Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol. 44, No. 1, January 2025

Cost Reduction and CO2 Emissions: Exploring the Nexus through Fleet Diversity

Mohamed H. Abdelati[1,*], Ali M. Abd-El-Tawwab[1], , Elsayed E. M. Ellimony[2], Mohammed Rabie[1]

[1] *Automotive and Tractors Engineering Dep., Faculty of Engineering, Minia University, Minia, Egypt*
[2] *Automotive and Tractors Engineering Dep., Faculty of Engineering, Mataria, Helwan University, Giza, Egypt*
* *Corresponding author(s) E-mail: m.hilal@mu.edu.eg*

A R T I C L E I N F O

Article history:
Received: 17 May 2024
Accepted: 4 November 2024
Online: 1 January 2025

Keywords:
Fleet Diversity
Operating Costs
Environmental Sustainability
Transportation Problem
Solid Transportation

A B S T R A C T

This research paper explores the impact of fleet diversity on operating costs and environmental sustainability in the transportation sector, with a case study of a beverage production company in Egypt. The study considers the optimal distribution of the company's transportation fleets, comparing scenarios with diverse fleet sizes and types to a scenario with a single type of fleet. The objective is to highlight fleet diversification's significance in reducing operating costs and CO2 emissions. The study employs Lingo Code to obtain optimal solutions for the transportation problem, revealing a 36.93% reduction in fuel consumption costs and a 39% decrease in carbon dioxide emissions when using diverse fleets. These findings provide valuable insights and recommendations for the beverage production industry and beyond, aiming to achieve a more sustainable and efficient transportation system.

1. Introduction

The transportation problem (TP) is a complex undertaking involving efficiently transferring commodities from multiple sources to multiple destinations while conforming to demand constraints and minimizing the total cost. In order to achieve an optimal solution (OS) to TP, existing solution procedures typically rely on the initial basic feasible solution (IBFS). The effectiveness of the IBFS is of utmost importance as it determines the degree of similarity between the solution obtained and the optimal one within the current procedure. TP, a prominent variant of the linear programming (LP) problem, has played a pivotal role in developing solution algorithms for LP [1].

In 1951, Dantzig introduced the Simplex method as an efficient approach to solving the LP problem. Subsequently, Dantzig applied the Simplex method to solve the TP, publishing the optimal solution. Additionally [2, 3], Dantzig proposed the North West Corner Method (NWC) as a new technique for obtaining the IBFS in TP. Charnes and Cooper developed the Stepping Stone Method (SSM) as the first optimality test method. The Modified Distribution Method (MODI) was introduced in 1955 as another optimality test method.

Furthermore, Reinfeld and Vogel devised the VAM algorithm to calculate the IBFS for TP [4]. Over time, researchers have made efforts to enhance the IBFS algorithm for TP. Notably, the Incessant Allocation Method has emerged as an algorithm claiming to provide a degeneracy-free solution and be five times faster than the Simplex Method. A greedy algorithm has also been developed to transform TP into a dual problem and minimize transportation costs. The combination of VAM and MODI algorithms has been widely employed since 1958 to obtain optimal solutions for TP. Nonetheless, it has been observed that without an IBFS, no TP algorithm can guarantee an optimal solution [5].

The multi-dimensional transportation problem represents an extension of TP in linear programming, addressing large-scale problems encompassing multiple subscripted variables. Constraints in this problem may involve sums, double sums, triple sums, or combinations thereof for variables associated with different commodities, origins, and destinations. The multi-index problem, also known as the multi-dimensional transportation problem, aims to minimize the cost of transporting a set of p different commodities (k=1, 2,..., p) from n origins (i=1, 2, …, n) to m destinations (j=1, 2, …, m). This problem entails determining the available and required amounts of various combinations [6]. Moreover, the same set of restrictions arises when a single commodity needs to be transported using different methods such as road, rail, sea, canal, or air. The presence of intermediate depots may also necessitate the application of a multi-index formulation. Another problem that can be addressed using this method is the capacitated transportation problem, which involves assigning an upper bound to each variable.

In real-world scenarios, transportation involves the movement of goods from diverse sources to numerous destinations and the consideration of various transportation methods. Such scenarios are known as solid transportation problems [5]. From a practical perspective, increasing transportation costs may result in higher selling prices. To mitigate these challenges, endeavors can be made to reduce overall transportation costs, leading to a subsequent decrease in selling prices [7]. In this regard, we propose an approach to resolving solid transportation problems that incorporate transportation capacity, demand, and supply as the fundamental components of our methodology [8, 9].

