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Original Article

Optimization of Green Freight Transportation for Carbon Emission and Fuel Consumption

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Abstract *- The goal of this research is to promote sustainable development by presenting an integrated approach to addressing the Transportation Problem (TP) with a focus on minimizing fuel consumption and reducing carbon dioxide emissions. Mathematical modeling techniques and Transportation algorithms are combined in the proposed solution, which is tailored to the specific context of the Indian Transport Authority transportation network. This approach's effectiveness in achieving a balance between reducing fuel consumption and transportation costs while maintaining service quality and customer satisfaction is demonstrated in the study. The optimization of the allocation of different routes can greatly reduce carbon dioxide emissions and Fuel consumption in different transportation methods like NWC, LCM, and VAM methods. The findings have significant implications for transportation planning and management, with an emphasis on the benefits of adopting sustainable transportation solutions to mitigate the adverse environmental impacts of transportation.*

Keywords *- Carbon Emission, Fuel Consumption, Green Freight Transportation, Optimization, Linear Programming, Operations Research.*

1. Introduction

Transportation Problems (TP) have been widely studied in the operations research field, focusing on finding the optimal way to distribute resources from sources to destinations while minimizing costs. The Shortest Path Problem (SPP) is a critical aspect of transportation, where the goal is to identify the path with the minimum distance, cost, or time between two points in a network. There have been numerous advancements in solving transportation and shortest path problems efficiently by leveraging mathematical programming, heuristics, and modern optimization techniques. In this aspect, many authors work in the mentioned field, like Dantzig & Ramser [1], who improved their classic work, laying the groundwork for modern transportation problems, particularly focusing on cost minimization in logistics, which is central to current supply chain optimizations. Sharma et al [2] presented a comparative study of solving transportation problems with the help of various methods of linear programming problems. Kaur & Kaur [3] compare several methods for solving transportation problems, including the stepping-stone method and the MODI method. The study highlights the computational efficiency of various techniques and suggests hybrid algorithms for large-scale instances. Kumar et al. [4] delve into MODI and Vogel's Approximation Method (VAM) for determining the optimal initial solution for transportation problems, focusing on computational ease and time complexity. Dijkstra [5] Re-explored in recent years due to its impact on shortest path algorithms, Dijkstra's algorithm is foundational to much of the work in shortest path research. Cherkassky et al. [6] evaluate classical shortest path algorithms and provide benchmarks of algorithmic efficiency for modern applications such as web mapping and traffic navigation systems. Yen [7] presented Yen's algorithm for finding multiple shortest paths, which is analyzed for its practical applications in real-time traffic systems and its ability to generate alternative paths in large transportation networks. Thorup [8] introduced Thorup's algorithm, which represents a major improvement over previous shortest path algorithms by achieving linear time complexity for certain classes of graphs, which has significant implications for real-time routing. Fan & Zhang [9] introduced a hybrid Genetic Algorithm (GA) to solve large-scale transportation problems. The GA approach is enhanced by local search techniques to improve the convergence rate toward the optimal solution. Hu & He [10] presented an improved A* algorithm to solve the shortest path problem in road networks with turn restrictions, addressing specific real-world applications in urban transportation systems. Xu & Ying [11] introduce an Ant Colony Optimization (ACO) approach to solve Multi-Objective Shortest Path Problems (MOSPP). The authors show significant improvements in computational time and solution accuracy when compared to traditional methods. Kumar & Sharma [12] study integrates fuzzy logic with Particle Swarm Optimization (PSO) to solve transportation problems under uncertainty, offering a novel approach to dealing with imprecise demand and supply data. Geisberger, R. et al. [13] introduce contraction hierarchies

(CH), which reduce the graph size and simplify routing computations, significantly speeding up shortest path queries in road networks. Fekete & Kreveld [14] develop novel algorithms based on geometric properties of transportation networks to enhance the speed of finding optimal transport routes, particularly for logistics companies.

