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CONTRIBUTIONS TO BOOKS

- Sharma T., Kwatra, G. (2008) Effectiveness of Social Advertising: A Study of Selected Campaigns, Corporate Social Responsibility, Edited by David Crowther & Nicholas Capaldi, Ashgate Research Companion to Corporate Social Responsibility, Chapter 15, pp 287-303.

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- Schemenner, R.W., Huber, J.C. and Cook, R.L. (1987), "Geographic Differences and the Location of New Manufacturing Facilities," Journal of Urban Economics, Vol. 21, No. 1, pp. 83-104.

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ANOTHER APPROACH OF SOLVING UNBALANCED TRANSPORTATION PROBLEM USING VOGEL'S APPROXIMATION METHOD

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ABSTRACT

Solution of any Transportation Problem (TP) necessitates Initial Basic Feasible Solution (IBFS) to get optimal schedule of shipment of goods. The better the initial solution is, less computational efforts and less time is required to generate optimal solution. One of the most powerful methods to determine IBFS is Vogel's Approximation Method (VAM) among many other methods available in the vast literature of TP. Very few literature are available on handling unbalanced TP using VAM. Initial solution of unbalanced TP is very much based on how VAM process 'ZERO' in the dummy cells. For this purpose we have presented another approach of getting IBFS of unbalanced TP using VAM and to test efficiency of proposed heuristic with the existing methods for the same VAM and VAM-Total Opportunity Cost (TOC).

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C630 Computational Techniques

KEYWORDS
Initial Basic Feasible Solution, Real Allocations, Total Opportunity Cost, Unbalanced Transportation Problem, Vogel's Approximation Method.

1.0 INTRODUCTION

The Transportation Problem (TP) deals with a situation in which a single product is to be transported from several sources (S) (called origin, supply / capacity centers) to several sinks (called destination, demand / requirement centers). In general, let there be m sources S_1, S_2, … S_m having $\mathbf{a_i}$ (i=1,2,…,m) units of supply or capacity, respectively, to be distributed among n destinations (D) D_1, D_2,…, D_n with $\mathbf{b_j}$ (j=1,2,…n) units of requirement, respectively. Let $\mathbf{c_{ij}}$ be the cost of shipping one unit of the commodity from sources i to destination j for each route. If $\mathbf{x_{ij}}$ represents number of units shipped per route from source i to destination j, then the problem is to determine the transportation schedule so as to minimize the total transportation cost satisfying supply and demand condition. That is, the problem is to determine how quantity of goods to be shipped from each origin to several destinations so as to minimize the total transportation cost.

Mathematically, Transportation Problem is stated as follows:

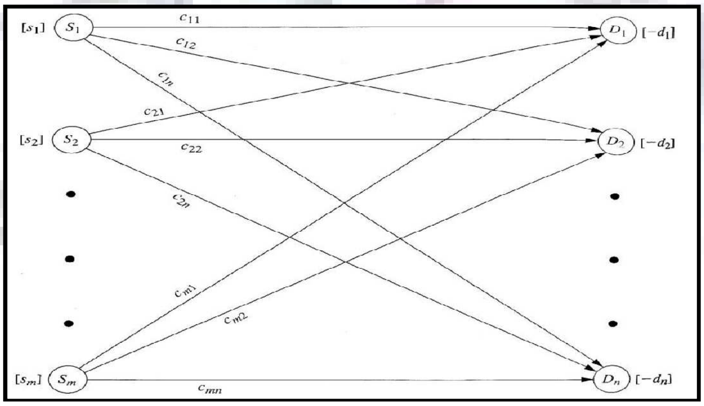
Minimize (total cost) $Z = \sum_{i}^{m} \sum_{j}^{n} c_{ij} * x_{ij}$

