani, 1979). The old and traditional concepts have rapidly advanced, resulting in the emergence of newer concepts and techniques. To cite a few, surface mine design, operational planning, production and cast analysis, dragline performance, dragline selection and balancing diagram (dragline cross-sections or range diagram) are commonly done by computer techniques.

Numerous computer packages have been developed to simulate dragline coal mining operations (Hrebar and Dagdelen, 1979; Morey and Lee, 1979; Stuart and Cobb, 1988; Baafi and Mirabediny, 1997).

According to Michaud and Calder (1993), most of the commercial programs that are presently available to facilitate dragline mine planning have been developed for specific mine properties or are limited in the coal geology and mining methods that they can simulate (Ramani and Bandopadhyay, 1985; Lee, 1988). For instance, tandem dragline operation in horizontal (real) and vertical mode requires a change in operational schemes (deployment schemes of dragline), and therefore mining techniques (operational parameters) used in the program have to be modified (Huddart and Runge, 1979; Sadri, 1982).

At this point, it is appropriate to mention that every available software is based on some specific model or assumptions and these assumptions are limitations which restrict the universal use of these packages. Especially, software packages for tandem operation are not available.

Keeping in view the complex tandem dragline operation, there exists an emergent need to develop a computer program for Indian geo-mining condition for each mode of tandem operation (i.e. horizontal and vertical tandem) for dragline planning and pit optimisation through three-dimensional balancing diagram and quantitatively assess the rate of coal exposure, percentage rehandle, cross-section areas and the rate of advancement etc. of each dragline for the analysis purpose. This study investigates the current dragline mining systems in Indian geo-mining conditions and operating environment and analyse machine performances with a view to bringing about - economic improvement in utilisation, productivity and operation of dragline projects. The analysis will be done by varying one parameter at a time and then finding more significant parameters. The details are the developed software or model have been discussed in results and discussion chapter.

1.2 Objectives of the study

The present research program has been undertaken primarily to quantitatively investigate assess the rate of coal exposure, rate of dragline advance, cross-sectional area excavated by each dragline according to its capacity and rehandle percentage in various geo-mining conditions and modes of operation having different machine specifications. For the development of the program, the critical parameters that influence the production of a dragline in tandem operation were identified. A sufficiently large number of operational data was collected from the field over two years as a part of the research work. The intent was to assess the relative changes in the rate of coal exposure and percentage rehandle from variations in operational, geo-mining and machine specification parameters individually or combined. The inter-relationship between these parameters has been incorporated into the program. The developed program's validation, efficacy and applicability have been checked by using input parameters (based on actual field conditions) in the program and verifying the output results in comparison to the manual balancing diagram. It is found that graphics-based program has yielded precise desired results. The application of the program can significantly reduce the time, manpower and cost required to analyze a wide variety of situations and alternatives in the planning and optimization process.

The objectives of the study are enumerated as:

1. To develop a computer graphics program for generation of three-dimensional balancing diagram for dragline planning in horizontal and vertical tandem modes, while considering operational, machine, and geo-mining factors.

2. Utilizing three-dimensional balancing diagram, determination of the rate of coal exposure, percentage rehandle and dragline advancement per annum in both horizontal and vertical tandem modes.

3. To explore the impact of different geo-mining and operational variables on the efficiency of draglines operating in both horizontal and vertical tandem modes, as listed below:

(i) Variation in dragline annual production capacities

(ii) Variation in cut width of the strip

(iii) Variation in dragline overburden bench height

(iv) Variation in coal seam thickness

(v) Variation in coal seam gradient

4. To study the cost and economics of dragline operations.

5. To critically analyse the case studies conducted in the field and make appropriate suggestions for better performance in light of the above studies.

1.3 Outline of the thesis

This thesis has been organised according to the objectives and the scope of work in the form of eight different chapters, as specified below.

Chapter 1- Introduction and objective of the study. This chapter provides a brief introduction to the study, its background, and the context within which it was conducted. Key discussions are the importance of surface mining and dragline operation assessment of dragline methods in India. The Chapter also covers tandem dragline planning through computers, followed by the main objectives of the research study.

Chapter 2- Literature Review. This chapter compiles a review of technical literature in the relevant areas of dragline planning and simulation. The Chapter covers the existing literature on the topic and deals with various aspects of tandem dragline operation. Starting from dragline history, classification, applicability, advantages, disadvantages, and limitations, dragline modes and methods of operation, single dragline vs tandem dragline operation, necessity and limitations of tandem dragline operation, horizontal and vertical tandem operations, their applicability, merits and limitations, are covered.

Chapter 3- Planning for dragline operations and the development of three-dimensional computer graphics program. This chapter compiles the review of technical literature in the relevant areas of dragline planning, purpose and method of drawing balancing diagram. The chapter discusses the process of developing the computer program for drawing balancing diagrams, the design parameters incorporated in the program, and the assumptions considered during its development. Two separate programs for horizontal tandem and vertical tandem operations have been developed.

Chapter 4- Validation and application of the developed three-dimensional balancing diagram. The chapter validates the efficacy of the developed three-dimensional balancing diagram through field data. The chapter also discusses the efficacy of the three-dimensional balancing diagram or model in different contexts, followed by applications of the model in dragline planning operations.

Chapter 5- Field Studies. This chapter provides an overview of the field studies conducted as part of this research. It includes a description of the coal mines where the studies were conducted, as well as the general, geological, and mining details of those mines.

Chapter 6- Dragline cost analysis. The chapter provides an overview of dragline performance and cost analysis. Annual production capacities, cycle time, and swing angle relationships of different draglines are discussed.

Chapter 7- Results and discussion. The results and discussion in this chapter present an overview of the parametric analysis and case studies undertaken in the thesis.

Chapter 8- Conclusions and suggestions for future work. The chapter provides an overview of the conclusions drawn from research work and analysis, as well as a few recommendations for future work.