Furthermore, promoting sustainable development in the trucking industry is paramount in mitigating air pollution and enhancing public well-being [10]. Vehicular emissions contribute to atmospheric pollution, leading to various adverse health conditions, including respiratory ailments, cardiovascular disorders, and premature mortality. In addition, reducing fuel consumption and curbing carbon dioxide (CO2) emissions makes it feasible to minimize the release of pollutants into the atmosphere, thereby creating a cleaner and healthier environment for society [11].

This research paper focuses on a case study of a company's transportation fleet in Egypt specializing in beverage production. We examine the company's current situation, considering the diversity of fleet sizes and types, and subsequently determine the optimal distribution of the fleets. Furthermore, we compare this optimal distribution with the scenario where the company's fleets are the same type. The primary objective of this study is to underscore the significance of diversifying the transportation fleet in reducing overall operating costs. Additionally, a vital objective of this research is to explore how diversifying the transportation fleet can substantially reduce overall operating costs and CO2 emissions. Finally, by evaluating the impact of fleet diversity on cost reduction and environmental sustainability, we aim to provide valuable insights and recommendations for companies in the beverage production industry and beyond, with the ultimate goal of achieving a more sustainable and efficient transportation system.

2. Literature Review

The solid transportation problem (STP) is one of the most fundamental questions in logistics and supply chain management, which is about delivering goods from a set of origins to a set of destinations. Related work: A few approaches have been established to tackle this issue through the years, with a specific focus on cost minimization subject to demand satisfaction, capacity constraints as well as other types of products. To be complete, the complexity of STP increases with real application constraints that engage several modes and vehicular capacities within mundane transportation logistics. Newer works have proposed multi-objective optimizations based on both cost and time to design better transport networks. For example, they are accounting for uncertain parameters like demand by introducing linear fractional models and relaxed consideration of solution spaces [12]. Hybrid computational methods such as PSO also efficiently provide near-optimal solutions for integer linear STPs, revealing their indica potential and feasibility when the problem variables are presented discretely [13].

Since the transportation sector is one of the significant contributors to global CO2 emissions, STP optimization is now viewed as an essential problem that must be solved to minimize cost and gain sustainability. Models that value various carbon options in fleet composition and schedule optimization have been developed, which provide evidence of the enormous potential for carbon reductions from these types of transportation fleets if reconfigured. For example, research has proven that combining conventional and green fleets reduces up to 6.90% emissions with cost efficiency [14], demonstrating the long-term significance of fleet variety. In addition, a study of incorporating heterogeneous fleets in public transport networks highlights the environmental and operational benefits achieved by using various vehicle types, by showing that CO2 emissions could be reduced on the order of 30% if CO2-intensive vehicles are avoided when transit network design considers emissions during the trip generating process [15]. The common theme of these studies is that we should consider environmental factors such as emissions in transportation models to satisfy economic and sustainability goals.

Increasing fleet diversity is essential for optimizing operational efficiency and environmental sustainability of transport systems. By utilizing a mix of electric, hybrid and conventional fuel vehicles, mobility fleets can better align vehicle capabilities with unique operational requirements—resulting in increased efficiency of the entire system. As an example, Senecal and Leach [16] point to the benefits of blending propulsion technologies, stating that a multifaceted fleet is necessary for tackling the complexities of 21st-century transportation systems — emissions abatement included.— Similarly, Wang et al. Bus fleets can have differing impacts on energy conservation and environmental protection by including various propulsion and fuel types, as concluded in which found that the inclusion of compressed natural gas (CNG) fueled buses reduced bus fleet emissions but increased overall fuel consumption. In addition to obtaining environmental benefits, Treanor [17] argues that the diversity of the fleets provides flexibility for organizations to adapt to changing market conditions and operational needs, which can lead to cost savings. All these studies combined show the contribution of fleet diversity towards sustainability by expediting emissions reduction, operational flexibility, and cost-effectiveness.

The optimal allocation of resources under environmental constraints is an important component of solid transportation that has attracted growing research interest [12, 18]. Researchers have explored many different methodologies for transportation optimization to make the transportation models more realistic under the uncertainty of supply, demand, and capacity. For example, research relevant to this study is probabilistic constraint approaches like the Weibull distribution models, as they better represent real-life uncertainties in transportation environments and lead to more robust solutions [19]. This is consistent with the high-level objective of building transportation networks that are more resilient and flexible to changing environmental and economic conditions.

Many studies have performed case studies with realistic numbers to confirm their results regarding the broader STP emissions impact. For example, specific research on the external route fleet reassignment in China and India reported that a 35–57% reduction in carbon emissions (with negligible operational cost increase) can be achieved through effective routine scheduling of airline fleets [20]. Likewise, an investigation carried out with public transport urban bus fleets indicated that the employment of low-viscosity oils in the engines could yield 5–10% lower energy consumption and CO2 emissions [21], therefore highlighting how even minor changes in operation can translate into significant environmental impacts. The following case studies are valuable in giving real-world examples of STP and emissions reduction strategies, representing the benefit of turning an optimization technique into practice with a given transportation network [22].

