Bi-Stage Optimization Model For Transportation of Construction Steel: An Indian Case Study

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Abstract. In a steel plant, one of the critical tasks of plant logistics is the transportation of the finished products. A steel company transportation system generally consists of a fleet of load-carrying trailers and rail, which are used to transport finished goods. In this paper, a two-stage mathematical model is developed for an Indian company that helps with strategic planning of the supply of finished construction steel (TMT Bar and Structural Steel) from multiple plant locations to the stockyards and then to the distributors. The transportation cost depends on various factors like the type of transportation mode, loading & unloading charges, and other fixed expenses. The steel demand also varies based on the season and other external factors like COVID-19, government policies, and so forth. The model proposed in the present research facilitates cost-effective network planning by achieving the most appropriate dispatching method considering various factors operating in multiple stages using a mixed fleet of trailers and rail. The model's key objective is to optimize the transportation cost and demand for construction steel. Keywords—optimization, transportation, construction steel, MILP, COVID-19

1 INTRODUCTION

Metals have long been regarded as one of the most important drivers of industrialization. Steel has always held a leading position amongst metals. A steel supply and demand are commonly viewed as indicators of economic progress as raw material and intermediary products. Therefore, it is not an exaggeration to argue that the steel sector will always be at the forefront of industrial progress and that it is the cornerstone of any economy. There is a significant dependency on steel for developing infrastructure, making vehicles, buildings, machinery, ships, and railways. Steel is required everywhere and thus there is a significant demand for iron, and steel production.

The iron and steel sector is highly complex and inherently connected with the economy of the world. Steel is required in many industries. The others sector which is directly connected with steel is the mining industry, the power industry for running the plant, and the coal industry, and along with these major industries, ferroalloy, refractory, and tools are the supporting industries. Steel goods are utilized in a broad range of applications, such as construction, machinery, arms, tools & tackle, the shipping Industry, and automobiles.

Currently in India, the steel industry contributes slightly over 2% of the national GDP while its indirect impact is substantially bigger due to other industries' dependency. The steel sector employs approximately half a million individuals directly and indirectly to two million. The construction industry, which includes physical infrastructure (except for railways) and real estate, accounts for about 62 percent of India's steel demand. In 2018, the industry grew by 8.6%. Even though growth is anticipated to slow to 5.4 percent in 2019, the sector is supposed to pick up in 2020 and beyond, expanding at around 7% until 2024 [1].

One of the key issues in India is high logistics cost, estimated to be 14.4% of GDP, whereas, in the US and Europe, it varies between 8-10%. India's supply chain and logistics segment are one of the largest worldwide and significant improvement is needed in this sector [2]. The cost of shipment by roadways is INR 2.58/ton-km as compared to INR 1.41/ton-km for railways and INR 1.06/ton-km for water routes [3].

Handling logistics requirements is difficult, time-consuming, and expensive for most Indian steel producers. Iron ore, other than coal or coking coal, is the most important raw material for steel production. So, whether it is transporting raw materials for making steel to steel plants or transporting finished steel to demand areas, bulk material shipment is often difficult. Furthermore, unlike China, Japan, or Korea, most Indian steel plants are situated inland, rather than near the sea. This makes managing transportation needs for many of these steel plants in India much more difficult.

Steel producers' preferred mode of transportation is, unsurprisingly, railways. Since the sea route must be partly leveraged to a few steel plants, the railway network meets more than 80% of the steel sector's overall logistics requirements. Furthermore, transporting bulk materials by road is not economically feasible and it is limited to fewer quantities. Railway infrastructure is restricted, making logistics management difficult for Indian steel producers. Furthermore, the Indian Railways' long-standing reliance on revenue through freight traffic, particularly bulk goods, has been well known. In other terms, since rail travel is subsidized by freight profits, the freight cost of moving goods via the railways, whether raw materials or finished steel, becomes deliberately much higher.

The demand for construction steel is also driven by the seasonal factor; in the rainy season, the construction of roads and buildings are held due to heavy rain, and floods in various parts of the country which causes low demand as compared to the other months in the year. The COVID-19 crisis also represents a huge crisis for the global economy with its catastrophic consequences for human health. A general drop in consumption, slowdowns, and distorted supply chains have hit customers. The expected steel demand in most nations is to decline considerably.

