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Optimization of Coal Transportation Cost for NTPC Owned Power Stations

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Abstract

The demand for electricity has been rising at an exponential rate since Independence. Though the power generation has increased manifold over these years, but it has not been able to keep pace with the increasing demand. Keeping in mind the per capita income in the nation, the policymakers need to arrive at a sustainable energy model to integrate self-sufficiency with affordability. The Coal Linkage agreements between the power stations, the Indian Railways and the coal blocks which were established a long time back continue to exist till today. Even though the rail connectivity and the number of mines have improved over these years, no major changes have been made in the coal allocation model pan India. The study seeks to optimize coal transportation cost for 19 NTPC owned power plants using Linear Optimization techniques and seeks to evaluate the annual profitability of these power stations. The study does not suggest the adoption of this optimized model but aims to draw an insight of the dire need to reallocate the coal blocks to achieve higher levels of supply chain surplus which could be passed on to the customers as customer surplus.
Keywords- Transportation, NTPC, Linear Programming, Optimization, Coal Linkage, Power plants

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I. Introduction

The growth of the economy is intimately related to the growth in its energy consumption, particularly in the case of developing countries like India. Electricity, by virtue of being an ordered, efficient and convenient form of energy has a crucial role to play in the multi -faceted development of the country. Coal-based thermal power stations continue to supply a major portion of electricity demand in India till date. A good understanding of the techno-economic concerns in India's power sector is an important first step towards correct energy planning and policy making.

A. Role of Coal-Based Power Generation in India

Over the last few decades, the demand for electricity in India has been on a rise at an annual compounded growth rate of about 9%. With the liberalization of the economy and the current trends in economic growth, policy makers anticipate that the demand shall increase at even a higher rate. With a coal-based power generating capacity of about 70% of total installed capacity, coal consumption by power utilities in 1996/97 was 199.6 million tons (Mt) (TEDDY, 2000/2001; Tata Energy Research Institute, 2000; New Delhi, India), which increased to around 250 Mt in 2000/01 and to 650Mt in 2016. As per the estimates of the Ministry of Coal, the demand for coal used by power stations is expected to increase to about 700 Mt by 2019-20. Even though the coal requirement estimates vary based on several assumptions, the fact stays that the need for coal-based power stations and thermal mix will remain prominent in the coming decades.

B. Coal Movement

Historically, most of the coal was available in Eastern and Central India, and the transportation to various consuming units was restricted to specific rail corridors running North-west or down South. The Standing Committee on Coal Linkages played a crucial role in deciding and setting quarterly or annual coal linkages. Linkage Committees appointed by the Government of India apportion coal production of each coal block to all major consumers based on their stated requirements and in mutual agreement with the supplying coalfields and Railway Authorities. Over the years, these agreements remained unchanged due to several socio-political reasons. Recently, the system of forming linkages has been done away with on a formal basis, although the parties continue to meet every quarter to decide the linkages. It is, however, contentious whether the coal linkage agreements are most optimal for the economy or not.

C. The Aim of the Study

At present, the coal supplied to generation plants is not necessarily from the nearest mine due to several underlying constraints. According to Coal India Executives, coal travels about 477 km on average from pithead to destination power plants. The aim of the study is to optimize the coal movement from 17 of the major coal mines of India to 19 thermal power stations in order to minimize the overall cost incurred by NTPC in procuring its coal. The optimization is modeled as a Transportation problem (Linear Programming Problem) involving supply and demand constraints. The study also seeks to analyze the original cost, optimized cost, estimated profit and the contribution of various power plants in the total cost.

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II. TRANSPORTATION MODEL

A. Choice of Methodological Framework

The analysis for this study has been carried out using the Transportation model which aims to find out optimum transportation schedule keeping in mind cost of transportation to be minimized. Transportation theory refers to the study of optimal transportation and allocation of resources between m sources and n destinations. The modeling framework adopted in this study enables a comparative assessment of changes in delivered costs for coal as well as overall system costs as a result of changes in various constraints in the model. Scenario analysis based on the model provides useful policy guidelines for the sector. It must, however, be kept in mind that results of the model are only indicative and a detailed assessment of individual projects should be undertaken before taking major policy decisions.

B. Scope of the Model

The Transportation model is used to examine the patterns of coal supply for meeting electricity requirements of the country. It analyses the cost of transportation with the current coal movement patterns and minimizes the overall coal transportation cost by providing alternate mines to power stations combination. The model used in this study was driven by the energy requirement at each of the power plants based on planned capacities, PLF and heat rates. The model then makes choices about the source and routing of coal from various coalfields to meet the generation requirements at each power plant such that the total system cost is minimized. The model thus analyses the original cost, optimized cost, estimated profit and the contribution of various power plants in the total cost.

