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by Muhammad Saman

Improved total difference method (ITDM): a new approach to solving transportation problem based on modifications of total difference method 1 and integration of total ratio cost matrix

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Abstract: In this paper, the initial basic feasible solution is referred to as the initial feasible solution (IFS). There are two phases in solving the transportation problem (TP). An IFS is determined in the first phase by using the least distribution cost, followed by the calculation of the optimal solution through the modification of total difference method (TDM 1), integrated with total ratio cost matrix (TRCM) in the second phase. In some cases, it has been found that TP has equal values of the distribution least costs so that the existing methods generate two or more IFS values. The newly developed algorithm obtains the optimal solution of TP. A total of 26 numerical examples were selected from reputed journals to evaluate the performance of the newly developed algorithm. The computational performances were compared to the existing methods in the literature and the results showed that this algorithm not only solves TP with similar values optimal solution but also produces better minimal solutions than existing methods.

Keywords: transportation problem; IFS; initial feasible solution; optimal solution; total difference method; TRCM; total ratio cost matrix.

Reference to this paper should be made as follows: Sam'an, M., Dasril, Y., Bujang, N.B. and Farikhin (2022) 'Improved total difference method (ITDM): a new approach to solving transportation problem based on modifications of total difference method 1 and integration of total ratio cost matrix', *Int. J. Computing Science and Mathematics*, Vol. 16, No. 1, pp.13–23.

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1 Introduction

Oil and gas companies incur huge operating expenditure for Oil distribution from refinery production factory to petrol stations throughout the country. Hitchcock (1941) said that optimum solution of the transportation problems (TP) is modelled by linear programming (LP) to achieve the most cost effective transportation routes and network. According to Juman and Hoque (2015), TP revolve around the distribution of the commodities and sources from suppliers to customers, whereby ideally, total supplies must equal total demand.

Generally, there are two phases in solving TP. The first phase involves finding an initial feasible solution (IFS), and the second phase involves searching for the optimal solution of TP based on the IFS obtained. A well performing algorithm is desired to find an IFS for TP because it can significantly affect the computation and iteration process of obtaining the optimal solution for TP. In certain situations, there is a possibility that the IFS is equal to the optimal solution for TP. Furthermore, there is also the possibility that two or more IFSs may not generate the best optimal solution for the TP. Therefore, this research creates a new algorithm for the IFS finding that can prevent two or more IFS complications.

Three well-known classical algorithms are used to obtain the IFS, i.e., northwest corner method (NCM), least cost method (LCM) and Vogel's approximation method (VAM). Many previous studies have been conducted to improve these classical algorithms by proposing an alternative algorithm. For instance, Shimshak et al. (1981) proposed modification of VAM through the heuristics approach to find an IFS for the unbalanced TP; while Goyal (1984) introduced a new version of VAM, known as the Goyal's VAM. Another method to solve TP i.e., total opportunity cost method (TOCM) was introduced by Kirca and Satir (1990). Furthermore, the combinations of TOCM and VAM was proposed by Mathirajan and Meenakshi (2004) and Korukoglu and Balli (2011). Islam et al. (2012) combined TOCM and distribution indicators (DIs) in order to obtain the optimal solution for TP. Khan et al. (2015) introduced the TOCM-SUM approach for a similar purpose. Allocation table method (ATM) and incessant allocation method (IAM) were presented by Ahmed et al. (2016) and Ahmed et al. (2016). Deshmukh (2012) presented a similar algorithm approach. Juman and Hoque (2015) compared VAM, zero suffix method (ZSM) and Sudhakar et al. (2012)'s method. The comparison showed that the Juman Hoque Method (JHM) is superior in obtaining the minimal total cost of 16 out of 18 standard test TP.

Hosseini (2017) did a modification of the total difference method 1 (TDM 1). The VAM algorithm calculates penalty for both rows and columns, while TDM 1 only considers penalty for rows of TP. Harrath and Kaabi (2018) introduced the global minimum method (GMM) and claimed that the performance is better than classical methods especially for large scale of TP. Azad and Hasan (2019) presented an effective algorithm, as known the Azad Hasan method (AHM), for allocating the lowest amount of demand and supply to the lowest distribution cost of the TP. They also claimed this new method is easier and involves less iteration than most of the classical methods. The modification of TDM 1 by adding the rules for selecting the highest penalty value and checking the lowest distribution cost, followed by the combination of TOCM and TDM 1 modification, was introduced (Amaliah et al., 2019). A novel approximation method i.e., the Karagul Sahin Approximation Method (KSAM) was developed (Karagul and Sahin, 2020).