Subject to the constraints

$\sum_{j}^{n} x_{ij} = a_i$, ▼ i = 1,2,…,m **(supply constraint)**

$\sum_{i}^{m} x_{ij} = b_j$, ▼ j = 1,2,…,n **(demand constraint)**

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



Original Unit Transportation Cost Matrix is known as TC matrix. Kirca and Satir [6] first transformed the TC Matrix to Total Opportunity Cost Matrix (TOCM), where for each row / column in the original TC Matrix, Row Opportunity Cost Matrix (ROCM) / Column Opportunity Cost Matrix (COCM) is generated by subtracting the smallest cost in the row /column from other cost elements in the same row / column. Transportation Cost Matrix obtained by adding corresponding elements of ROCM and COCM is known as TOCM; i.e. TOCM = ROCM + COCM. Kirca and Satir [6] effectively use the Greedy algorithm (LCM) with some tie-breaking rules on the TOC matrix to generate an IBFS to the TP. Mathirajan and Meenakshi [7] used VAM on the TOC matrix instead of TC matrix which showed significant improvement in IBFS. Now we shall develop TOC Matrix of a balanced TP using an example. Table – 1 and Table – 2 shows the TC and TOC matrix respectively as shown below:

TABLE – 1

Balanced Transportation Problem (**TC**) Matrix				
↓S \ D →	A	B	C	Supply
01	2	7	4	50
02	3	3	1	80
03	5	4	7	70
04	1	6	2	140
Demand	70	90	180	340

TABLE – 2

Balanced Transportation Problem (**TOC**) Matrix				
↓S \ D →	A	B	C	Supply
01	1	9	5	50
02	4	2	0	80
03	5	1	9	70
04	0	8	2	140
Demand	70	90	180	340

Necessary and sufficient condition for the existence of a feasible solution to the transportation problems is called **rim condition** given by Total Supply = Total Demand i.e. $\boldsymbol{\Sigma\, a_i = \Sigma\, b_j}$

Most of the TP are Unbalanced in nature. If total demand is not the same as total supply, the problem is called **Unbalanced Transportation Problem**.

(i) When the total capacity of the origins exceeds the total requirement of destinations (**Supply Imbalance TP**), a dummy destination (column) is introduced in the transportation matrix which absorbs the excess capacity. The cost of shipping from each origin to this dummy destination is assumed to be zero. The insertion of a dummy destination establishes equality between the total origin capacities and total destination requirements. The problem is then amenable for solution by the transportation algorithm. For some of the unbalanced TP, the dummy values are taken as positive numbers. Few TPs use unit inventory holding costs in the cells of dummy column.

(ii) When total capacity of origins is less than the total requirement of destinations (**Demand Imbalance TP**), a dummy origin (row) is introduced in the transportation matrix to meet out the excess demand. The cost of shipping from the dummy origin to each destination is assumed to be zero. The introduction of a dummy origin establishes the equality between the total capacity of origins and the total requirement of destinations. The problem is then amenable for solution by the transportation algorithm. For some of the unbalanced TP, the dummy values are taken as positive numbers. Few TPs use unit shortage cost in the cells of dummy row.

An attempt to get better initial solutions for the problem is made so that computational effort at the second step becomes easier and less number of iterations is required to determine the optimum solution. A number of heuristic are available to get an initial basic feasible solution. Although some heuristics can find an initial feasible solution very quickly, often the solution they find is not very good in terms of minimizing total transportation cost. On the other hand, some heuristics may not find an initial solution so quickly, but the solution they find is often very good in terms of minimizing total cost. Well known heuristics methods are North West Corner Rule, Least Cost Cell Method, Vogel's Approximation Method (VAM) [1, 2]**.** Shimshak [3] et al's version of VAM, Goyal's [4] version of VAM, Ramakrishnan's [5] version of VAM show improvement in determination of initial feasible solution for large scale Transportation Problems. Kirca and Satir [6] developed a heuristic to obtain efficient initial basic feasible solution, called **T**otal **O**pportunity **C**ost (**TOC**). Mathirajan and Meenakshi [7] extended TOC using the VAM procedure. They coupled VAM with the total opportunity cost TOC and achieved very efficient initial solutions. An **I**mproved version of VAM (**IVAM**) was suggested by Serdar Korukoglu and Serkan Balli [8]. Goyal [4] and Ramakrishnan [5] proposed to use maximum shipping cost as the cost in the dummy cells. Hence they discourage making allocations in the cells of dummy row / dummy column until last step.