The economic cycle has been grounded to a standstill due to resource-side constraints caused by inter-state border closures, as well as labor shortages and workplace closures, leading to record low levels. Prices remained low due to weak domestic demand, significant inventory build-ups, and supply chain bottlenecks, which hindered prompt production ramp-ups. Many critical raw materials, such as coking coal, limestone, refractory, ferroalloys, and ferrous scrap, are in short supply. In India, higher power costs make the steel sector less competitive and appealing as a product compared to other alternatives.

The inspiration of the present research work is to suggest a mathematical formulation that focuses on numerous difficulties connected with network planning for an Indian company while obtaining the most appropriate and cost-effective transportation method functioning in multiple stages using trailers and rail networks.

The rest of the paper is as follows: Section 2 delivers an outline of the steel sector and reviews the literature on the steel products supply chain. The mathematical model along with the case study is presented in Section 3. The results are given in Section 4 while the very last section concludes the study and describes the future direction of the research.

Objectives:

The main objective is to optimize the cost of transportation and demand for construction steel. Investigated the various constraint which is based on the real scenarios applicable for transportation in any metal industry. To explore the scope of the Two-Stage Optimization Model for various application fields.

2 LITERATURE REVIEW

First, confirm that you have the correct template for your paper size. This template has been tailored for output on the A4 paper size. If you are using US letter-sized paper, please close this file and download the Microsoft Word, Letter file. The steel supply chain process from raw material to commercial goods has previously been addressed from many different decision horizons. Studies focused on operational, logistic, and transportation perspectives including strategic planning also addressed in a few studies. Operational planning and logistical decisions of the distribution of products from the supply point to the demand fulfilment location should be effective with less lead time and low-cost strategy implementation is vital for the success of the supply chain. Paper presents the bottleneck of steel industries in traditional decision-making of the by-product handling of logistics and transportation by application of genetic algorithms via artificial intelligence to optimize by-product transport through the firm in-route information, transport demand frequency, and vehicle routing systematization, due to the rising fuel cost and imbalance in supply-demand leads to price competition and there is a decline in profits [4]. The authors discuss efficiently managing location by a hybrid algorithm based on fuzzy theory, AHP (analytical hierarchy process), and goal programming approach. Objectives are to minimize risk, uncovered demand, distance, and several sites, and maximize suitability by considering capacity, demand, utilization, and budgetary constraints [5]. The various supply chain challenges in the steel industry are its complexity and prominent factors such are demand fluctuation, production process, raw material supply, transportation issue, and price uncertainty which impacts the supply chain. The supply chain of steel manufacturing considers multistage objectives in the global market [6]. The strategic and tactical network design is a vital issue of responsiveness and efficiency of the steel supply chain, the steel demand is ever-increasing simultaneously with the expansion of production, distribution, inventory, and capacity expansion plan, and effective supply chain network design is required. A mixed-integer linear programming (MILP) and mixed integer nonlinear programming(MINLP) model were formulated to efficiently design a multi-commodity supply chain network assuming demand is normally distributed[7]. The article focuses on the competitive advantages and sustainable supply chain to balance environmental, social, and economic aspects, steel products at the end of the life cycle can be reused by including reverse logistics in the supply chain and building a closed-loop supply chain a multi mathematical model through scenery-based method is approached following a fuzzy goal programming approach[8]. The process mapping technique, categorized and identified impacts on asset utilization, inventory, and lead time, and proposed an integrated supply chain structure from a traditional, suboptimal and uncoordinated system discussed by authors[9]. The article proposes a model for the least cost strategy considered safety stock, cost of transportation, and inventory by the heuristic algorithm and proposes the MINLP model for supply chain optimization[10]. The rolling horizon approach, multi-echelon, multiproduct distribution network describes a control strategy to maximize profit and to find optimal decision variables in the supply chain and the developed MILP dynamic model compares the centralized and decentralized behavior business management approach discussed in the paper[11]. The authors proposed a supply chain network for processing capabilities, and economic uncertainties by balancing export and process capacities by a multi-period stochastic model on a finite number of realizations and based on 2 stage problem[12]. This article considered multiple customers, multiple suppliers, and multiple manufacturers in the supply chain addressing multi-product, multi-site and multi-period, multi aggregate production planning circumstances. The multi-objective MINLP model is discussed to deal with aggregate production planning; cost parameters and demand fluctuation are considered as uncertainty and then transformed into linear one-objective function to minimize supply chain losses[13]. A multi-period optimization model proposed in the paper describes a bi-level decomposition algorithm in a flexible network supply chain for intermittent deliveries, delivery delays, sales, inventories, and production shortfalls considering a short time horizon to reduce computational expenses[14]. The application of fuzzy programming technique in solving real transportation problem of multi objectives on minimization the underused capacity, deterioration rate and transportation cost from sources to destination sites of companies by railway or roadways and build non-dominated compromise solution[15]. The research paper presents MOTTP (Multi-Objective Time Transportation Problem) with non-linear objective function minimizing lead time, shipping time loading unloading time for iron ore transportation in steel industries[16]. The authors discuss the problem of distribution from factory to demand center using a single-source transportation model target of minimizing the total cost, solved by Linear programming method as well as traditional methods Modified Distribution and Vogel's Approximation method[17]. The two-stage supply chain fixed cost distribution allocation problem configuring retailers, distributors, and manufacturers are discussed in the paper. The model incorporates fixed costs of transportation route and facilities objective function is the minimization of supply chain total cost incurred in allocating the distributor to manufacturing plant and retailer to a distributor[18]. The supply chain issues are modeled by a researcher with variations of demands in different periods and capacity constraints to minimize the configuration cost of the supply chain[19]. The article comprises the modeling of the two-stage transportation problem of a distribution network with a fixed cost which includes the manufacturing center, distribution point, and customers by incorporating linear programming and the proposed hybrid genetic algorithm[20]. The paper talks about the production-distribution problem as it plays important role in reducing overall supply chain cost, MILP model is proposed in this paper for designing multi-period and multi-objective supply chain networks[21]. The researcher focuses on managing seasonal demand by appropriately selecting replenishment decision variables and managing service levels in the supply chain[22]. A simulation study that signifies the bullwhip effect and inventory management of the steel manufacturing supply chain [23]. The optimal scheduling of warehouse management in steel manufacturing developed a heuristic concept of the steel supply chain[24]. The paper presents designing a supply chain model to meet the facility location-allocation problem, supply chain considering multiple transportation alternatives, multiple suppliers, multiple plants, multiple customer zones, and multiple products[25].

