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Integrating customer responsiveness and distribution cost in designing a two-echelon supply chain network with considering capacity level and piecewise linear cost

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Abstract. When designing supply chains, firms are often faced with the competing demands of improved customer responsiveness and reduced cost. In this paper, we present a two echelon distribution network design problem in supply chain system which includes location, transportation and customer responsiveness decisions. Customer responsiveness is measured by the delivery delay cost. Unlike most of past research, our model allows for multiple levels of capacities available to the distribution centers and piecewise linear transportation cost between suppliers and distribution centers for obtaining economic of scale.

A hybrid heuristic combining Tabu search with Simulated Annealing (SA) sharing the same tabu list is developed for solving the problem. We comprise the hybrid algorithm with the optimal solution, Simulated Annealing algorithm and Tabu search algorithm. The results indicate that the method is efficient for a wide variety of problem sizes.

Keywords: facility location, integrated supply chain design, distribution, customer responsiveness, capacity level, simulated annealing, tabu search

1 Introduction

Strategic supply chain design and redesign have become a major challenge for firms as they simultaneously try to improve customer responsiveness and reduced costs. Location and transportation costs are major cost factors in designing and managing a supply chain. Although a decision support system that integrated these cost elements with customer responsiveness goals is a considerable undertaking for most businesses, doing so can provide a company with a tremendous competitive advantage in the marketplace.

An important supply chain design consideration that has been ignored in the distribution network models is customer responsiveness. In these models, a customer may be assigned to a distribution center that is very far away if doing so reduces the total costs. This may not be desirable in a highly competitive business environment. Many companies consider service time, defined as how long it takes to the customer site when they are needed, to be a critical performance metric. In the supply chain system, determining the locations of the distribution centers is critical, because it will impact both the total costs (facility location costs and transportation costs) and the customer responsiveness. There is a clear to need to evaluate trade offs among the total costs and customer responsiveness.

Facility location problems (FLP), which are typically used to design distribution networks, involve determining the sites to install resources, as well as the assignment of potential consumers to those resources. One example of FLP, is the location of manufacturing plants, the assignment of warehouses to these plants and finally the assignment of retailers to each warehouse.

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For a thorough review of facility location problem see Hamacher and Drezner [8], Barmel and Simchi-Levi [2], and Daskin [4]. And for a review of facility location problem in distribution network design see Klose and Drexl [10].

Bramel and Simchi-Levi[2] show three models to solve classical cases of FLP. The first one, called P-Median Problem, deals with the optimal location of P identical warehouses, for which there are M candidate sites. These warehouses must serve incoming orders from N retailers. This model does not consider installation costs, and the capacity of each warehouse is unlimited. The second problem is called capacitated facility location problem (CFLP). In this case the number of warehouses is variable and there are capacity constraints for each warehouse, as well as installation fixed costs. The third model, called distribution system design problem (DSDP), considers multiple plants with fixed capacities (the number and location of plants are fixed and known), and considers K different products in contrast with the single-product previous models. Daskin[4] develops a similar and deeper review of logistics network design problems.

Geoffrion and Graves[5] propose a Bender's decomposition approach to solve a capacitated single source, multi-commodity network flow problem. Van Roy[16] develops a cross-decomposition algorithm to solve a CFLP that combines Bender's decomposition and Lagrangian into a single framework. Cournuejols et al.[3] compare different heuristics and relaxations for the CFLP. Beasley[1] discusses the performance of Lagrangian heuristics on four different location problems. Both Cournuejols et al.[3] and Beasley[1] conclude that Lagrangian heuristics are quite robust compared to other greedy heuristics. Sridharan[18] presents a more extensive review of different versions of CFLP and their solution techniques. Jayaraman[9] studied the capacitated warehouse location problem that involves locating a given number of warehouses to satisfy customer demands for different products. Pirkul and Jayaraman[15], and Mazzola and Neebe[12] develop Lagrangian heuristics for multi-commodity CFLPs under different assumptions. Tragantalerngsak et al.[19] considered a two-echelon facility location problem in which the facilities in the first echelon are uncapacitated and the facilities in the second echelon are capacitated. The goal is to determine the number and locations of facilities in both echelons in order to satisfy customer demand of the product. They developed a Lagrangean relaxation based branch and bound algorithm to solve the problem. Melkote and Daskin[13] develop a capacitated facility location/network design model with both fixed facility costs and arc costs among the network nodes. They propose a branch and bound algorithm using bounds obtained by Lagrangian relaxation. Grunert[7] presents a capacitated facility location/network design model and uses tabu search for solving the problem. Goldengorin[6] presents an uncapacitated distribution network design problem and uses branch and bound algorithm for solving the model.

