Journal of Kufa for Mathematics and Computer **Vol.2 ,No.3 ,June, 2015, pp 85-92**

A New Algorithm For Solving Transportation Problem With Network Connected Sources

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Abstract: Solving transportation problems where products to be supplied from one side(sources) to another (demands) with a goal to minimize the overall transportation cost represents an activity of great importance. Most of the works done in the field deals with the problem as two-sided model (Sources such as factories and Demands such as warehouses) with no connections between sources or demands.

However, real world transportation problems may come in another model where sources are connected in a network like graph in which each source may supply other sources in a specific cost. The work in this paper suggests an algorithm and a graph model with mathematical solution for finding the minimum feasible solution for such widely used transportation problems. In this work, the graph representing the problem in which all sources are connected together in a network model with specific cost on each edge is converted into a new graph where additional virtual sources representing supplies between sources are added to the graph , new costs between the added sources and the demands are also calculated, and then modified Kruskal's algorithm is applied to get the minimum feasible solution.

The proposed solution is a straight forward model with strong mathematical and graph models. It can be widely used for solving real world transportation problems with feasible time and space complexity where time complexity of $O(E^2 + V^2)$ is required, where E represents the number of edges and V represents the number of vertices. Different numerical examples were used to study the effectiveness and correctness of the proposed algorithm.

الملخص :

تعتبر مسالة حل مشاكل النقل التي تتألف من جانبين الجانب الأول يمثل المنتجات الموردة (المصادر) والجانب الثاني(المطالب) والتي تهدف إلى تقليل تكلفة النقل الشاملة من المسائل ذات ألأهمية الكبيرة .إن معظم الحلول المطروحة في هذا المجال تعالج مشكلة النقل ذات الاتجاهين (من المصدر كالمصانع مثلا إلى الطلب كالمخازن) مع عدم وجود اتصالات مباشرة بين المصادر. في حين نرى ان هناك في مشاكل النقل في العالم الحقيقي قد يأتي في نموذج آخر حيث ترتبط المصادر فيما بينها بشبكة حيث أن كل مصدر يمكن أن يجهز المصادر الأخرى ضمن تكلفة محددة . تهدف الدراسة في هذا البحث إلى استنباط خوارزمية ونموذج بيان مع الحل الرياضي لإيجاد حل لمشكلة النقل بالتكلفة الدنيا ضمن الحلول الممكنة لمثل هذه المشاكل الشائعة على نطاق واسع. وتتلخص الخوارزمية المقترحة في هذا العمل بتحويل البيان الذي يمثل المشكلة حيث ترتبط جميع المصادر معا في نموذج شبكي بتكلفة محددة على كل حافة إلى بيان جديد حيث يتم إضافة مصادر وهمية إضافية تمثل الإمدادات بين المصادر في البيان الأصلي، كما ويتم احتساب التكاليف الجديدة بين المصادر المضافة والمطالب، ومن ثم يتم تطبيق خوارزمية كروسكال المعدّلة للحصول على احد الحلول الممكنة ذات التكلفة الدنيا. يمثل الحل المقترح نموذجا مباشرا للحل مدعوما بالنماذج الرياضية والبيان ويمكن استخدامه على نطاق واسع من أجل حل مشاكل النقل في العالم الحقيقي. كما ويتميز النموذج المقترح بالكفاءة العالية من ناحية السرعة والتخزين حيث تم حساب تعقيد الوقت ويساوي $O(E^2+V^2)$، حيث يمثل E عدد الحواف ويمثل V عدد من القمم. وقد استخدمت أمثلة عددية مختلفة لدراسة فعالية وصحة الخوارزمية المقترحة.

Keywords: Algorithm, Graph, Transportation Problem, Sorting, Kruskal's Algorithm.

1. Introduction

The transportation problem is concerned with finding the minimum cost of transporting a single commodity from a given number of sources (e.g. factories) to a given number of destinations (e.g. warehouses)[1]-[3].