All proposed methods above by previous researchers illustrate the importance of the least distribution costs of TP as a basis for allocating the amount of supply and demand of the TP because it will affect the value of IFS, the performance computation process, the iteration steps, and the minimum total cost.

However, these proposed methods can only run perfectly if the TP do not have equal least cost during the TP computation. Whenever there is equal least cost in TP computation, the methods will fail to determine the least cost. Several alternative solutions have been proposed by choosing one of the equal least cost values available. Nevertheless, these alternative solutions for TP will result in more than one IFS value. Consequently, the IFS value generated will be different and depending on the least cost value which is chosen to compute the IFS.

Therefore, the objective of this research is to overcome the limitations and complications of having two or more IFS values generated through the modification of TDM 1, followed by integrating with total ratio cost matrix (TRCM), which is named as Improved TDM (I-TDM). The proposed I-TDM is designed to obtain an optimal IFS value for the TP.

The rest of this paper is organised as follows. Section 2 introduces the formulation of TP. Section 3 presents the ITDM, Section 4 illustrates the numerical experiment by using the proposed algorithm mentioned in Section 3, while comparative studies are discussed in Section 5, and the conclusion of this research is given in Section 6.

2 Formulation of transportation problem

The formulation of TP is illustrated in Figure 1 with the aim to determine the approximation value of x_{ij} that minimises the total distribution cost as follows

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

subject to

$$\begin{aligned} &\textstyle\sum_{j=1}^{n} x_{ij} \leq s_i, \; i = 1, 2, \ldots, m \\ &\textstyle\sum_{i=1}^{m} x_{ij} \leq d_j, \; j = 1, 2, \ldots, n \\ &x_{ij} \geq 0, \qquad \forall i, j \end{aligned} \tag{2}$$

where m represents total supply, n represents total demand, s_i is ith supply, d_j is jth demand, c_{ij} is distribution cost from ith supply to jth demand, x_{ij} is the number of approximation unit to assign from ith supply to jth demand, min T is minimal total distribution cost, while, total supply identically to total demand is referred as balanced TP and given as

$$\sum_{i=1}^{m} s_i = \sum_{j=1}^{n} d_j \tag{3}$$

Figure 1 The transportation problem table

	D_1	D_2	...	D_n	s_i
S_1	x_{11} c_{11}	x_{12} c_{12}	...	x_{1n} c_{1n}	s_1
S_2	x_{21} c_{21}	x_{22} c_{22}	...	x_{2n} c_{2n}	s_2
⋮	⋮	⋮	⋱	⋮	⋮
S_m	x_{m1} c_{m1}	x_{m2} c_{m2}	...	x_{mn} c_{mn}	s_m
d_j	d_1	d_2	...	d_n	

3 Improved TDM (I-TDM)

The proposed algorithm was checked to see whether or not equation (3) is satisfied, followed by the calculation of row ratio matrix (α_{ij}) and column ratio matrix (β_{ij}) by using equations (4) and (5), respectively. By determining the sum of α_{ij} and β_{ij}, the resulting value is called TRCM. The new proposed algorithm in detail is shown in Algorithm 1,

$$\alpha_{ij} = \frac{c_{ij}}{\theta_i}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{4}$$

$$\beta_{ij} = \frac{c_{ij}}{\theta_j}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{5}$$

where $\theta_i = \min(c_{ij}) = (c_{i1}, c_{i2}, \ldots, c_{in})$ and $\theta_j = \min(c_{ij}) = (c_{1j}, c_{2j}, \ldots, c_{mj})$