Melo et.al[14] present a dynamic multi-commodity capacitated distribution network design problem but they can not propose a solution algorithm for solving the problem. Lu and Bostel[11] present a facility location model for reveres logistics system and propose an algorithm based on lagrangian relaxation for solving the model.

In this paper we present an integrated supply chain design model which optimizes location, transportation and customer responsiveness decisions, simultaneously. Customer responsiveness is measured by the delivery delay cost.

The goal of our model is to determine simultaneously the best sites for the distribution centers and determining capacity for distribution centers and the best strategy for distributing the product from the suppliers to the distribution centers and from distribution centers to the customers. Also in our model we have three layers (suppliers, distribution centers, and customers) and we use piecewise linear transportation cost between suppliers and distribution centers for obtaining economics of scale.

One major drawback in most of past research is that they assume the capacity of distribution centers are known and assignment of customers to the distribution centers are limited by the capacity of distribution centers. In our model, we use different capacity levels for distribution centers that make the problem more realistic and assignment of customers to the distribution centers more flexible.

One of the possible objectives in supply chain design models is to maximize the capacity utilization of distribution centers. Our results show that use of capacity levels for distribution centers increase the capacity utilization to a high level.

The capacitated facility location/network problem has been shown to be non polynomial (NP)-hard problem. Since combining facility location/network decisions by considering capacity level and piecewise linear transportation cost are more complex than capacitated facility location/network problem, so this problem belongs to the class of NP-hard problems. For this reason, a hybrid heuristic combining Tabu search with Simulated Annealing (SA) sharing the same tabu list is developed for solving the problem.

The reminder of this paper is organized as follows. In section 2, mathematical formulation of the problem is presented. In section 3, the hybrid Tabu-SA algorithm is developed for solving the problem. Section 4, discusses some computational results. Finally, section 5 contains some conclusions and future research development.

2 Model formulation

In this section, we formulate an integrated model that can be used to explore the trade off between the location, and transportation costs and customer responsiveness. We explore this trade off in the context of a multi echelon distribution system composed of multiple suppliers, multiple distribution centers, and multiple customers.

We assume to know the location and demand of each customer, whose demands are specified on units of a single representative commodity. Also the location of each potential distribution center is known. Also, we assume to know capacity levels for each distribution center, and, we assume to know the segments for the piecewise linear transportation cost between suppliers and distribution centers.

Before presenting the model, let us introduce the notation that will be used throughout the paper.

Index sets

K: Set of customers.

J: Set of potential distribution centers.

I: Set of suppliers.

N: Set of capacity levels available to the potential distribution centers.

DS: Set of segments for shipping goods between suppliers and distribution centers.

Parameters & notations

D_k: Demand of customer k, $(\forall k \in K)$

b_j^n: Capacity with level n for the potential distribution center j, $(\forall j \in J,\ \forall n \in N)$

F_j^n: Fixed cost for opening and operating distribution center j with capacity level n, $(\forall j \in J,\ \forall n \in N)$

V_i: Capacity of supplier i, $(\forall i \in I)$

m_{jk}: Cost per unit of shipment from distribution center j to customer k $(\forall i \in J,\ \forall k \in K)$

C_{ij}^p: Variable unit shipping cost from supplier i to distribution center j when total goods lies within segment p, $(\forall i \in I,\ \forall j \in J,\ \forall p \in DS)$

u_k: The duration within which the goods must be delivered to customer k, (service level for customer k, for example, 2 hours, 4 hours, ...), $(\forall k \in K)$

t_{jk}: The required time for delivering the goods from distribution center j to customer k, $(\forall j \in J,\ \forall k \in K)$

S: Penalty cost for delay in delivery for one unit of demand in one unit of time.