Usually the zero cells in dummy row / dummy column are treated the same way as real cost cells and then the problem is solved as balanced problem. Various heuristics are available for finding IBFS of Transportation Problem. One of the most efficient methods to determine IBFS is VAM. Allocations in the TP matrix always depend on all previous allocations. While applying Original VAM to find IBFS of any Unbalanced TP, first allocation is made to dummy cell in the problem matrix. Hence, actually we begin the solution with allocation in a dummy (fictitious) cell first, which is least preferred for making allocation. However the cost in the dummy cells is zero, it does not add to the initial cost of transportation, it affects the remaining allocations in the matrix and quality of initial solution of unbalanced TP. However, insertion of dummy row below the real origins / dummy column after the real destinations suggests that we desire allocations to be done in corresponding dummy cells at last.

2.0 ANOTHER METHOD FOR SOLVING UNBALANCED TRANSPORTATION PROBLEM

In this article we propose that zero / non-zero cost dummy cells should not be treated as real cost cells until last allocation. It should also be taken care that at any stage dummy cells should not be considered for computing penalties or shipment of goods while using VAM for getting IBFS of unbalanced TP. All initial allocations are done in '**REAL**' cells and allocations to dummy cells are done at the end. We shall call this method '**VAM-R'**. Goal of this methodology is the same suggested by Goyal [4]. Objective of this paper is to compare IBFS obtained using proposed algorithm with solution using original VAM applied to unbalanced TP and solution using original VAM applied to TOC matrix of unbalanced Transportation (VAM-TOC).

2.1 PROPOSED ALGORITHM – [VAM-R]

Following is the algorithm for another method of solving unbalanced transportation problem.

Step **1**: Balance the given transportation problem if either (total supply > total demand) or (total supply < total demand).

Step **2**: Determine the penalty cost for each row and each column by subtracting the lowest cell cost in the row or column from the next lowest cell cost in the same row or same column.

Here ignore computing penalty for dummy row / dummy column. Also ignore zero / non-zero dummy cell values while computing penalties.

Step **3**: Select the rows or columns with the highest penalty costs. If tie occurs in highest penalties among rows or columns, then select least cost cell in those rows or columns. Further if there is tie in least cost cells, select the cell with maximum possible allocation at lowest cost. (i.e. allocating as much as possible to the feasible cell at the lowest transportation cost.) If tie occurs in allocating maximum possible amount then select cell in the row (column) with maximum supply (demand).

Step **4**: Strike off the row or column for which supply or demand is exhausted.

Step **5**: Repeat steps 2-4 on the reduced matrix until all requirements have been met in such a way that allocation(s) in the dummy cells will be done at the end.

Step **6**: Compute total transportation cost for the feasible allocations using the original transportation cost matrix.

To compare our method with Goyal's method [4], we have taken an example illustrated by Goyal [4] and then solved using both methods. The results are shown in Table – 3, Table – 4 and Table – 5 respectively. These tables show TC matrix illustrated by Goyal, IBFS using Goyal's method and IBFS using VAM-R.

TABLE – 3

↓From \ To →	**1**	**2**	**3**	**Available**
A	06	10	14	**50**
B	12	19	21	**50**
C	15	14	17	**50**
Required	**30**	**40**	**55**	**125 / 150**

IBFS using Goyal's Method is shown below.

TABLE – 4

↓From \ To →	**1**	**2**	**3**	**Dummy**	**Available**
A	06	10 [40]	14 [10]	**21**	**50**
B	12 [30]	19	21	**21 [20]**	**50**
C	15	14	17 [45]	**21 [5]**	**50**
Required	**30**	**40**	**55**	**25**	**150**

IBFS using proposed algorithm [VAM-R] is shown below.