Algorithm 1: A New Heuristic TP Algorithm

Data: Initialization: Number of rows is m, Number of column is n, supply (s_i), demand (d_j), distribution cost (c_{ij}), the number of approximation unit (x_{ij})
Result: min T by Eq. (1)
Calculate α_{ij} by Eq. (4) and β_{ij} by Eq. (5);
Calculate the TRCM which is the entries are the sum of the row and column ratio matrix;
TRCM is denoted by ω_{ij}.;
repeat
    {Produce a minimal total distribution cost} ;
    for *i=1 to n* **do**
        Find the penalty (F_j) for each j^{th} column by $F_j = \sum_{i=1}^{m}(\omega_{ij} - \min(\omega_{ij}))$;
        Select highest of F_j (HF) by HF = $\max(F_j)$;
        In case of a break-even (i.e. equal HF);
        (a) select HF with the smallest ω_{ij} ;
        (b) if (a) is equal, then select F_j with the greatest total of TRCM by $T\omega_j = \Sigma_{i=1}^{m}\omega_{ij}$;
        (c) if (b) is equal, then select penalty with the max allocation of x_{ij}.
        Select the least ω_{ij} of HF. If tie, then select least ω_{ij} with max x_{ij};
        Allocate the x_{ij} to it;
        There may arise the following three cases;
        if $\min(s_i, d_j) = s_i$ **then**
            $x_{ij} = s_i$, $d_j = d_j - s_i$, $s_i = 0$, cross out of s_i
        end
        if $\min(s_i, d_j) = d_j$ **then**
            $x_{ij} = d_j$, $s_i = s_i - d_j$, $d_j = 0$, cross out of d_j
        end
        if $s_i = d_j$ **then**
            $s_i = 0$, $d_j = 0$, cross out of s_i and d_j
        end
    end
    Recalculate the penalty without considering the cross out rows and columns
until *(*$\sum_{i=1}^{m} s_i = \sum_{j=1}^{n} d_j$*)*;

4 Algorithm in practice

This research used 26 test problems taken from selected journals to explain the proposed algorithm. For instance, the numerical example of Jude et al. (2017) was: Given a company has four supply plants which produces 6, 9, 7, and 12 cars. The company supplies to four customers, whose demands are 10, 4, 6 and 14 cars, respectively. The distribution cost of the car is shown in Table 1. The objective is to obtain the minimum total distribution cost. The problem is presented in Table 1, solved by using Algorithm 1 as follows,

Table 1 An original data of transportation problem

	D_1	D_2	D_3	D_4	s_i
S_1	2.0	6.0	5.0	3.0	6.0
S_2	9.0	6.0	2.0	1.0	9.0
S_3	5.0	2.0	3.0	6.0	7.0
S_4	7.0	7.0	2.0	4.0	12.0
d_j	10.0	4.0	6.0	14.0	

The solution of the transportation problem example in Table 1 is solved by using Algorithm 1 as follows:

Step 1: Calculating α_{ij} and β_{ij}. For $i, j = 1, 2, 3, 4$ are obtained as bellows:

$$\alpha_{ij} = \begin{pmatrix} 1.0 & 3.0 & 2.5 & 1.5 \\ 9.0 & 6.0 & 2.0 & 1.0 \\ 2.5 & 1.0 & 1.5 & 3.0 \\ 3.5 & 3.5 & 1.0 & 2.0 \end{pmatrix} \text{ and } \beta_{ij} = \begin{pmatrix} 1.0 & 3.0 & 2.5 & 3.0 \\ 4.5 & 3.0 & 1.0 & 1.0 \\ 2.5 & 1.0 & 1.5 & 6.0 \\ 3.5 & 3.5 & 1.0 & 4.0 \end{pmatrix}$$

Step 2: Calculating ω_{ij}. For i, j = 1,2,3,4 is produced as bellow

$$\omega_{ij} = \begin{pmatrix} 1.0+2.0=3.0 & 3.0+3.0=6.0 & 2.5+2.5=5.0 & 1.5+3.0=4.5 \\ 9.0+4.5=13.5 & 6.0+3.0=9.0 & 2.0+1.0=3.0 & 1.0+1.0=2.0 \\ 2.5+2.5=5 & 1.0+1.0=2.0 & 1.5+1.5=3.0 & 3.0+6.0=9.0 \\ 3.5+3.5=7 & 3.5+3.5=7 & 1.0+1.0=2.0 & 2.0+4.0=6.0 \end{pmatrix}$$

Step 3: Calculating F_j. For j=1 so F_1 is obtained is F_1 of column-1 = 19.5; column-2 = 15.0; column-3 = 6.00; column-4 = 13.0.

Step 4: Selecting the highest of F_1 is F_1 of column-2

Step 5: Selecting the least ω_{ij} in F_1 of column-2 is ω_{11}.

Step 6: Allocating the x_{11} to ω_{11} with $x_{11} = \min(s_1, d_1) = \min(6, 10) = 6$ such that $s_1 = s_1 - s_1 = 1 - 1 = 0$ and $d_1 = d_1 - s_1 = 10 - 6 = 4$. Since $s_1 \neq 0$ and $d_1 = 4$ then cross out of s_1.