LB_p: Lower bound of segment p, $(\forall p \in DS)$

UB_p: Upper bound of segment p, $(\forall p \in DS)$

Decision variables

$$Y_{jk} = \begin{cases} 1 & \text{if customer } k \text{ is assigned to distribution center } j.\ (\forall k \in K,\ \forall j \in J) \\ 0 & \text{otherwise} \end{cases}$$

$$U_j^n = \begin{cases} 1 & \text{if distribution center } j \text{ is opened with capacity level } n.\ (\forall j \in J,\ \forall n \in N) \\ 0 & \text{otherwise} \end{cases}$$

X_{ij}^p: Variable denoting the total amount flowing from supplier i to distribution center j when total amount lies within segment p, $(\forall i \in I,\ \forall j \in J,\ \forall p \in DS)$

XB_{ij}^p: Binary variable denoting whether the flow from supplier i to distribution center j lies within segment p, $(\forall i \in I,\ \forall j \in J,\ \forall p \in DS)$

For obtaining economic of scale, we use piecewise linear transportation cost between suppliers and distribution centers. Let Q_{ij} denote the amount of product shipped between supplier i and distribution center j, and we assume that we have p segments for shipping products, then the transportation cost between supplier i and distribution center j is computed as follows:

$$C_{ij} = \begin{cases} 0 & \text{if } Q_{ij} = 0 \\ C_{ij}^1 & \text{if } 0 < Q_{ij} \le UB_1 \\ C_{ij}^2 & \text{if } LB_2 < Q_{ij} \le UB_2 \\ \vdots & \\ C_{ij}^p & \text{if } LB_p < Q_{ij} \le UB_p = \sum_{k \in K} D_k \end{cases}$$

In this structure: $LB_i = UB_{i-1} + 1$ for $i = 2, 3, \cdots, n$.

And we assume that: $C_{ij}^1 \le C_{ij}^2 \le \cdots \le C_{ij}^p$.

The objective function minimizes the following costs:

The fixed cost of locating distribution centers with capacity level, given by the term:

$$\sum_{j \in J} \sum_{n \in N} F_j^n U_j^n$$

The shipment cost from suppliers to the distribution centers, given by the term:

$$\sum_{i \in I} \sum_{j \in J} \sum_{p \in DS} C_{ij}^p X_{ij}^p$$

The shipment cost from distribution centers to the customers, given by the term:

$$\sum_{j \in J} \sum_{k \in K} m_{jk} D_k Y_{jk}$$

The delivery delay cost: we define f_{jk} as follows:

$$f_{jk} = \begin{cases} 1 & \text{if } t_{jk} > u_k \\ 0 & \text{otherwise } (k \in K,\ j \in J) \end{cases}$$

Note that f_{jk} is a parameter. Then the annual delivery delay cost is computed as follows:

$$\sum_{j \in J} \sum_{k \in K} S D_k Y_{jk} (t_{jk} - u_k) f_{jk}$$

If $t_{jk} \le u_k$ then $f_{jk} = 0$ and we have not delivery delay cost between customer k and distribution center j. In fact f_{jk} is used for that if between customer k and distribution center j, $t_{jk} \le u_k$, then we must have not delivery delay cost between them. Because the objective function is minimizing the total cost, so we can minimize the total delivery delay cost as a measure of maximizing customer responsiveness. S is a penalty for delay in delivery for one unit of demand in one unit of time. In fact S is used for capturing the time in to the cost.

So the problem can be formulated as follows:

$$\min \quad \sum_{j\in J}\sum_{n\in N} F_j^n U_j^n + \sum_{i\in I}\sum_{j\in J}\sum_{p\in DS} C_{ij}^p X_{ij}^p + \sum_{j\in J}\sum_{k\in K} m_{jk} D_k Y_{jk} + \sum_{j\in J}\sum_{k\in K} SD_k Y_{jk}(t_{jk}-u_k) f_{jk} \tag{1}$$

subject to:

$$\sum_{j\in J} Y_{jk} = 1, \quad \forall k \in K \tag{2}$$

$$\sum_{n\in N} U_j^n \le 1, \quad \forall j \in J \tag{3}$$

$$\sum_{k\in K} D_k Y_{jk} = \sum_{i\in I}\sum_{p\in DS} X_{ij}^p, \quad \forall j \in J \tag{4}$$