The data of the model include

1. The level of supply at each source and the amount of demand at each destination.
2. The unit transportation cost of the commodity from each source to each destination.

Since there is only one commodity, a destination can receive its demand from more than one source. The objective is to determine how much should be shipped from each source to each destination so as to minimize the total transportation cost.

Given a transportation model with m sources and n destinations. Each source or destination is represented by a node. The route between a source and destination is represented by an arc joining the two nodes. The amount of supply available at source i is a_i , and the demand required at destination j is b_j . The cost of transporting one unit between source i and destination j is c_{ij} . Let x_{ij} denotes the quantity transported from source i to destination j. The cost associated with this movement is :

Cost × quantity = $c_{ij} x_{ij}$ . .

Minimize $$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \qquad (1)$$

Subject to $$\sum_{j=1}^{n} x_{ij} = a_i, i = 1, 2, 3, \dots, m \qquad (2)$$

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

where $$x_{ij} \geq 0 \qquad (4)$$

The two sets of constraints will be consistent i.e.; the system will be in balance if :

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \qquad (5)$$

The resulting formulation in equations 1-5 is called a balanced transportation model, and in case of unbalanced model, equation (5) becomes

$$\sum_{i=1}^{m} a_i \neq \sum_{j=1}^{n} b_j \qquad (6)$$

Nigus and Sharma proposed a heuristic approach to solve balance andunbalanced transportation problem[4].

NIKOLIĆ solved such problem using total time minimizing approach[5].

Zrinka Lukač, Dubravko Hunjet and Luka Neralić, proposed a model for solving the production-transportation problem in the petroleum industry[6].

Mohammad Kamrul Hasan, presented that the proposed direct methods for finding optimal solution of a transportation problem do not reflect optimal solution continuously[7].

Jose E. Florez et al. proposed a new model for planning Multi-Modal transportation problems[8].

Gaurav Sharma, S. H. Abbas and Vijay Kumar Gupta proposed an approach for solving transportation problem with various methods of linear programming problem[9].

Hakim proposed an alternative method to find initial basic feasible solution of a transportation problem[10].

Hlayel Abdallah Ahmad proposed an approach for solving transportation problems using the best candidates method[11,12].

Kadhim B. S. Al janabi and Anwar Nsaif Jasim proposed an approach for solving transportation problem using modified Kruskal's Algorithm[13].

Abdul Sattar S., Gurudeo A. T., Ghulam M. introduced a comparative study of initial basic feasible solution methods for transportation problems using Mathematical Theory and Modeling[14].

2. Proposed Approach and Formulation

In the proposed model, sources are assumed to be connected to each other via a complete network, this means that a source may supply other sources and may be supplied from other sources as well. The following examples illustrate the proposed approach.

Example 1

The following transportation example contains two sources S_1 and $S_2$and two demands D_1 and D_2 as shown in figure 1.

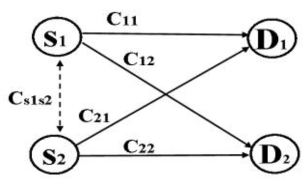

Figure 1. Basic Transportation Example with two Sources and Two Demands.

Since S_1 and S_2 are connected to each other with unit costC_{s1s2}, two more virtual sources to be created S_3 and S_4 where S_3 represents the amount supplied from S_1 to S_2 with cost C_{s1s2},and S_4represents the amount supplied from S_2 to $S_1$with cost C_{s1s2}.And hence the model isconverted into a new graph as shown in figure2.

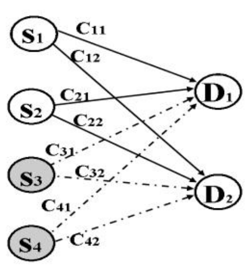

Figure 2. Proposed Model for Transportation Example with two Sources and Two Demands.

