International
Journal
Of Advanced Research in Engineering & Management (IJAREM)
ISSN: 2456-2033 || PP. 05-11

Transportation model: Application of Turkish Hard Coal Enterprises (TTK)

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Abstract: The transportation model is a special form of the Linear Programming model. This model deals with transporting goods from sources (supply centers) to destinations (demand centers). A balance between the demand requirements of destinations and the supply quantities of sources must be ensured. The aim of the transportation model is to determine the amount of goods to be transported from each source to each destination such that the total transportation cost is minimized; in other words, to optimize transportation costs. Transportation models are widely used in real life. Given that these problems may contain numerous variables and constraints, it is important to solve them accurately and rapidly. With the rapid development of computer software, various package programs have been introduced. In this study, information regarding transportation models and solution methods is provided. Subsequently, a transportation model was constructed using a dataset compiled from information available on the Turkish Hard Coal Enterprise (TTK) website. This model was solved using Python, R, and Excel, and the results were compared to provide recommendations.

Keywords: Linear programming, Transportation model, Optimization, Python, R

1. Introduction

Transportation provides companies with the physical means to carry out logistics activities. Transportation models are a special type of linear programming models. These models focus on the movement of goods from sources (supply centers) to destinations (demand centers). The purpose of the transportation model is to determine the shipment quantities that minimize the total cost of transporting goods from any source to any destination. In other words, it aims to optimize shipping costs [1].

In modern societies where planning plays a crucial role, transportation is essential for ensuring the necessary movement of people and goods. Since the 1960s, the transportation model has been used to solve problems in various sectors, such as the distribution of products to markets, assignment and transshipment problems, facility location selection, allocation of jobs to machines or personnel, and production scheduling [2].

The transportation model was first proposed by Frank L. Hitchcock in 1941 [3]. It was later developed by Koopmans (1949) and G. B. Dantzig (1951) [4,5]. Kantorovich, A. Charnes and W. W. Cooper, Russell, and other scholars also contributed to its development [6].

Some of the previous studies related to the transportation problem are as follows: Ulucan and Tarım (1997) conducted a study on cost minimization in the maritime transportation of petroleum products [7]. Chen and Wang (1997) developed a linear programming model for integrated steel production and distribution planning [8]. Şafak (2000) examined the optimality conditions of distribution problems [9]. Balakrishnan et al. (2000) conducted a study on optimizing delivery charges for a distributor network [10]. Ergülen (2005) attempted to optimize firm costs to minimize transportation expenses [11]. Ghazali et al. (2012) obtained an optimal solution to a transportation problem for a trading company in Malaysia using a linear programming model [12]. Şen (2015) prepared a master's thesis titled "Optimization of distribution costs for vehicles distributed nationwide: An application of the transportation model" [13]. Tan and Patır (2017) formulated a distribution plan for a beverage company operating in Bingöl using transportation models [14]. Candan (2019) completed a doctoral dissertation titled "Cost Minimization with Transportation Models and Supply Chain Management Application in the Footwear Industry" [15]. Askerbeyli (2020) focused on minimizing the total transportation costs of products manufactured in a steel production facility [16]. Arman et al. (2021) studied the distribution of products to customers by an electronics company operating in Istanbul [17]. Al-Momayez (2023) prepared a master's thesis titled “Transportation Model: A Real-Life Application Using Python” [18]. Many more studies exist in the literature concerning the transportation problem.

In this study, a transportation model was constructed using a dataset compiled from information on the Turkish Hard Coal Enterprise’s website. This model was then solved using Python, R, and Excel. The obtained results were analyzed and recommendations were provided.

2. Materials and Methods

2.1. Transportation Model

The transportation model is a specialized linear programming model that aims to transport goods from specific sources (e.g., factories) to specific destinations (e.g., warehouses), that is, from production centers to distribution (consumption) centers, at the lowest possible cost.

2.2. General Structure of Transportation Models

In a transportation model, the primary concern is the movement of goods from sources to destinations. During this transportation process, a balance must be maintained between both demand requirements and supply quantities. Furthermore, the total transportation cost from sources to destinations must be minimized. The model assumes that transportation costs are directly proportional to the quantities transported. A general representation of the transportation model can be visualized as in Figure 2.1.