$$\sum_{i\in I}\sum_{p\in DS} X_{ij}^p \le \sum_{n\in N} b_j^n U_j^n, \quad \forall j \in J \tag{5}$$

$$\sum_{j\in J}\sum_{p\in DS} X_{ij}^p \le V_i, \quad \forall i \in I \tag{6}$$

$$\sum_{p\in DS} XB_{ij}^p \le 1, \quad \forall i \in I, \forall j \in J \tag{7}$$

$$X_{ij}^p \le UB_p XB_{ij}^p, \quad \forall i \in I, \forall j \in J, \forall p \in DS \tag{8}$$

$$X_{ij}^p \le LB_p XB_{ij}^p, \quad \forall i \in I, \forall j \in J, \forall p \in DS \tag{9}$$

$$\begin{aligned} & Y_{jk} \in \{0,1\}, \quad \forall j \in J, \forall k \in K \\ & U_j^n \in \{0,1\}, \quad \forall j \in J, \forall n \in N \\ & XB_{ij}^p \in \{0,1\}, \quad \forall i \in I, \forall j \in J, \forall p \in DS \end{aligned} \tag{10}$$

$$X_{ij}^p \neq 0, \quad \forall i \in I, \forall j \in J, \forall p \in DS \tag{11}$$

The model minimizes the total costs made of: the fixed cost for opening distribution centers, the shipment cost from suppliers to the distribution centers, the shipment cost from distribution centers to the customers, and the delivery delay cost. Constraints (2) ensure that each customer is assigned to exactly one distribution center. Constraints (3) ensure that each distribution center can be assigned at most one capacity level. Constraints (4) are the flow conservation constraints associated with each distribution center, ensuring that the flow into a distribution center equals the sum of demands of the customers allocated to the distribution center. Constraints (5) are the capacity constraints associated with the distribution centers. Constraints (6) represent the capacity restrictions of the suppliers in terms of their total shipments to the distribution centers.

Constraints (7) ensure that each flow between the suppliers and distribution centers can only lie within one segment. Constraints (8), (9) are concerned to the upper bound and lower bound of each segment, and make a connection between the flow and binary segment variables.

Constraints (10), (11) enforce the integrality and non-negativity restrictions on the corresponding decision variables, respectively.

3 Solution approach

A hybrid heuristic combining Simulated Annealing with Tabu Search sharing the same tabu list is used for solving the problem. The parameters for the hybrid algorithm are as follows:

T_0: Initial temperature,

C: Rate of the current temperature decreases (cooling schedule),

ST: Freezing temperature (the temperature at which the desired energy level is reached),

X: A feasible solution

$C(X)$: The value of objective function for X, The steps of proposed hybrid Tabu-SA based heuristic are as follows:

Step 1. $X_{best} = \emptyset$, select an initial solution, (X_0)

$X_{best} = X_0,\ X = X_0$

Step 2. Generate solution X_n in the neighborhood of X.

Step 3. Is the candidate move in the tabu list? If yes, go to Step 4. Otherwise go to Step 5.

Step 4. If $C(X_n) \leq C(X_{best})$ then $X = X_n, X_{best} = X_n$, update the tabu list and go to Step 6, otherwise go to step 2 for choosing another candidate move.

Step 5. Let $\Delta C = C(X_n) - C(X)$.

- 5.1. If $\Delta C \leq 0$ then $X = X_n, r = r+1$, update the tabu list and if $C(X_n) < C(X_{best})$ then $X_{best} = X_n$.
- 5.2. If $\Delta C \leq 0$ then $y \to U(0,1),\ z = e^{-\frac{\Delta C}{T_0}}$. If $y < z$ then $X = X_n$.

Step 6. Should the procedure stop under temperature T_0? If yes, go to Step 7, otherwise go to Step 2.

When the number of accepted solutions under temperature T_0 reaches to a predefined value, the following condition should be checked:

$$\frac{|AOV_c - AOV_b|}{AOV_b} \leq \varepsilon$$

where AOV_c is the average objective value of accepted solutions under the temperature T_0, AOV_b is the average objective value of accepted solutions before the temperature T_0, ε is a predefined equilibrium value $(0 < \varepsilon < 1)$. If the above condition is satisfied, the procedure stops under temperature T_0. This condition was proposed by Skiscim & Golden[17].