The unit costs can be calculated using table 1 and table 2 as follows:

Table 1. Matrix Representation of Example 1

Destinations / Source	D_1	D_2	Supply
S_1	X_{11} C_{11}	X_{12} C_{12}	a_1
S_2	X_{21} C_{21}	X_{22} C_{22}	a_2
S_3	Y_{11} C_{31}	Y_{12} C_{32}	a_3
S_4	Y_{21} C_{41}	Y_{22} C_{42}	a_4
Demand	b_1	b_2	$\sum_{i=1}^{3} a_i = \sum_{j=1}^{2} b_j$

Where

$C_{31}= C_1 + C_{11}$, $C_{32}= C_1 + C_{12}$

$C_{41}= C_2 + C_{21}$, $C_{42}= C_2 +C_{22}$

And for simplicity, we assumed that

$C_1=C_{s1s2}$ and $C_2=C_{s2s1}$

Table 2. Added Sources and Costs.

Added source	
S_3	$S_2 \rightarrow S_1$
S_4	$S_1 \rightarrow S_2$
Added cost	
C_{31}	$C_{s1s2}+ C_{11} = C_1 + C_{11}$
C_{32}	$C_{s1s2+} C_{12} = C_1 + C_{12}$
C_{41}	$C_{s1s2+} C_{21} = C_2 + C_{21}$
C_{42}	$C_{s1s2+} C_{22} = C_2 +C_{22}$

and the total cost can be calculated as

$$Z = \sum_{1}^{2}\sum_{1}^{2} C_{ij} X_{ij} + \sum_{s=1}^{2}\sum_{j=1}^{2} (C_s + C_{sj}) Y_{sj} \quad (7)$$

Example 2

The second transportation example contains three sources S_1, $S_2$and S_3 and two demands D_1 and D_2 as shown in figure 3.

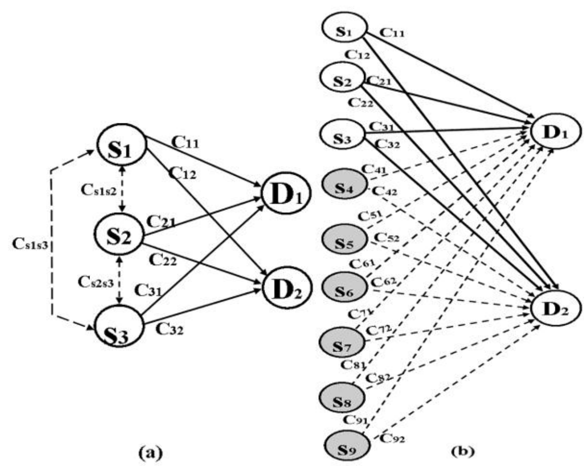

Figure 3. (a) Basic Transportation Example with 3 Sources and 2 Demands,(b) Proposed Model.

Where S_4 through S_9 represent the new added virtual sources, S_4 represents the amount supplied from S_1 to S_2 with cost C_{s1s2} , and S_5 represents the amount supplied from S_2 to S_1 with cost C_{s1s2} and so on. The cost on each edge is calculated as follows:

Table 3.Matrix Representation of Example 2

Destinations / Source	D_1	D_2	Supply
S_1	X_{11} C_{11}	X_{12} C_{12}	a_1
S_2	X_{21} C_{21}	X_{22} C_{22}	a_2
S_3	X_{21} C_{31}	X_{32} C_{32}	a_3
S_4	Y_{11} C_{41}	Y_{12} C_{42}	a_3
S_5	Y_{21} C_{51}	Y_{22} C_{52}	a_5
S_6	Y_{31} C_{61}	Y_{32} C_{62}	a_6
S_7	D_{11} C_{71}	D_{12} C_{72}	a_7
S_8	D_{21} C_{81}	D_{22} C_{82}	a_8
S_7	D_{31} C_{91}	D_{32} C_{92}	a_9
Demand	b_1	b_2	$\sum_{i=1}^{3} a_i = \sum_{j=1}^{2} b_j$