3 CASE BACKGROUND

The plant locations of the case under consideration are in the industrial cities of states Odisha, Chhattisgarh, and Jharkhand. The finished steel product (construction steel) is dispatched to the various stockyards in the key cities of the northern part of the country, further products are dispatched to the various distributors in road transport as per their demand and order quantity. The model of transport in these cities is via Rail and road transport. The transportation cost is a major portion of the total cost as the price of fuel is increasing gradually, also the company facing the challenge of uncertain demand due to seasonality or other external factors.

The plants comprise the dispatch section, in the dispatch area the trailers are parked and the quality inspection checks finished steel is ready with all necessary documents like LR copy, purchase order, and weigh slip. Some contractors are working to load the steel in the trailers with the help of load-loading vehicles and charge a fixed contractual price. Nowadays the dispatch of steel products is preferred in the Rail mode, however, this required a lot of capital investment and approval from govt authorities. For Rail mode the wagons (racks) are arranged on the railway tracks mostly 43 wagons are there but it can vary also, steel products are loaded into the wagons with the help of cranes.

The combination of both models of transport is used or the dispatch, based on the quantity and distance. In this case, we have chosen four stockyards locations to full fill, six distributors. All factories are connected to all stockyards and stockyards connected are connected to all distributors. The company wants to decide on the selection of factories on supply of steel (TMT & Structural) to the stockyard and then distributor with optimal cost. This paper built a two-stage integer linear programming to minimize cost and get the most optimal supply route in Steel transport.