C. Description of the Transportation Model

The transportation model is a special case of linear programming problem statement in which the objective function is to minimize the total transportation cost between a set of m destinations and n sources. The decision variables involved in the problem is therefore, m x n. The objective function is subjected to m+n-1 constraints which include the maximum available supply from each source and the demand from each destinations. The total number of equations is therefore, m+n. However, the last equation is simply a linear combination of the remaining m+n-1 equations. The redundancy is avoided by subjecting the function to m+n-1 constraints. The solution consists of developing a basic feasible solution using any of the below mentioned techniques and then optimizing it using iterative schemes.

D. Algorithm Adopted for the Mode

1) North West Corner (NWC) Rule

The North-West Corner Rule is one of the method adopted to compute the initial feasible solution of the transportation problem. In this method, the top left corner is allocated the desired amount based on the corresponding demand and supply. The only pre-requisite to this method is that the demand must be equal to the total supply. If the total supply is not equal to the total demand, a dummy destination or source is included in the model and the corresponding cost is made zero in the cost matrix.

2) Least Cost Method (LCM)

The Least Cost Method is another method used to obtain the initial feasible basic solution for the problem. In this method, the cell with the lowest cost is allotted the maximum possible amount. The lower cost cells are preferred over the higher-cost cell with the objective to have the least cost of transportation. It requires less iterations using LCM and therefore, this method produces better results than the North-west Corner because it takes into consideration the unit transportation cost while allocating, whereas the North-West corner method only considers the demand and supply and allocation begin with the extreme left corner, regardless of the shipping cost.

3) Vogel's Approximation Method (VAM)

The Vogel's Approximation Method or VAM is an iterative scheme used to find out the initial basic feasible solution of the transportation problem. Like LCM, it also considers the unit transportation cost involved between ith source and jth destination, but in a relative sense.

E. Data and Assumptions

All data used in the study is based on secondary information published by the Coal India Limited (CIL), the Planning Commission, the Indian Railways and most importantly NTPC With the problem statement comprising of 19 power plants and 17 coal mines, the model had over 300 variables to be assigned values in order to optimize the movement patterns and hence to eliminate any further complexity and to simplify the problem statement, the following assumptions were taken:

- The dependence on imported coal is assumed to be negligible.
- Blending and coal quality requirements for an individual plant is ignored. It is assumed that the coal is uniform in property in every coal block and no constraint shall be put based on the boiler design operating conditions for individual power stations
- Only running coal blocks are chosen for optimization. NTPC Badarpur, which is currently not operational, has not been included in the study

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- The coal consumption is adopted at 85% Plant Load Factor (in Million tonnes per annum).

III. COAL CONSUMPTION AND PRODUCTION

In this study, we assumed that all planned additions to coal-based generating capacity fructify to meet future electricity demands. Capacity and PLF as specified by the CEA were used for the existing power plants, while a PLF of 85% was assumed. Each of the 19 coal-based thermal power plants included in the model was assigned to one of the five power planning regions of the country (North, South, East, West, and Northeast) and was characterized by its installed capacity, plant efficiency, heat-rate and coal requirements.

NTPC PROJECTS	COAL CONSUMPTION (Metric tonnes per day)
Singrauli Super Thermal Power Station	28074
Korba	34264
Farakka Super Thermal Power Project	34062
Vindhyachal Super Thermal Power Project	66809
Rihand Thermal Power Project	40297
Kahalgaon Super Thermal Power Project	38553
NTPC Dadri	23355
Talcher Super Thermal Power Station	49592
Feroze Gandhi Unchahar Thermal Power Station	21622
Talcher Thermal Power Station	7521
Simhadri Super Thermal Power Station	27491
Tanda Thermal Power Station	6161
Sipat Thermal Power Station	36999
Mauda Super Thermal Power Station	35503
Barh Super Thermal Power Station	18281
Kudgi Super Thermal Power station	20961
NTPC Bongaigaon	5277
Solapur Super Thermal Power Station	1084

Fig. 1: Coal consumption by various NTPC owned power stations (at 85% PLF)

A. Coal Supply

There was a steep increase in the domestic coal supply by about 9.2 percent to around 291 million tonnes (MTs) in the first three quarters of the financial year 2017. This resulted in a robust 24.59 MTs increase in absolute terms compared to 266 MT during second quarter of 2016. The increase in coal supplies to thermal power stations in November 2017 was around 9 percent higher at 40.92 MTs against 37.56 MTs supplied in November 2016. In January 2018, the Central government decided to take several corrective measures, which included improving rail infrastructure and setting up power plants near the coal mines. With the tremendous increase in coal demand, it is obvious that the coal transportation costs will contribute to a major portion of the payments made by the power corporations. With a new optimized coal movement pattern, transportation costs can be drastically minimized and help power corporations reduce the cost borne by them to produce electricity and in turn make greater profits. The long-term effect would be a reduction in the amount charged from the consumers for a particular quantity of electricity.