Where

$C_{41}=C_{21}+C_{s1s2}, C_{42}=C_{22}+C_{s1s2},$

…

$C_{91}=C_{21}+C_{s2s3}$, $C_{92}=C_{22}+C_{s2s3}$

For simplicity, we are going to assume that

C_1=Cs1s2

C_2= Cs2s3

C_3=Cs1s3 … and so on

and the total cost is given by:

$$Z=\sum_{i=1}^{3}\sum_{j=1}^{2}C_{ij}X_{ij}+\sum_{s=1}^{3}\sum_{j=1}^{2}(C_s+C_{sj})Y_{sj}+\sum_{s=1}^{3}\sum_{j=1}^{2}(C_s+C_{sj})D_{sj} \quad (8)$$

Table 4 shows the required added virtual sources and the unit costs.

Table 4. Added Sources and Costs for Example 2

Added source	
S_4	$S_2 \rightarrow S_1$
S_5	$S_1 \rightarrow S_2$
S_6	$S_1 \rightarrow S_3$
S_7	$S_3 \rightarrow S_1$
S_8	$S_2 \rightarrow S_3$
S_9	$S_3 \rightarrow S_2$
Added cost	
C_{41}	$C_{s1s2} + C_{11}$
C_{42}	$C_{s1s2} + C_{12}$
C_{51}	$C_{s1s2} + C_{21}$
C_{52}	$C_{s1s2} + C_{22}$
C_{61}	$C_{s1s3} + C_{31}$
C_{62}	$C_{s1s3} + C_{32}$
C_{71}	$C_{s1s3} + C_{11}$
C_{72}	$C_{s1s3} + C_{12}$
C_{81}	$C_{s2s3} + C_{31}$
C_{82}	$C_{s2s3} + C_{32}$
C_{91}	$C_{s2s3} + C_{21}$
C_{92}	$C_{s2s3} + C_{22}$

Example 3

General example with m sources and n demands

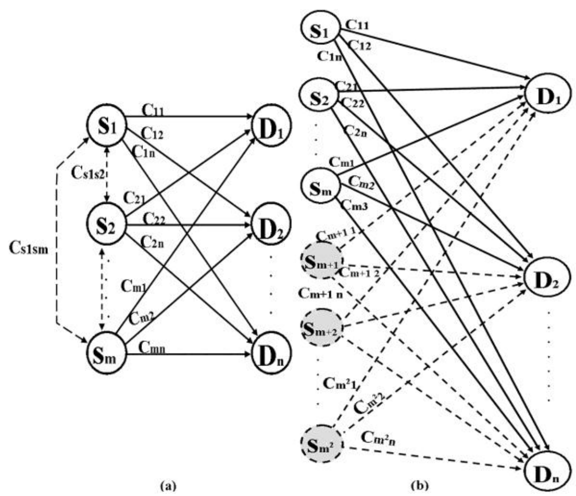

Figure 4. (a) General Example with m Sources and n Demands. (b) The Proposed Model.

Where S_{m+1} represents the amount supplied from S_1 to S_2 with cost C_{s1s2} , and S_{m+2} represents the amount supplied from S_2 to S_1 with cost C_{s1s2} , ... , S_{m^2-1} represents the amount supplied from S_1 to S_m with cost C_{s1sm} , and S_{m^2} represents the amount supplied from S_m to S_1 with cost C_{s1sm}

The cost on each edge is calculated as follows:

$C_{m+1\ 1}=C_{21}+C_{s1s2}$, $C_{m+1\ 2}=C_{22}+C_{s1s2}$, . . . , $C_{m+1\ n}=C_{2n}+C_{s1s2}$
$C_{m+2\ 1}=C_{11}+C_{s1s2}$, $C_{m+2\ 2}=C_{12}+C_{s1s2}$, . . . , $C_{m+2\ n}=C_{1n}+C_{s1s2}$
...
$C_{m^2-1\ 1}=C_{m1}+C_{s1sm}$, $C_{m^2-1\ 2}=C_{m2}+C_{s1sm}$, . . . , $C_{m^2-1\ n}=C_{mn}+C_{s1sm}$
$C_{m^2 1}=C_{11}+C_{s1sm}$, $C_{m^2 2}=C_{12}+C_{s1sm}$, . . . , $C_{m^2 n}=C_{1n}+C_{s1sm}$

Table 5. Added Sources and Costs for Example 3

Added source	
S_{m+1}	$S_1 \rightarrow S_2$
S_{m+2}	$S_2 \rightarrow S_1$
. .	
S_{m^2-1}	$S_1 \rightarrow S_m$
S_{m^2}	$S_m \rightarrow S_1$
Added cost	
$C_{m+1\ 1}$	$C_{s1s2}+C_{21}$
$C_{m+1\ 2}$	$C_{s1s2}+C_{22}$
. .	
$C_{m+1\ n}$	$C_{s1s2}+C_{2n}$
. .	
$C_{m^2 1}$	$C_{s1sm}+C_{11}$
$C_{m^2 2}$	$C_{s1sm}+C_{12}$
. .	
$C_{m^2 n}$	$C_{s1sm}+C_{1n}$

3. Proposed Algorithm

Given a transportation problem with m sources and n demands, the sources are connected in a network like model where each source is connected to all other sources which means that each source can be supplied from other sources. The proposed algorithm is explained in the following steps:

Step 1: Convert the network like connected sources into virtual sources labeled S_{m+1} to S_{m^2}

Step 2: Generate (m^2-m) edges connecting the virtual sources to the demands.

Step 3: Calculate the unit costs of transportation between the newly generated sources and demands.

Step 4: Generate the complete graph.

Step 5: Generate an ascending ordered array based on the unit cost of transportation. The array contains the edges and the related costs.

*Step 6:*Delete the edge having minimum cost and the related source/demand depending on which one is satisfied first, and delete all the related edges. Add the minimum cost to the overall.

Step 7: repeat step 6 until all demands/sources are satisfied.

4. Proposed Algorithm Pseudo code

1. Graph(G)
2. Input S_i, D_j, a_i, b_j, C_k and C_{ij} where i=1 to m, j=1to n, k=m+1 to m^2
3. Generate m^2-m virtual sources and (m^2-m)*n edges
4. Calculate new costs Cs_is_ji=1 to m and j=1 to m and I ≠ j
5. Generate the new graph G1
6. A= Ø, Total Cost=0
7. For each (u,v) in G1 ordered by weight(u,v) increasing:
8. A=A U {(u,v)}
9. Find supply X_{uv}
10. Total Cost +=C_{uv} * X_{uv}
11. IF SOURCE capacity is covered
12. Delete all rows corresponding to S
13. End if
14. IF DEMAND capacity is covered
15. Delete all rows corresponding to D
16. End if
17. Union (u,v)
18. Return A, Total Cost

5. Testing Examples

Example 1: Numerical example with two sources and two demands. as shown in figure 5 (a).

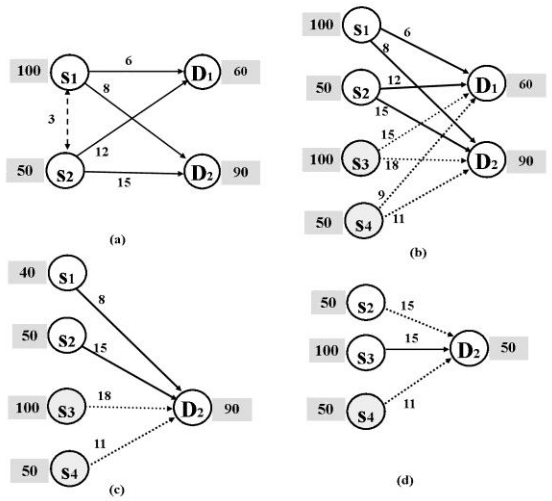

Figure 5. (a) Transportation Example, (b) Proposed Model, (c) and (d) Finding Minimum Feasible Solution.