Mathematical Model:

Sets:

I : Set of Factories

J: Set of Stockyards

K: Set of Distributors

Parameters:

$X1_{ij}$ = Tons of TMT transported from factory i to stockyard j

$X2_{ij}$ = Tons of Structural steel transported from factory i to stockyard j

$Y1_{jk}$ = Tons of TMT transported from stockyard j to distributor k

$Y2_{jk}$ =Tons of Structural steel transported from stockyard j to distributor k

$C1_{ij}$ = per/ton cost of trailer transportation from factory i to stockyard j

$C2_{ij}$ =per/ton cost of rail transportation from factory i to stockyard j

$C3_{jk}$ = per/ton trailer transportation cost from stockyard j to distributor k

$PRF1_i$ =Production of TMT from factory i

$PRF2_i$ = Production of Structural steel from factory i

$FCL1_i$ =Fixed loading cost for Trailer from factory i to stockyard j.

$FCL2_i$ =Fixed loading cost for Rail from factory i to stockyard j.

P_i = Binary for loading charge if factory selected for TMT

Q_i =Binary variable for loading if factory selected for Structure.

Minimize:

$$\sum_i \sum_j X1_{ij}C1_{ij} + \sum_i \sum_j X1_{ij}C2_{ij} + \sum_i \sum_j X2_{ij}C1_{ij} + \sum_i \sum_j X2_{ij}C2_{ij} + \sum_j \sum_k Y1_{jk}C3_{jk} + \sum_j \sum_k Y2_{jk}C3_{jk} + \sum_i P_i\, FCL1_i + \sum_i P_i\, FCL2_i + \sum_i Q_i\, FCL1_i + \sum_i Q_i\, FCL2_i$$

s.t.

$$\sum_J X1_{ij} \leq PRF1_i \quad (1)$$

The constraint states that the total quantity of TMT from factory i can supply to stockyard j should be less than production capacity.

$$\sum_J X2_{ij} \leq PRF2_i \quad (2)$$

The constraint states that the total quantity of structure from factory i can supply to stockyard j should be less than production capacity.

$$\sum_J X1_{ij} = \sum_k Y1_{jk} \quad (3)$$

The total demand from distributors for TMT should be equal to the supply from stockyards.

$$\sum_J X2_{ij} = \sum_k Y2_{jk} \quad (4)$$

The total demand from distributors for structure should equal the supply from stockyards.

$$\sum_J X1_{ij} \leq \sum_i P_i\, FCL1_i + \sum_i P_i\, FCL2_i \quad (5)$$

The loading cost for (Rail & Trailer) will be only applicable if the factory is selected (P_i) for TMT supply.

$$\sum_J X2_{ij} \leq \sum_i Q_i\, FCL1_i + \sum_i Q_i\, FCL2_i \quad (6)$$

Loading cost for (Rail & Trailer) will be only applicable if the factory is selected (Q)i for Structure supply.

$$\sum_J X1_{ij} \leq 30000 \quad (7)$$

The transportation from Rail should not be more than 30000 for TMT due to rack unavailability.

$$\sum_J X2_{ij} \leq 30000 \quad (8)$$

The transportation from Rail should not be more than 30000 for structure due to rack unavailability.

$$\sum_J Y1_{jk} \leq 80000 \quad (9)$$

Stockyards can handle the TMT supply of a maximum of 80000 Mt

$$\sum_J Y2_{jk} \leq 80000 \quad (10)$$

Stockyards can handle the Structure supply of a maximum of 80000 Mt.

$X1_{ij} = integer$
$Y1_{jk} = integer$
$X2_{ij} = integer$
$Y2_{jk} = integer$
$P_i = Binary$
$Q_i = Binary$

Inputs:

Table 1 Supply of construction steel from factories

Factory	TMT (MT)	Structure Steel (MT)
Factory 01	60000	55000
Factory 02	90000	60000
Factory 03	70000	45000

Factory 01 is situated at Angul, Odisha, Factory 02 is at Raigarh (C.G) and Factory 03 is under operation at Patratu (Jharkhand).

