Analysing impact of strategies adopted by decision makers on performance parameters of bi-criteria transportation problem

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Abstract: The most common methodology adopted for evaluation of optimal transportation schedule is the conventional cost benefit analysis which provides decision makers with a monetary assessment of a transportation schedule. A mechanism is needed to capture the impact of strategy adopted by decision makers in case of bi-criteria transportation problem on the performance parameters like cost and time. In this paper, an algorithm has been proposed to solve bi-criteria transportation problem with the objective of minimising both cost and time which satisfies the constraints of demand and supply. The algorithm also enables one to obtain the optimal transportation schedule by incorporating the decision makers' priority towards cost and time. Consequently, the algorithm provides a scope to evaluate the impact of strategy adopted by decision makers in obtaining the optimal solution on total cost and time of transportation. The algorithm is explained with the help of an elaborate illustration. The result obtained by the proposed algorithm is compared with that suggested by researchers in the past for validation. The impact of variation in decision maker's strategy is assessed in terms of percentage change in total cost of transportation and maximum time taken for transportation following the optimal route.

Keywords: bi-criteria transportation problem; cost minimisation; impact of strategy; time minimisation.

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1 Introduction

The classical transportation problem (TP) deals in optimising the distribution of commodities from different sources to different destinations with the objective of minimising total cost of transportation. TP involves many shipping routes from various sources to different destinations. Single objective TP determines the number of units of an item that should be shipped from an origin to a destination so as to minimise the cost or time of transportation satisfying the required quantity of goods or services at each destination. Basic feasible solution for cost optimisation TP can be obtained by North West corner method, least cost method and Vogel's approximation method (Taha, 2007). The optimal solution for cost optimisation TP can be obtained by steppingstone method and MODI method (Taha, 2007).

Single objective TPs like cost minimisation or time minimisation TP can be solved using the conventional methods to find initial feasible solution. A simple algorithm has been proposed by Uddin (2012) to determine the initial basic feasible solution for time minimisation TP which provides result which is very close to the optimal solution. The algorithm requires computation of distribution indicator (DI) for each row and column by taking difference between largest and second largest entry in the row/column. Thereafter, allocation is made in the cell having lowest entry along the largest DI in row/column. An alternate method to find a basic feasible solution to cost optimised TP is the best candidate method which is faster than the conventional methods and provides a solution with less complexity (Hlayel and Alia, 2012). The concern of managers in fast-changing global market is the cost uncertainty associated with cost matrix in TP. Adlakha and Arsham (1998) addressed this issue and proposed an algorithm which enables managers to determine the sensitivity of current optimal solution to uncertainties. Fixed-charge TP with logarithmic objective function has been studied by researchers and its structural behaviour is compared with TP with polynomial objective function (Acharya et al., 2018). Acharya et al. (2015) discussed the paradox associated with fixed cost TP and suggested paradoxical range of flow.

In practical situation, a TP may have more than one objective function and may have more than one mode of transport. The decision makers (DM) decide the optimal route of transportation which satisfies all the objectives. Bi-criteria TP has been studied by researchers since 1970s (Aneya and Nair, 1979). Ahmed et al. (2014) proposed a convergent algorithm to generate efficient pairs of values for the objective function for solving bottleneck cost TP. Dripping method has been used to find a set of efficient solution for bi-criteria TP (Pandian and Anuradha, 2011). Ellaimony et al. (2015) presented an algorithm for bi-criteria multistage TP using dynamic programming technique. Minimisation of transportation cost as linear programming model is discussed by Marques et al. (2007). Lexicographic approach for cost minimising TP and time minimising TP was applied by Arora and Puri (1979); it proposes to minimise quantity sent in costliest route and in the subsequent costliest routes and similar approach is also applied for time minimisation TP. Lexicographic order of approaching the optimal solution for bi-criteria TP has been used by other researchers also (Burkard and Rendl, 1991; Nikolic, 2007). Kumar et al. (2010) formulated an algorithm to solve bi-criteria fixed charge TP in fuzzy environment using a linear ranking function, without converting it into crisp environment. Fuzzy programming technique was also used by Vinotha et al. (2012) to solve bi-objective TP. A bi-criteria problem was designed for a redundancy allocation problem with heterogeneous backup scheme and mixed redundancy (Juybari et al., 2021). Bodkhe et al. (2010) used fuzzy programming technique with hyperbolic membership function to solve a bi-objective TP as a vector minimum problem. Murad et al. (2010) constructed an optimisation model for TP related to mill stones companies. An optimal solution was obtained by modelling the TP as bi-criteria two-stage TP with a special structure depending on the capacities of suppliers, warehouses and requirements of the destinations. Scheduling of jobs on parallel machines is a well-known problem which has been optimised by minimising completion time and delivery time (Mateo et al., 2018).

