MAKÜ | Journal of Mehmet Akif Ersoy University
Economics and Administrative Sciences Faculty

e-ISSN: 2149-1658
Volume: 11 / Issue: 3
September, 2024
pp.: 944-959

Can the Fixed-Cost Transportation Problem Be Solved with the Initial Solution Methods of the Transportation Problem?

Kenan KARAGÜL[1]

1. Assoc. Prof. Dr., Pamukkale University, kkaragul@pau.edu.tr, https://orcid.org/0000-0001-5397-4464

https://doi.org/10.30798/makuiibf.1389617

Abstract

From the dawn of humanity's existence to the present day and beyond, there will always be production and service systems to meet the demands at every point of consumption. In this context, transporting goods from production and service resources to consumption points will continue to play a significant role. Supply Chain Management and its sub-systems, particularly logistics and hence the Transportation Problem, will be crucial for the functioning of these systems. This study focuses on the Fixed-Cost Transportation Problem. A novel heuristic approach has been proposed for this problem, and the success of the heuristic has been analyzed through a group of test problems compared with similar methods in the literature. The proposed heuristic has shown promising results.

Keywords:* *Fixed-Cost Transportation Problem, Transportation Problem, Heuristics, Vogel's Approximation Method (VAM), Modified Distribution Method (MODI).

Article Type	**Application Date**	**Admission Date**
Research Article	January 4, 2024	August 21, 2024

To cite this article: Karagül, K. (2024). Can the Fixed-Cost Transportation Problem be solved with the initial solution methods of the transportation problem?. *Journal of Mehmet Akif Ersoy University Economics and Administrative Sciences Faculty*, *11*(3), 944-959. https://doi.org/10.30798/makuiibf.1389617

1. INTRODUCTION

Logistics holds a critical significance in today's global and local industrial production and service systems, encompassing highly complex phenomena. The organizational success of an industrial system relies on the efficient management of both forward and reverse flows of materials, products, and information. The coordination and optimization of these processes are consolidated under the concept of Supply Chain Management (SCM). SCM encompasses networks designed to comprehensively address all stages, from sourcing a product or service to production processes, from production processes to storage, and from storage to distribution.

Before the U.S. Air Force made Leontief's work applicable to dynamic situations, Hitchcock (1941) and Koopmans (1947) independently addressed an intriguing special case. This specific scenario tackled by Hitchcock and Koopmans can be referred to as the Transportation Problem (TP). TP was initially proposed by Hitchcock in 1941 and by Koopmans in 1947 (Dantzig, 1951). TP and Fixed-Cost Transportation Problem (FCTP) constitute indispensable logistic process components to be considered in the operational dimension of SCM. TP aims to determine transportation routes and modes, most efficiently by modelling with linear programming, optimizing a multitude of variables. This optimization process targets cost minimization, efficient resource utilization, and operational efficiency. On the other hand, FCTP aims to develop the best transportation plan for materials and products within a specified cost constraint, taking into account the fixed costs of different transportation modes. FCTP is an NP-Hard problem, which implies that its mathematical models are solvable up to a certain dimension. Hence, studies in the literature focus on proposing solution approaches for FCTP utilizing various heuristic algorithms, and research on new solution approaches for FCTP is ongoing.

For professionals in both academic and industrial fields within the logistics domain, generating solutions for TP and FCTP that contribute multidimensional positive impacts such as minimizing supply chain costs, managing resources most effectively and efficiently, and enhancing customer satisfaction is crucial. Solving these operational problems enhances competitive advantage and positively affects business efficiency.

This research aims to propose initial solution approaches from a novel FCTP-specific perspective. In this context, the hypothesis is put forward that effective initial solutions for FCTP can be obtained by using classical initial solution methods employed for the TP. The rest of this paper is organized as follows: the second section provides a comprehensive analysis of the existing literature; the third section explains the details of the research methodology and provides an applied analysis based on the case study; and the final section discusses the contributions of the research and provides limitations.

2. LITERATURE REVIEW

The process of transporting homogeneous goods from production facilities in different geographical regions to warehouses located in various other regions in a way that meets supply and demand constraints, with the aim of minimizing costs, can be build a mathematically as a Linear Programming model. This approach is referred to as the TP. The mathematical modelling of the TP using Linear Programming was developed by George Dantzig in the year 1947.

The first general solution approach for the Fixed-Charged Transportation Problem (FCTP) was proposed by Balinski in 1961, which builds upon the Transportation Problem (TP) framework. In his work, Balinski suggested a solution by normalizing the minimum of supply and demand to the fixed charge, thereby obtaining a new cost matrix, and resolving the TP using this approach (Balinski, 1961). Numerous studies in the literature have either directly applied the Balinski approach or proposed alternative methodologies. Demircioğlu and Coşkun conducted a solution implementation of an FCTP industrial problem using the Balinski approach. In their study, the authors addressed a distribution problem for three supply centers and 24 demand points, regulating fixed and variable costs, as well as supply and demand quantities through the Balinski approach to solve this real-world problem. A comparison with the existing state revealed that the company achieved significant savings to a certain extent in the obtained solution (Demircioğlu & Coşkun, 2018).