2. Preliminaries

In this section, some basic definitions are reviewed.

2.1. Transportation Problem Model

Given m origins and n destinations, the transportation problem can be formulated as the following linear programming problem model:

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

Subject to constraint:

$$\sum_{j=1}^{n} x_{ij} \leq a_i \qquad i=1, 2, \ldots\ldots\ldots m$$

$$\sum_{i=1}^{m} x_{ij} \geq b_j \qquad j=1, 2, \ldots\ldots\ldots n$$

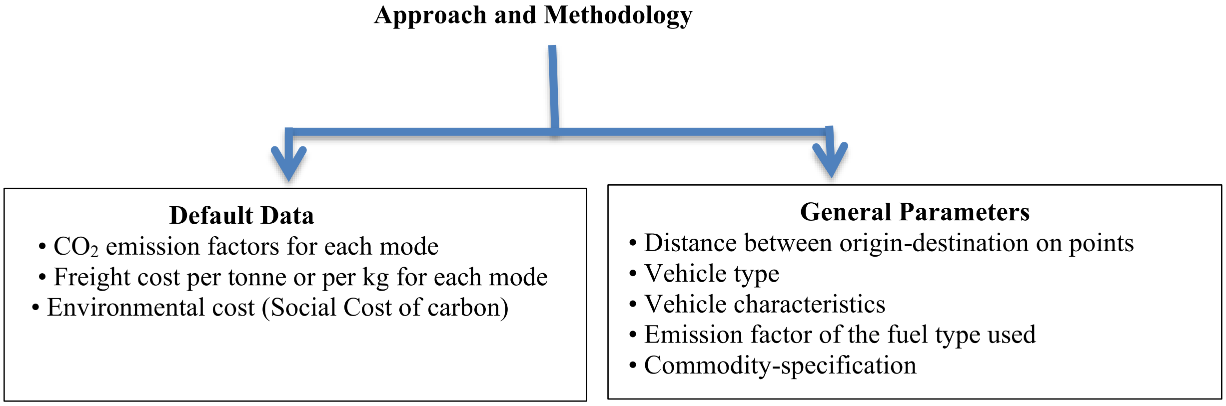
$$x_{ij} \geq 0, \qquad \text{for all i and j}$$

Where x_{ij} is the amount of units shipped from origin I to destination j and c_{ij} is the cost of shipping one unit from origin i to destination j. The amount of supply at origin is a_i, and the amount of destination j is b_j. The objective is to determine the unknown x_{ij} that minimizes the total transportation cost while satisfying all supply and demand constraints.

2.2. Basic Definitions and Calculation Rules

Some general terms and definitions used in this methodology report are explained below.

- ***Freight tonne carried*: ** It is the number of tonnes of freight carried on a particular transport vehicle.
- ***Freight Tonne-Kilometers Performed*:** A metric tonne of freight carried in one kilometer. It is the sum of the products of tonnes of freight carried and the distance between the origin and destination points.
- ***Gross Vehicle Weight*:** It is the total weight of the vehicle and the load certified by an authority as permissible.
- ***Fuel Consumption*:** It is the amount of fuel consumed by a vehicle to travel a given distance.
- ***Payload Capacity:*** It is the maximum mass of freight allowed, usually expressed in mass-related parameters such as tonnes.
- ***Emission Factor*:** It is a coefficient that relates the amount of GHG emissions to a specific business activity.
- ***Scheduled Service (aviation):*** Services provided by an airline for remuneration according to a published timetable and open to the general public for usage.



For the calculation of GHG emissions, CO_2 (carbon dioxide equivalent) is considered, as carbon dioxide constitutes the largest share in the production of GHGs. It represents the impact of other pollutants on the environment using a conversion factor in CO_2, which would cause similar effects. Uniform emission factors are considered for each mode of transport, and the transportation vehicle is considered such that the emissions are calculated per unit of CO_2e.