Flórez et al. (2011) studied multimodal TP where a set of goods is being transported from various sources to different destination with the combinations of at least two mode of transport. They combined linear programming with automated planning techniques to obtain good quality solutions. Tkachenko and Alhazov (2001) solved multi-criteria TP of nonlinear type which do not have any classical solution algorithms. A mixed-integer linear programming model was used by researchers to configure a closed-loop supply chain network which includes several criteria like demand market, multiple products, recovery technologies (Amin and Zhang, 2014). Multicriteria scheduling using fuzzy theory and tabu search have been implemented by researchers to obtain optimum scheduling (Lee et al., 2002). Berzina and Istranikova (1999) formulated algorithm for solving two-stage TP based on duality theory. Bhatia et al. (1976) solved different types of time-cost trade-off TP. Researchers have proposed algorithm for fixed charge bi-criteria TP to find an optimum time-cost trade-off pair by giving same priority to both time and cost. They concluded that the optimum trade-off pair is characterised by least D_1-distance from ideal point (Basu et al., 1994; Acharya et al., 2015). A multi-index bi-criteria fixed charge TP was studied by researchers giving time higher priority and a trade-off between time and cost has been proposed (Singh et al., 2019). In real situations which involve allocating commodities from various sources to different destinations; DM decide the optimal allocation based on many criteria like cost, availability, scarcity, distance, time, etc. While deciding the strategy, DM give weight to each criterion as per the requirement of project. It is observed that while finding optimal transportation route for bi-criteria or multi-criteria TP; researchers have given equal priority to all the criteria which is not always the case in a practical situation. The role of DM in deciding optimal transportation route is not addressed. Thus, in this paper, an algorithm is developed to solve bi-criteria TP which finds optimal solution by considering the strategy adopted by DM in prioritising each criterion. Optimal solution for bi-criteria TP is computed by assigning unequal weight to cost and time as decided by DMs. Proposed algorithm has been explained with the help of an example. Optimal solution for five different strategies adopted by DM has been presented to show its impact on cost and time of transportation. Thereby, an attempt has been made to show how the change in strategy adapted by DM affects optimal solution of bi-criteria TP.

2 Mathematical formulation of bi-criteria TP

Let there be m sources of supply having capacity a_i (i = 1, 2, …, m) respectively to be transported among n destinations with demand b_j (j = 1, 2, …, n), respectively. Let c_{ij} be the cost of transportation of one unit of commodity from source i to destination j and t_{ij} be the time required for transportation from source i to destination j for each route. Let x_{ij} represents the number of units of commodity transported from source i to destination j. The problem is to determine the transportation schedule so as to minimise the cost and time of transportation while satisfying the constraints of supply and demand.

Mathematically, the problem in general may be stated as follows:

$$\text{Minimise (total cost) } C = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{1}$$

$$\text{Minimise (total time) } \hat{T} = \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij} h_{ij} \tag{2}$$

where

$$h_{ij} = \begin{cases} 1 & \text{if } x_{ij} > 0 \\ 0 & \text{if } x_{ij} = 0 \end{cases} \tag{3}$$

subject to constraints

$$\sum_{j=1}^{n} x_{ij} = a_i,\ i = 1, 2, \ldots, m \ (\textit{supply constraints}) \tag{4}$$

$$\sum_{i=1}^{m} x_{ij} = b_j,\ j = 1, 2, \ldots, n \ (\textit{demand constraints}) \tag{5}$$

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

2.1 Proposed algorithm

The optimal solution is obtained following the steps described below.