Recent research in the realm of the TP has seen a somewhat limited exploration of initial solution propositions. Kirca and Satir (1990) were pioneers in proffering an inaugural solution for the TP, rigorously testing it across a spectrum of 480 distinct problem instances (Kırca and Satir, 1990). Khani et al. leveraged Kirca and Satir's foundational Total Opportunity Cost Matrix (TOCM) approach as the bedrock algorithm for their initial solution proposal (Khani et.al., 2015). Karagül and Şahin advanced a novel starting solution methodology coined as KSAM, tailored specifically for the TP. Within this study, a meticulous comparative performance analysis of 24 designated test problems was undertaken, each assessed through a variety of distinct initial solution methodologies (Karagül and Şahin,2020). Mutlu and colleagues introduced a method hinging on the minimization of the highest cost as a means of formulating inaugural solutions (Mutlu et.al., 2022).

Mallick and their team took the case of the distribution of pharmaceuticals produced by pharmaceutical companies to regional warehouses as an exemplary scenario for addressing the TP. They managed to achieve optimal solutions using the Vogel’s Approximation Method (VAM) and the Stepping Stone Technique (Mallick et al., 2023). Szkutnik-Rogoz and Małachowski introduced and implemented three different coding environments, namely R, Octave, and Matlab, for Linear Programming to obtain optimal solutions for the TP. They utilized initial solution approaches such as the northwest corner, the least cost in a matrix, and the VAM (Szkutnik-Rogoz and Małachowski, 2023).

Yılmaz and their research team concentrated on investigating initial solution approaches for TPs. They designed structures that incorporated the arithmetic, square root, and harmonic means of unit costs in the Tuncay Can Method, which relies on geometric averages preprocessing introduced in 2015 and conducted performance analyses (Yılmaz et al., 2023). Jamali and Rahman initiated a discussion on initial solution approaches for the TP, highlighting scenarios where the Least Cost Method (LCM) and VAM yield suboptimal solutions (Jamali and Rahman, 2023). Muhtarulloh and their colleagues carried out a comparative analysis of two existing initial solution methods, namely the Sumathi-Sathiya Method and KSAM, for a test dataset of 100 randomly generated TPs and shared their results (Muhtarulloh et al., 2022). Lestari and their team devised a distribution model for a company engaged in producing rubber-based materials for the TP. They initially obtained solutions using the North West Corner, Least Cost, and VAM, subsequently reaching optimal solutions with the Stepping Stone and Modified Distributions (MODI) approaches (Lestari et al., 2023). Akbar and their team harnessed an online data source where unit costs could be acquired for TPs, and they produced solutions using the North West Corner, Least Cost, and VAM. They suggested the North West Corner approach as a straightforward and efficient initial solution approach (Akbar et al., 2023). Abdelati proposed the Cost Quantity Method (CQM) as an initial solution approach for TPs. This method involves planning distribution on a unit cost matrix, where the smallest unit cost is calculated as a ratio (Abdelati, 2023). Tarigan and their colleagues compared two initial solution methods in the literature for Transportation Problems, TOC-SUM and KSAM. They argued the superiority of the KSAM approach over the TOC-SUM approach through comparisons of initial and optimal solutions (Tarigan et al., 2023).

Shivani evaluated TPs within a framework that could accommodate uncertainties arising from input data. In this context, she proposed a novel solution approach for the TP by addressing input data through a rough interval approach (Shivani, 2023b). Kalaivani and Kaliyaperumal prepared input matrices for solving with the MODI and VAM tools by introducing fuzziness to Transportation Problem input data using neutrosophic numbers and presented solutions (Kalaivani and Kaliyaperumal, 2023). Shivani and Ebrahimnrjad suggested a solution approach for Unbalanced Transportation Problems created using rough interval fuzzy numbers (Shivani and Ebrahimnrjad, 2023b).

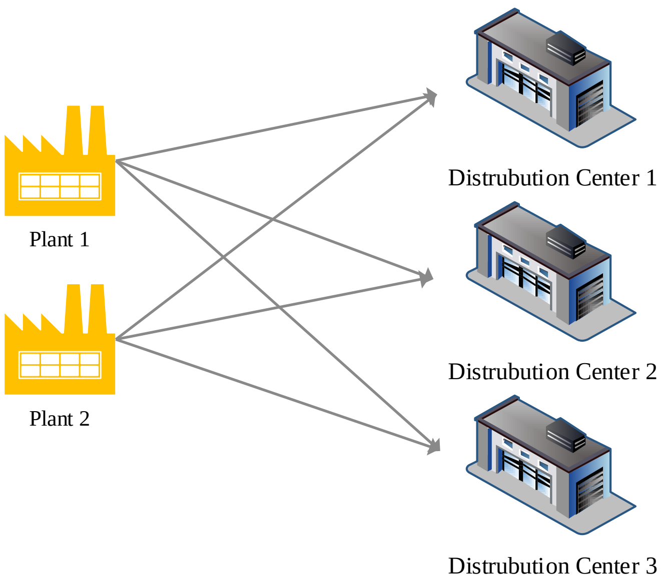
Sarhani and their research team have diligently conducted a comprehensive literature survey in the realm of intuitive algorithms, initial solutions, and the domain of constrained and discrete optimization. Their endeavor illuminates recent strides in this area of study (Sarhani et al., 2022). Angmalisang and colleagues have introduced the Leaders and Followers Algorithm, designed to procure optimal solutions for Balanced TPs, subjecting it to a thorough comparative analysis against various methodologies. The fruit of their research shines brightly, showcasing a commendable degree of relative success, as evidenced across a diverse set of 138 test problems (Angmalisang et al., 2023). Aroniadi and Beligiannis have crafted two distinctive iterations of the Particle Swarm Optimization Algorithm, tailored specifically for the intricate art of solving the TP. Their ingenuity has led to the creation of solutions that are both innovative and effective (Aroniadi and Beligiannis, 2023). In a groundbreaking contribution to the field, Shivani has proposed novel repair functions in tandem with network-based Genetic Algorithm approaches, particularly tailored for the Nonlinear FCTP. This breakthrough ushers in a new era of problem-solving methodologies (Shivani, 2023a). Shivani and Ebrahimnejad have jointly spearheaded a pioneering approach for tackling the complexities of the Multi-Objective Fractional TP, marking a significant advancement in this intricate field (Shivani and Ebrahimnejad, 2023a).