Table 2. The demand of the TMT and Structural steel from distributors in MT

Items	D 01	D 02	D 03	D 04	D 05	D 06
TMT	35000	32000	38000	34000	30000	35000
Structural Steel	22000	24000	28000	24000	28000	29000

Here D stands for Distributor, a total of six distributors situated in northern cities of India.

D01 - Lucknow
D02 - Meerut
D03 - Gurgaon
D04 - Delhi
D05 - Rohtak
D06 – Varanasi

Table 3. The INR/Ton cost of the Rail and Trailer transportation from factories to stockyards

Transport Mode.	Stockyard 01 (Ludhiana)	Stockyard 02 (Faridabad)	Stockyard 03 (Agra)	Stockyard 04 (Kanpur)
Trailer	4832	3922	3470	2686
Rail	3190	3142	2768	2387
	4043	3135	2807	2028
	2880	2578	2195	1814
	4035	3127	2675	1948
	2537	2578	2195	1624

The INR/Ton cost has been calculated based on the Indian Railways (Freight Operation Information System) portals and for the road transaction, the distance is taken from Google map and 2.58 Rs/ton _km (Niti Ayog Report) for calculation.

Table 4. The INR/Ton cost of Trailer transportation from stockyards to distributors.

	D1 (Lakhnu)	D2 (Meerath)	D3 (Gurgaon)	D4 (Delhi)	D5 (Rohtak)	D6 (Varanasi)
Stockyard 01	516	774	929	797	789	3039
Stockyard 02	433	237	111	129	266	2108
Stockyard 03	129	645	609	596	697	1662
Stockyard 04	245	1326	1290	1277	1437	877

The distance has been calculated based on the Google map, and a cost of 2.58 Rs/ton_km (Niti Ayog Report) has been considered.

The estimated loading charges at factories for trailers is INR 2000, and for Rail INR 100000 fixed charges are considered.

4 RESULTS

In this section after running the model with the help of the excel solver the following results have been received for "XYZ" company:

4.1 The total cost of transportation = 1058942260 (**105.9 Cr.)**
4.2 The transportation cost for TMT from Factories to distributors = 600066540 (**60 Cr**.)
4.3 The Transportation cost for Structure from factories to distributors = 458875720 (**45.88 Cr)**

Table 5. Transportation of TMT in MT from Factories to Stockyards

	Stockyard 01 (Ludhiana)	Stockyard 02 (Faridabad)	Stockyard 03 (Agra)	Stockyard 04 (Kanpur)
Factory 01	0	30000	0	0
Factory 02	0	30000	0	0
Factory 03	0	0	30000	0

Table 6. Transportation of TMT in MT via Road (Trailers) from Factories to Stockyards

Transportation of TMT in MT via Road (Trailers) from Factories to Stockyards				
	Stockyard 01 (Ludhiana)	Stockyard 02 (Faridabad)	Stockyard 03 (Agra)	Stockyard 04 (Kanpur)
Factory 01	0	0	0	14000
Factory 02	0	20000	0	40000
Factory 03	0	0	14000	26000

5 CONCLUSION

In this paper, the author developed a two-stage programming model for the dispatch of its finished products (TMT and Construction Steel) to its distributors situated in various cities in the northern region of India. The aim is to figure out the least-cost strategy for the delivery of the finished product. A combination of the Rail and Trailers employed by the company. The model has taken the detail, based on real scenarios, and is applicable for steel transportation in any metal industry. The developed model has been useful for the reference for the various companies looking to optimize transportation cost. The model has also discussed the various constraint which is applicable in scenarios and also help the factory manage its products based on the detail. The model also successfully incorporates the limitations associated with the number of Rail racks available and stockyard handling capacity selected and also helps to achieve balanced networks for the transportation of steel. The model can additionally be adjusted to different other input scenarios, follow-on by a more robust map that can be customized to diverse steel producers.

There are numerous ways to expand on this paper. The current approach is based on deterministic steel production; however stochastic modeling can be used to expand it to unpredictable production levels. The model's variable expenses are assumed to be set fixed, and dynamic cost functions could be used in future research. The concept can be extended to many phases, allowing the supply network to also be continued further downstream. Future research could also cover activities that support or enhance the management of the steel supply chain. The role of many stakeholders in the evolution of an ecosystem may be evaluated.

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