When comparing these studies to the existing literature, it is evident that the field has evolved from a strong focus on cost minimization towards a more holistic vision of sustainability. One way this change manifests is a growing literature tackling emissions reductions through fleet diversity and operational efficiency. Traditional STP models targeted minimizing transportation costs, while most recent studies have adopted a multi-dimensional approach accounting for economic and environmental objectives. Implementing green technologies, optimization algorithms, and multi-objective modeling have simultaneously improved transportation network efficiencies and supported global sustainability targets for logistics.

3. Methodology

The This case study examines one of Egypt's prominent water and carbonated water manufacturing companies, with a daily production rate exceeding 70,000 pallets across various products. The company operates eight factories in different industrial cities in Egypt and maintains 25 primary product distribution centers. These products are stored until they are redistributed to hypermarkets and retail centers.

The company operates three types of trucks, classified as Type A, B, and C, each with different capacities. Type A trucks can transport 150 pallets, Type B trucks can transport 300 pallets, and Type C trucks can transport 500 pallets. The average fuel consumption per 100 kilometers has been calculated for each truck type, yielding consumption rates of 17, 25, and 30 liters for Type A, B, and C trucks, respectively.

The transportation problem at hand would have been a classic transportation problem if all trucks were of the same type, size, and capacity and were used solely for transporting a single product. However, given the discrepancy in truck capacities and three product types (p1, p2, and p3) that the company manufactures and distributes, the transportation problem has evolved into a four-dimensional solid transportation problem.

Considering its multi-dimensional nature, this paper addresses the transportation problem associated with the current state of the company's fleet. We aim to determine the optimal distribution and solution while assuming that all trucks in the fleet are of Type A. By identifying the optimal solution in terms of supply and demand quantities, we seek to ascertain whether utilizing multiple transport fleets yields a more optimal solution compared to having a uniform fleet capacity. The methodology employed to address the transportation problem is outlined below:

1) Configuration of the transportation network: The transportation network was established, connecting all sources and destinations. The shortest distances between each source and destination were determined and recorded in Table 2.
2) Estimation of production and demand: The average daily production rate of each factory was estimated and presented in Figure 1. Additionally, the average daily demand for each distribution center was determined and depicted in Figure 2.
3) Calculation of fuel consumption cost: The cost of fuel consumption for transporting each pallet from a source to a destination was calculated. The fuel consumption cost for Type A trucks transporting one pallet is shown in Table 3. Similarly, Table 4 displays the cost for Type B trucks, and Table 5 presents the cost for Type C trucks.
4) A solution to the classic transportation problem: As mentioned previously, the classic transportation problem was solved by utilizing only Type A trucks. The optimal solution was obtained by applying a mathematical model described by Equations 1 to 4.
5) A solution to the multidimensional solid transportation problem: The multidimensional solid transportation problem was addressed by employing a mathematical model described by Equations 5 to 9.
6) Comparison of optimal solutions and carbon emissions: In addition to comparing the optimal solutions obtained from both models, the difference in carbon dioxide (CO2) emissions between the two cases was calculated. By analyzing the outputs of the models, we were able to assess the environmental impact and determine if the utilization of multiple transport fleets significantly reduced CO2 emissions compared to a uniform fleet capacity.