Karagül introduced a novel initial solution approach based on the KSAM approach, which is recommended as an initial solution methodology for the FCTP (Karagül, 2022). Yousefi et al. proposed an intuitive algorithm for solving the FCTP by utilizing priority-based GA, SA, and the Keshtel Algorithm (KA), incorporating four different consolidated cost calculation procedures. This algorithm resolves the consolidated cost matrices as standard Transportation Problems and selects the one with the lowest cost among the four solutions. When examining the comparative algorithm solution table, it becomes evident that solutions based on the consolidated cost matrix are more effective than others (Yousefi et al., 2017). Yousefi et al. recommended four intuitive algorithms for the FCTP, including Priority Based and Spanning Tree Based Simulated Annealing and Genetic Algorithm, resulting in the generation of solutions (Yousefi et al., 2018).

3. METHODOLOGY

In this section, we will first introduce the FCTP and its mathematical model. Subsequently, we will present the variable definitions for the proposed solution algorithm, outline the algorithm's steps, and illustrate the algorithm's solution process using a visual example.

Figure 1. Fixed-Cost Transportation Problem



Source: (Adlakha et al., 2018)

Yousefi et al., (2018) included the mathematical model in their article as follows:

$$Min\ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(c_{ij} x_{ij} + f_{ij} y_{ij}\right) \quad (1)$$

$s.t.$

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

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

$$x_{ij} \geq 0, \forall i, j \quad (4)$$

$$y_{ij} = \begin{cases} 1, & x_{ij} > 0 \\ 0, & otherwise \end{cases}, \forall i, j \quad (5)$$

If necessary, detailed information about the mathematical model can be obtained from the study of Yousefi et al., (2018).

3.1. Proposed Heuristics

The definitions of the nomenclature of the proposed heuristic are as follows.

Nomenclature

m: Number of supply centers

n: Number of demand centers

C: Unit variable transportation cost matrix (mxn)

F: Fixed cost per route matrix (mxn)

s: Supply vector ($mx1$)

d: Demand vector ($nx1$)

$norC$: Normalized C matrix between 1 and 2 (mxn)

$norF$: Normalized F matrix between 1 and 2 (mxn)

nsF: Cost per supply unit of $norF$ (mxn)

ndF: Cost per demand unit of $norF$ (mxn)

uC: Restructured unit cost matrix

Steps of the Proposed Heuristic

A1] Read the dataset. Read inC and inF matrices. These matrices represent unit variable transportation cost and fixed cost per route, respectively. They are associated with supply quantities and demand quantities.

A2] Preparation of problem data for solving through transformation.

Identification and configuration of input data, m, n, C, F, s, and d.

$$C = [c_{ij}]mxn \tag{6}$$

$$F = [f_{ij}]mxn \tag{7}$$

$$s = [s_i]mx1 \tag{8}$$

$$d = [d_j]nx1 \tag{9}$$

A3] Calculation of the normalized C matrix between 1 and 2.

$$norC = rescale(C, 1, 2) \tag{10}$$

A4] Calculation of the normalized F matrix between 1 and 2.

$$norF = rescale(F, 1, 2) \tag{11}$$

A5] Calculation of fixed costs per unit of supply and demand.

$$nsf_{ij} = \frac{norf_{ij}}{s_i}, \forall\, i, j \tag{12}$$

$$nsF = [nsf_{ij}]mxn \tag{13}$$

$$ndf_{ij} = \frac{norf_{ij}}{d_j},\ \forall\, i, j \tag{14}$$

$$ndF = [ndf_{ij}]mxn \tag{15}$$

A6] Obtaining the restructured unit variable transportation cost matrix.

$$uC = norC + nsF + ndF \tag{16}$$

A7] Providing m, n, and uC to be integrated and solved with the (VAM+MODI) algorithm, and obtaining the solution.

A8] Calculation of the actual cost of the solution obtained with the (VAM+MODI) algorithm.

3.2. Illustrative Example

The illustrative example is constructed using the data provided in the Table 1 and Table 2 which is taken from Adlakha et al. (2006) article where the problem is referred to as $P10$.

A1] Read the dataset. Read inC and inF matrices.