1.	Jayant and Bina mines (NCL)	22
2.	Kusmunda and Gevra Mines (SECL)	120
3.	Singareni (SCCL)	60.38
4.	Lalmatia Colliery, Indonesia (ECL)	24.38
5.	Nigahi mines (NCL)	15
6.	Amlori and Dudhichua mines (NCL)	21.17
7.	Rajmahal Coalfield of Eastern Coalfield Limited (ECL)	17
8.	Piparwar Mines (CCL)	16.375
9.	Lingraj Block & Kaniha coal block of Mahanadi Coalfields Ltd.(MCL)	23
10.	North Karanpura coalfields	8
11.	Jagannath Mines of Mahanadi Coalfields Limited. (MCL)	6
12.	Kalinga Block of Talcher Coalfields	10.03
13.	Dipika Mines of South Eastern Coalfields Limited.(SECL)	25
14.	Mahanadi Coalfields Ltd in Odisha (MCL)	137.901
15.	Amrapali block of North Karanpura coalfields	12
16.	Pakri Barwadih coal block	18
17.	Makum coal mines at Margherita, Assam (ECL)	1.2

Fig. 2: Coal Supply from allocated coal blocks (in Million tonnes per annum)

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B. Linkage and Cost Parameters

Historically power plants were allocated quarterly linkages with certain coalfields based on coal requirements as stated by the plants, availability of coal at the coalfields and the capacity of the Railways to transport the coal between the supply and demand points. Accordingly, linkages were allowed based on information as available from Indian Railways Freight table(March 2018) considering open rakes being employed for transportation and costs were determined using the same. Pithead power plants were provided fixed linkages from coalfields where they are located since alternative options would be irrational in such cases. Based on Railway Authorities reports and their statements during the linkage committee meetings, the Railways did not indicate capacity constraints in moving coal in the short term. Also, coal is a high priority good in railway movement implying that capacity would be spared (by shifting other commodities to alternative routes) for its movement if required. Therefore, capacity constraints in rail movement are not included in the model. The cost matrix was hence prepared for the 19 selected power stations and 17 coal mines.

Rs per tonne	Jayant and Bina mir	Kusmunda and Gev	Singareni	Lalmatia Colliery,	Nigahi mines	Amlori and Dudhicl	Rajmahal Coalfield	Piparwar Mines (ba	Lingraj Block & Kan	North Karanpura coalfields
Singrauli	198.7	1364.6	2142	1286.2	198.7	198.7	1286.2	851.5	1830.3	1129.2
Korba	1320.1	198.7	1320.1	1646.2	1320.1	1320.1	1646.2	1286.2	851.5	1286.2
Ramagundam	2232.4	1414.2	198.7	2566.6	2232.4	2232.4	2566.6	2264.5	1895.2	2296.6
farakka	1414.2	1459	2419.2	449.4	1414.2	1414.2	449.4	969.8	1414.2	851.5
Vindhyachal	198.7	1364.6	2142	1286.2	198.7	198.7	1286.2	851.5	1830.3	969.8
Rihand	198.7	1414.2	2206.5	1320.1	198.7	198.7	1320.1	969.8	1895.2	1129.2
Kahalgaon	1286.2	1597.2	2513.5	198.7	1286.2	1286.2	198.7	1129.2	1552.7	851.5
Dadri	1597.2	2142	2387.2	2109.8	1597.2	1597.2	2109.8	1986.5	2513.5	1921.8
Talcher Super Ther	1830.3	851.5	1797.9	1597.2	1830.3	1830.3	1597.2	1286.2	198.7	1286.2
Unchahr	851.5	1459	2206.5	1320.1	851.5	851.5	1320.1	1286.2	1895.2	1129.2
Talcher Thermal	1830.3	851.5	1797.9	1597.2	1830.3	1830.3	1597.2	1286.2	198.7	1286.2
Simhadri	2799	1414.2	1320.1	2232.4	2799	2799	2232.4	1797.9	1129.2	1797.9
Tanda	851.5	1646.2	2419.2	1286.2	851.5	851.5	1286.2	1129.2	2018.9	1129.2
Sipat	1286.2	358.3	1286.2	1690.7	1286.2	1286.2	1690.7	1286.2	851.5	1286.2
Mauda	1739.6	1129.2	733.1	2264.5	1739.6	1739.6	2264.5	1830.3	1459	1830.3
Barh	1129.2	1552.7	2478.2	618.4	1129.2	1129.2	618.4	851.5	1552.7	733.1
Kudgi	2639.6	2465.2	1364.6	3024.8	2639.6	2639.6	3024.8	2832.2	2606.4	2832.2
Bogaigaon	1986.5	2264.5	3144.4	1286.2	1986.5	1986.5	1286.2	1690.7	2206.5	1597.2
Solapur	2533.4	2296.6	1286.2	2925.2	2533.4	2533.4	2925.2	2738.3	2520.1	2745.9