2.3. Numerical Problem

In this study, consider the transportation problem between six major demand cities (Mumbai, Delhi, Bhopal, Kolkata, Chennai, and Hyderabad) and six supply cities (Pune, Jaipur, Bhubaneswar, Indore, and Ranchi). We will calculate fuel consumption and carbon emissions using the transportation problem method. Supply capability, demand of destination, distance between supply centers, and demand destination are represented in the following table.

Table 1. Supply Capacity of Various Cities and Demand of the Destination

Supply Centers	**Supply Capacity**	**Demand Destination**	**Demand**
Ahmadabad	500	Mumbai	500
Pune	700	Delhi	800
Jaipur	350	Bhopal	250
Bhubaneswar	250	Kolkata	650
Indore	500	Chennai	300
Ranchi	900	Hyderabad	700

Table 2. Distance Matrix between Supply Centers and Demand Destinations

	Mumbai	**Delhi**	**Bhopal**	**Kolkata**	**Chennai**	**Hyderabad**
Ahmadabad	521	977	589	2056	1771	1132
Pune	151	1364	787	1878	1199	560
Jaipur	1172	296	577	1514	2052	1425
Bhubaneswar	1592	1857	1171	443	1226	1050
Indore	587	761	193	1617	1444	805
Ranchi	1661	1356	1048	403	1735	1270

Table 3. Fuel Consumption and Carbon Emission records of various modes of transportation

Mode of Transportation	**Fuel consumption**	**Emission factors**
Truck	3.75 km/liter	2.64kg/liter
Train	0.30liter/ton-km	Diesel: 2.64 kg CO2/liter
Air	4.8 liters/seat-km	2.35 kg CO2/liter

The above Tables 1 to 2 present the data on supply capacities of various cities, demand at several destinations, and distance between various source and destination cities. Distances are an important factor in evaluating various objectives of transportation models, including transportation cost, time, fuel consumption, carbon emission, etc. Among these, carbon emissions are the leading contributor to global warming. Primarily resulting from human activities such as burning fossil fuels, industrial processes, and transportation activities. In this study, the primary objective is to minimize carbon emissions during transportation activities. In this context, Table 3 provides data on average fuel consumption for different transportation modes like truck, train, and air, along with the corresponding carbon emissions. Based on Table 3, the transportation matrices of fuel consumption and carbon emission between defined cities are constructed as follows.

Table 4. Matrix of Fuel Consumption and Carbon Emission between Supply Centers and Demand Destinations

Cities	**Distance (D) (In KM)**	**Fuel Consumption (FC)**			**Carbon Emissions (CE)**		
		Truck	**Train**	**Air**	**Truck**	**Train**	**Air**
		D / 3.75 km/liter	**D* 0.30 liters/ton-km**	**D * 4.8 liters/seat-km**	**= FC * 2.64 kg CO_2/liter**	**FC * Cities 2.64 kg CO_2/liter**	**FC * 2.35 kg CO_2/liter**
Mumbai-Ahmadabad	521	138.9	156.3	2500	365.11	412.63	5875
Mumbai – Pune	151	40.2	45.3	724.8	106.12	119.59	1703.28
Mumbai – Jaipur	1172	312.5	35.58	5625.6	825	93.93	13220.16
Mumbai – Bhubaneswar	1592	317.8	477.6	7641.6	838.99	1260.86	17956.35

