Journal of King Saud University – Engineering Sciences xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original article

A novel approximation method to obtain initial basic feasible solution of transportation problem

Kenan Karagul [a], Yusuf Sahin [b,*]

[a] Logistics Department, Pamukkale University, Denizli, Turkey
[b] Business Administration Department, Mehmet Akif Ersoy University, Burdur, Turkey

ARTICLE INFO

Article history:
Received 7 May 2018
Accepted 17 March 2019
Available online xxxx

Keywords:
Transportation problem
Initial solution
Approximation method

ABSTRACT

The transportation problem is one of the important problems in the field of optimization. It is related to finding the minimum cost transportation plan for moving to a certain number of demand points from a certain number of sources. Various methods for solving this problem have been included in the literature. These methods are usually developed for an initial solution or optimal solution. In this study, a novel method to find the initial solution to the transportation problem is proposed. This new method called Karagul-Sahin Approximation Method was compared with six initial solution methods in the literature using twenty-four test problems. Compared to other methods, the proposed method has obtained the best initial solution to 17 of these problems with remarkable calculation times. In conclusion, the solutions obtained by the proposed method are as good as the solutions obtained with Vogel's approach and as fast as the Northwest Corner Method.

1. Introduction

Developments in communication and information technologies and the ever-increasing competition, especially in production sector, have led to the need for effective and low-cost delivery of raw materials, in-process inventory, final product or related information from the points of the origin to the final consumption points. This need can be fulfilled especially with the help of concepts related to logistics. At this point, logistics is gaining importance as a solution for manufacturing companies. In addition to providing control of services and operations, logistics also provides a healthy and low-cost transportation capability. The elements of the logistics can vary according to time and sector. The differentiation of requirements and technology has caused the logistics-related components to change over time. However, transportation cost has always been an important component of most logistics costs for many companies. Freight transport corresponds to one-third to two-thirds of the total logistics cost (Ballou, 1999). Therefore, transporting items efficiently is a critical problem for all companies.

Companies send their products from the production points (*origins*) to the target points (*destinations*) where the product is consumed. While there is a limited supply at each production point, there is a specific demand that must be met for each customer. At this point, transportation models are used to determine the minimum cost shipping plan to meet the customer's demands under certain constraints (Albright and Winston, 2009). The transportation problem (TP), which emerged in various contexts and attracts much attention in the literature, is an important network structured linear programming problem (Bazaraa et al., 2010). The first step in TP's solution procedure is to determine the appropriate initial basic feasible solution (IBFS) (Ahmed et al., 2016a,b). It is necessary to start with an IBFS in order to find the optimal solution. The initial solution value affects the best solution and the solution time. Therefore, it is important to start with a good initial solution (Hosseini, 2017).

1.1. Related literature

The well-known classical methods to obtain the IBFS are North-West Corner (NWC), the Matrix Minima (MM), the Row-Minima (RM), the Column-Minima (CLM), Vogel's Approximation (VAM) and Russell's Approximation (RAM) methods (Deshpande, 2009).

* Corresponding author.
E-mail addresses: kkaragul@pau.edu.tr (K. Karagul), ysahin@mehmetakif.edu.tr (Y. Sahin).

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

https://doi.org/10.1016/j.jksues.2019.03.003
1018-3639/

Please cite this article as: K. Karagul and Y. Sahin, A novel approximation method to obtain initial basic feasible solution of transportation problem, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2019.03.003

In order to control the optimality of the initial solution, the Stepping Stone and Modified Distribution (MODI) methods are generally preferred.

Many methods have been proposed in the literature to find the initial solution of the transportation problem. Kirca and Satir (1990) developed a heuristic method (Total Opportunity-cost Method – TOM) to find an IBFS to the transportation problem. Mathirajan and Meenakshi (2004) incorporated the total opportunity cost (TOC) concept with VAM. Korukoglu and Ballı (2011) improved VAM by using and regarding alternative allocation costs. In these methods, additional two alternative allocation costs are calculated in VAM procedure considering the highest three penalty costs and then a minimum of them is selected. Pandian and Natarajan (2010) developed a method called "Zero Point Method" for transportation problems with mixed constraints in a single stage. Khan (2011) used the pointer costs which is calculated by taking the difference of the highest cost and next smaller to the highest cost for each row and each column, unlike the VAM method. Islam et al. (2012) presented a new approach called Total Opportunity Cost Table (TOCT). In this method, they calculated the distribution indicators (DI) by the difference of the greatest unit cost and the nearest-to-the-greatest unit cost. The highest two DI are taken as the basic cell and loads imposed on the original transport table corresponding to the basic cells of the TOCT. Khan et al. (2015) developed a new heuristic method namely "TOCM-SUM Approach" to find an initial solution. They calculated the pointer cost for each row and column of the TOCM by taking the sum of all entries in the respective row or column and made a maximum possible allocation to the lowest cost cell corresponding to the highest pointer cost.

Mhlanga et al. (2014) developed an innovative application that manipulates the rows or columns before applying the North West Corner. In this method, the informed and imaginative manipulation of cost matrix makes the North West Corner method quite effective. Das et al. (2014) proposed a method called "Advanced Vogel's Approximation Method (AVAM)" to overcome the difficulty arising in case that the lowest cost and the next lowest cost is the same in the VAM method. Can and Kocak (2016) offered an alternative approximation method for balanced TP, the geometric average of the transportation costs involved in the transportation table is taken (Tuncay Can Approximation Method – TCM). At the next stage of the method, an assignment is made to the cell which has the nearest cost to this average cost taking into account the demand and production constraints. Ahmed et al. (2016a,b) proposed a new approach named as Allocation Table Method (ATM) to find an initial basic feasible solution for the balanced TP. The proposed method is an iterative method based on the allocation table. The assignment is carried out taking into account the lowest demand or supply amount. In addition to these studies, Uddin et al. (2011, 2013, 2015), Babu et al. (2013, 2014), Ahmed et al. (2014, 2015, 2017), Hosseini (2017), Morade (2017), Kumar et al., (2018), Prajwal et al., (2019), also proposed similar methods to find IBFS.