Table 1. Unit Variable Transportation Costs

inC	$W1$	$W2$	$W3$	$W4$	Supply
$P1$	34	97	57	37	76
$P2$	99	49	8	70	83
$P3$	50	78	47	63	63
Demand	73	31	66	52	222

Source: (Adlakha et al., 2006)

Table 2. Fixed Costs per Route

inF		$W1$	$W2$	$W3$	$W4$	Supply
	$P1$	91	47	44	68	76
	$P2$	26	62	60	45	83
	$P3$	57	40	32	96	63
	Demand	73	31	66	52	222

Source: (Adlakha et al., 2006)

A2] Preparing the Read Problem Data for Solution through Transformation. Defining and configuring the input data as m, n, C, F, s, d.

Table 3. Number of Supply and Demand Centers

Variable	Value
m	3
n	4

Table 4. Unit Variable Transportation Costs

C matrix	$W1$	$W2$	$W3$	$W4$
$P1$	34	97	57	37
$P2$	99	49	8	70
$P3$	50	78	47	63

Table 5. Fixed Costs per Route

F matrix	$W1$	$W2$	$W3$	$W4$
$P1$	91	47	44	68
$P2$	26	62	60	45
$P3$	57	40	32	96

Table 6. Supply and Demand Quantities

	$P1$	$P2$	$P3$	-	Total
s	76	83	63	-	222
	$W1$	$W2$	$W3$	$W4$	Total
d	73	31	66	52	222

A3] Calculation of the C matrix normalized between 1 and 2

Table 7. Normalized Unit Variable Transportation Costs

$norC$	$W1$	$W2$	$W3$	$W4$
$P1$	1.2857	1.978	1.5385	1.3187
$P2$	2.0000	1.4505	1.0000	1.6813
$P3$	1.4615	1.7692	1.4286	1.6044

A4] Calculation of the F matrix normalized between 1 and 2

Table 8. Normalized Fixed Costs per Route

$norF$	$W1$	$W2$	$W3$	$W4$
$P1$	1.9286	1.3000	1.2571	1.6000
$P2$	1.0000	1.5143	1.4857	1.2714
$P3$	1.4429	1.2000	1.0857	2.0000

A5] Calculation of the Fixed Costs per Unit Supply and Unit Demand

Table 9. Distribution of Fixed Costs per Unit of Supply

nsF	$W1$	$W2$	$W3$	$W4$
$P1$	0.025376	0.017105	0.016541	0.021053
$P2$	0.012048	0.018244	0.0179	0.015318
$P3$	0.022902	0.019048	0.017234	0.031746

Table 10. Distribution of Fixed Costs per Unit of Demand

ndF	$W1$	$W2$	$W3$	$W4$
$P1$	0.026419	0.041935	0.019048	0.030769
$P2$	0.013699	0.048848	0.022511	0.024451
$P3$	0.019765	0.03871	0.01645	0.038462

A6] Obtaining the Reconfigured Unit Variable Transportation Cost Matrix

Table 11. Reconfigured Unit Variable Transportation Costs

uC	$W1$	$W2$	$W3$	$W4$
$P1$	1.3375	2.0371	1.5741	1.3705
$P2$	2.0257	1.5176	1.0404	1.7211
$P3$	1.5042	1.8270	1.4623	1.6746

A7] Providing m, n, and uC for an Integrated Solution Using the (VAM+MODI) Algorithm and Obtaining the Solution

Table 12. (VAM+MODI) Assignment Solution

Optimal	$W1$	$W2$	$W3$	$W4$	Total	Supply
$P1$	24	0	0	52	76	76
$P2$	0	17	66	0	83	83
$P3$	49	14	0	0	63	63
Total	73	31	66	52	222	-
Demand	73	31	66	52	-	222

Table 13. Calculated Real Costs for the (VAM+MODI) Solution

Explanation	Results
Proposed Approach Solution Cost	8021
Article Solution (Adlakha et.al.2006)	8021
Deviation (%)	0

3.3. Performance Analysis of the Proposed Heuristics

Test problems were obtained from Yousefi et al. (2017). The structural properties of the dataset and data generation parameters are provided in Table 14.

Table 14. Fixed-Charge Transportation Test Problems Characteristics

Problem size		Total	Problem	Range of variable costs		Range of fixed costs	
				Lower limit	Upper limit	Lower limit	Upper limit
Small	5 × 10	5000	A	3	8	50	200
	10 × 10	8000	B	3	8	100	400
	10 × 20	10000	C	3	8	200	800
Medium	15 × 15	15000	D	3	8	400	1600
	10 × 30	15000					
	20 × 30	20000					
Large	50 × 50	50000					
	30 × 100	30000					
	50 × 200	50000					

Source: (Yousefi et.al.,2017)

In the study by Yousefi et al. (2017), the authors compared three different heuristic algorithms, including one they developed themselves, with solutions generated by Lingo. To perform a fair comparison, gaps in the Lingo solutions were subtracted to create a Best Known Solution (BKS) definition for the problems. The deviations presented in the results table provided by the authors were also calculated again with BKS as the reference. The performance of the proposed method was similarly assessed using BKS as the reference. Yousefi et al. (2017) presented solutions from Genetic Algorithm (GA), Simulated Annealing (SA), Keshtel Algorithm (KA), a new algorithm proposed by the authors named Heuristic Consolidated Cost (HCC), and Lingo solutions in Table 15.