Fig. 3: Freight Rate (The Indian Railways)

Rs per tonne	Kalinga Block of Tal	Dipika Mines of Sou	Mahanadi Coalfield	Makum coal mines	Pakhri Barwadih co	Amrapali block	jagannath mines mahanadi
Singrauli	1862.7	1364.6	1597.2	2712.7	733.1	1129.2	1862.7
Korba	851.5	198.7	618.4	2825.6	1364.6	1286.2	851.5
Ramagundam	1895.2	1459	1646.2	3642.5	2419.2	2296.6	1921.8
farakka	1414.2	1508.3	1286.2	2077.6	1129.2	851.5	1459
Vindhyachal	1830.3	1364.6	1597.2	2712.7	733.1	969.8	1862.7
Rihand	1895.2	1414.2	1646.2	2732.6	733.1	1129.2	1895.2
Kahalgaon	1552.7	1646.2	1414.2	2264.5	969.8	851.5	1597.2
Dadri	2513.5	2142	2387.2	3064.7	1797.2	1921.8	2653
Talcher Super Ther	198.7	851.5	618.4	2805.7	1414.2	1286.2	198.7
Unchahr	1895.2	1459	1690.7	2706.1	969.8	1129.2	1921.8
Talcher Thermal	198.7	851.5	618.4	2805.7	1414.2	1286.2	198.7
Simhadri	1129.2	1414.2	1286.2	3084.6	1954.1	1797.9	1286.2
Tanda	2018.9	1646.2	1765.4	2652.9	969.8	1129.2	2051.2
Sipat	851.5	358.3	618.4	2838.9	1414.2	1286.2	969.8
Mauda	1459	1129.2	1286.2	3091.2	1986.5	1830.3	1508.3
Barh	1552.7	1552.7	1320.1	2264.5	851.5	733.1	1552.7
Kudgi	2606.4	2465.2	2573.2	3735.5	2765.8	2832.2	2619.7
Bogaigaon	2206.5	2264.5	2051.2	1286.2	1739.6	1597.2	2232.4
Solapur	2520.1	2296.6	2478.2	3649.1	2666.2	2745.9	2533.4

Fig. 4: Freight Rate (The Indian Railways)

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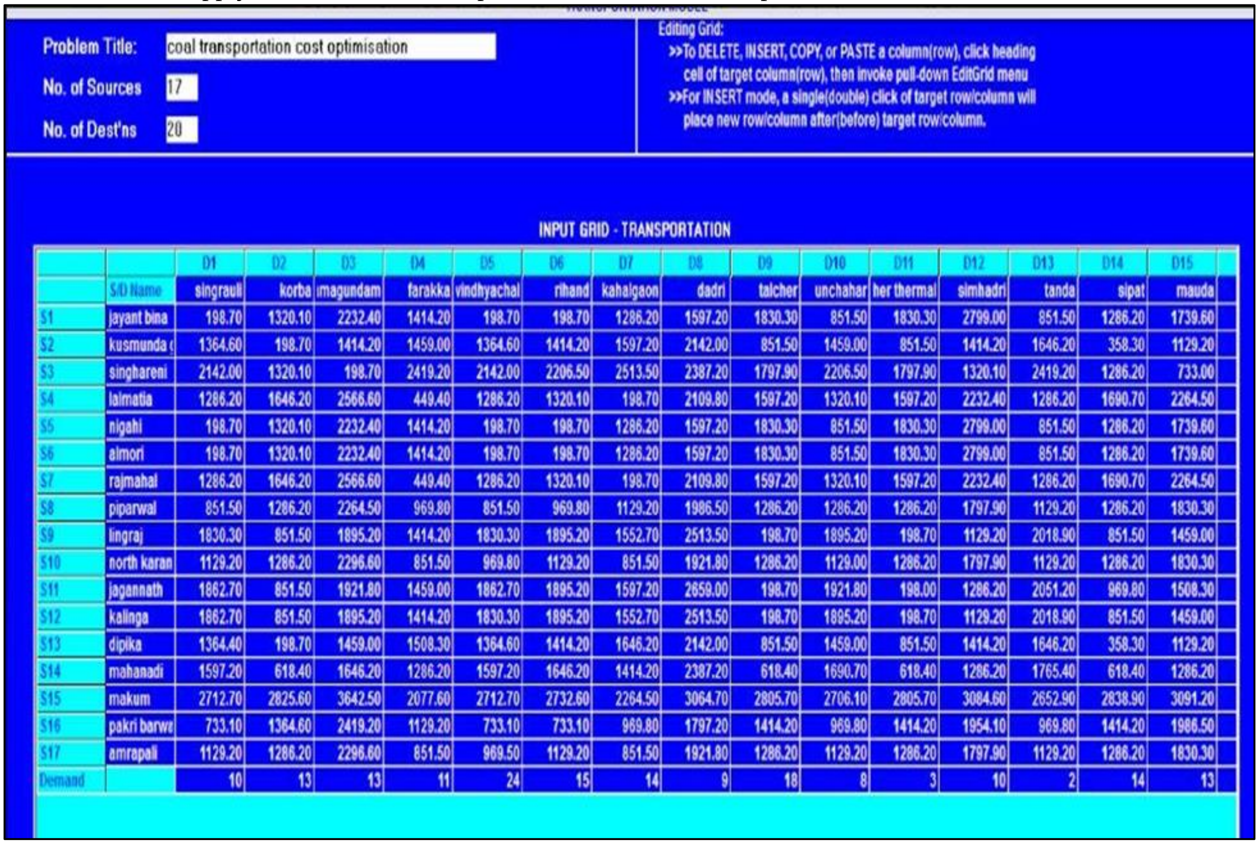
IV. FORMULATION OF THE TRANSPORTATION PROBLEM ON TORA AND RESULTS