TABLE – 5

↓From \ To →	1	2	3	Dummy	Available
A	06	10 [40]	14 [10]	0	50
B	12 [30]	19	21	0 [20]	50
C	15	14	17 [45]	0 [5]	50
Required	30	40	55	25	150

2.2 COMPARISON BETWEEN VAM, GOYAL'S METHOD AND VAM-R

IBFS using VAM-R algorithm is better than solution using conventional VAM for unbalanced TP. It is interesting to note that both method, Goyal's method and VAM-R, give the same initial solution which comes out to be 1665. However optimum solution is 1615. If we solve the same problem using VAM it requires **2** improvements while Goyal's method and our method require only one improvement for the same optimum solution. Goyal [4] suggested that the costs of transportation in dummy cells are assumed equal to the highest unit transportation cost before applying VAM. With this modification to applying VAM for unbalanced TP, the allocation of units in dummy cells is given least priority. VAM-R algorithm differs from Goyal's modification to applying VAM in two ways. One, it considers transportation costs in the dummy cells equal to zero as compared to highest unit transportation cost suggested by Goyal [4]. Second, values in the dummy cells are avoided while computing penalties for each row and each column at every stage and hence they are avoided for making allocation until last real allocation is done.

Next, we shall take another example to illustrate our method when dummy cell values are zero.

Example-1: - Here we wish to minimize the cost of advertisement (Rs.) in different age-group (13-18, 19-25, 26-35, above 35) using different media (M1, M2, M3). Vohra N. D. [9]

Table – 6 and Table – 7 respectively shows the original TC matrix and IBFS using VAM.

TABLE – 6

Media	←- Age Groups --→				Supply
	13-18	19-25	26-35	> 35	
M1	10	07	10	10	40
M2	12	09	12	10	30
M3	14	12	09	12	20
Demand	30	25	15	10	80 / 90

TABLE – 7

Media	←- Age Groups --→					Supply	Penalties				
	13-18	19-25	26-35	> 35	Dummy		P1	P2	P3	P4	P5
M1	10 [15]	07 [25]	10	10	0	40	7	←(3)	0	0	-
M2	12 [10]	09	12	10 [10]	0 [10]	30	←(9)	1	2	2	←(2)
M3	14 [5]	12	09 [15]	12	0	20	9	3	←(3)	2	2
Demand	30	25	15	10	10	90					
P1	2	2	1	0	0						
P2	2	2	1	0	-						
P3	2	-	1	0	-						
P4	(2) ↑	-	-	0	-						
P5	2	-	-	(2)↑	-						

IBFS USING VAM

We obtained IBF non-degenerate Solution Using VAM as Rs. 750.

This solution requires 1 improvement to reach optimum solution as Rs. 740

Now we shall solve the same example using VAM-R which results in optimal solution as shown in Table – 8.

TABLE – 8

Media	←- Age Groups --→					Supply	P1	P2	P3	P4
	13-18	19-25	26-35	> 35	Dummy					
M1	10 [15]	07 [25]	10	10	0	40	←(3)	0	0	-
M2	12 [15]	09	12	10 [10]	0 [5]	30	1	2	2	←(2)
M3	14	12	09 [15]	12	0 [5]	20	3	←(3)	2	2
Demand	30	25	15	10	10	90				
P1	2	2	1	0	X					
P2	2	-	1	0	X					
P3	↑(2)	-	-	0	X					
P4	2	-	-	↑(2)	X					

IBFS USING VAM-R IBF non-degenerate Solution Using VAM-R is Rs. 740 which is **Optimum Solution**.

Hence proposed algorithm, VAM-R, works efficiently on unbalanced TP as it reduces the computational task, i.e. number of iteration(s) required for improvement of IBFS to get optimum solution and time required to reach optimum solution. Also the number of penalties has reduced.

Remark:-

1. Here P1, P2 … P4, P5 denote respective row penalties and column penalties.
2. 'X' denotes that 'no' penalty is computed for dummy column.
3. Values in **[ ]** show actual non-zero allocation in corresponding cells.
4. ←(3) under P1 denotes highest penalty to be considered for allocation in the lowest cost cell in row M1 and so on.

Example-2: - Next, we take an example where dummy values are non-zero.

TABLE – 9

↓ Supplier \ Outlet →	O1	O2	O3	Supply
S1	5	1 [10]	7	10
S2	6 [60]	4 [10]	6 [10]	80
S3	3 [15]	2	5	15
Demand	75	20	50	145 / 105

Table – 9 shows original TC matrix.