Mumbai – Indore	587	156.5	176.1	2817.6	413.16	464.9	6621.36
Mumbai – Ranchi	1661	442.9	498.3	7972.8	1169.25	1315.51	18736.08
Delhi-Ahmadabad	977	260.5	293.1	4689.6	687.72	773.78	11020.56
Delhi- Pune	1364	363.7	409.2	6547.2	960.16	1080.28	15385.92
Delhi – Jaipur	296	78.9	88.8	1420.8	208.29	234.43	3338.88
Delhi – Bhubaneswar	1857	495.2	557.1	8913.6	1307.32	1470.74	20949.96
Delhi- Indore	761	202.9	228.3	3652.8	535.65	602.71	8584.08
Delhi – Ranchi	1356	361.6	406.8	6508.81	954.62	1073.95	15295.7
Bhopal – Ahmadabad	589	157	176.7	2827.2	414.48	466.48	6643.92
Bhopal – Pune	787	209.8	236.1	3777.6	553.87	623.3	8877.36
Bhopal – Jaipur	577	153.8	173.1	2769.6	406.03	456.98	6508.56
Bhopal – Bhubaneswar	1171	312.2	351.3	5620.8	824.2	927.43	13208.88
Bhopal – Indore	193	51.4	57.9	926.4	135.69	152.85	2177.04
Bhopal – Ranchi	1048	279.4	314.4	5030.4	737.61	830.01	11821.44
Kolkata – Ahmadabad	2056	548.2	616.8	9868.8	1447.24	1628.35	23426.68
Kolkata – Pune	1878	500.8	563.4	9014.4	1322.11	1487.37	21183.8
Kolkata – Jaipur	1514	403.7	454.2	7267.2	1065.76	1199.08	17077.92
Kolkata – Bhubaneswar	443	118.1	132.9	2126.4	311.78	350.85	4997.04
Kolkata – Indore	1617	431.2	485.1	7761.6	1138.36	1280.66	18239.76
Kolkata – Ranchi	403	107.4	120.9	1934.4	402.75	319.17	4545.84
Chennai – Ahmadabad	1771	472.2	531.3	8500.8	1246.6	1402.63	19976.88
Chennai – Pune	1199	319.7	359.7	5755.2	843.74	949.6	13524,72
Chennai – Jaipur	2052	547.2	615.6	9849.6	1444.6	1625.18	23146.56
Chennai – Bhubaneswar	1226	326.9	367.8	5884.8	863.01	970.99	13829.28
Chennai – Indore	1444	385	433.2	6931.2	1016.4	1143.64	16288.32
Chennai – Ranchi	1735	462.6	520.5	8328	1221.26	1374.12	19570.8
Hyderabad – Ahmadabad	1132	301.8	339.6	5433.6	796.75	896.54	12768.96
Hyderabad – Pune	460	122.6	138	2208	323.66	364.32	5188.8
Hyderabad – Jaipur	1425	380	427.5	6840	1003.2	1128.6	16074
Hyderabad – Bhubaneswar	1050	280	315	5040	739.2	831.6	11844
Hyderabad – Indore	805	214.6	241.5	3864	566.54	637.56	9080.4
Hyderabad – Ranchi	1270	1338.6	381	6096	893.9	1005.84	14325.6

2.3.1. Mode of Transportation is Truck

Here, with the help of Table 4, a Matrix of fuel consumption is constructed for the defined cities with the objective of minimizing fuel consumption during the transportation of products from one city to another. The fuel consumption is determined based on the selected mode of transportation. In this case, the transportation mode considered is a truck for all routes connecting various destinations to numerous locations. The matrix of fuel consumption is represented as follows.

Table 4. Matrix of fuel consumption when the mode of transportation is a truck

	Mumbai	**Delhi**	**Bhopal**	**Kolkata**	**Chennai**	**Hyderabad**	**Supply**
Ahmadabad	138.9	260.5	157.0	548.2	472.2	301.8	500
Pune	40.2	363.7	209.8	500.8	319.7	122.6	700
Jaipur	312.5	78.9	153.8	403.7	547.2	380	350
Bhubaneswar	317.8	495.2	312.2	118.1	326.9	280	250
Indore	156.5	202.9	51.4	431.2	385.0	214.6	500
Ranchi	442.9	361.6	279.4	107.4	462.6	1338.6	900
Demand	500	800	250	650	300	700	

To obtain feasible solutions and optimal solutions, we are going to apply the North West Corner Method, Least Cost Method, Row Minimum Method, Vogel Approximation Method, and MODI method, respectively, and after the implementation of the defined methods of transportation problem, we obtained the feasible solutions as follows.