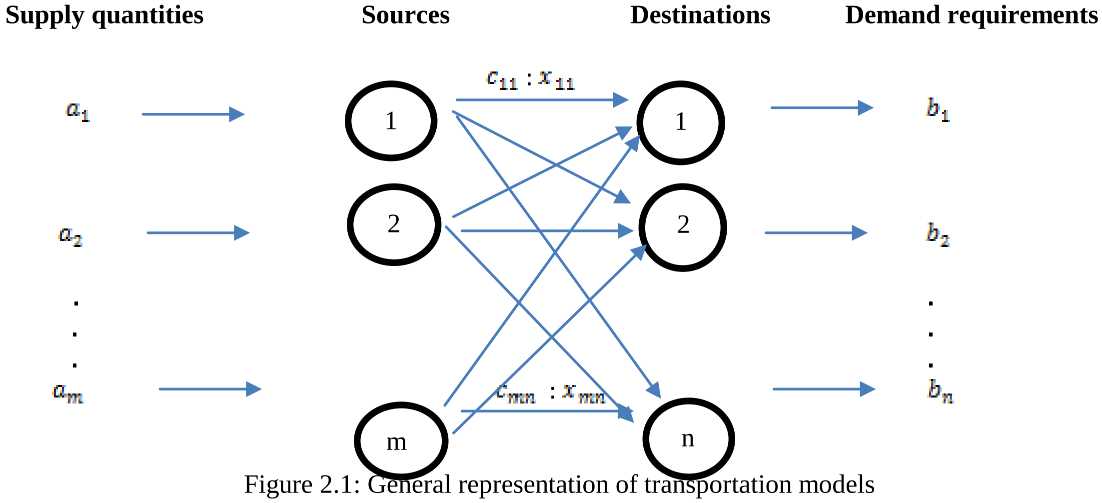

Figure 2.1: General representation of transportation models

Here, there are m sources and n destinations. The connections indicate the routes between the sources and destinations [1].

The connection from source i to destination j is characterized as follows:

c_{ij}: Unit transportation cost $(i = 1,2, \dots, m \quad j = 1,2, \dots, n)$
x_{ij}: Quantity transported
a_i: Supply quantity of source i
b_j: Demand quantity of destination j

The objective of the model is to determine x_{ij} values that satisfy all supply and demand constraints while minimizing total transportation cost.

Accordingly, the transportation model is formulated as follows:

$$Min\ Z: \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$$

Subject to: $\sum_{i=1}^{m} x_{ij} = b_j \quad , \quad (j = 1,2, \dots, n)$ (Demand constraints)

$\sum_{j=1}^{n} x_{ij} = a_i \quad , \quad (i = 1,2, \dots, m)$ (Supply constraints)

$x_{ij} \geq 0$

Transportation models may be balanced or unbalanced. A balanced model satisfies $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$. Unbalanced models can be converted into balanced ones by introducing dummy variables. If the problem is to be solved by the simplex method, there is no need for balancing. The solution is achieved by taking constraints $\leq a_i$ and $\geq b_j$.

2.3. Solution Algorithm of the Transportation Model

The following steps are followed when solving transportation problems:

1. Determine an initial feasible basic solution.
2. Check whether this solution is optimal.
3. If optimal, record the optimal solution.
4. If not, improve the solution and return to step 2.

When solving transportation problems, an initial solution is first found. For the solution to be valid, the number of allocated cells as a result of the solution to a transportation problem consisting of i rows (source) and j columns (target) must be equal to $(i + j - 1)$.

2.4. Initial Solution Techniques for Transportation Models

The methods used to find the initial feasible basic solution of transportation problems are as follows:

1. Northwest Corner Rule
2. Least Cost Method
3. Vogel's Approximation Method (VAM)

Among these, VAM typically yields the solution closest to optimality.

4. Results

Transportation models are widely used in real-life applications. In this study, a transportation model was established using a dataset compiled from information available on the Turkish Hard Coal Enterprise (TTK) website for the year 2023. The model was subsequently solved using Python, R, and Excel, and the obtained results were interpreted to provide recommendations.

Coal is a mineral composed primarily of carbon, hydrogen, and oxygen, with small amounts of sulfur and nitrogen, exhibiting distinct chemical and physical properties.

Coal, which holds significant importance among energy raw materials and has a wide range of consumption areas, is produced in more than fifty countries. Due to its critical role in electricity generation and steel production, it plays an essential role in national development and energy planning.

The two major consumption sectors of coal are the iron and steel industry and thermal power plants. In Turkey, the most significant hard coal reserves are located in the Zonguldak Basin, where mining activities are carried out by the Turkish Hard Coal Enterprise.