In this paper, a novel approximation method called Karagul-Sahin Approximation Method (KSAM) is proposed to obtain IBFS of the TP. The performance of the proposed method is compared with the classical approximation methods. In the following sections of the study, the mathematical model of the TP, existing methods in the literature, proposed method (KSAM), and results are presented, respectively.

1.2. Problem statement

This is an optimization problem that arises especially in the planning of the distribution of goods and services from different sources of supply to a certain number of demand points. The network structure of the TP is shown in Fig. 1. The supply and demand points are expressed as nodes. The flow between the nodes is expressed by arrows. Typically, the capacity of suppliers (m) and the demand of the customers (n) are known. The main goal in a classical TP is to minimize the total cost of transporting goods from their origins to their destination (Anderson et al., 2011). The first model of TP was proposed by Hitchcock (1941), and then, Dantzig (1951) and Charnes et al. (1955) developed solution methods for this problem. Fig. 1 shows a network with m suppliers and n customers.

The TP concerns the transfer of products from a certain number of sources to a certain number of destination points with minimum transportation cost. Assume that the source i has s_i piece of product to be distributed to the targets, and the target j has d_j pieces of demand to be met. c_{ij} means the cost of carrying a unit product from source i to target j. x_{ij} is the decision variable that indicates the quantity of product to be carried on this connection. The notation used in a classical transport model and the mathematical model of the problem are presented below (Cökelez, 2016).

Mathematical Model:

$$min.z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}.x_{ij} \tag{1}$$

s.t.

$$\sum_{j=1}^{n} x_{ij} \leq s_i \quad i = 1,\ 2,\ 3,\ \ldots, m \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} \geq d_j \quad j = 1,\ 2,\ 3,\ \ldots,\ n \tag{3}$$

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

The first equation is the objective function of the TP. The goal is to minimize the total cost of transport. The constraints (2) and (3) are constraints on supply and demand, respectively.

2. Proposed solution method

In this section, the details of the proposed method are explained. KSAM is an iterative method consisting of 5 steps. The solution process begins with a change that was initially applied to the transport table. First of all, Eq. (4) and Eq. (5) are used for this transformation. The obtained ratio (r_{ij} and r_{ji}) are multiplied

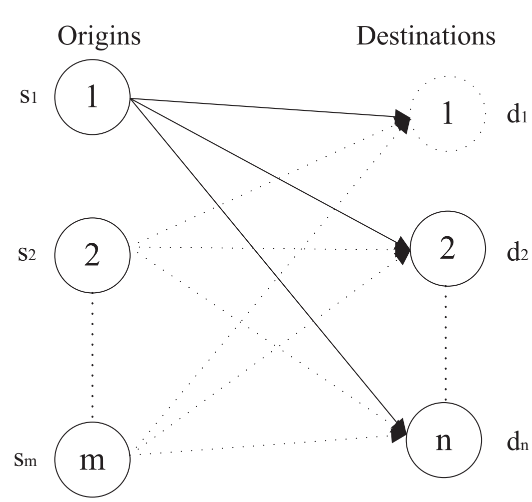

Fig. 1. The network structure of the transportation problem.

by cost and two new matrices A (wcd) and B (wcs) are formed to be used in assignments. The obtained value is called the weighted transportation cost matrix by demand/supply. The proposed method performs the assignments, starting from the smallest values in the new matrices created. At this point, it does not matter whether the problem is balanced or unbalanced. The method can produce good solutions for both problems.

2.1. Notation

r_{ij}: Proportional demand matrix (pdm)
r_{ji}: Proportional supply matrix (psm)
A: Weighted transportation cost matrix by demand (wcd)
B: Weighted transportation cost matrix by supply (wcs)

$$r_{ij} = \frac{d_j}{s_i}, i = 1, 2, 3, \cdots, m \text{ and } j = 1, 2, 3, \cdots n \tag{4}$$

$$r_{ji} = \frac{s_i}{d_j}, j = 1, 2, 3, \cdots n \text{ and } i = 1, 2, 3, \cdots, m \tag{5}$$

$$r_{ij} * r_{ji} = 1 \tag{6}$$

The steps of the method are shown below;

Step 1: Calculate the r_{ij} (pdm) and r_{ji} (psm) values for matrix A (wcd) and B (wcs).

Step 2: Calculate the weighted transportation cost matrix by multiplying the rates and the cost values and form A (wcd) and B (wcs) matrices.

Step 3: To start with the smallest weighted costs in the matrices wcd and wcs, make assignments taking into account the demand and supply constraints.

Step 4: If all demands are met, finish the algorithm. Otherwise, go back to Step 3.

Step 5: Compare the solution values of assignment matrices. Set the smaller solution as the initial solution.

A numerical example of the proposed method is presented above (Russell, 1969). This problem, consisting of 5 demands and

Table 1
Transportation table for numerical example.

	D_1	D_2	D_3	D_4	D_5	Supply (S)
S_1	73	40	9	79	20	**8**
S_2	62	93	96	8	13	**7**
S_3	96	65	80	50	65	**9**
S_4	57	58	29	12	87	**3**
S_5	56	23	87	18	12	**5**
Demand (D)	**6**	**8**	**10**	**4**	**4**	**32**

Table 2
r_{ij} pd matrix (pdm).

	D_1	D_2	D_3	D_4	D_5	S
S_1	**=6/8** =0.75	1.00	1.25	0.50	0.50	**8**
S_2	0.86	1.14	1.43	0.57	0.57	**7**
S_3	0.67	0.89	1.11	0.44	0.44	**9**
S_4	2.00	2.67	3.33	1.33	1.33	**3**
S_5	1.20	1.60	2.00	0.80	0.80	**5**
D	**6**	**8**	**10**	**4**	**4**	

Table 3
r_{ji} ps matrix (psm).