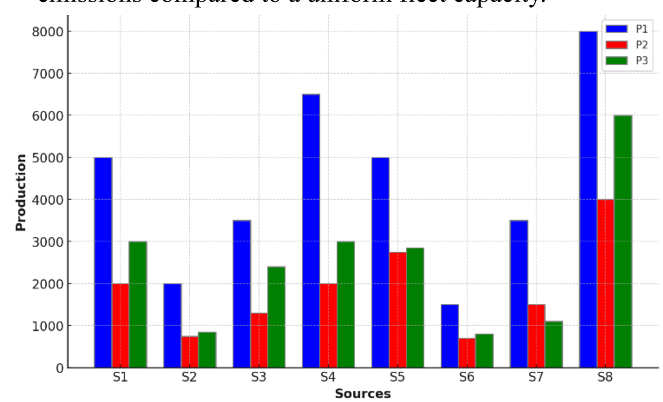

Figure 1: Average Daily Production per Source

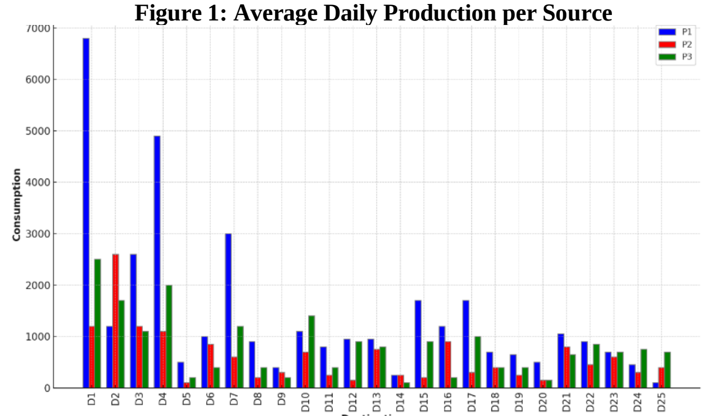

Figure 2: Average Daily Production per Destination

3.1. Transportation Fleets

The economic development of any country is intricately tied to the growth and effectiveness of its transportation systems. Transportation is a vital component of economic activity by facilitating the movement of production elements from their locations to distribution points where products are delivered to consumers. The suitability and cost-effectiveness of transportation play a crucial role in reducing production costs and ensuring that commodities reach consumers at the most affordable price, as well as at the right price [23].

Transportation encompasses the movement of people, goods, information, capital, and communication between local and international supply and demand centers. It employs various mediums and means, adhering to regulatory, technical, and informational frameworks aimed at reducing the cost of the final product, maximizing profitability, and enhancing customer satisfaction.

While the presence of a single type of transportation in an organization's fleet may offer some advantages, such as simplified maintenance and the possibility of procuring spare parts at a better price, having a diverse range of truck types and sizes used in the transportation process yields more significant savings in operational costs [24]. This diversity reduces fuel consumption, and the need for spare parts ensures faster delivery of products to meet demand, particularly over short distances, and provides multiple options and alternatives in utilizing different means to achieve an optimal or near-optimal solution. Additionally, the variety of trucks allows for more accessible garage design and more accurate estimation of trucks moving from sources to destinations without complications in solving mathematical models.

3.2. Quantification of Carbon Dioxide (CO2) Emissions

To safeguard our environment and address the wide-ranging consequences of climate change, it is crucial to comprehend and quantify carbon dioxide emissions. Carbon dioxide, a potent greenhouse gas, plays a pivotal role in maintaining the delicate equilibrium of our planet. We can pave the way toward a sustainable future by employing precise calculations.

To illustrate the significance of carbon dioxide emissions, let us explore the domain of diesel fuel [25]. Through diligent analysis and meticulous evaluation, it is possible to determine the exact quantity of carbon dioxide emitted from this particular fuel source. Equipped with conversion factors, such as 22.3562 kilograms of CO2 per gallon of diesel, we can access accurate estimations [26].

For this investigation, it is imperative to acknowledge the conversion rates: 1 gallon equals 3.78541178 liters, and 1-pound equals 0.45359 kilograms. Consequently, bearing these conversions in mind, we ascertain that 1 liter of diesel fuel leads to 2.678835758 kilograms of CO2 emissions [27].

The intricate nature of petroleum diesel's density adds another layer of complexity to this subject. Under normal conditions, petroleum diesel possesses a density of approximately 0.85 kilograms per liter. By utilizing this knowledge, we can calculate that 1 kilogram of diesel fuel produces a remarkable 3.17 kilograms of CO_2 emissions.

By amalgamating meticulous calculations and scientific analysis, we shed light on the profound impact of carbon dioxide emissions. This newfound understanding catalyzes shaping sustainable practices and strengthening our commitment to preserving the irreplaceable natural resources of our planet.

3.3. Mathematical Model

For a plant wants to move a number of units of homogenous product from multiple sources to a number of destinations. Every destination (j) requires a certain number of product units (bj), while each source (i) can provide a certain amount of product units (ai). The cost of moving one unit from source (i) to a destination (j) is (cij), and is recognized for all combinations (i, j) to minimize the total Transportation cost (Z) [28].

The quantity shipped to the destination j from source i is (xij). The total amount that shipped out of i is ai ≥ 0, and the sum received by destination j is bj≥ 0. We temporarily impose restrictions on the total quantity shipped equals the total quantity received,

The cost of shipping xij units is cij xij. Since the negative shipment has no valid explanation for the problem, we limit each xij to non- negative. Therefore, the classical transportation problem can be mathematically formulated as follows[29, 30]:

$$\text{Min.}\, Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad (1)$$

Subject to:

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

$$\sum_{i=1}^{nm} x_{ij} = b_j, j = 1, 2, \dots, n. \quad (3)$$

$$x_{ij} \geq o \;\forall\; i \text{ and } j. \quad (4)$$

The mathematical form of solid transportation problem is given by [31]:

$$\text{Min Z} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} c_{ijk} x_{ijk} \quad (5)$$