The coking coal reserves in the Zonguldak basin are found in the Kozlu, Üzülmez, and Karadon regions. The Armutçuk region contains semi-coking coal, which can be blended with coking coals for use in the iron and steel industry; therefore, it was not included in this study. Amasra coal does not possess coking properties but can be blended with metallurgical coal without impairing its coking ability.

Coal production quantities (tons) by establishments for 2023 are presented in Table 3.1.

Table 3.1: Coal production quantities by establishments in 2023 (tons) [21]

Establishments	Coal production quantities
Kozlu	203871
Üzülmez	323764
Karadon	457922
Amasra	3170
TOTAL	988727

Sectoral hard coal consumption in Turkey is given in Table 3.2.

Table 3.2: Hard Coal Consumption by Sectors (x1000 tons) [20]

Sectors	2020	2021	2022	2023
Thermal Power Plants	21854	19746	21169	24793
Coke Plants	6197	6276	5700	5690
Iron and Steel Industry	1090	1249	1069	915
Industry (except iron and steel)	4404	5377	3784	4262
Other	6254	4625	3401	3197
TOTAL	39799	37273	35123	38857

In 2023, thermal power plants had the largest share in hard coal consumption in Turkey, with a rate of 63.81%. The remaining consumption was in coke plants at 14.64%, iron and steel plants at 2.35%, industry (excluding iron and steel) at 10.97%, and other industries at 8.23% [19].

The quantities of hard coal sold by TTK to the iron-steel and energy sectors by years are presented in Table 3.3.

Table 3.3: Hard Coal Sales by Sectors, 2012-2023 [20]

Years	SECTORS			TOTAL
	Energy (ÇATES)	Iron-steel (Kardemir-Erdemir)	Various Teshin	
2012	835061	416418	157191	1408670
2013	750086	431864	132428	1314378
⋮	⋮	⋮	⋮	⋮
2022	821446	171575	61336	1054357
2023	630373	139883	18230	788486
TOTAL	6904825	3485805	975764	11366395

Detailed sales to the Iron and Steel sector are presented in Table 3.4.

Table 3.4: Hard Coal Sales to Erdemir and Kardemir (tons) [20]

Years	Kardemir	Erdemir	TOTAL
2010	451981	46659	498640
2011	388751	40374	429126
⋮	⋮	⋮	⋮
2022	154957	16618	171575
2023	122200	17684	139884

Since the 2000s, a restructuring program has been implemented at TTK to increase production and reduce costs. Transportation costs are also included in these operational expenses.

In this study, a transportation model was established to minimize the cost of transporting produced hard coal to demand centers. Production centers are Kozlu, Üzülmez, Karadon, and Amasra, while demand centers are Kardemir, Erdemir, and ÇATES.

The supply quantities of production centers in 2023 (from Table 3.1), the demands of demand centers in 2023 (from Table 3.3 and Table 3.4) and the distances (km) between production centers and consumption centers are given in Table 3.5.

Table 3.5: Supply and Demand of Production and Consumption Centers and their distances (km)

	Kardemir	Erdemir	Çatalağzı	**Supply**
Kozlu	107	44,7	21,1	203871
Üzülmez	97,6	52,7	16,4	323764
Karadon	109	59	6	457922
Amasra	102	153	80,8	3170

Demand	122200	17684	630373

Assuming that transportation cost is directly proportional to distance, distances were used as cost coefficients in the objective function.

When we define the decision variables as;

X_{ij}: The quantity of goods to be transported from the $i.$ production center to the $j.$ consumption center

($i.$ production center: respectively Kozlu, Üzülmez, Karadon, Amasra; $j.$ consumption center: respectively Kardemir, Erdemir, Çatalağzı)

The transportation model is established as follows:

Objective function:
Min Z:

$$107X_{11} + 44.7X_{12} + 21.1X_{13} + 96.7X_{21} + 52.7X_{22} + 16.4X_{23} + 109X_{31} + 59X_{32} + 6X_{33} + 102X_{41} + 153X_{42} + 80.8X_{43}$$

Constraints:
Supply Constraints:

$$X_{11} + X_{12} + X_{13} \leq 203871$$
$$X_{21} + X_{22} + X_{23} \leq 323764$$
$$X_{31} + X_{32} + X_{33} \leq 457922$$
$$X_{41} + X_{42} + X_{43} \leq 3170$$