TABLE – 10

↓ Supplier \ Outlet →	O1	O2	O3	Supply
S1	5	1 [10]	7	**10**
S2	6 [60]	4 [10]	6 [10]	**80**
S3	3 [15]	2	5	**15**
Dummy	**5**	**3**	**2 [40]**	**40**
Demand	**75**	**20**	**50**	**145**

Table – 10 shows IBFS using VAM-R algorithm. IBFS using VAM-R is Rs. 595 which is the same as **Optimum Solution**. Here, **non-zero** cell values in the dummy column represent unit penalties for unsatisfied demand at respective retail outlet. Thus, VAM-R works efficiently in case of non-zero dummy cell-values.

3.1 COMPUTATIONAL EXPERIMENT AND MEASURES OF PERFORMANCE

Quality of any heuristic is major concern because closer the IBFS to optimum solution, less number of iterations is required to determine optimum feasible solution. For testing efficiency and evaluating performance of the proposed algorithm, VAM-R, with available heuristics, VAM and VAM-TOC, computational experiment were carried out on a set of **12 unbalanced TP** of both type – Supply Imbalance and Demand Imbalance; with zero and non-zero values in dummy cells. Performance measures used to determine efficiency of proposed heuristic are as follows:

1) Percentage of Optimum Solutions by each heuristics and
2) Average Number of Iterations required to obtain optimal solution using the initial solution by any heuristic.

3.2 ANALYSIS AND COMPARISON

Comparison of Percentage of Optimum Solutions and Average Number of Iterations required determining optimal solution using the initial solution by any heuristic.

Table – 11 shows IBFS using three heuristics; VAM, VAM-TOC and VAM-R along with Number of Iterations required to obtain optimal solution using the initial solution by any heuristic.

TABLE – 11

IBFS using VAM	No. of Iteration to reach optimum solution	IBFS using VAM-TOC	No. of Iteration to reach optimum solution	IBFS using VAM-R	No. of Iteration to reach optimum solution	Optimum Solution using MODI method
820	2	740	1	760	1	**720**
1510	1	1540	1	1510	1	**1465**
740	2	**710**	**0**	**710**	**0**	**710**
97	3	113	1	**92**	**0**	**92**
168	1	140	1	**128**	**0**	**128**
917	1	909	1	917	1	**893**
98	1	98	1	**90**	**0**	**90**
2752	1	**2424**	**0**	**2424**	**0**	**2424**
700	**0**	**700**	**0**	**700**	**0**	**700**
14544	**0**	**14544**	**0**	**14544**	**0**	**14544**
180	**0**	196	**1**	**180**	**0**	**180**
1590	**0**	**1590**	**0**	**1610**	**1**	**1590**
Total =	**12**	**Total =**	**7**	**Total =**	**4**	-

SUMMARY RESULTS

TABLE – 12

Heuristics Surveyed	(% of Best Solution , Standard Error)	Average Number of Iterations required to reach Optimum Solution for IBFS that are non-optimal
VAM – R	**(66.67%, 13.61%)**	**1.0**
VAM	**(33.33%, 13.61%)**	**1.5**
VAM – TOC	**(41.67%, 14.23%)**	**1.0**

4 CONCLUSION

Vogel's Approximation Method is applied to original Transportation Cost matrix in two different ways. One is conventional VAM approach and other is alternative approach of using VAM for Unbalanced TP, i.e. VAM-R. Also VAM is applied to Total Opportunity Cost (TOC) matrix, as suggested by Mathirajan and Meenakshi [7], (VAM-TOC). Original VAM is weaker to produce good quality IBFS of unbalanced TP. VAM-R approach of making allocations to all 'REAL' cells first and allocations in the dummy cells be made at last benefit much in the terms of defined performance measures. Large proportion of problems produces optimum solution very quickly and requires less computational effort and less time to reach optimal solution. VAM-R is more competent to handle dummy cells in unbalanced TP and hence produce better quality IBF solutions of unbalanced TP.

Summary Results Table – 12 clearly shows that, for unbalanced Transportation Problem, applying VAM-R is more efficient than original VAM and VAM-TOC heuristics in terms of percentage of best solutions and average number of iterations required to reach optimal solution.

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