Table 5. Fuel Consumption and Carbon Emission, when the mode of transportation problem is a truck

S. No	**Name of Methods**	**Fuel Consumptions**	**Carbon Emission= Fuel Consumptions*2.64**
1.	North West Corner Method	1,640,425 liters	4,330,722 kg CO2
2.	Least Cost Method	542,430 liters	1,432,015.2 kg CO2
3.	Row Minimum Method	530,045 liters	1,399,318.8 kg CO2
4.	Vogel Approximation Method	493,445 liters	1,302,694.8 kg CO2

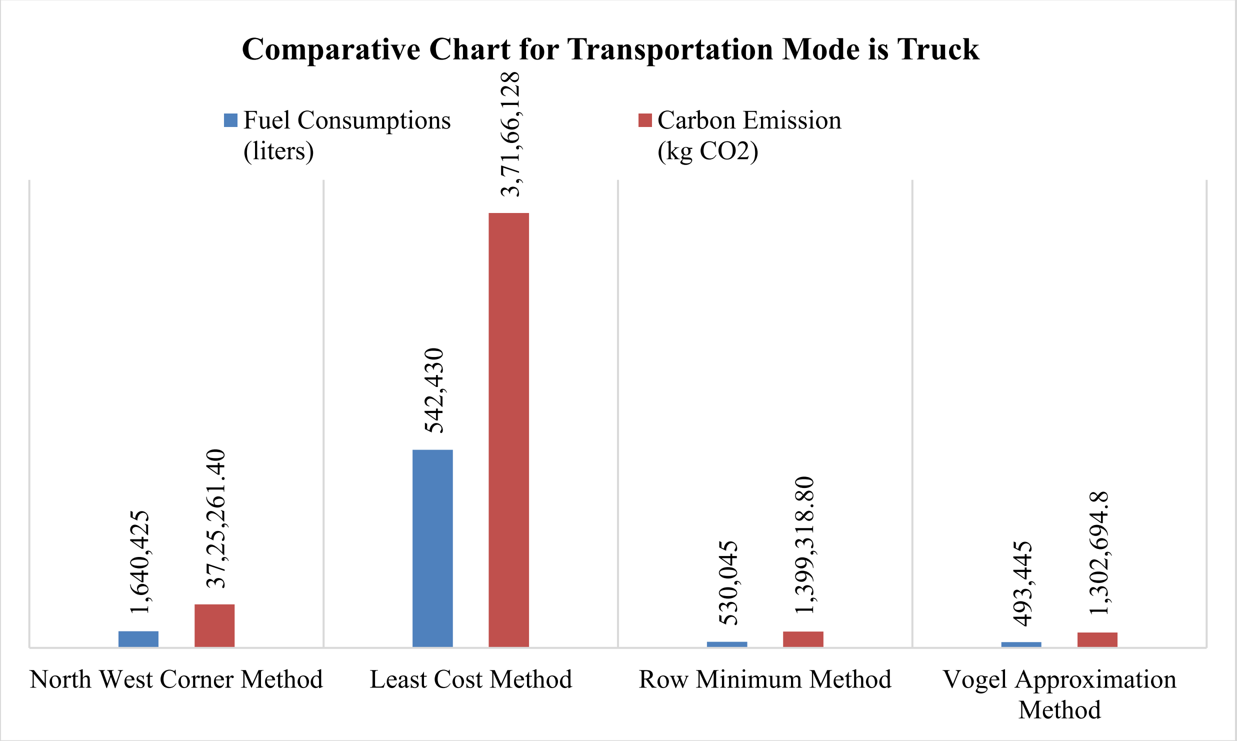


Fig. 1 Comparative Chart of Transportation Mode is Truck

Table 5 and Figure 1 present a comparative analysis of fuel consumption and corresponding carbon emissions for truck transportation using four methods. The North West Corner Method shows the highest fuel use and emissions, while the Vogel Approximation Method yields the lowest values. Least Cost and Row Minimum methods provide intermediate results, indicating improved efficiency over the initial approach.