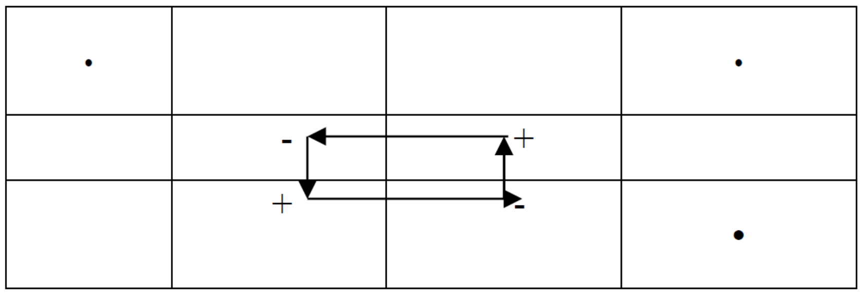
Step 1

Iteration k = 0. Construct the basic feasible solution by least cost method for cost objective transportation problem (COTP).

Step 2

For each iteration k, calculate the total cost C^k using equation (1) and maximum time in the route T^k of transportation from the given bi-criteria TP.

Figure 1 Creating loop to compute deviation in cost and time using steppingstone method



Step 3

Optimality test: For iteration $k = k + 1$. Mark all cells with allocations by a dot (.) and leave rest of the cells blank.

For each unallocated cell (i, j), construct a loop starting from $(i, j)^{\text{th}}$ cell. The closed loop starts with the selected unoccupied cell, assign a plus sign (+) to this cell. Trace a path along the rows (or columns) to an occupied cell denoted by dot (.), assign a minus sign to the corner and continue down the column (or row) to an occupied cell. Then, assign plus and minus sign alternatively to the corners. Trace the path back to selected unoccupied cell.

a Compute the deviation in cost dc_{ij} due to unit allocation in an unallocated cell (i, j) by using the steppingstone method.

b Compute the deviation time dt_{ij} due to unit allocation in an unallocated cell (i, j) by using the following relation:

$$dt_{ij} = t_{ij} - \tau \tag{7}$$

where τ represents time corresponding to smallest allocation amongst the cells marked with minus sign on corners of closed loop.

c Compute dimensionless change in cost and time using the following relations:

$$\Delta c_{ij} = \frac{dc_{ij}}{c^*} \text{ and } \Delta t_{ij} = \frac{dt_{ij}}{t^*} \tag{8}$$

where

$$c^* = \min\{c_{ij} > 0, \text{ for all unallocated cells}\} \tag{9}$$

$$t^* = \min\{t_{ij} > 0, \text{ for all unallocated cells}\} \tag{10}$$

d Compute payoff P_{ij} which is defined as below where α is the weight given to cost criterion.

$$P_{ij} = \alpha \Delta c_{ij} + (1-\alpha)\Delta t_{ij} \text{ where } \alpha \text{ is a constant, } 0 < \alpha < 1. \tag{11}$$

Significance of payoff P_{ij}: It shows the opportunity cost for allocating one unit of the commodity in the unallocated cell (i, j). If P_{ij} is positive, this implies that there will be no decrease in cost or time due to the new allocation in the cell (i, j) and vice versa.

Step 4

There are two possible cases:

a If all $P_{ij} \geq 0$, then the current allocation is the *optimal solution* for bi-criteria TP. The procedure terminates, go to Step 7.

b If at least one $P_{ij} < 0$, then an improved solution can be obtained by entering the unoccupied cell (i, j) which corresponds to $\max\{|P_{ij}|, P_{ij} < 0, i = 1, 2, 3, \ldots, m, j = 1, 2, 3, \ldots, n\}$ in the basis. This cell is termed as 'entering cell'.

Step 5

Construct a closed path for unoccupied cell selected in Step 4(b). The closed loop starts with the selected unoccupied cell, assign a plus sign (+) to this cell. Trace a path along the rows (or columns) to an occupied cell, assign a minus sign to the corner and continue down the column (or row) to an occupied cell. Then, assign plus and minus sign alternatively to the corners. Trace the path back to selected unoccupied cell.