Table 15. Comparison Table of Solution Results

P. Group	P. Size	Lingo	BKS	GA	SA	KA	HCC	Proposed Algorithm
	5×10	21810	21810	21935.8	22299.1	21873.1	21850	21906
	10×10	28401	28401	28813.5	29525.35	28908.6	28435	28494
	10×20	35372	35372	36951.9	37800.75	37079.9	35558	35558
	15×15	49955	49955	52376.3	53709.6	52133.1	50030	50044
A	10×30	50830	50830	52594.5	53229.95	52323	50956	52392
	20×30	65270	65270	67897.9	68695.4	68887.6	65676	65676
	50×50	158856	158681.2584	162212.6	164213.3	163422.1	158684	158668
	30×100	102207	102207	104571.4	105763.1	105496.1	102260	104112
	50×200	173151	168372.0324	171823	172999.5	172543.3	168496	170750
Average		76206	75655	77686	78693	78074	75772	76400
	5×10	24348	24348	24434.1	24990.25	24476.15	24725	24725
	10×10	31017	31017	31304	31940.55	31302.85	31333	31333
	10×20	39858	39858	40644.5	40926.8	40547.95	40252	42117
	15×15	58766	58766	60148	60689.8	60330.05	58932	59110
B	10×30	60445	59344.901	62441.5	63150.85	62835.2	59362	60917
	20×30	70740	70740	72331.4	73034.1	72478.05	70759	70918
	50×50	167981	167258.6817	172111.3	173574.8	172359.3	167260	167099
	30×100	112122	112122	115098.5	116308.6	115591.3	112289	112313
	50×200	192867	186174.5151	192000.9	194021	192974.2	186393	192716
Average		84238	83292	85613	86515	85877	83478	84583
	5×10	25296	25296	25401	26025.05	25418.35	25338	25461
	10×10	36873	36873	37544	38093.65	37584.2	37844	37359
	10×20	44645	44645	45883.7	46570.35	45874.25	45443	46492
	15×15	58725	58725	60685	61285.05	60333.05	59319	59614
C	10×30	63258	63258	64674.7	65375.85	64917.25	64159	64331
	20×30	78237	78237	81147.1	82099.25	81213.15	79835	79841
	50×50	185074	184074.6004	187934.3	189080.1	188735.7	184083	182606
	30×100	132153	131796.1869	135643.6	136937.2	136038.5	131800	134092
	50×200	233710	220365.159	227418.2	229242.5	228110.2	221096	229009
Average		95330	93697	96259	97190	96469	94324	95423
	5×10	30107	30107	30313.8	31436.3	30392.7	30836	31228
	10×10	39760	39760	40150.4	41224.75	40128.25	41013	41751
	10×20	60267	60267	62000.2	62720.35	62066.75	63133	64784
	15×15	73913	73913	76503.5	77622.4	76764.7	75829	74884
D	10×30	80971	80971	82872	84249.8	83175	82705	85275
	20×30	99204	98985.7512	100622.2	102059.3	101144.6	102203	105881
	50×50	218209	215765.0592	218694.7	220083	219398.2	215793	220838
	30×100	171059	170528.7171	174298.8	177568.4	176040.5	170533	176590
	50×200	308963	285481.812	298771.8	303272.1	301846.3	287137	310552
Average		120273	117309	120470	122248	121217	118798	123531

The deviation values of the solution values in Table 15 from the BKS are shown as percentages in Table 16 and Figure 2.

Table 16. Comparison of Solutions with BKS

P. Group	P. Size	Lingo Dev (%)	GA Dev (%)	SA Dev (%)	KA Dev (%)	HCC Dev (%)	Proposed Heuristic Dev (%)
A	5×10	0.00	0.58	2.24	0.29	0.18	0.44
	10×10	0.00	1.45	3.96	1.79	0.12	0.33
	10×20	0.00	4.47	6.87	4.83	0.53	0.53
	15×15	0.00	4.85	7.52	4.36	0.15	0.18
	10×30	0.00	3.47	4.72	2.94	0.25	3.07
	20×30	0.00	4.03	5.25	5.54	0.62	0.62
	50×50	0.11	2.23	3.49	2.99	0.00	-0.01
	30×100	0.00	2.31	3.48	3.22	0.05	1.86
	50×200	2.76	2.05	2.75	2.48	0.07	1.41
	Average	0.32	2.83	4.47	3.16	0.22	0.94
B	5×10	0.00	0.35	2.64	0.53	1.55	1.55
	10×10	0.00	0.93	2.98	0.92	1.02	1.02
	10×20	0.00	1.97	2.68	1.73	0.99	5.67
	15×15	0.00	2.35	3.27	2.66	0.28	0.59
	10×30	1.82	5.22	6.41	5.88	0.03	2.65
	20×30	0.00	2.25	3.24	2.46	0.03	0.25
	50×50	0.43	2.90	3.78	3.05	0.00	-0.10
	30×100	0.00	2.65	3.73	3.09	0.15	0.17
	50×200	3.47	3.13	4.21	3.65	0.12	3.51
	Average	0.72	2.42	3.66	2.66	0.46	1.70
C	5×10	0.00	0.42	2.88	0.48	0.17	0.65
	10×10	0.00	1.82	3.31	1.93	2.63	1.32
	10×20	0.00	2.77	4.31	2.75	1.79	4.14
	15×15	0.00	3.34	4.36	2.74	1.01	1.51
	10×30	0.00	2.24	3.35	2.62	1.42	1.70
	20×30	0.00	3.72	4.94	3.80	2.04	2.05
	50×50	0.54	2.10	2.72	2.53	0.00	-0.80
	30×100	0.27	2.92	3.90	3.22	0.00	1.74
	50×200	5.71	3.20	4.03	3.51	0.33	3.92
	Average	0.72	2.50	3.76	2.62	1.04	1.80
D	5×10	0.00	0.69	4.42	0.95	2.42	3.72
	10×10	0.00	0.98	3.68	0.93	3.15	5.01
	10×20	0.00	2.88	4.07	2.99	4.76	7.49
	15×15	0.00	3.50	5.02	3.86	2.59	1.31
	10×30	0.00	2.35	4.05	2.72	2.14	5.32
	20×30	0.22	1.65	3.11	2.18	3.25	6.97
	50×50	1.12	1.36	2.00	1.68	0.01	2.35
	30×100	0.31	2.21	4.13	3.23	0.00	3.55
	50×200	7.60	4.66	6.23	5.73	0.58	8.78
	Average	1.03	2.25	4.08	2.70	2.10	4.95