2.3.2. Mode of Transportation is Train

Here, with the help of Table 4, a Matrix of fuel consumption is constructed for the defined cities with the objective of minimizing fuel consumption during the transportation of products from one city to another. The fuel consumption is determined based on the selected mode of transportation. In this case, the transportation mode considered is the train for all routes connecting various destinations to numerous locations. The matrix of fuel consumption is represented as follows.

Table 6. Matrix of fuel consumption when the mode of transportation is Train

	Mumbai	**Delhi**	**Bhopal**	**Kolkata**	**Chennai**	**Hyderabad**	**Supply**
Ahmadabad	156.3	293.1	176.7	616.8	531.3	339.6	500
Pune	45.3	409.2	236.1	563.4	359.7	138	700
Jaipur	35.58	88.8	173.1	454.2	615.6	427.5	350
Bhubaneswar	477.6	557.1	351.3	132.9	367.8	315	250
Indore	176.1	228.3	57.9	485.1	433.2	241.5	500
Ranchi	498.3	406.8	314.4	120.9	520.5	381	900
Demand	500	800	250	650	300	700	

To obtain feasible solutions and optimal solutions, we are going to apply the North West Corner Method, Least Cost Method, Row Minimum Method, Vogel Approximation Method, and MODI method, respectively, and after the implementation of the defined methods of transportation problem, we obtained the feasible solutions as follows.

Table 7. Fuel Consumption and Carbon Emission, when the mode of transportation problem is the train

S. No	**Name of Methods**	**Fuel Consumptions**	**Carbon Emission= Fuel Consumptions*2.64 kg CO2/ liters**
1.	North West Corner Method	1,058,130 liters	2,793,463.2 kg CO2
2.	Least Cost Method	600,303 liters	1,584,799.92 kg CO2
3.	Row Minimum Method	596,475 liters	1,574,694 kg CO2
4.	Vogel Approximation Method	524,040 liters	1,383,465.6 kg CO2