Select the smallest quantity amongst the cells marked with minus sign on corners of closed loop. Allocate this value to the selected unoccupied cell and add it to other occupied cells marked with plus signs. Subtract this from the occupied cells marked with minus signs.

Step 6

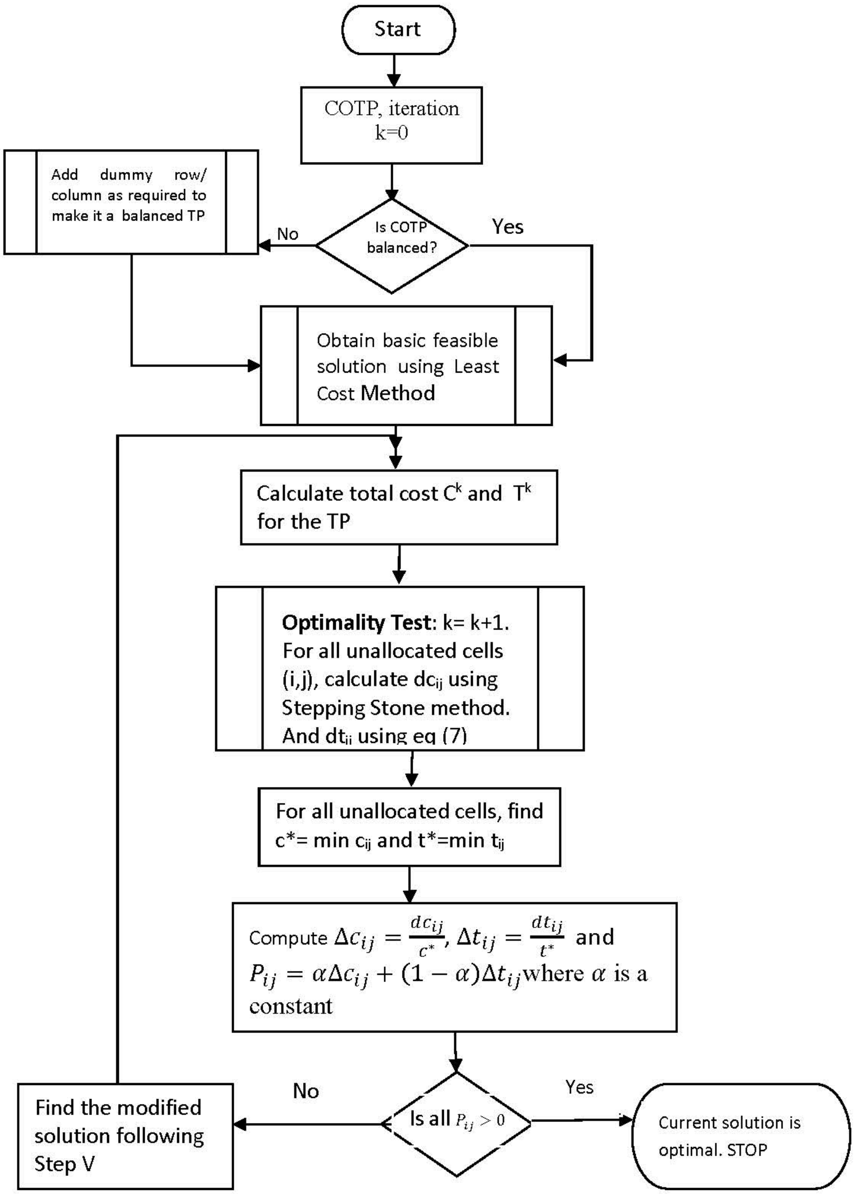
Modified solution: Obtain a new improved solution by allocating units to the unoccupied cell according to Step 5 and go to Step 2.

Step 7

Compute the corresponding total cost and time of transportation. Also, compute the maximum time taken for transportation in this route.