	D_1	D_2	D_3	D_4	D_5	S
S_1	**=8/6** =1.33	1.00	0.80	2.00	2.00	**8**
S_2	1.17	0.88	0.70	1.75	1.75	**7**
S_3	1.50	1.13	0.90	2.25	2.25	**9**
S_4	0.50	0.38	0.30	0.75	0.75	**3**
S_5	0.83	0.63	0.50	1.25	1.25	**5**
D	**6**	**8**	**10**	**4**	**4**	

Table 4
Matrix A: Weighted cost matrix by demand (wcd).

	D_1	D_2	D_3	D_4	D_5	S
S_1	54.75	40.00	11.25	39.50	10.00	**8**
S_2	53.14	106.29	137.14	**4.57**	**7.43**	**7**
S_3	64.00	57.78	88.89	22.22	28.89	**9**
S_4	114.00	154.67	96.67	16.00	116.00	**3**
S_5	67.20	36.80	174.00	14.40	9.60	**5**
D	**6**	**8**	**10**	**4**	**4**	

Table 5
Matrix B: Weighted cost matrix by supply (wcs).

	D_1	D_2	D_3	D_4	D_5	S
S1	97.33	40.00	**7.20**	158.00	40.00	**8**
S2	72.33	81.38	67.20	14.00	22.75	**7**
S3	144.00	73.13	72.00	112.50	146.25	**9**
S4	28.50	21.75	**8.70**	9.00	65.25	**3**
S5	46.67	14.38	43.50	22.50	15.00	**5**
D	**6**	**8**	**10**	**4**	**4**	

Table 6
Solution 1: Getting from wcd.

	D_1	D_2	D_3	D_4	D_5	S
S_1			**8**			**8**
S_2				**4**	**3**	**7**
S_3	**5**	**4**				**9**
S_4	**1**		**2**			**3**
S_5		**4**			**1**	**5**
D	**6**	**8**	**10**	**4**	**4**	
TOTAL COST: 1.102						

Table 7
Solution 2: Getting from wcs.

	D_1	D_2	D_3	D_4	D_5	S
S_1			**8**			**8**
S_2				**3**	**4**	**7**
S_3	**6**	**3**				**9**
S_4			**2**	**1**		**3**
S_5		**5**				**5**
D	**6**	**8**	**10**	**4**	**4**	
TOTAL COST: 1.104						

Table 8
Solution value with other methods.

Solution methods	Value	Solution Times (seconds)	Deviation from optimal solution (%)
Optimal	**1102**	–	0.00
KSAM	**1102**	**0.0003**	**0.00**
RAM	1104	0.0011	0.18
VAM	1104	0.0038	0.18
RM	1123	0.0013	1.87
MM	1123	0.0018	1.87
CLM	1491	0.0010	26.09
TCM	1927	0.0038	42.81
NWC	1994	0.0004	44.73

Please cite this article as: K. Karagul and Y. Sahin, A novel approximation method to obtain initial basic feasible solution of transportation problem, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2019.03.003

supply points, is shown in Table 1. The problem is addressed with a balanced TP.

The first thing to do is to calculate the ratio of r_{ij} and r_{ji}. The values obtained as a result of calculating these ratios are shown in Tables 2 and 3.

The process to be performed after the rates are calculated is to multiply these rates by the costs shown in Table 1. After this multiplication, A and B matrices are constructed with weighted transportation costs. Matrices A and B are shown in Tables 4 and 5, respectively.

The smallest proportional opportunity costs are 4.57 in Matrix A, and 7.20 in Matrix B. The first assignments must be made to these cells. The biggest assignment that can be made to this cell in Matrix A is 4 units, while in Matrix B it is 8 units. The second smallest value in Matrix A is 7.43, and 8.70 in Matrix B. These cells can be assigned 3 units in Matrix A and 2 units in Matrix B. Once the assignments are made in this order, the solutions are shown in Tables 6 and 7 are reached.

The total cost is 1102 for wcd solution and 1104 for wcs solution. The wcd solution is taken as the initial solution. If this problem is to be solved by using a mathematical model, the optimal solution is 1102. The optimal solution is achieved with the first initial solution to the proposed method. The initial solution values of this problem obtained by other solution methods in the literature are summarized in Table 8 and Fig. 2. As can be seen from Table 8, KSAM, VAM and RAM methods provide the perfect approximate solutions to the optimal solution. At this point, it can be said that the proposed method produces solutions as fast as the NWC and as effective as the VAM.

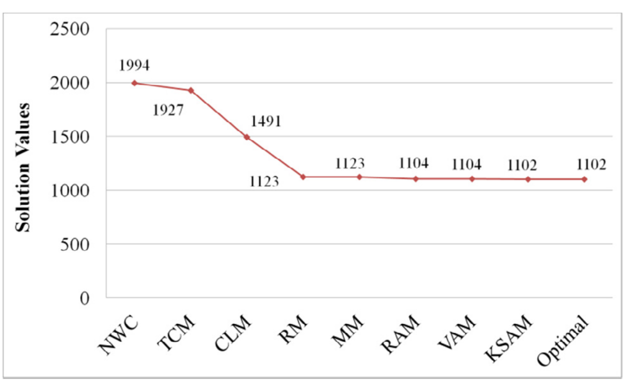

Fig. 2. Solution values of the methods.