When we examine Table 16, the first column displays the gaps of the Lingo solver compared to the optimal solutions. Successively, the deviations from BKS results as a percentage are presented for GA, SA, KA, HCC, and the Proposed Heuristic. The Proposed Heuristic outperformed the GA, SA, and KA algorithms for the A, B, C, and D group problems. Furthermore, the HCC algorithm appears to be quite competitive in solving A, B, and C group problems. However, it can be observed that it loses competitiveness in solving D group problems, where the fixed costs are defined in a high range. Nonetheless, it is clear that for HCC and the Proposed algorithm, deviations increase from Group A to D. However, for GA, SA, and KA, it's not as clear to say that this deviation is increasing significantly. The percentage deviation values of the solutions provided by the methods in Table 16 for different problem groups from the best solution are presented in Figure 2, Figure 3, Figure 4 and Figure 5, respectively.

Figure 2. Deviations from the best solutions for problem group A (%)

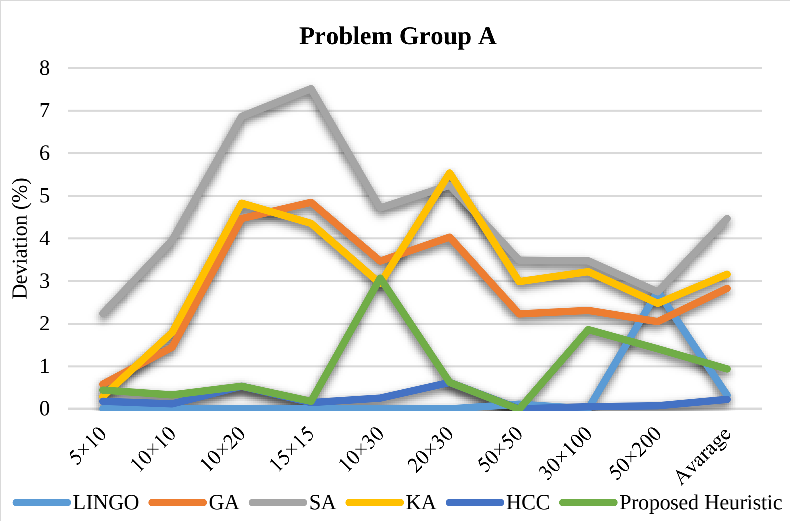


Figure 3. Deviations from the best solutions for problem group B (%)

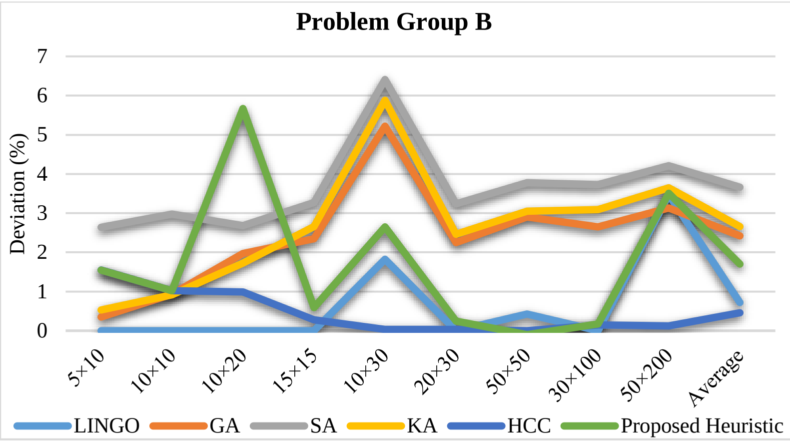


Figure 4. Deviations from the best solutions for problem group C (%)