2.2 Flowchart

Figure 2 Flowchart of proposed algorithm



3 Numerical solution of bi- criteria TP using proposed algorithm

Consider the following bi-criteria TP discussed by Ahmed et al. (2014) for finding the set of efficient solutions. The following table gives the cost and time of transporting material from origins O_i, $i = 1, 2, 3$ to destinations D_j, $j = 1, 2, 3, 4$. The entry in lower left corner in each cell denotes the time of transportation on the corresponding route and the entry in upper left corner of each cell is the cost per unit transportation on that route.

	D_1	D_2	D_3	D_4	*Supply*
O_1	5	2	4	3	8
	10	68	73	52	
O_2	6	4	9	5	19
	66	95	30	21	
O_3	2	3	8	1	17
	97	63	19	23	
Demand	11	3	14	16	

The problem is to find an optimal solution for the bi-criteria TP where cost and time are given different weightage by DM.

Solution: The solution of the problem is illustrated for the situation when cost is given higher weightage (80%) than that given to time (20%) by DM.

Iteration, k=0: Consider the COTP and find the basic feasible solution using least cost method.

	D_1	D_2	D_3	D_4	*Supply*
O_1	5	2	4	3	8
O_2	6	4	9	5	19
O_3	2	3	8	1	17
Demand	11	3	14	16	

A basic feasible solution for the bi-criteria TP is:

	D_1		D_2		D_3		D_4	
O_1	5		2	*3*	4	*5*	3	
	10		68		73		52	
O_2	6	*10*	4		9	*9*	5	
	66		95		30		21	
O_3	2	*1*	3		8		1	*16*
	97		63		19		23	

The quantities in the shaded column represent the allocations in the given cells. The basic feasible solution for the problem is $x_{12} = 3$, $x_{13} = 5$, $x_{21} = 10$, $x_{23} = 9$, $x_{31} = 1$ and $x_{34} = 16$.

The corresponding total cost of transportation, $C^0 = 185$, total time of transportation, $\hat{T}^0 = 357$ and maximum time for transportation in this route, $T^0 = 97$.

Optimality test: For iteration $k = 1$, optimality test is applied to basic feasible solution obtained in iteration $k = 0$ following Step 3. The corresponding calculations are tabulated in Table 1.

Table 1 Optimality test, $k = 1$

Iteration	*Cell*	dc_{ij}	dt_{ij}	Δc_{ij}	Δt_{ij}	$P_{ij} = 0.8\Delta c_{ij} + 0.2\Delta t_{ij}$	*Sign* P_{ij}
0				*Basic feasible solution*			
1	1, 1	4	–63	1.3	–6.3	–0.19	< 0
	1, 4	3	–21	1	–2.1	0.38	> 0
	2, 2	–3	27	–1	2.7	–0.26	< 0
Entering cell →	*2, 4*	*0*	*–45*	*0*	*–4.5*	*–0.9*	*< 0*
	3, 2	0	–34	0	–3.4	–0.68	< 0
	3, 3	3	–78	1	–7.8	–0.76	< 0

Modified solution: Following Step 5, a modified solution is obtained by allocating 10 units in entering cell (2, 4), and the corresponding optimal solution is obtained as follows:

	D_1		D_2		D_3		D_4	
O_1	5		2	3	4	5	3	
	10		68		73		52	
O_2	6		4		9	9	5	10
	66		95		30		21	
O_3	2	11	3		8		1	6
	97		63		19		23	

The total cost of transportation, $C^1 = 185$, total time of transportation, $\hat{T}^1 = 312$ and the maximum time for transportation in this route, $T^1 = 97$.

In iteration k = 2, optimality test is performed again with the modified solution obtained in iteration 1 and is tabulated in Table 2.