3. Results and discussions

In this section, it was used 24 different transportation problems to evaluate the performance of the proposed method. These problems were agglomerated from different sources **(Singh, 2015; Shafaat and Goyal, 1988; Ahmed et al., 2016a,b; Can, 2015; Kara, 2000; Rohela et al., 2015; Shafaat and Goyal, 1988 *etc*). Some of these problems are unbalanced and the rest are balanced problems. The details of the problems are shown in Table 9. For example, PR01 has four (4) sources and six (6) customers. This problem is a balanced TP and optimal solution to the problem is 430. All methods were encoded in MATLAB and the experiments were executed on a PC with 2.40 GHz Intel Dual Core and 8 GB RAM under Linux operating system. The optimal solution values of the problems were calculated using the mathematical model shown in Section 1.2, JuMP (Julia for Mathematical Optimization), and JuliaOpt® (optimization packages for the Julia language) (https://www.juliaopt.org/).

Table 10 shows the solution values obtained by solving the problems detailed above and percentages of deviations from the optimal solution. If the table is examined, the proposed method has been successful in finding the best initial solution in 17 of 24 problems. This is followed by VAM (16), RAM (10), RM (9), MM (6), CLM (5), TCM (4) and NWC (2) methods, respectively. Figs. 3 and 4 show the solution values and the deviation of the methods from the best solution. It is clear that the proposed method can produce very close results with the optimal solution. On the other hand, the VAM method can also produce solutions that are very close to the optimal solution. For all problems, the mean deviation of the VAM method is 1.76% while the mean deviation of the KSAM method is 1.90%.

The solution times and solution speed of the methods are shown in Tables 11 and 12. In terms of the solution time, very good results were obtained with the proposed method. The minimum solution time for all problems except three problems belongs to the KSAM. Table 12 shows the solution speeds of the methods according to the VAM method. In order to better express the time performance of the methods, the solution time of the VAM method was divided by the solution time of other methods to obtain a ratio. The rate obtained by this process shows how fast the methods provide solutions compared to the VAM method. For example, the proposed method can solve the PR21 twenty times faster than the VAM methods. Figs. 5 and 6 also shows the solution time and speed comparisons of the methods. In general, the proposed method has shown superior results both in terms of solution time and quality. The results in Tables 10 and 11 clearly show that the proposed method is as efficient as the VAM method and can produce solutions as fast as the NWC method.***

Table 9
Details of the problems.

Number	Name	Problem Size	Optimal Solution	Status	Number	Name	Problem Size	Optimal Solution	Status
1	Pr01	4x6	430	Balanced	**13**	Pr13	3x3	1669	Unbalanced
2	Pr02	3x4	12075	Balanced	**14**	Pr14	3x3	1515	Unbalanced
3	Pr03	3x4	4010	Balanced	**15**	Pr15	3x3	530	Balanced
4	Pr04	5x5	1102	Balanced	**16**	Pr16	3x4	3400	Balanced
5	Pr05	3x4	2850	Balanced	**17**	Pr17	3x3	129	Unbalanced
6	Pr06	3x4	3320	Balanced	**18**	Pr18	3x4	5300	Balanced
7	Pr07	4x4	410	Balanced	**19**	Pr19	4x5	204	Balanced
8	Pr08	3x3	1390	Balanced	**20**	Pr20	4x6	830	Balanced
9	Pr09	3x4	3100	Balanced	**21**	Pr21	3x3	820	Balanced
10	Pr10	3x3	820	Balanced	**22**	Pr22	3x4	6798	Balanced
11	Pr11	3x3	1763	Balanced	**23**	Pr23	4x6	71	Balanced
12	Pr12	3x3	1695	Unbalanced	**24**	Pr24	3x3	710	Unbalanced

Please cite this article as: K. Karagul and Y. Sahin, A novel approximation method to obtain initial basic feasible solution of transportation problem, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2019.03.003

Table 10
Solution and deviation values of the methods.