The problem statement was formulated on TORA as a classical transportation model. In order to achieve balance in the problem, a dummy destination is added which consumes the coal left from every coal block. The contribution of this dummy destination is eliminated in the objective function by setting a freight rate of zero from each of the coal blocks.

The formulation comprises of the cost matrix which is the freight rate between two corresponding demand and supply side. The demand and supply constraints are also specified in Million tonnes per annum.



Problem Title: coal transportation cost optimisation
No. of Sources 17
No. of Dest'ns 20

Editing Grid:
>>To DELETE, INSERT, COPY, or PASTE a column(row), click heading cell of target column(row), then invoke pull-down EditGrid menu
>>For INSERT mode, a single(double) click of target row/column will place new row/column after(before) target row/column.

INPUT GRID - TRANSPORTATION

		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
	S/D Name	singrauli	korba	imagundam	farakka	vindhyachal	rihand	kahalgaon	dadri	talcher	unchahar	her thermal	simhadri	tanda	sipat	mauda
S1	jayant bina	198.70	1320.10	2232.40	1414.20	198.70	198.70	1286.20	1597.20	1830.30	851.50	1830.30	2799.00	851.50	1286.20	1739.60
S2	kusmunda (	1364.60	198.70	1414.20	1459.00	1364.60	1414.20	1597.20	2142.00	851.50	1459.00	851.50	1414.20	1646.20	358.30	1129.20
S3	singhareni	2142.00	1320.10	198.70	2419.20	2142.00	2206.50	2513.50	2387.20	1797.90	2206.50	1797.90	1320.10	2419.20	1286.20	733.00
S4	lalmatia	1286.20	1646.20	2566.60	449.40	1286.20	1320.10	198.70	2109.80	1597.20	1320.10	1597.20	2232.40	1286.20	1690.70	2264.50
S5	nigahi	198.70	1320.10	2232.40	1414.20	198.70	198.70	1286.20	1597.20	1830.30	851.50	1830.30	2799.00	851.50	1286.20	1739.60
S6	almori	198.70	1320.10	2232.40	1414.20	198.70	198.70	1286.20	1597.20	1830.30	851.50	1830.30	2799.00	851.50	1286.20	1739.60
S7	rajmahal	1286.20	1646.20	2566.60	449.40	1286.20	1320.10	198.70	2109.80	1597.20	1320.10	1597.20	2232.40	1286.20	1690.70	2264.50
S8	piparwal	851.50	1286.20	2264.50	969.80	851.50	969.80	1129.20	1986.50	1286.20	1286.20	1286.20	1797.90	1129.20	1286.20	1830.30
S9	lingraj	1830.30	851.50	1895.20	1414.20	1830.30	1895.20	1552.70	2513.50	198.70	1895.20	198.70	1129.20	2018.90	851.50	1459.00
S10	north karan	1129.20	1286.20	2296.60	851.50	969.80	1129.20	851.50	1921.80	1286.20	1129.00	1286.20	1797.90	1129.20	1286.20	1830.30
S11	jagannath	1862.70	851.50	1921.80	1459.00	1862.70	1895.20	1597.20	2659.00	198.70	1921.80	198.00	1286.20	2051.20	969.80	1508.30
S12	kalinga	1862.70	851.50	1895.20	1414.20	1830.30	1895.20	1552.70	2513.50	198.70	1895.20	198.70	1129.20	2018.90	851.50	1459.00
S13	dipika	1364.40	198.70	1459.00	1508.30	1364.60	1414.20	1646.20	2142.00	851.50	1459.00	851.50	1414.20	1646.20	358.30	1129.20
S14	mahanadi	1597.20	618.40	1646.20	1286.20	1597.20	1646.20	1414.20	2387.20	618.40	1690.70	618.40	1286.20	1765.40	618.40	1286.20
S15	makum	2712.70	2825.60	3642.50	2077.60	2712.70	2732.60	2264.50	3064.70	2805.70	2706.10	2805.70	3084.60	2652.90	2838.90	3091.20
S16	pakri barwa	733.10	1364.60	2419.20	1129.20	733.10	733.10	969.80	1797.20	1414.20	969.80	1414.20	1954.10	969.80	1414.20	1986.50
S17	amrapali	1129.20	1286.20	2296.60	851.50	969.50	1129.20	851.50	1921.80	1286.20	1129.20	1286.20	1797.90	1129.20	1286.20	1830.30
Demand		10	13	13	11	24	15	14	9	18	8	3	10	2	14	13