Subject to:

$$\sum_{j=1}^{n} \sum_{k=1}^{p} x_{ijk} = a_i \qquad i = 1, 2, ..., m \quad (6)$$

$$\sum_{i=1}^{m} \sum_{k=1}^{p} x_{ijk} = b_j \qquad j = 1, 2, ..., n \quad (7)$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ijk} = e_k \qquad k = 1, 2, ..., p \quad (8)$$

$$x_{ijk} \geq 0 \; for\; all\; j, j, k \quad (9)$$

Where:

z = objective function

m = number of sources of the STP

n = number of destinations of the STP

p = number of different modes of the STP

x_{ijk} = the amount that shipped by conveyance k from source i to destination j

c_{ijk} = unit transportation cost in STP

a_i = amount of products available in source i

b_j = demand at destination j

e_k = the amount of product that can carried by conveyance k

4. Results and Discussion

The previous case study highlighted the importance of diversifying truck capacities within fleets. The study examined the impact of having a single type of truck size compared to the current situation, which involves a diverse range of trucks. Optimal solutions were obtained for both cases using Lingo Code.

Using the Lingo software[32, 33], the optimal solution for addressing the classical transportation problem was 111,246 LE. Additionally, by solving the problem based on realistic data, a solution was found for the multidimensional solid transportation problem, with an optimal solution of 70,165.50 LE. These results emphasize the significance of employing multiple transport fleets, resulting in a 36.93% reduction in fuel consumption costs. This reduction translates to an annual savings of 15 million LE when comparing the optimal solutions for both cases.

Furthermore, in terms of fuel consumption, diversifying fleets, as indicated by the case study results, led to the emission of 25,000 kg of carbon dioxide per day. On the other hand, using a single type of truck resulted in 41,000 kg of carbon dioxide per day, reducing carbon dioxide emissions by approximately 39%. Table (1) compares the fuel consumption costs and CO2 emissions between the single-type fleet and the diverse fleet

Table 1: Comparison of Fuel Consumption Costs and CO2 Emissions between Single-Type and Diverse Fleet

Fleet Type	Fuel Consumption Costs (LE)	CO2 Emissions (kg/day)
Single-Type Fleet	111,246	41,000
Diverse Fleet	70,165.50	25,000

5. Conclusions

The case study conducted on a beverage production company in Egypt affirms the effectiveness of diversifying transport fleets in reducing operating costs and fuel consumption while offering flexibility and alternatives for decision-makers. The results demonstrate an annual cost saving of approximately 15 million pounds when employing diverse transport trucks and achieving optimal distribution. Utilizing the Lingo program proved highly efficient in finding optimal solutions quickly. Future research can explore the impact of fleet diversity on other objectives, such as time and damage assessment, provided relevant data is available. Overall, the study emphasizes the importance of diversifying transportation fleets to enhance operational efficiency and sustainability in the industry.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] W. L. Winston, *Operations research: applications and algorithms*. Cengage Learning, 2022.

[2] G. Dantzig, "Linear programming and extensions," in *Linear programming and extensions*: Princeton university press, 2016.

[3] M. H. Abdelati, M. I. Khalil, K. Abdelgawwad, and M. Rabie, "ALTERNATIVE ALGORITHMS FOR SOLVING CLASSICAL TRANSPORTATION PROBLEMS," *Journal of Advanced Engineering Trends*, vol. 39, no. 1, pp. 13-24, 2020.

[4] A. R. Khan, A. Vilcu, N. Sultana, and S. S. Ahmed, "Determination of initial basic feasible solution of a transportation problem: a TOCM-SUM approach," *Buletinul Institutului Politehnic Din Iasi, Romania, Secţia Automatica si Calculatoare*, vol. 61, no. 1, pp. 39-49, 2015.

[5] G. Guo and J. Obłój, "Computational methods for martingale optimal transport problems," *The Annals of Applied Probability*, vol. 29, no. 6, pp. 3311-3347, 2019.

[6] M. H. Abdelati, A. M. Abd-El-Tawwab, E. E. M. Ellimony, and M. Rabie, "Solving a multi-objective solid transportation problem: a comparative study of alternative methods for decision-making," *Journal of Engineering and Applied Science*, vol. 70, no. 1, p. 82, 2023.

[7] F. Chevli, J. M. Dhodiya, and M. Patel, "A study of Solid Fixed Charge Transportation Problem and its Solution by Grey Situation Decision-Making Theory," *International Journal of Creative Research Thoughts (IJCRT)*, 2018.