Name		Optimal	NWC	RM	CLM	MM	VAM	RAM	TCM	KSAM
Pr01	Solution	**430**	740	490	480	450	450	460	680	**430**
	Dev (%)	0.00	72.09	13.95	11.63	4.65	4.65	6.98	58.14	0.00
Pr02	Solution	**12075**	12200	13175	**12075**	12825	12075	**12075**	16825	12200
	Dev (%)	0.00	1.04	9.11	0.00	6.21	0.00	0.00	39.34	1.04
Pr03	Solution	**4010**	6580	**4010**	**4010**	**4010**	**4010**	**4010**	6880	**4010**
	Dev (%)	0.00	64.09	0.00	0.00	0.00	0.00	0.00	71.57	0.00
Pr04	Solution	**1102**	1994	1123	1491	1123	1104	1104	1927	**1102**
	Dev (%)	0.00	80.94	1.91	35.30	1.91	0.18	0.18	74.86	0.00
Pr05	Solution	**2850**	4400	**2850**	3600	**2850**	**2850**	2900	5350	**2850**
	Dev (%)	0.00	54.39	0.00	26.32	0.00	0.00	1.75	87.72	0.00
Pr06	Solution	**3320**	4160	**3320**	**3320**	**3320**	**3320**	3520	4320	3620
	Dev (%)	0.00	25.30	0.00	0.00	0.00	0.00	6.02	30.12	9.04
Pr07	Solution	**410**	540	470	435	435	470	440	470	**415**
	Dev (%)	0.00	31.71	14.63	6.10	6.10	14.63	7.32	14.63	1.22
Pr08	Solution	**1390**	1500	1450	1500	1450	1500	**1390**	1720	**1390**
	Dev (%)	0.00	7.91	4.32	7.91	4.32	7.91	0.00	23.74	0.00
Pr09	Solution	**3100**	6050	**3100**	3200	**3100**	**3100**	**3100**	6400	**3100**
	Dev (%)	0.00	95.16	0.00	3.23	0.00	0.00	0.00	106.45	0.00
Pr10	Solution	**820**	**820**	855	**820**	855	**820**	**820**	**820**	**820**
	Dev (%)	0.00	0.00	4.27	0.00	4.27	0.00	0.00	0.00	0.00
Pr11	Solution	**1763**	1858	1822	1832	1832	1801	**1786**	**1786**	**1786**
	Dev (%)	0.00	5.39	3.35	3.91	3.91	2.16	1.30	1.30	1.30
Pr12	Solution	**1695**	1786	1774	1760	1784	1731	1744	1738	**1719**
	Dev (%)	0.00	5.37	4.66	3.83	5.25	2.12	2.89	2.54	1.42
Pr13	Solution	**1669**	1766	1728	1752	1752	1705	1698	1706	**1690**
	Dev (%)	0.00	5.81	3.54	4.97	4.97	2.16	1.74	2.22	1.26
Pr14	Solution	**1515**	1615	1545	1685	1715	**1515**	1615	1695	1545
	Dev (%)	0.00	6.60	1.98	11.22	13.20	0.00	6.60	11.88	1.98
Pr15	Solution	**530**	560	560	555	555	**530**	**530**	**530**	555
	Dev (%)	0.00	5.66	5.66	4.72	4.72	0.00	0.00	0.00	4.72
Pr16	Solution	**3400**	4750	**3400**	4650	3550	**3400**	3550	5850	**3400**
	Dev (%)	0.00	39.71	0.00	36.76	4.41	0.00	4.41	72.06	0.00
Pr17	Solution	**129**	153	153	137	137	**129**	133	185	**129**
	Dev (%)	0.00	18.60	18.60	6.20	6.20	0.00	3.10	43.41	0.00
Pr18	Solution	**5300**	6700	6000	6000	6700	**5300**	6100	6300	**5300**
	Dev (%)	0.00	26.42	13.21	13.21	26.42	0.00	15.09	18.87	0.00
Pr19	Solution	**204**	358	**204**	238	**204**	**204**	210	296	210
	Dev (%)	0.00	75.49	0.00	16.67	0.00	0.00	2.94	45.10	2.94
Pr20	Solution	**830**	855	**830**	855	**830**	**830**	**830**	935	855
	Dev (%)	0.00	3.01	0.00	3.01	0.00	0.00	0.00	12.65	3.01
Pr21	Solution	**820**	**820**	855	**820**	855	**820**	**820**	**820**	**820**
	Dev (%)	0.00	0.00	4.27	0.00	4.27	0.00	0.00	0.00	0.00
Pr22	Solution	**6798**	8580	**6798**	6826	6826	**6798**	6826	13,991	**6798**
	Dev (%)	0.00	26.21	0.00	0.41	0.41	0.00	0.41	105.81	0.00
Pr23	Solution	**71**	109	83	95	85	**77**	85	113	**77**
	Dev (%)	0.00	53.52	16.90	33.80	19.72	8.45	19.72	59.15	8.45
Pr24	Solution	**710**	915	**710**	735	735	**710**	**710**	800	775
	Dev (%)	0.00	28.87	0.00	3.52	3.52	0.00	0.00	12.68	9.15
Number of best solution			**2**	**9**	**5**	**6**	**16**	**10**	**4**	**17**
Mean Deviation (%)			**30.55**	**5.01**	**9.70**	**5.19**	**1.76**	**3.35**	**37.26**	**1.90**

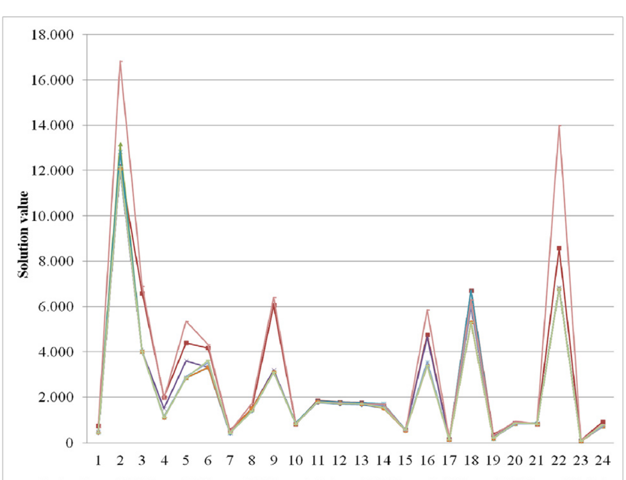

Fig. 3. Solution values of the methods.

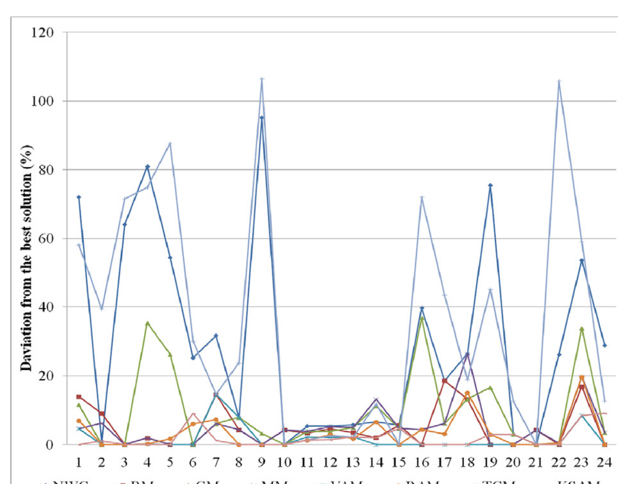

Fig. 4. Deviation from the optimal solution.

Please cite this article as: K. Karagul and Y. Sahin, A novel approximation method to obtain initial basic feasible solution of transportation problem, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2019.03.003

Table 11
Solution times of the methods (seconds).