Where S_3 represents the amount supplied from S_1 to S_2 with cost 3 ,and S_4represents the amount supplied from S_2 to S_1 with cost 3.

$C_{31}=C_{21}+C_{s1s2} = 12+3 = 15$

$C_{32}=C_{22}+C_{s1s2} = 15+3 = 18$

$C_{41}=C_{11}+C_{s1s2} = 6+3 = 9$

$C_{42}=C_{12}+C_{s1s2} = 8+3 = 11$

The complete solution is show in table 6,where all the edge costs are arranged in an increasing order[13]. In step 1, the first element represents the edge with minimum cost which is S_1D_1 with a unit cost of 6. And since D_1 is satisfied, all the edges coming into D_1 is removed from the table (S_4D_1, S_2D_1, and S_3D_1). In step 2, the new minimum cost is S_1D_2 with unit cost equals to 8, all the edges from S_1 is deleted since S_1 is covered. In step 3, the minimum cost is 11 on the edge S_4D_2 which means that D_2 is covered.

Table 6. Representation of the Proposed Algorithm for Example 1

N	Edge	cost	step1 Cost = 6*60 = 360		step2 Cost=360+8*40 = 680		step3 Cost = 680+11*50 =1230	
1	S_1D_1	6	X		X		X	
2	S_1D_2	8	S_1D_2	8	X		X	
3	S_4D_1	9	X		X		X	
4	S_4D_2	11	S_4D_2	11	S_4D_2	11	X	
5	S_2D_1	12	X		X		X	
6	S_2D_2	15	S_2D_2	15	S_2D_2	15	X	
7	S_3D_1	15	X		X		X	
8	S_3D_2	18	S_3D_2	18	S_3D_2	18	X	

Example 2. Numerical example with three sources and two demands (unbalanced system).

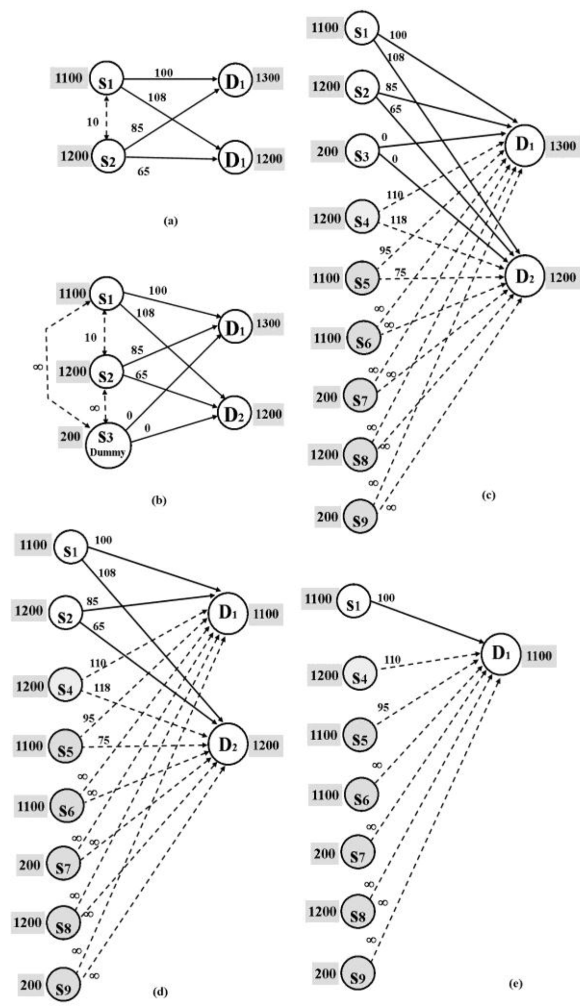

Figure 6. (a) Unbalanced Problem, (b)Equivalent balanced Model, (c) Proposed Model, (d) and (e) Finding Minimum Feasible Solution.