Step 7: Re-calculating the penalty without considering d_2 such that for j= 2 is obtained F_2 of column-1 = 10.5; column-2 = 12.0; column-3= 2.00; column-4 = 11.0.

Step 8: Repeat Step 3 until Step 6 such that $\sum_{i=1}^{m} s_i = \sum_{j=1}^{n} d_j$. The final result is shown in Table 2

Step 9: Finally, calculating minimal total distribution cost by using equation (1). The result of min T is 83. The feasible solution table of example 1 shown in Table 2.

5 Result of comparison

This section provides a comparison between the existing algorithms i.e., TDM 1 (Hosseini, 2017), AHM (Azad and Hasan, 2019), KSAM (Karagul and Sahin, 2020), and TOCM-MT (Amaliah et al., 2019)) with the proposed algorithm. The comparison results are shown in Table 3. The test problems used in this section are taken from 26 different reputable journals (Kaur et al., 2019; Babu et al., 2013; Karagul and Sahin, 2020; Juman et al., 2013; Juman and Hoque, 2015; Sujatha, 2015; Das et al., 2014; Deshmukh, 2012; Rahman et al., 2017; Islam et al., 2012; Rahman, 2017,?; Jude et al., 2017; Amaliah et al., 2019; Geetha and Anandhi, 2018; Kulkarni and Datar, 2010), where several TP are balanced and the rest are unbalanced problems. The details of the problems is shown in Table 3.

Table 2 The improved TDM with a penalty based on Jude et al. (2017) numerical example

	D_1	D_2	D_3	D_4	s_i
S_1	2.0 (6.0)	6.0 (0.0)	5.0 (0.0)	3.0 (0.0)	6.0
S_2	9.0 (0.0)	6.0 (0.0)	2.0 (0.0)	1.0 (9.0)	9.0
S_3	5.0 (3.0)	2.0 (4.0)	3.0 (0.0)	6.0 (0.0)	7.0
S_4	7.0 (1.0)	7.0 (0.0)	2.0 (6.0)	4.0 (5.0)	12.0
d_j	10.0	4.0	6.0	14.0	
$F*1$	19.5	15.0	6.00	13.5	
$F*2$	10.5	12.0	2.00	11.5	
$F*3$	2.00	0.00	1.00	3.00	
$F*4$	0.00	0.00	0.00	0.00	

Table 3 shows that in terms of IFS the proposed algorithm can solve 10 out of 26 of the test problems which is better compared to TDM 1 algorithm and similar with the other 9 TPs. Moreover, Table 3 also indicates that the TDM 1 algorithm generates better results compared to the proposed algorithm for TP5 and the rest of TP (TP2, TP8, TP12, TP13, TP22 and TP23). The TDM 1 algorithm produced two IFSs, while the proposed algorithm produced only one IFS and for the test problems of TP2, TP8 and TP22, all IFSs produced by TDM 1 algorithm are worse off compared to the proposed algorithm. Next, for test problems of TP12 and TP13, the first IFS produced by the TDM 1 algorithm is equal to the proposed algorithm. In contrast, the second IFS produced by the TDM 1 algorithm is worse than the proposed algorithm. As for test problem TP23, both IFSs produced by the TDM 1 algorithm are better than the proposed algorithm.

The proposed algorithm presented 13 better results out of 26 test problems compared to the AHM algorithm and broke-even with remaining 8 test problems. Table 3 shows that the AHM algorithm produced better results compared to the proposed algorithm for TP5 and for the remaining of TP (TP1, TP3, TP14 and TP22), the AHM algorithm generated two and two of IFS, while the proposed algorithm generated only one IFS. For the test problem of TP1, TP3, TP14 and TP22, all IFSs produced by the AHM algorithm are worsted than the proposed algorithm.

Table 3 also shows that the proposed algorithm provided 15 better results out of 26 test problems compared to weighted transportation cost matrix by supply (WCS) of the KSAM algorithm. Seven of the test problems have equal results and for the remaining TP i.e., TP4, TP16, TP19 and TP21, the WCS of the KSAM algorithms produced two IFSs which. For TP4, TP16 and TP21, both IFSs produced by WCS of KSAM algorithms are not good compared to the proposed algorithm. For TP21, the first IFS produced by the KSAM algorithm is equal to the proposed algorithm, while the KSAM algorithm is not good as the proposed algorithm in producing IFS. Table 3 also shows that the proposed algorithm produced 16 better results out of 26 test problems, compared to the weighted transportation cost matrix by demand (WCD) of the KSAM algorithm and achieved similar results with the 7 test problems. The remaining 3 problems (TP5, TP22 and TP23), the WCD of the KSAM algorithm produced better results than the proposed algorithm. However, for one test problem (TP8), the WCD of the KSAM algorithm produced two IFSs while the other IFSs produced by worse optimal solution compared to the proposed algorithm.