Name	NWC	RM	CLM	MM	VAM	RAM	TCM	KSAM
Pr01	**0.0004**	0.0010	0.0018	0.0020	0.0025	0.0008	0.0055	**0.0004**
Pr02	0.0004	0.0008	0.0008	0.0011	0.0014	0.0004	0.0009	**0.0002**
Pr03	0.0003	0.0017	0.0005	0.0023	0.0016	0.0005	0.0009	**0.0002**
Pr04	0.0004	0.0013	0.0010	0.0018	0.0038	0.0011	0.0038	**0.0003**
Pr05	0.0004	0.0004	0.0005	0.0008	0.0011	0.0004	0.0018	**0.0002**
Pr06	0.0008	0.0004	0.0005	0.0008	0.0010	0.0007	0.0010	**0.0003**
Pr07	0.0004	0.0005	0.0004	0.0085	0.0013	0.0004	0.0008	**0.0002**
Pr08	0.0003	0.0003	0.0005	0.0019	0.0008	0.0005	0.0006	**0.0002**
Pr09	0.0004	0.0003	0.0004	0.0012	0.0011	0.0012	0.0010	**0.0002**
Pr10	0.0003	0.0008	0.0005	0.0013	0.0008	0.0003	0.0153	**0.0002**
Pr11	0.0004	0.0007	0.0006	0.0016	0.0018	0.0021	0.0033	**0.0001**
Pr12	0.0003	0.0003	0.0004	0.0009	0.0009	0.0004	0.0009	**0.0001**
Pr13	0.0004	0.0003	0.0004	0.0008	0.0015	0.0008	0.0011	**0.0002**
Pr14	**0.0003**	0.0004	0.0005	0.0010	0.0009	0.0004	0.0008	0.0009
Pr15	0.0004	0.0004	0.0004	0.0009	0.0013	0.0004	0.0021	**0.0001**
Pr16	0.0004	0.0003	0.0004	0.0007	0.0011	0.0004	0.0011	**0.0002**
Pr17	0.0004	0.0007	0.0009	0.0009	0.0017	0.0028	0.0023	**0.0001**
Pr18	0.0004	0.0005	0.0006	0.0009	0.0014	0.0033	0.0009	**0.0001**
Pr19	0.0003	0.0003	0.0004	0.0007	0.0009	0.0005	0.0007	**0.0002**
Pr20	0.0004	0.0004	0.0005	0.0007	0.0008	0.0007	0.0008	**0.0001**
Pr21	0.0013	0.0027	0.0018	0.0041	0.0100	0.0047	0.0055	**0.0001**
Pr22	0.0003	0.0021	0.0014	0.0034	0.0020	0.0006	0.0011	**0.0001**
Pr23	0.0003	0.0004	0.0005	0.0008	0.0018	0.0004	0.0013	**0.0001**
Pr24	**0.0003**	0.0004	0.0005	0.0013	0.0010	0.0004	0.0013	**0.0003**

Table 12
Solution speed comparisons (ratio).

Name	NWC	RM	CLM	MM	VAM	RAM	TCM	KSAM
Pr01	**6.25**	2.50	1.39	1.25	1.00	3.13	0.45	**6.25**
Pr02	3.50	1.75	1.75	1.27	1.00	3.50	1.56	**7.00**
Pr03	5.33	0.94	3.20	0.70	1.00	3.20	1.78	**8.00**
Pr04	9.50	2.92	3.80	2.11	1.00	3.45	1.00	**12.67**
Pr05	2.75	2.75	2.20	1.38	1.00	2.75	0.61	**5.50**
Pr06	1.25	2.50	2.00	1.25	1.00	1.43	1.00	**3.33**
Pr07	3.25	2.60	3.25	0.15	1.00	3.25	1.63	**6.50**
Pr08	2.67	2.67	1.60	0.42	1.00	1.60	1.33	**4.00**
Pr09	2.75	3.67	2.75	0.92	1.00	0.92	1.10	**5.50**
Pr10	2.67	1.00	1.60	0.62	1.00	2.67	0.05	**4.00**
Pr11	4.50	2.57	3.00	1.13	1.00	0.86	0.55	**18.00**
Pr12	3.00	3.00	2.25	1.00	1.00	2.25	1.00	**9.00**
Pr13	3.75	5.00	3.75	1.88	1.00	1.88	1.36	**7.50**
Pr14	**3.00**	2.25	1.80	0.90	1.00	2.25	1.13	1.00
Pr15	3.25	3.25	3.25	1.44	1.00	3.25	0.62	**13.00**
Pr16	2.75	3.67	2.75	1.57	1.00	2.75	1.00	**5.50**
Pr17	4.25	2.43	1.89	1.89	1.00	0.61	0.74	**17.00**
Pr18	3.50	2.80	2.33	1.56	1.00	0.42	1.56	**14.00**
Pr19	3.00	3.00	2.25	1.29	1.00	1.80	1.29	**4.50**
Pr20	2.00	2.00	1.60	1.14	1.00	1.14	1.00	**8.00**
Pr21	7.69	3.70	5.56	2.44	1.00	2.13	1.82	**20.00**
Pr22	6.67	0.95	1.43	0.59	1.00	3.33	1.82	**20.00**
Pr23	6.00	4.50	3.60	2.25	1.00	4.50	1.38	**18.00**
Pr24	**3.33**	2.50	2.00	0.77	1.00	2.50	0.77	**3.33**

4. Conclusion

In this paper, a novel approximation method is proposed to create an efficient IBFS to transportation problem which is an important problem in the field of optimization. The method, built on an heuristic structure, differs from the previous methods in that it takes into account the supply – demand coverage ratio (weights) as well as the cost. Another different and superior aspect of the method is that it can solve all transportation problems in the same way regardless of whether the problem is balanced or unbalanced. In order to demonstrate the performance of the method, 24 test problems which are detailed in Table 9 were analyzed. Compared with other methods, KSAM has shown the best initial solution to 17 of these problems. This is followed by VAM, RAM, RM, MM, CLM and TCM methods, respectively. In terms of the solution time, KSAM also showed the best performance. The best solution times for all the problems except for the three problems belong to the proposed method. Compared to the solution times of the VAM method, twenty times faster solutions have been obtained for some problems (See Table 12). On the other hand, the VAM method provided the lowest mean deviation for optimal solution proximity. The VAM method, on average, provides close solutions to the best solution with 1.76%, while the ratio for KSAM is 1.90%. These values are very close to each other. If the results are evaluated in general, it can be said that Karagul-Sahin Approximation Method (KSAM) achieves good solutions as fast as the solutions obtained by the VAM method even faster than the Northwest Corner method. Achieving an effective initial solution for the transportation problem will also reduce the time to reach the optimal solution by methods such as MODI and Stepping Stone. In future