Table 2 Optimality test, iteration $k = 2$

Iteration	*Cell*	dc_{ij}	dt_{ij}	Δc_{ij}	Δt_{ij}	$P_{ij} = 0.8\Delta c_{ij} + 0.2\Delta t_{ij}$	*Sign* P_{ij}
2	1, 1	4	–63	1.3	–6.3	–0.19	< 0
	1, 4	3	–21	1	–2.1	0.38	> 0
	2, 1	0	45	0	4.5	0.9	> 0
Entering cell →	*2, 2*	*–3*	*27*	*–1*	*2.7*	*–0.26*	*< 0*
	3, 2	0	–5	0	–0.5	–0.1	< 0
	3, 3	3	–4	1	–0.4	0.72	> 0

Modified solution: Allocation is made in the cell (2, 2) and the corresponding optimal solution obtained in iteration 2 is as follows:

	D_1		D_2		D_3		D_4	
O_1	5		2		4	8	3	
	10		68		73		52	
O_2	6		4	3	9	6	5	10
	66		95		30		21	
O_3	2	11	3		8		1	6
	97		63		19		23	

The total cost of transportation, C^2 = 176, total time of transportation, $\hat{T}^2 = 339$ and the maximum time for transportation in this route, T^2 = 97.

For iteration k = 3, optimality test is again performed with the new allocation obtained in iteration 2 and is tabulated in Table 3.

Table 3 Optimality test, iteration $k = 3$

Iteration	*Cell*	dc_{ij}	dt_{ij}	Δc_{ij}	Δt_{ij}	$P_{ij} = 0.8\Delta c_{ij} + 0.2\Delta t_{ij}$	*Sign* P_{ij}
3	1, 1	4	–63	2	–6.3	0.34	> 0
	1, 2	3	–27	1.5	–2.7	0.66	> 0
	1, 4	3	–21	1.5	–2.1	0.78	> 0
	2, 1	0	45	0	4.5	0.9	> 0
	3, 2	3	–32	1.5	–3.2	0.56	> 0
	3, 3	3	–11	1.5	–1.1	0.98	> 0

From Table 3, it is observed that all $P_{ij} > 0$ which signifies that the solution obtained in the previous iteration ($k = 2$) is an optimal solution.

Optimal solution: Hence, the optimal solution for the bi-criteria TP is given by:

$$x_{13} = 8, x_{22} = 3, x_{23} = 6, x_{24} = 10, x_{31} = 11, x_{34} = 6$$

Total cost of transportation C = 176, total time of transportation $\hat{T} = 339$ and maximum time in the route T = 97.

The strategy adopted by DM had lead to a reduction in cost as well as total time of transportation.

4 Impact of strategies adopted by DM on performance parameters

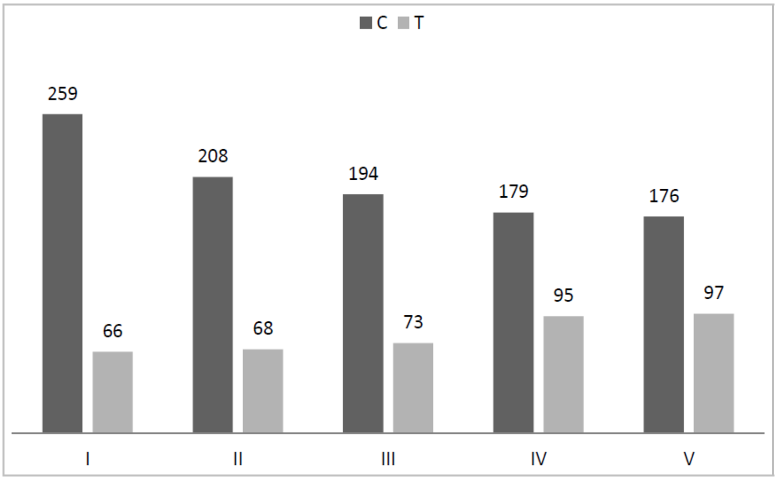
The bi-criteria TP is solved for five different cases where both cost and time has been given different weightage by DM to obtain the optimal transportation schedule. The optimal transportation schedule along with total cost of transportation and maximum time taken in the transportation route is obtained for each of the five cases and is depicted in Table 4 along with the number of iterations needed to obtain optimal solution.