Demand Constraints:

$$X_{11} + X_{21} + X_{31} + X_{31} \geq 122200$$
$$X_{12} + X_{22} + X_{32} + X_{42} \geq 17684$$
$$X_{13} + X_{23} + X_{33} + X_{43} \geq 630373$$
$$x_{ij} \geq 0 \quad (i = 1,2,3,4 \ ; \ j = 1,2,3)$$

This model was solved using Python, R, and Excel. According to Python results;

17,684 tons of coal should be sent from the Kozlu production center to the Erdemir Iron and Steel Factory, 122,200 tons from the Üzülmez production center to the Kardemir Iron and Steel Factory, 172,451 tons from the Üzülmez production center to the Çatalağzı Thermal Power Plant, and 457,922 tons from the Karadon production center to the Çatalağzı Thermal Power Plant.

Thus, the demands of the consumption centers are fully met. The minimum transportation distance is 18292923.2 km, which is the objective function value.

The minimum total transportation cost can be calculated in direct proportion to the objective function value of 18292923.2 km.

It was wondered whether there were differences in the solution results, and the established model was also solved using the R program.

According to R results;

17,684 tons of coal should be sent from the Kozlu production center to the Erdemir Iron and Steel Factory, 122,200 tons from the Üzülmez production center to the Kardemir Iron and Steel Factory, 172,451 tons from the Üzülmez production center to the Çatalağzı Thermal Power Plant, and 457,922 tons from the Karadon production center to the Çatalağzı Thermal Power Plant. Thus, the demands of the consumption centers are fully met. The objective function value is found to be 18292923.

The minimum transportation distance is 18292923.2 km, which is the objective function value. The minimum total transportation cost can be calculated in direct proportion to the objective function value of 18292923.2 km.

As can be seen, the results obtained with the Python and R programs are the same. The established model was also analyzed with ExcelQM and the same results were obtained.

The initial solutions obtained with the initial solution techniques are given in Table 3.6.

Table 3.6: Initial solutions obtained with initial solution techniques

Initial solution techniques	**Shipping Quantities**	**Objective function value**
Northwest Corner Rule	Kozlu-Kardemir Demir Çelik Fab. = 122200 Kozlu-Erdemir Demir Çelik Fab. = 17684 Kozlu-Çatalağzı Termik Santrali = 63987 Üzülmez- Çatalağzı Termik Santrali = 323764 Karadon- Çatalağzı Termik Santrali = 242622	21981462,1
Vogel Approach	Üzülmez-Kardemir Demir Çelik Fab. = 122200 Üzülmez -Erdemir Demir Çelik Fab. = 17684 Üzülmez -Çatalağzı Termik Santrali = 172451 Karadon -Çatalağzı Termik Santrali = 457922	18434395,2
Least Cost Method	Üzülmez-Kardemir Demir Çelik Fab. = 119030 Üzülmez -Erdemir Demir Çelik Fab. = 17684 Üzülmez -Çatalağzı Termik Santrali = 172451 Karadon -Çatalağzı Termik Santrali = 457922 Amasra-Kardemir Demir Çelik Fab. = 3170	18448343,2

According to these results, the Vogel Approach provides the best initial solution, as it yields the lowest objective function value.

5. Discussion and Conclusion

In this study, a transportation model was developed using a dataset compiled from the 2023 Turkish Hard Coal Sector Report (May 2024) and the 2023 Activity Report published by the Turkish Hard Coal Enterprise (TTK). The constructed model was solved using various computer programs.

According to the Python, R and ExcelQM solutions:

17,684 tons of coal should be transported from the Kozlu production center to the Erdemir Iron and Steel Plant, 122,200 tons from the Üzülmez production center to the Kardemir Iron and Steel Plant, 172,451 tons from the Üzülmez production center to the Çatalağzı Thermal Power Plant, 457,922 tons from the Karadon production center to the Çatalağzı Thermal Power Plant.

Thus, the demands of all consumption centers are fully met. The minimum transportation distance is 18,292,923.2 km, and the minimum transportation cost can be calculated proportionally based on this value.

In conclusion, the transportation model satisfies all supply and demand constraints and provides the optimal solution. The results obtained using Python, ExcelQM, and R are identical.

By comparing historical transportation costs with the model-generated costs, managers can determine whether to adopt this model.

In future studies, various sensitivity analyses can be performed regarding model parameters, offering insights into potential scenarios.

Simulation studies may also be conducted to answer questions such as:
"What would be the outcome if the number and locations of sales warehouses were increased near the production centers?"

NOTE: This study is summarized from the first author's master's thesis.

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