Please cite this article as: K. Karagul and Y. Sahin, A novel approximation method to obtain initial basic feasible solution of transportation problem, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2019.03.003

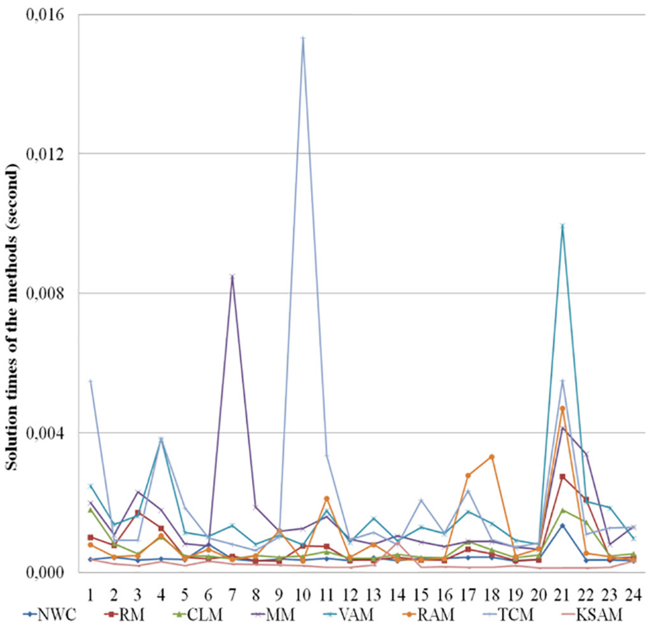

Fig. 5. Solution times of the methods (seconds).

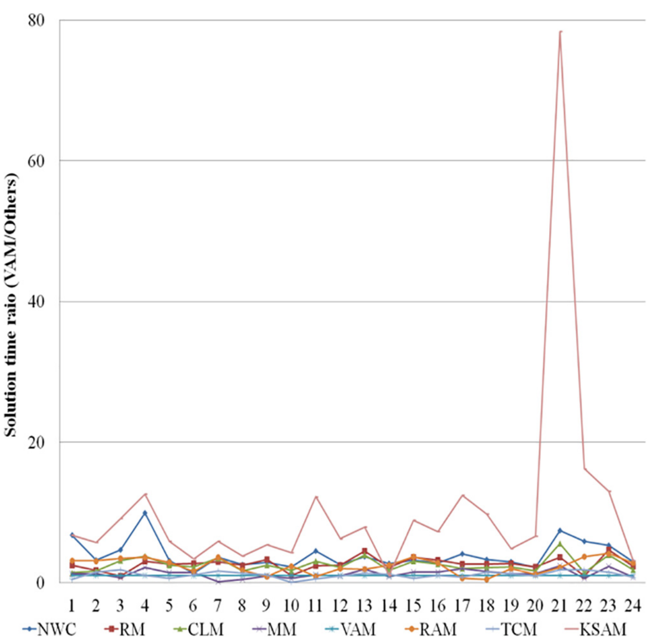

Fig. 6. Comparison of solution speed (ratio).

works, the proposed method can be integrated with the Stepping Stone and MODI methods to evaluate optimal solution calculating performance.

Conflict of interest

No conflict of interest was declared by the authors.

References

Ahmed, M.M., Tanvir, A.S.M., Sultana, S., Mahmud, S., Uddin, M.S., 2014. An effective modification to solve transportation problems: a cost minimization approach. Ann. Pure Appl. Math. 6 (2), 199–206.

Ahmed, M.M., Islam, M.A., Katun, M., Yesmin, S., Uddin, M.S., 2015. New procedure of finding an initial basic feasible solution of the time minimizing transportation problems. Open J. Appl. Sci. 5 (10), 634–640.

Ahmed, M.M., Khan, A.R., Ahmed, F., Uddin, M.S., 2016a. Incessant allocation method for solving transportation problems. Am. J. Oper. Res. 6 (3), 236.

Ahmed, M.M., Khan, A.R., Uddin, M.S., Ahmed, F., 2016b. A new approach to solve transportation problems. Open J. Optimization 5 (01), 22–30.

Ahmed, M.M., Sultana, N., Khan, A.R., Uddin, M., 2017. An Innovative Approach to Obtain an Initial Basic Feasible Solution for the Transportation Problems, 22(1), 23–42.

Albright, S.C., Winston, W.L., 2009. Practical Management Science. South-Western Learning, Mason.

Anderson, D.R., Sweeney, D.J., Williams, T.A., Camm, J.D., Martin, R.K., 2011. An Introduction to Management Science: Quantitative Approaches to Decision Making, Revised. Cengage Learning.

Babu, M.A., Helal, M.A., Hasan, M.S., Das, U.K., 2013. Lowest Allocation Method (LAM): a new approach to obtain feasible solution of transportation model. Int. J. Sci. Eng. Res. 4 (11), 1344–1348.

Babu, M.A., Das, U.K., Khan, A.R., Uddin, M.S., 2014. A simple experimental analysis on transportation problem: a new approach to allocate zero supply or demand for all transportation algorithm. Int. J. Eng. Res. Appl. (IJERA) 4 (1), 418–422.

Ballou, R.H., 1999. Business Logistics Management. Prentice-Hall International, New Jersey.