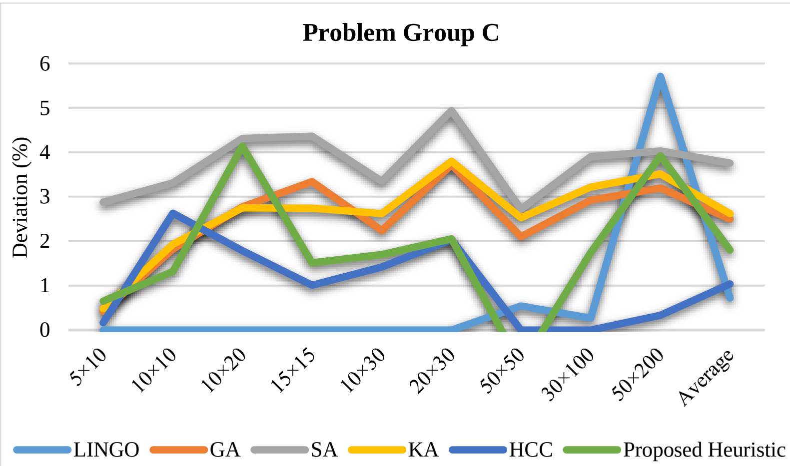
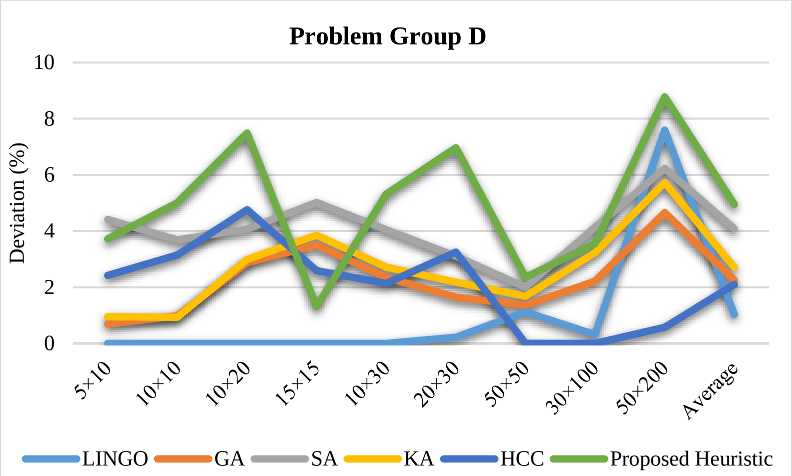


Figure 5. Deviations from the best solutions for problem group D (%)



4. CONCLUSION

The study addresses the Transportation Problem and Fixed-Cost Transportation Problem, which are critical issues in the logistics industry. The Fixed-Cost Transportation Problem, being classified as NP-Hard, becomes more challenging to solve with increasing problem size when utilizing mathematical methods. Examination of test problems reveals that the Lingo mathematical solver encounters difficulties in solving medium-sized problems and fails to reach optimal solutions for larger problem instances. Consequently, heuristic algorithms and novel approaches play a significant role in solving Fixed-Cost Transportation Problems.

In this research, a new variable transportation cost matrix is developed by employing certain heuristic operations based on unit variable transportation cost and fixed-cost matrices for the Fixed-Charge Transportation Problem. The study demonstrates efforts to reach optimal solutions using the VAM and the MODI. The results obtained in this study suggest that the proposed heuristic approach offers promising solutions compared to the literature. When examining the deviations of problem groups in comparison to the BKS, it is observed that all groups yield deviations less than 5%.

These findings indicate that various heuristic methods based on the proposed approach can be utilized to produce effective solutions in the logistics industry. For future research, these and similar approaches can be recommended as new research methodologies, potentially paving the way for further developments in this field.

The study does not necessitate Ethics Committee permission.

The study has been crafted in adherence to the principles of research and publication ethics.

The author declares that there exists no financial conflict of interest involving any institution, organization, or individual(s) associated with the article.

The entire work was carried out by its only, stated author.

REFERENCES

Abdelati, M.H. (2023). 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, 4*(8), 1–10.

Adlakha, V., Kowalski, K., & Vemuganti, R.R. (2006). Heuristic algorithms for the fixed-charge transportation problem. *OPSEARCH, 43*, 132–151. https://doi.org/10.1007/BF03398770

Akbar, Y.R., Zain, I., Septianingsih, R.., & Nuraini, P. (2023). The transportation method for efficient cost of shipping goods. *International Journal of Economics, Management, Business, And Social Science (IJEMBIS), 3*(1), 67–76. https://doi.org/10.59889/ijembis.v3i1.114

Angmalisang, H.Y., Angmalisang, H., & Sumarauw, S.J. (2023). Leaders and followers algorithm for balanced transportation problem. *Computer Engineering and Applications Journal, 12*(2), 79-87. https://doi.org/10.18495/COMENGAPP.V12I2.436

Aroniadi C, Beligiannis G.N. (2023). Applying particle swarm optimization variations to solve the transportation problem effectively. *Algorithms, 16*(8), 372. https://doi.org/10.3390/a16080372

Balinski, M. L. (1961). Fixed-cost transportation problems. *Naval Research Logistics, 8*(1), 41-54.

Dantzig, G.B. (1951). Application of the simplex method to a transportation problem, In Koopmans, T.C. (Ed), *Activity Analysis of Production and Allocation* (pp. 359-373). John Wiley and Sons.

Demircioğlu, M., & Coşkun, İ. T. (2018). Sabit maliyetli ulaştırma problemleri için Balinski yöntemi uygulaması. *Pamukkale Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, (31), 275-284. https://doi.org/10.30794/pausbed.414850

Hitchcock F.L. (1941). The distribution of a product from several sources to numerous localities, *Journal of Mathematics and Physics, 20*, 224−230.