Where S_4 represents the amount supplied from S_2 to S_1 with cost 10 and S_5 represents the amount supplied from S_1 to S_2 with cost 10, and so on. The new unit costs are calculated as follows:

$C_{41}= C_{s1s2} + C_{11} = 10 +100 = 110$

$C_{42}= C_{s1s2} + C_{12} = 10 +108 = 118$

$C_{51}= C_{s1s2} + C_{21} = 10 + 85 = 95$

$C_{52}= C_{s1s2} + C_{22} = 10 + 65 = 75$

$C_{61}= C_{s1s3} + C_{31} = \infty + 0 = \infty$

$C_{62}= C_{s1s3} + C_{32} = \infty + 0 = \infty$

$C_{71}= C_{s1s3} + C_{11} = \infty +100 = \infty$

$C_{72}= C_{s1s3} + C_{12} = \infty +108 = \infty$

$C_{81}= C_{s2s3} + C_{31} = \infty + 0 = \infty$

$C_{82}= C_{s2s3} + C_{32} = \infty + 0 = \infty$

$C_{91}= C_{s2s3} + C_{21} = \infty + 85 = \infty$

$C_{92}= C_{s2s3} + C_{22} = \infty + 65 = \infty$

And the complete solution is show in table 7.

Table 7. Representation of the Proposed Algorithm for Example 2.

N	Edge	cost	step1 Cost = 0*200 = 0		step2 Cost = 0+65*1200 = 78000		step3 Cost = 78000+95*1100 = 182500	
1	S_3D_1	0	X		X		X	
2	S_3D_2	0	X		X		X	
3	S_2D_2	65	S_2D_2	65	X		X	
4	S_5D_2	75	S_5D_2	75	X		X	
5	S_2D_1	85	S_2D_1	85	X		X	
6	S_5D_1	95	S_5D_1	95	S_5D_1	95	X	
7	S_1D_1	100	S_1D_1	100	S_1D_1	100	X	
8	S_1D_2	108	S_1D_2	108	X		X	
9	S_4D_1	110	S_4D_1	110	S_4D_1	110	X	
10	S_4D_2	118	S_4D_2	118	X		X	
11	S_6D_1	∞	S_6D_1	∞	S_6D_1	∞	X	
12	S_6D_2	∞	S_6D_2	∞	X		X	
13	S_7D_1	∞	S_7D_1	∞	S_7D_1	∞	X	
14	S_7D_2	∞	S_7D_2	∞	X		X	
15	S_8D_1	∞	S_8D_1	∞	S_8D_1	∞	X	
16	S_8D_2	∞	S_8D_2	∞	X		X	
17	S_9D_1	∞	S_9D_1	∞	S_9D_1	∞	X	
18	S_9D_2	∞	S_9D_2	∞	X		X	

6. Conclusion

Many techniques were used to solve traditional transportation problems with the goal to find out the minimum feasible solution. The work in this paper proposed a new approach to solve the transportation problems in which sources are connected to each other in a network like model where sources can be supplied from other sources with specific costs. The proposed approach is based mainly on converting the transportation model with network like sources into a traditional graph model with additional virtual sources and edges, new unit costs are calculated, and then the costs of the edges are arranged in ascending order from which the edge having minimum cost is considered first until all demands or sources are verified.

Figures 1 through 6 and the results show in tables 6 and 7 give clear explanation for the proposed algorithm and its performance on different types of the transportation models both balanced and unbalanced.

The accuracy, scalability and effectiveness of the proposed approach were studied using two different numerical examples. The proposed approach works with a time complexity $O(E^2 + V^2)$.

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