Table 4 Optimal solution obtained by proposed algorithm for bi-criteria TP for five different cases based on varying weights assigned to cost and time

Case	*Weight given by DM*		*Optimal solution of BCTP*	*Objective values*		*Number of iterations*
	Cost	*Time*		*C*	*T*	
I	0.01	0.99	$x_{11} = 8, x_{21} = 3, x_{24} = 16, x_{32} = 3, x_{33} = 14, x_{34} = \varepsilon$	259	66	4
II	0.5	0.5	$x_{11} = 5, x_{12} = 3, x_{21} = 6, x_{23} = 13, x_{33} = 1, x_{34} = 16$	208	68	3
III	0.7	0.3	$x_{21} = 9, x_{12} = 3, x_{14} = 5, x_{23} = 10, x_{33} = 1, x_{34} = 16$	194	73	3
IV	0.8	0.2	$x_{13} = 8, x_{22} = 3, x_{23} = 6, x_{24} = 10, x_{31} = 11, x_{34} = 6$	176	97	3
V	0.99	0.01	$x_{13} = 8, x_{21} = 10, x_{22} = 3, x_{23} = 6, x_{31} = 1, x_{34} = 16$	176	97	3

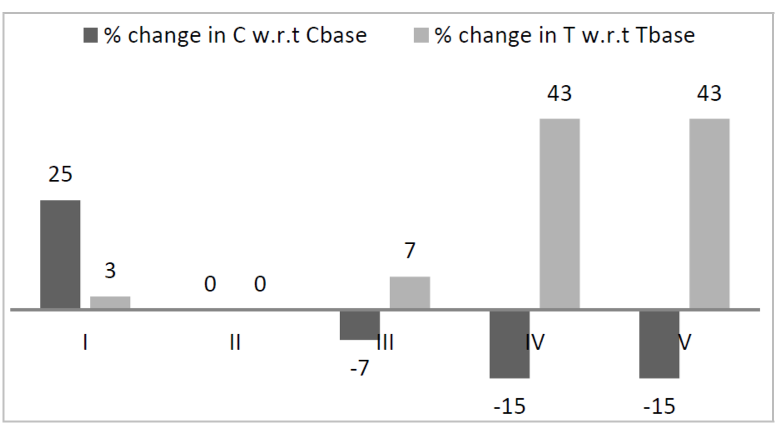
Figure 3 shows how cost and time varies with variation in strategies adopted by DM to obtain the optimal transportation schedule. It is observed that by increasing the weight assigned to cost, there is a decrease in total cost of transportation but at the same time we observe a proportionate increase in time of transportation.

Figure 3 Variation in total cost of transportation (*C*) and maximum time of transportation (*T*) of optimal transportation schedule for five different strategies adopted by DM



Case II is considered as a reference case where both time and cost are given equal weightage. Impact of variation of weight assigned to the two criteria by DM is studied. The optimal solutions for each case are compared with that of reference case. Percentage increase or decrease in total cost of transportation and maximum time is computed to show the impact of variation in strategy on the performance indicators and is depicted in Figure 4.

Figure 4 Impact of strategy on the performance parameters



Note: Total cost of transportation (*C*) and maximum time of transportation (*T*).

It is observed that by increasing the priority of cost, there is maximum of 15% decrease in total cost of transportation but in the process, there is 43% increase in the time of delivery. So, the role of DM is to select an optimal strategy which will help in reducing the risk associated with the project and achieve required performance objective by keeping the cost within budget and achieve the required completion time.

From Figure 4, it is observed that if cost is given 70% weightage and 30 % weightage is given to time, then percentage change in both the performance parameter is 7%. This may be considered by DM to keep both cost and time within considerable limits depending on the circumstances of the project.