[8] A. Kuiri, B. Das, and S. K. Mahato, "An optimization of solid transportation problem with stochastic demand by Lagrangian function and KKT conditions," *RAIRO - Operations Research*, vol. 55, pp. S2969-S2982, 2021, doi: 10.1051/ro/2020136.

[9] M. Alardhi, H. A. Abdelwali, A. M. Khalfan, and M. H. Abdelati, "Using the Minimize Distance Method to Find the Best Compromise Solution of Multi-objective Transportation Problem with Case Study."

[10] T. V. Johnson, "Review of diesel emissions and control," *International Journal of Engine Research*, vol. 10, no. 5, pp. 275-285, 2009.

[11] J. Sullivan *et al.*, "CO2 emission benefit of diesel (versus gasoline) powered vehicles," ed: ACS Publications, 2004.

[12] A. Das and G. M. Lee, "A multi-objective stochastic solid transportation problem with the supply, demand, and conveyance capacity following the weibull distribution," *Mathematics*, vol. 9, no. 15, p. 1757, 2021.

[13] B. Singh and A. Singh, "Hybrid particle swarm optimization for pure integer linear solid transportation problem," *Mathematics and Computers in Simulation*, vol. 207, pp. 243-266, 2023.

[14] M. A. Islam and Y. Gajpal, "Optimization of conventional and green vehicles composition under carbon emission cap," *Sustainability*, vol. 13, no. 12, p. 6940, 2021.

[15] J. Duran-Micco, E. Vermeir, and P. Vansteenwegen, "Considering emissions in the transit network design and frequency setting problem with a heterogeneous fleet," *European Journal of Operational Research*, vol. 282, no. 2, pp. 580-592, 2020.

[16] P. Senecal and F. Leach, "Diversity in transportation: Why a mix of propulsion technologies is the way forward for the future fleet," *Results in Engineering*, vol. 4, p. 100060, 2019.

[17] S. D. Treanor, "The flexibility and benefits of operating a diverse fleet: an analysis using real options," *Management Research Review*, vol. 35, no. 6, pp. 462-472, 2012.

[18] H. A. Mohamed, "IMPROVING SOLUTION QUALITY IN TRANSPORTATION PROBLEMS: A NOVEL ALGORITHM FOR EFFICIENT RESOURCE ALLOCATION," *AGPE THE ROYAL GONDWANA RESEARCH JOURNAL OF HISTORY, SCIENCE, ECONOMIC, POLITICAL AND SOCIAL SCIENCE*, vol. 4, no. 8, pp. 1-10, 08/02 2023. [Online]. Available: https://agpegondwanajournal.co.in/index.php/agpe/article/view/297.

[19] M. Rith, A. M. Fillone, and J. B. M. Biona, "Development and application of the Weibull distribution-based vehicle survivorship models for a metropolis of a developing country," *Songklanakarin Journal of Science & Technology,* vol. 42, no. 6, 2020.

[20] Q. Cui, Y.-l. Lei, and Y. Li, "Potential carbon emissions reduction from fleet schedule reconfiguration of China's and India's external routes," *Patterns,* vol. 3, no. 11, 2022.

[21] V. Macián, B. Tormos, L. Ramírez, T. Pérez, and J. Martínez, "CO2 emissions reduction by using low viscosity oils in public urban bus fleets," *WIT Transactions on the Built Environment,* vol. 146, pp. 255-266, 2015.

[22] A. El-Wahab, M. Rabie, M. H. Abdelati, M. I. Khalil, and K. Abdelgawwad, "A case study of reducing the total wasted time for the bus movement of Public Transportation Authority in Cairo (CTA)," *SVU-International Journal of Engineering Sciences and Applications,* vol. 2, no. 2, pp. 82-87, 2021.

[23] J. Neff and A. P. T. Association, "2008 Public Transportation Fact Book," 2008.

[24] J.-P. Rodrigue, *The geography of transport systems*. Routledge, 2020.

[25] D. H. Cusworth *et al.*, "Quantifying global power plant carbon dioxide emissions with imaging spectroscopy," *AGU Advances,* vol. 2, no. 2, p. e2020AV000350, 2021.

[26] R. Cong, M. Saito, R. Hirata, A. Ito, and S. Maksyutov, "EXPLORATION ON QUANTIFYING CARBON DIOXIDE (CO 2) EMISSION FROM ROAD TRAFFIC IN MEGACITY," *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences,* vol. 42, no. 4, 2018.

[27] B. Jereb, O. Stopka, and T. Skrúcaný, "Methodology for estimating the effect of traffic flow management on fuel consumption and CO2 production: A case study of Celje, Slovenia," *Energies,* vol. 14, no. 6, p. 1673, 2021.