Bazaraa, M.S., Jarvis, J.J., Sherali, H.D., 2010. Linear Programming and Network Flows. John Willey & Sons, New Jersey, USA.

Can, T., 2015. Yöneylem Araştırması, Nedensellik Üzerine Diyaloglar I". Beta Publications, Istanbul, p. 2015.

Can, T., Koçak, H., 2016. Tuncay Can's Approximation Method to obtain initial basic feasible solution to transport problem. Appl. Comput. Math. 5 (2), 78–82.

Charnes, A., Henderson, A., Cooper, W.W., 1955. An Introduction to Linear Programming. John Wiley & Sons.

Cökelez, S., 2016. Yöneylem/İşlem Araştırması 1 Optimizasyon Modelleri, Çözüm Teknikleri ve Bilgisayar Uygulama ve Yorumları. Nobel Yayınevi, Ankara.

Dantzig, G.B., 1951. Maximization of a linear function of variables subject to linear inequalities. New York.

Das, U.K., Babu, M.A., Rahman, A., Sharif, M., 2014. Advanced Vogel's Approximation Method (AVAM): a new approach to determine penalty cost for better feasible solution of transportation problem. Int. J. Eng. 3 (1), 182–187.

Deshpande, V.A., 2009. An optimal method for obtaining initial basic feasible solution of the transportation problem. In: National Conference on Emerging Trends in Mechanical Engineering (ETME-2009), Vol. 20, p. 21.

Hitchcock, F.L., 1941. The distribution of a product from several sources to numerous localities. Stud. Appl. Math. 20 (1–4), 224–230.

Hosseini, E., 2017. Three new methods to find initial basic feasible solution of transportation problems. Appl. Math. Sci. 11 (37), 1803–1814.

Islam, M.A., Haque, M.M., Uddin, M.S., 2012. Extremum difference formula on total opportunity cost: a transportation cost minimization technique. Prime Univ. J. Multidiscip. Quest 6 (1), 125–130.

Kara, İ., 2000. Doğrusal Programlama. Bilim Teknik Yayınevi, Eskisehir.

Khan, A.R., 2011. A resolution of the transportation problem: an algorithmic approach. Cell 4 (6), 9.

Khan, A.R., Vilcu, A., Sultana, N., Ahmed, S.S., 2015. Determination of initial basic feasible solution of a transportation problem: a TOCM-SUM approach. Buletinul Institutului Politehnic Din Iasi, Romania, Secţia Automatica si Calculatoare, 61 (1), 39–49

Kirca, Ö., Şatir, A., 1990. A heuristic for obtaining and initial solution for the transportation problem. J. Oper. Res. Soc. 41 (9), 865–871.

Korukoglu, S., Ballı, S., 2011. A improved Vogel's Approximation Method for the transportation problem. Math. Comput. Appl. 16 (2), 370–381.

Kumar, R., Gupta, R., Karthiyayini, O., 2018. A new approach to find the initial basic feasible solution of a transportation problem. Int. J. Res. Granthaalayah 6 (5), 321–325.

Mathirajan, M., Meenakshi, B., 2004. Experimental analysis of some variants of Vogel's approximation method. Asia-Pacific J. Oper. Res. 21 (04), 447–462.

Mhlanga, A., Nduna, I.S., Matarise, F., Machisvo, A., 2014. Innovative application of Dantzig's North-West Corner rule to solve a transportation problem. Int. J. Educ. Res. 2 (2), 1–12.

Morade, N.M., 2017. New method to find initial basic feasible solution of transportation problem using MSDM. Int. J. Comput. Sci. Eng. (JCSE) 5 (12), 223–226.

Optimization packages for the Julia language. https://www.juliaopt.org/. (Date of access: 22.05.2018).

Pandian, P., Natarajan, G., 2010. A new algorithm for finding a fuzzy optimal solution for fuzzy transportation problems. Appl. Math. Sci. 4 (2), 79–90.

Prajwal, B., Manasa, J., Gupta, R., 2019. Determination of initial basic feasible solution for transportation problems by: "Supply–Demand Reparation Method" and "Continuous Allocation Method". In: Logistics, Supply Chain and Financial Predictive Analytics. Springer, Singapore, pp. 19–31.

Rohela, N., Agrawal, S.K., Gupta, D., Pawar, M., 2015. A new improve method for solving transportation problem. Int. J. Appl. Math. Stat. Sci. (IJAMSS) 4 (6), 17–24.

Russell, E.J., 1969. Letters to the Editor – Extension of Dantzig's Algorithm to finding an initial near-optimal basis for the transportation problem. Oper. Res. 17 (1), 187–191.

Shafaat, A., Goyal, S.K., 1988. Resolution of degeneracy in transportation problems. J. Oper. Res. Soc. 39 (4), 411–413.

Please cite this article as: K. Karagul and Y. Sahin, A novel approximation method to obtain initial basic feasible solution of transportation problem, Journal of King Saud University – Engineering Sciences, https://doi.org/10.1016/j.jksues.2019.03.003

Singh, S., 2015. Note on transportation problem with new method for resolution of degeneracy. Univ. J. Indus. Bus. Manage. 3 (1), 26–36.

Uddin, M.M., Khan, A.R., Roy, S.K., Uddin, M.S., 2015. A New Approach for Solving Unbalanced Transportation Problem due to Additional Supply. Bulletin of the Polytechnic Institute of Iasi, Romania. Section Textile, Leathership.

Uddin, M.M., Rahaman, M.A., Ahmed, F., Uddin, M.S., Kabir, M.R., 2013. Minimization of transportation cost on the basis of time allocation: an algorithmic approach. Jahangirnagar J. Math. Math. Sci. 28, 47–53.

Uddin, M.S., Anam, S., Rashid, A., Khan, A.R., 2011. Minimization of transportation cost by developing an efficient network model. Jahangirnagar J. Math. Math. Sci. 26, 123–130.