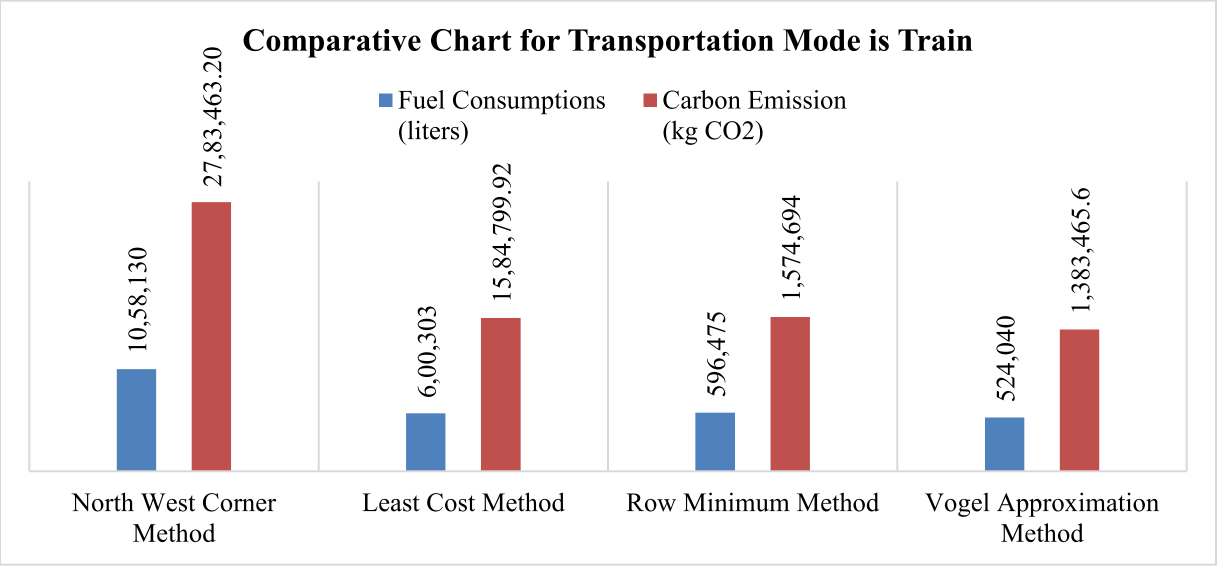


Fig. 2 Comparative Chart of Transportation Mode is Train

Table 7 and Figure 2 illustrate a comparative analysis of fuel consumption and carbon emissions for train transportation using four optimization methods. The North West Corner Method records the highest fuel usage and emissions. The Vogel Approximation Method provides the lowest fuel consumption and carbon emission values, indicating maximum efficiency. The Least Cost and Row Minimum methods show moderate performance, offering better optimization than the initial allocation method.

2.3.3. Mode of Transportation is Air

Here, with the help of Table 4, a Matrix of fuel consumption is constructed for the defined cities with the objective of minimizing fuel consumption during the transportation of products from one city to another. The fuel consumption is determined based on the selected mode of transportation. In this case, the transportation mode considered is air for all routes connecting various destinations to numerous locations. The matrix of fuel consumption is represented as follows.

Table 8. Matrix of fuel consumption when the mode of transportation is Train

	Mumbai	**Delhi**	**Bhopal**	**Kolkata**	**Chennai**	**Hyderabad**	**Supply**
Ahmadabad	2500	4689.6	2827.2	9868.8	8500.8	5433.6	500
Pune	724.8	6547.2	3777.6	9014.4	5755.2	2208	700
Jaipur	5625.6	1420.8	2769.6	7267.2	9849.6	6840	350
Bhubaneswar	7641.6	8913.6	5620.8	2126.4	5884.8	5040	250
Indore	2817.6	3652.8	926.4	7761.6	6931.2	3864	500
Ranchi	7972.8	6508.81	5030.4	1934.4	8328	6096	900
Demand	500	800	250	650	300	700	

To obtain feasible solutions and optimal solutions, we are going to apply the North West Corner Method, Least Cost Method, Row Minimum Method, Vogel Approximation Method, and MODI method, respectively, and after the implementation of the defined methods of transportation problem, we obtained the feasible solutions as follows.

Table 9. Fuel Consumption and Carbon Emission, when the mode of transportation problem is Air

S. No	**Name of Methods**	**Fuel Consumptions**	**Carbon Emission= Fuel Consumptions*2.35**
1.	North West Corner Method	15,804,573.6 liters	37,140,748 kg CO_2
2.	Least Cost Method	9,766,802 liters	22,951,984.7 kg CO_2
3.	Row Minimum Method	9,543,202 liters	22,426,524.7 kg CO_2
4.	Vogel Approximation Method	9,134,402 liters	21,465,844.7 kg CO_2