Table 3 The comparison of experiment results with existing algorithm

		Initial feasible solution (IFS)					
				KSAM			
TP	$m \times n$	*TDM1*	*AHM*	*WCS*	*WCD*	*TOCM-MT*	*I-TDM*
TP1	3×5	40	42 &45	43	43	40	40
TP2	4×6	118 &129	118	123	117	114	114
TP3	5×6	98	110 &103	101	103	100	98
TP4	4×4	435	410	435 &470	415	415	415
TP5	5×5	1102	1496	1104	1102	1127	1104
TP6	5×4	2292000	2328050	2418050	2229000	2228500	2168500
TP7	3×3	4450	5025	5025	4525	5225	4525
TP8	3×4	930 &960	920	1050	1040 &1060	930	920
TP9	3×4	859	799	894	924	799	799
TP10	3×4	476	412	516	476	412	412
TP11	4×5	3709	3511	3735	3598	3502	3502
TP12	3×4	104 &105	104	127	109	104	104
TP13	3×4	1060 &1100	1060	1060	1060	1060	1060
TP14	3×5	280	325 &445	340	280	280	280
TP15	3×3	555	595	555	655	555	555
TP16	3×5	870	870	924 &963	930	870	870
TP17	3×3	230	95	95	95	96	95
TP18	3×4	248	241	240	248	240	240
TP19	4×3	81	81	81&127	81	81	81
TP20	4×4	83	112	130	83	83	83
TP21	4×4	2400	3760	2520 &2540	2500	2400	2360
TP22	3×4	1080 &1090	1095 &965	995	965	960	980
TP23	3×4	4720 &4740	5140	5050	4810	4830	4820
TP24	4×3	1465	1675	1465	1545	1465	1465
TP25	3×4	608	678	608	628	658 &678	606
TP26	4×3	980	1020	850	880	980	840

Table 3 also illustrates that the proposed algorithm can solve the test problems better than the TOCM-MT algorithm (10 out of 26 test problems). Both the algorithms have equal results in 14 of test problems. For the one remaining of test problem (TP22), the TOCM-MT algorithm produced better results than the proposed algorithm. For TP25, the TOCM-MT algorithm produced two IFSs. All IFSs produced by the TOCM-MT algorithm are not as good compared to the proposed algorithm.

Babu et al. (2020) proposed the improved VAM (IVAM) to overcome the limitations and computational errors of VAM to determine the IFS of TP. When the IVAM was compared to the proposed algorithm, the IFS is superior to that of IVAM. However, in the case of large scale TP, the IVAM has been proven to solve the problems, while the proposed algorithm has not been tested on TP of this scale. Our research is currently focused on overcoming the same cost matrix for TP. Large scale TP can be considered by researchers in future to develop this research.

6 Conclusions

The determination of IFS is an important part in TP in order to obtain optimal solution, i.e., the minimum total distribution cost. This proposed algorithm is based on the integration of TRCM and of the modified TDM1 algorithms. It also takes into account the ratio cost matrix by row and column as well as the distribution least cost and includes the penalty calculations for each column. This proposed algorithm has the ability to determine the IFS effectively and efficiently. Another unique benefit of this new algorithm is the capability to solve TP that has equal values of least distribution cost, balance and unbalanced TP problems.

Twenty-six test problems selected from reputable journals indicate that the proposed algorithm's numerical results are comparably better than the existing methods. The proposed algorithm achieved better performance than the TDM1, AHM, TOCM-MT, and KSAM algorithms for most test problems. It is recommended that the proposed algorithm should be integrated with the Stepping Stone and MODI methods in future research which will explore the evaluation of the optimal solution TP, large scale of TP and determination of optimal solutions in the event of information uncertainty about the parameters of TP.

Acknowledgements

The authors would like to express their gratitude and appreciation to Universiti Tun Hussein Onn Malaysia (UTHM) Research Management Center through research grant TIER 1 (H777).

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