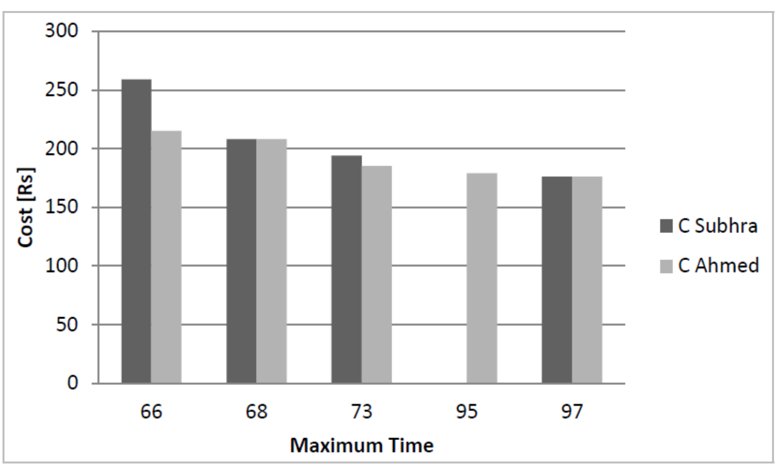
5 Comparison of results

The bi-criteria TP considered in Section 3 for illustration of the algorithm was solved by Ahmed et al. (2014). They have derived a set of efficient solutions for the given bi-criteria TP which is tabulated in Table 5 along with the corresponding total cost of transportation and maximum time of transportation.

Table 5 Efficient solutions of bi-criteria TP by Ahmed et al. (2014)

Efficient solution of BCTP	*Objective values*		*Number of iterations*
	C	*T*	
$x_{11} = 6, x_{14} = 2, x_{21} = 5, x_{23} = 14, x_{32} = 3, x_{34} = 14$	215	66	6
$x_{11} = 5, x_{12} = 3, x_{21} = 6, x_{23} = 13, x_{33} = 1, x_{34} = 16$	208	68	6
$x_{12} = 2, x_{13} = 6, x_{21} = 11, x_{23} = 8, x_{32} = 1, x_{34} = 16$	185	73	6
$x_{13} = 8, x_{21} = 11, x_{22} = 3, x_{23} = 5, x_{33} = 1, x_{34} = 16$	179	95	6
$x_{13} = 8, x_{21} = 10, x_{22} = 3, x_{23} = 6, x_{31} = 1, x_{34} = 16$	176	97	6

Figure 5 Comparison of results obtained by proposed algorithm and that by Ahmed et al. (2014)



Total costs of transportation obtained by the proposed algorithm is compared with those obtained by Ahmed et al. (2014) for given time of transportation for the optimal transportation schedule and are depicted in Figure 5. It is observed that the results obtained by the proposed algorithm are comparable to that obtained by Ahmed et al. (2014).

Advantage of the proposed algorithm: The method proposed by Ahmed et al. (2014) is unable to tell under what conditions the above solutions would be an efficient solution for the bi-criteria TP. Whereas, the proposed algorithm explicitly states the criteria set by DM for deciding the optimal transportation route and thereby shows the impact of the adopted strategy on performance parameters. Also, the number of iterations required to obtain optimal solution by the proposed algorithm is less than that by Ahmed et al. (2014).

6 Conclusions

The proposed algorithm computes optimal solution for bi-criteria TP by considering DM strategy of prioritising certain criteria based on requirement of the project. The algorithm computes optimal solution by assigning unequal weights to each criterion as per decision taken by DMs. It is observed that by increasing the weight of cost criteria, there is significant decrease in the cost of transportation but there is significant increase in transportation time. Thus, a trade-off between time and cost is required to meet the requirement of the project. The proposed algorithm explicitly shows the impact of each strategy taken by DMs on the objectives of the problem.

The algorithm can be applied to any bi-criteria TP (balanced/unbalanced). It is simple, robust and yields solution optimising cost and time simultaneously. Also, number of iterations required to obtain optimal solution using the proposed algorithm is considerably less.

Steppingstone method is used to check the optimality condition which is sometimes found to be time consuming. Programming in MATLAB or C can reduce computation time. MATLAB program can be developed to compute all possible optimal solutions for different combinations of weights assigned to both criteria. This will enable DMs to get an overall idea of the impact of each strategy on the objective function and would help them to select optimal strategy suitable for a given problem which satisfies the requirement of their project.

It can be concluded that the proposed algorithm depicts the role of DM in deciding the optimal transportation route for a bi-criteria TP. It provides optimal solution based on the decision taken by DMs regarding the priority of each criterion. It provides a clear understanding of the impact of strategy adopted by DM on performance indicators (cost and time of transportation).

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