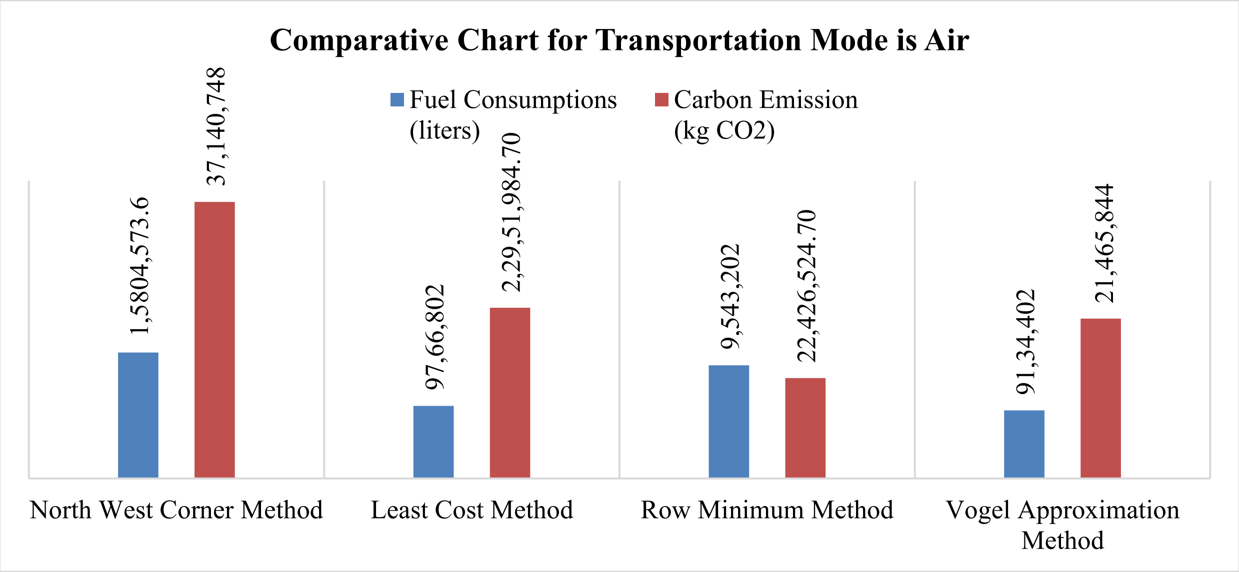


Fig. 3 Comparative Chart of Transportation Mode is Air

The image presents a comparative analysis of fuel consumption and carbon emissions for a transportation problem solved using four methods: North West Corner, Least Cost, Row Minimum, and Vogel Approximation. Vogel Approximation shows the lowest fuel use (524,040 liters) and emissions (1,383,465.6 kg CO_2), while North West Corner records the highest. A bar chart visually compares fuel consumption and emissions across methods.

Table 10. Fuel Consumption for all modes of transportation

Mode of Transportation	NWCR	LCM	RMM	VAM
Truck	1,640,425 liters	542,430 liters	530,045 liters	493,445 liters
Train	1,058,130 liters	600,303 liters	596,475 liters	524,040 liters
Air	15,804,573.6 liters	9,766,802 liters	9,543,202 liters	9,134,402 liters

Table 11. Carbon Emissions for all modes of transportation

Mode of Transportation	NWCR	LCM	RMM	VAM
Truck	4,330,722 kg CO_2	1,432,015.2 kg CO_2	1,302,694.8 kg CO_2	1,302,694.8 kg CO_2
Train	2,793,463.2 kg CO_2	1,584,799.92 kg CO_2	1,574,694 kg CO_2	1,383,465.6 kg CO_2
Air	37,140,748 kg CO_2	22,951,984.7 kg CO_2	22,426,524.7 kg CO_2	21,465,844.7 kg CO_2

4. Conclusion

The comparative analysis of fuel consumption and carbon emissions across different transportation modes—truck, train, and air—using NWCR, LCM, RMM, and VAM reveals significant efficiency variations. Among all methods, the Vogel Approximation Method (VAM) consistently demonstrates the lowest fuel consumption and carbon emissions for every mode, highlighting its superiority in optimizing transportation problems. Air transport exhibits the highest fuel usage and emissions overall, followed by truck and train, indicating its comparatively larger environmental impact. Conversely, train transportation shows relatively moderate consumption and emissions, making it a more sustainable option. The North West Corner Rule (NWCR) results in the highest values, indicating lower efficiency. Therefore, selecting an appropriate optimization method, particularly VAM, plays a crucial role in reducing operational costs and environmental impact in multimodal transportation systems.

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