Jamali, J., Rahma, T.M. (2023). Investigating the pitfalls of the least cost and Vogel's approximate methods: Understanding the impact of cost matrix pattern. *Journal of Engineering Science, 14*(1), 123-135. https://doi.org/10.3329/jes.v14i1.67641

Kalaivani, K., Kaliyaperumal, P. (2023). A neutrosophic approach to the transportation problem using single-valued trapezoidal neutrosophic numbers. *Proyecciones (Antofagasta), 42*(2), 533-547. https://dx.doi.org/10.22199/issn.0717-6279-5374

Karagül, K. (2022, December 10-13). *Sabit maliyetli ulaştırma problemi için yeni bir çözüm yaklaşımı* [Conference Paper]. 1st International Conference on Scientific and Academic Research, Konya, Türkiye.

Karagül, K., Şahin, Y. (2020). A novel approximation method to obtain initial basic feasible solution of transportation problem. *Journal of King Saud University - Engineering Sciences, 32*(3), 211-218.

Khani, A.R., Vilcu, A., Uddini, M.D.S., & Ungureanu, F. (2015). A competent algorithm to find the initial basic feasible solution of cost minimization transportation problem. *Buletinul Institutului Politehnic Din Iaşi, Publicat de Universitatea Tehnica, Georghe Asachi Din Iaişi Tomul, LXI* (LXV), Fasc. 2.

Kirca, O., Satir, A. (1990). A heuristic for obtaining an initial solution for the transportation problem. *Journal of the Operational Research Society, 41*, 865–871.

Lestari, S., Mustari,G.I., & Muttaqien, Z. (2023). Implementation of transportation methods in optimization of rubber product distribution costs in PT. IRC INOAC. *Jurnal Teknik, 12*(1), 26-33.

Mallick, C., Bhoi, S.K., Singh, T., Swain, P., Ruskhan, B., Hussain, K., & Sahoo, K.S. (2023). Transportation problem solver for drug delivery in pharmaceutical companies using steppingstone method. *International Journal of Intelligent Systems and Applications in Engineering,11*(5), 343–352.

Muhtarulloh, F., Meirista, M., & Cahyandari, R. (2022). Penyelesaian masalah transportasi menggunakan metode Sumathi-Sathiya dan metode pendekatan Karagul-Sahin (KSAM). *Jurnal Eureka Matika, 10*(1), 43-52.

Mutlu, Ö, Karagül, K., & Şahin, Y. (2022). Avoid maximum cost method for determining the initial basic feasible solution of the transportation problem. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 28*(4), 569-576.

Sarhani, M., Voß, Ma., & Jovanovic, R. (2022). Initialization of metaheuristics: comprehensive review, critical analysis, and research directions. *International Transactions in Operational Research, 30*(6), 3361-3397. https://doi.org/10.1111/itor.13237

Shivani, R.D. (2023a). Solving non-linear fixed-charge transportation problems using nature inspired non-linear particle swarm optimization algorithm. *Applied Soft Computing, 146*, https://doi.org/10.1016/j.asoc.2023.110699

Shivani, R.D. (2023b). A method to solve fractional transportation problems with rough interval parameters. In Kumar, R., Verma, A.K., Sharma, T.K., Verma, O.P., Sharma, S. (Eds.), *Soft Computing: Theories and Applications. Lecture Notes in Networks and Systems*, (Vol. 627). Springer. https://doi.org/10.1007/978-981-19-9858-4_59

Shivani, R.D., Ebrahimnejad, A. (2023a). On solving fully rough multi-objective fractional transportation problem: development and prospects. *Computational and Applied Mathematics, 42*, 266. https://doi.org/10.1007/s40314-023-02400-z

Shivani, R.D., Ebrahimnrjad, A. (2023b). An approach for unbalanced fully rough interval transportation problem. *Hacettepe Journal of Mathematics and Statistics, 52*(5), 1408-1424. https://doi.org/10.15672/hujms.980108

Szkutnik-Rogoz, J., Malachowski, J. (2023). Optimization programming tools supporting supply chain management. *Bulletin of The Polish Academy of Sciences Technical Sciences, 71*(3). https://doi.org/10.24425/bpasts.2023.145570

Tarigan, M.L., Tastrawati, N. K. T., & Utari, I. A. P. A. (2023). Optimisasi biaya transportasi menggunakan metode stepping stone dengan solusi awal TOC-SUM approach dan KSAM. *E-Jurnal Matematika, 12*(1), 77-86. https://doi.org/10.24843/MTK.2023.v12.i01.p403

Yılmaz Soydan, N.T., Çilingirtürk, A. & Can, T. (2023). Simulation for appropriate mean selection for Can's approximation method in transportation models. *Manisa Celal Bayar Üniversitesi Sosyal Bilimler Dergisi, 21*(1), 189-200. https://doi.org/10.18026/cbayarsos.1117589

Yousefi, K., Afshari, A.J., & Hajiaghaei-Keshteli, M. (2017). Solving the fixed-charge transportation problem by new heuristic approach. *Journal of Optimization in Industrial Engineering, 12*(1), 41-52. https://doi.org/10.22094/joie.2017.738.1469

Yousefi, K.J., Afshari, A., & Hajiaghaei-Keshteli, M. (2018). Fixed-charge transportation problem with discount. *Journal of Industrial and Production Engineering, 35*(7), 444-470.