Fig. 5: Input Window Screen on TORA

A. *Formulation of the Classical Transportation Model*

The problem statement consists of 19 destinations (NTPC power stations) which are currently supplied coal from 17 Coal blocks which belong to Coal India Limited (CIL). Since the demand is less than the total supply, a dummy destination is added named as 'DUMMY'. The demand of this dummy destination is the excess supply from all the coal blocks. The classic transportation model is then formulated as follows.

- The total supply of the product from coal blocks i is a_i , where i = 1, 2,... .,17
- The total demand for the coal at destination j is b_j , where j = 1, 2,... ., 20
- The cost of transporting one unit of coal from coal block i to destination j is equal to c_{ij}, where i = 1, 2... 17 and j = 1, 2. . . 20. The total cost of a shipment is linear to the shipment size (there is no batch size or lot size discount provided).
- DECISION VARIABLE x_{ij} = the size of the shipment from source i to destination j, where i = 1, 2. . . 17 and j = 1, 2. . . 20. This is a set of 17 x 20 = 340 variables.

$$\text{Minimize} \quad \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \, .$$

Subject to the following constraints:

$$\sum_{j=1}^{n} x_{ij} \leq a_i \, , \quad \text{for } i = 1, 2, \ldots, m.$$

where m = 17 and n = 20

$$\sum_{i=1}^{m} x_{ij} \geq b_j \, , \quad \text{for } j = 1, 2, \ldots, n.$$

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B. Results using Different Iterative Techniques

The value of the optimum objective function obtained from each of the iterative techniques was exactly same. However, the solution proposed by each of the techniques is optimal and alternative in nature.

1) Least Cost Method

	Jayant and Bina mi	Kusmunda and Gevi	Singareni	Lalmatia Colliery,	Nigahi mines	Amlori and Dudhich	Rajmahal Coalfield (	Piparwar Mines (ba	Lingraj Block & Kaniha	coal block of Mal	jagannath mines ma	Kalinga Block of Tal	Dipika Mines of Soc	Mahanadi Coalfields	Makum coal mines (	Pakhri Barwadih co	Amrapali block of North	Karanpura coal fields
Singrauli	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Korba	0	2	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	13
Ramagundam	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
farakka	0	0	0	2	0	0	9	0	0	0	0	0	0	0	0	0	0	11
Vindhyachal	3	0	0	0	15	6	0	0	0	0	0	0	0	0	0	0	0	24
Rihand	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	15
Kahalgaon	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	14
Dadri	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Talcher Super Ther	0	0	0	0	0	0	0	0	13	0	3	2	0	0	0	0	0	18
Unchahr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8
Talcher Thermal	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
Simhadri	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	10
Tanda'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Sipat	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	14
Mauda	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
Barh	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	7
Kudgi	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Bongaigaon	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2
Solapur	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Dummy	0	118	22	0	0	0	8	16	0	8	0	8	0	137	0	8	12	337

Fig. 6: Optimal Solution using Least Cost Method (LCM)

2) North West Corner (NWC) Method

	Jayant and Bina mi	Kusmunda and Gevi	Singareni	Lalmatia Colliery,	Nigahi mines	Amlori and Dudhich	Rajmahal Coalfield (	Piparwar Mines (ba	Lingraj Block & Kaniha	coal block of Mal	jagannath mines ma	Kalinga Block of Tal	Dipika Mines of Soc	Mahanadi Coalfields	Makum coal mines (	Pakhri Barwadih co	Amrapali block of North	Karanpura coal fields
Singrauli	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Korba	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
Ramagundam	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
farakka	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	11
Vindhyachal	3	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	24
Rihand	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	15
Kahalgaon	0	0	0	4	0	0	10	0	0	0	0	0	0	0	0	0	0	14
Dadri	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Talcher Super Ther	0	0	0	0	0	0	0	0	13	0	3	2	0	0	0	0	0	18
Unchahr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8
Talcher Thermal	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
Simhadri	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	10
Tanda'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Sipat	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
Mauda	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
Barh	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	7
Kudgi	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Bongaigaon	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Solapur	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Dummy	0	93	22	0	0	0	7	16	0	8	0	8	25	137	1	8	12	337