[28] M. A. Babu, M. M. Ahmmed, Z. R. Salim, M. S. Babu, and M. Abdul, "A Brief Overview of the Classical Transportation Problem," 2020.

[29] H. A. Taha, "Operation Research: An Introduction, 7th," 2003.

[30] M. Abdelati, A. M. Abd-El-Tawwab, E. E. M. Ellimony, and M. Rabie, "A NEW APPROACH FOR FINDING AN INITIAL SOLUTION NEAR TO OPTIMUM FOR THE SOLID TRANSPORTATION PROBLEMS," *AGPE THE ROYAL GONDWANA RESEARCH JOURNAL OF HISTORY, SCIENCE, ECONOMIC, POLITICAL AND SOCIAL SCIENCE,* vol. 4, no. 3, pp. 93-101, 2023.

[31] H. Mollanoori, R. Tavakkoli-Moghaddam, C. Triki, M. Hajiaghaei-Keshteli, and F. Sabouhi, "Extending the solid step fixed-charge transportation problem to consider two-stage networks and multi-item shipments," *Computers & Industrial Engineering*, vol. 137, p. 106008, 2019, doi: 10.1016/j.cie.2019.106008.

[32] J. X. Xie and Y. Xue, "Optimization modeling and LINDO/LINGO software," *Beijing: The press of Tsinghua University,* 2005.

[33] D. M. Tulett and G. Y. Ke, "Using LINGO for Business Students," in *Operations Research Forum*, 2022, vol. 4, no. 1: Springer, p. 3.

Appendix

Table 2: Distance between each factory and distribution center (km)

	1	2	3	4	5	6	7	8
1	56	56	83	288	138	184	155	560
2	64	68	74	310	158	231	118	536
3	62	33	67	260	116	177	185	584
4	281	239	253	71	188	237	368	816
5	503	460	454	292	466	512	604	1081
6	238	200	270	91	152	166	304	765
7	143	125	156	178	66	118	285	678
8	118	107	130	214	75	148	274	627
9	173	140	171	211	92	148	319	667
10	126	118	153	345	109	91	259	632
11	183	173	213	266	113	54	319	661
12	218	200	244	269	126	54	326	681
13	138	161	131	368	251	296	77	529
14	113	130	90	318	201	243	90	541
15	227	236	218	466	363	391	102	461
16	470	472	423	798	563	614	279	408
17	630	662	600	958	763	816	445	388
18	730	723	670	985	863	872	555	432
19	945	932	932	1285	1070	1105	775	560
20	800	803	740	1115	887	946	605	425
21	159	167	215	416	237	230	301	584
22	159	167	215	416	221	190	301	595
23	246	358	300	346	250	100	389	672
24	466	522	605	723	590	620	779	490
25	566	600	650	779	629	664	827	960

Table 3: The cost of transporting one pallet using type A

	1	2	3	4	5	6	7	8
1	0.46	0.46	0.68	2.37	1.13	1.51	1.27	4.6
2	0.53	0.56	0.61	2.55	1.3	1.9	0.97	4.41
3	0.51	0.27	0.55	2.13	0.95	1.45	1.52	4.8
4	2.31	1.97	2.08	0.59	1.55	1.95	3.03	6.71
5	4.13	3.78	3.73	2.4	3.83	4.21	4.96	8.88
6	1.95	1.65	2.22	0.75	1.25	1.37	2.5	6.29
7	1.17	1.03	1.28	1.46	0.54	0.97	2.34	5.57
8	0.97	0.88	1.07	1.76	0.61	1.21	2.25	5.15
9	1.42	1.15	1.41	1.73	0.75	1.21	2.62	5.48
10	1.03	0.97	1.26	2.83	0.89	0.75	2.13	5.19
11	1.51	1.42	1.75	2.19	0.93	0.45	2.62	5.43
12	1.79	1.65	2.01	2.21	1.03	0.45	2.68	5.59
13	1.13	1.32	1.07	3.03	2.06	2.43	0.63	4.35
14	0.93	1.07	0.74	2.61	1.65	1.99	0.74	4.45
15	1.87	1.94	1.79	3.83	2.98	3.21	0.84	3.79
16	3.86	3.88	3.47	6.56	4.63	5.05	2.29	3.35
17	5.17	5.44	4.93	7.87	6.27	6.71	3.65	3.19
18	6	5.94	5.51	8.09	7.09	7.17	4.56	3.55
19	7.77	7.66	7.66	10.56	8.79	9.08	6.37	4.6
20	6.57	6.6	6.08	9.16	7.29	7.77	4.97	3.49
21	1.31	1.37	1.77	3.42	1.95	1.89	2.47	4.8
22	1.31	1.37	1.77	3.42	1.81	1.56	2.47	4.89
23	2.02	2.94	2.47	2.84	2.05	0.82	3.19	5.52
24	3.83	4.29	4.97	5.94	4.85	5.09	6.4	4.03
25	4.65	4.93	5.34	6.4	5.17	5.45	6.79	7.89