Fig. 7: Alternative Optimal Solution using North West Corner Method

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3) Vogel's Approximation Method (VAM)

	Jayant and Bina mir	Kusmunda and Gevi	Singareni	Lalmatia Colliery,	Nigahi mines	Amlori and Dudhicl	Rajmahal Coalfield :	Piparwar Mines (ba	Lingraj Block &	Kaniha coal block of	Mal jagannath mines ma	Kalinga Block of Tal	Dipika Mines of Sou	Mahanadi Coalfield	Makum coal mines :	Pakhri Barwadih co	Amrapali block of North Karanpura coal fields	
Singrauli	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Korba	0	2	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	13
Ramagundam	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
farakka	0	0	0	3	0	0	8	0	0	0	0	0	0	0	0	0	0	11
Vindhyachal	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	12
Rihand	0	0	0	0	3	12	0	0	0	0	0	0	0	0	0	0	0	15
Kahalgaon	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	14
Dadri	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	9
Talcher Super Ther	0	0	0	0	0	0	0	0	15	0	3	0	0	0	0	0	0	18
Unchahr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8
Talcher Thermal	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
Simhadri	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	10
Tanda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Sipat	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	14
Mauda	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
Barh	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7
Kudgi	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Bogaigaon	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
Solapur	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Dummy	0	118	22	7	0	0	0	16	8	8	0	0	0	137	1	8	12	337

Fig. 8: Alternative Optimal Solution using VAM

V. RESULTS AND CONCLUSION

The results obtained from solving the transportation problem indicate a tremendous decrease in the original transportation cost. The original cost calculated based on the present coal movement pattern was Rs 12874.3 crores whereas the cost obtained with the newly proposed coal movement pattern is Rs 9967.11 crores which in turn gives a profit of 2907.19 crores. Although the estimated profit would not reach the above-mentioned level due to the assumptions taken in the course of analysis.

The optimum solution suggests no change in the allocation of coal blocks for the pit head power stations as they are already using the most optimum pattern possible.

The solution proposes to reallocate the coal blocks to some of the cost-intensive plants like Dadri, Kudgi, Solapur, Unchahar and Mauda, Barh and Tanda.

The new model suggests that Kudgi and Mauda together contribute to about two-third of the total profitability.

However, we would not suggest any changes to be made in the current coal movement patterns across the country based on this study due to the several underlying assumptions, making the study not suitable for implementation in a real-world situation. The study, however, clearly states that there is a need to reallocate the coal blocks for all the coal-based power projects in India which will result in the generation of revenues worth thousands of crores to the Indian economy.

PROJECTS	MTPA	ORIGINAL FREIGHT RATE	ORIGINAL COST	OPTIMISED COST	PROFITS
Singrauli	10	198.7	1987	1987	0
Korba	13	198.7	2583.1	2583.1	0
Ramagundam	13	198.7	2583.1	2583.1	0
farakka	11	449.4	4943.4	4943.4	0
Vindhyachal	24	198.7	4768.8	4768.8	0
Rihand	15	198.7	2980.5	2980.5	0
Kahalgaon	14	198.7	2781.8	2781.8	0
Dadri	9	1986.5	17878.5	14374.8	3503.7
Talcher Super Ther	18	198.7	3576.6	3576.6	0
Unchahr	8	1129.2	9033.6	7758.4	1275.2
Talcher Thermal	3	198.7	596.1	596.1	0
Simhadri	10	1129.2	11292	11292	0
Tanda'	2	1129.2	2258.4	1939.6	318.8
Sipat	14	358.3	5016.2	5016.2	0
Mauda	13	1286.2	16720.6	9530.3	7190.3
Barh	7	733.1	5131.7	4328.8	802.9
Kudgi	8	2765.8	22126.4	10916.8	11209.6
Bogaigaon	2	1286.2	2572.4	2572.4	0
Solapur	4	2478.2	9912.8	5144.8	4768
			128743	99674.5	29068.5

Fig. 9: Comparative Analysis of the Adopted and New model

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In the above table,
* MTPA Million tonnes per annum
*Freight rates are in Rs. per tonnes
*Cost and Profits are in Million Rupees per annum

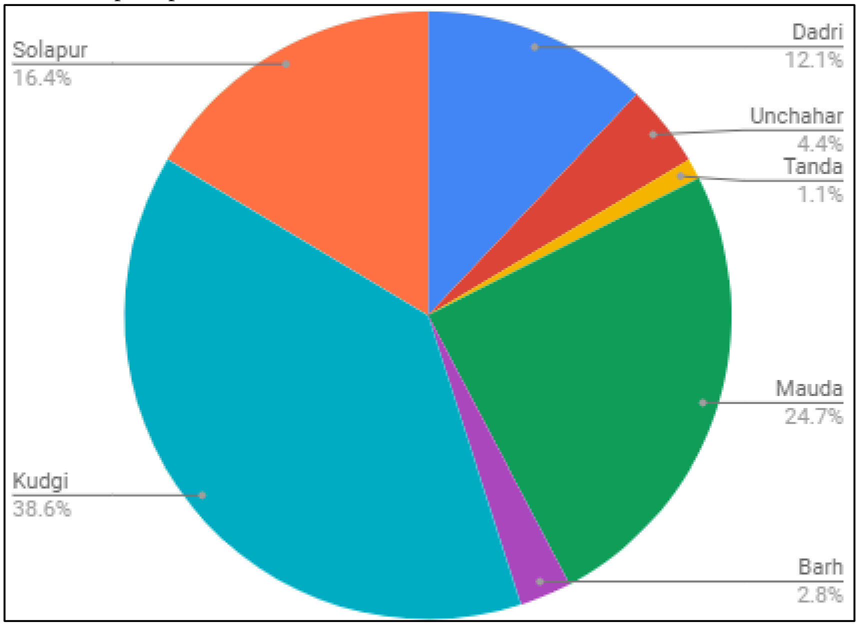

Fig 10: Contribution to the total profitability

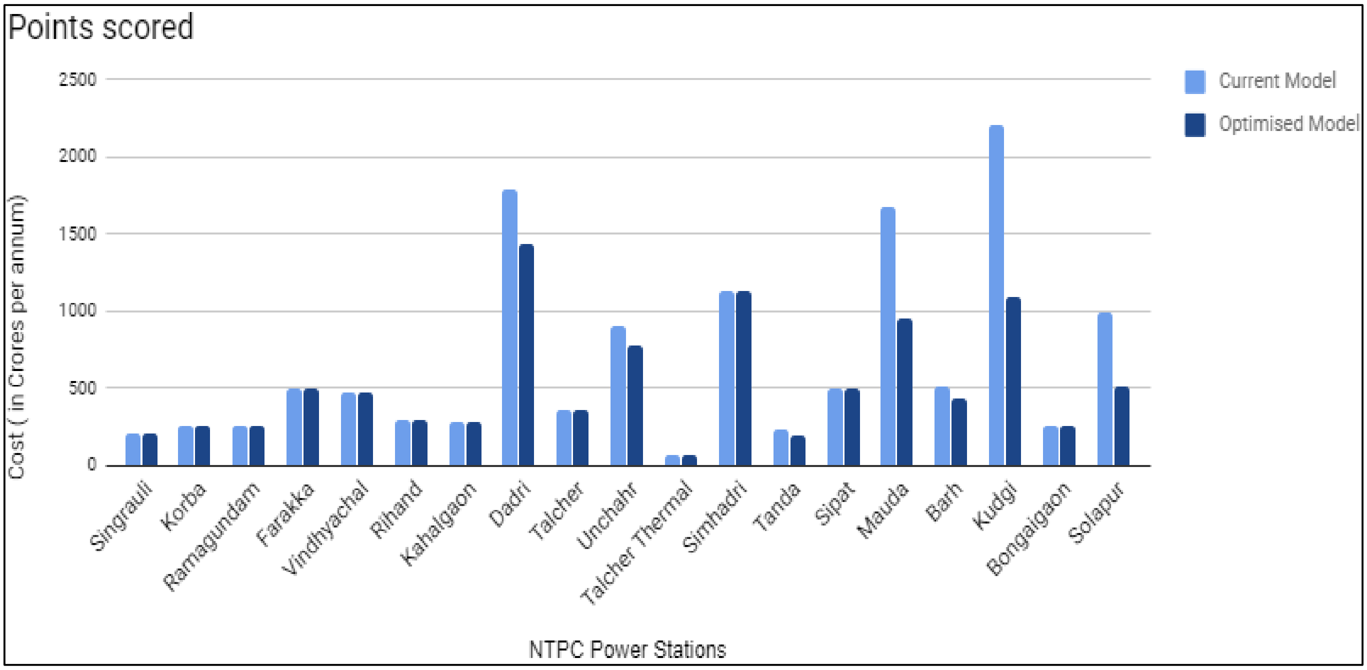

Fig. 11: Comparative Analysis of the current and optimized model

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