Table 4: The cost of transporting one pallet using type B

	1	2	3	4	5	6	7	8
1	0.34	0.34	0.5	1.74	0.83	1.11	0.94	3.38
2	0.39	0.41	0.45	1.87	0.95	1.4	0.71	3.24
3	0.37	0.2	0.4	1.57	0.7	1.07	1.12	3.53
4	1.7	1.44	1.53	0.43	1.14	1.43	2.22	4.93
5	3.04	2.78	2.74	1.76	2.82	3.09	3.65	6.53
6	1.44	1.21	1.63	0.55	0.92	1	1.84	4.62
7	0.86	0.76	0.94	1.08	0.4	0.71	1.72	4.1
8	0.71	0.65	0.79	1.29	0.45	0.89	1.66	3.79
9	1.05	0.85	1.03	1.27	0.56	0.89	1.93	4.03
10	0.76	0.71	0.92	2.08	0.66	0.55	1.56	3.82
11	1.11	1.05	1.29	1.61	0.68	0.33	1.93	3.99
12	1.32	1.21	1.47	1.63	0.76	0.33	1.97	4.11
13	0.83	0.97	0.79	2.22	1.52	1.79	0.47	3.2
14	0.68	0.79	0.54	1.92	1.21	1.47	0.54	3.27
15	1.37	1.43	1.32	2.82	2.19	2.36	0.62	2.79
16	2.84	2.85	2.56	4.82	3.4	3.71	1.69	2.47
17	3.81	4	3.63	5.79	4.61	4.93	2.69	2.34
18	4.41	4.37	4.05	5.95	5.21	5.27	3.35	2.61
19	5.71	5.63	5.63	7.76	6.46	6.68	4.68	3.38
20	4.83	4.85	4.47	6.74	5.36	5.72	3.66	2.57
21	0.96	1.01	1.3	2.51	1.43	1.39	1.82	3.53
22	0.96	1.01	1.3	2.51	1.34	1.15	1.82	3.59
23	1.49	2.16	1.81	2.09	1.51	0.6	2.35	4.06
24	2.82	3.15	3.66	4.37	3.56	3.75	4.71	2.96
25	3.42	3.63	3.93	4.71	3.8	4.01	5	5.8

Table 5: The cost of transporting one pallet using type C

	1	2	3	4	5	6	7	8
1	0.24	0.24	0.36	1.25	0.6	0.8	0.67	2.44
2	0.28	0.3	0.32	1.35	0.69	1	0.51	2.33
3	0.27	0.14	0.29	1.13	0.5	0.77	0.8	2.54
4	1.22	1.04	1.1	0.31	0.82	1.03	1.6	3.55
5	2.19	2	1.97	1.27	2.03	2.23	2.63	4.7
6	1.04	0.87	1.17	0.4	0.66	0.72	1.32	3.33
7	0.62	0.54	0.68	0.77	0.29	0.51	1.24	2.95
8	0.51	0.47	0.57	0.93	0.33	0.64	1.19	2.73
9	0.75	0.61	0.74	0.92	0.4	0.64	1.39	2.9
10	0.55	0.51	0.67	1.5	0.47	0.4	1.13	2.75
11	0.8	0.75	0.93	1.16	0.49	0.23	1.39	2.88
12	0.95	0.87	1.06	1.17	0.55	0.23	1.42	2.96
13	0.6	0.7	0.57	1.6	1.09	1.29	0.33	2.3
14	0.49	0.57	0.39	1.38	0.87	1.06	0.39	2.35
15	0.99	1.03	0.95	2.03	1.58	1.7	0.44	2.01
16	2.04	2.05	1.84	3.47	2.45	2.67	1.21	1.77
17	2.74	2.88	2.61	4.17	3.32	3.55	1.94	1.69
18	3.18	3.15	2.91	4.28	3.75	3.79	2.41	1.88
19	4.11	4.05	4.05	5.59	4.65	4.81	3.37	2.44
20	3.48	3.49	3.22	4.85	3.86	4.12	2.63	1.85
21	0.69	0.73	0.94	1.81	1.03	1	1.31	2.54
22	0.69	0.73	0.94	1.81	0.96	0.83	1.31	2.59
23	1.07	1.56	1.31	1.51	1.09	0.44	1.69	2.92
24	2.03	2.27	2.63	3.15	2.57	2.7	3.39	2.13
25	2.46	2.61	2.83	3.39	2.74	2.89	3.6	4.18