Step 7. $T_0 = C \times T_0$.

Step 8. Is the stopping criterion $(T_0 < ST)$ matched? If yes, stop, otherwise, go to Step 2. The steps of proposed hybrid Tabu-SA Algorithm are shown in Fig. 1.

In the section 3.1, 3.2, we describe the initial solution construction and different types of move for generating the candidate move which we use for hybrid Tabu-SA algorithm.

3.1 Initial solution construction

For obtaining the initial solution, first we assign customers to the distribution centers, randomly. For each of the opened distribution center the capacity level is selected randomly, and then we use the heuristic algorithm (H_1) for assigning each open distribution center to the suppliers. The procedure for obtaining the initial solution is as follows.

Step 1. Put customers into a set K.

Step 2. 1- Select a customer from K randomly. 2- Delete the customer from K.

Step 3. Select a distribution center randomly.

Step 4. If we select this distribution center for the first time then select a capacity level for this distribution center randomly.

Step 5. If remaining capacity of the distribution center is greater than the demand of the customer then assign the customer to the distribution center and go to Step 6 otherwise go to Step 3 for selecting another distribution center.

Step 6. Is K empty? If yes, go to Step 7, otherwise go to Step 2.

Step 7. By using the heuristic algorithm (H_1), assign each open distribution center to the suppliers and determine amount of goods must be shipped form the suppliers to the opened distribution centers.

Before presenting the improvement phase, let us describe the heuristic algorithm (H_1) that we propose for assigning each open distribution center to the suppliers. The steps of H1 are as follows:

For each of the opened distribution center (a_j), let L_j be the sum of the demands of the customers that are assigned to a_j.

Step 1. 1-Put all of the opened distribution centers into a set K. 2- Put all of the suppliers into a set K.

Step 2. Select a distribution center (a_j) from K, randomly.

Step 3. Determine that L_j lies in which segment (for example segment p).

$X_{best} = \phi$

Select an initial solution, X_0

$X_{best} = X_0$, $X = X_0$

While ($T_0 < ST$) Do

While ($\frac{|AOV_c - AOV_b|}{AOV_b} \le \varepsilon$) Do

Generate solution X_n in the neighborhood of X ,

$\Delta C = C(X_n) - C(X)$

If the candidate move is in the tabu list, then

If $C(X_n) < C(X_{best})$ then

$X = X_n$, $X_{best} = X_n$, update the tabu list

Else

Generate another solution X_n in the neighborhood of X

End If

Else

If $\Delta C \le 0$ then

$X = X_n$, update the tabu list

If $C(X_n) < C(X_{best})$ then

$X_{best} = X_n$

End If

Else

Generate $y \rightarrow U(0,1)$ Randomly

Set $z = e^{-\frac{\Delta C}{T_0}}$

If $y < z$ then

$X = X_n$, update the tabu list

End If

End If

End If

End While

$T_0 = C \times T_0$

End While

Fig. 1. Proposed hybrid Tabu-SA Algorithm

Step 4. For each supplier i in the set E, calculate $M_{ij}^{p} = C_{ij}^{p} \times L_j$.

Step 5. Select the supplier from E that has the minimum value M_{ij}^{p}. (supplier i)

(1) If the remaining capacity of supplier (i) is greater than of L_j then $X_{ij}^{p} = L_j,\ XB_{ij}^{p} = 1$ and delete the distribution center a_j from K and go to Step 7.

(2) If the remaining capacity of supplier (i) is equal to L_j then $X_{ij}^{p} = L_j,\ XB_{ij}^{p} = 1$ and delete the distribution center a_j from K and supplier (i) from E and then go to Step 7.

(3) If the remaining capacity of supplier (i) is less than L_j, then $X_{ij}^{p} = T_i,\ XB_{ij}^{p} = 1$, which T_i is the remaining capacity of supplier (i), and then delete the supplier (i) from E, and $L_j = L_j - T_i$, and go to Step 3.

Step 7. Is K empty? If yes stop, otherwise go to Step 2.

3.2 Improving the initial solution

In this phase, the main objective is to improve the initial solution. We apply four different types of move for generating a candidate move: mov1, mov2, mov3, mov4. We generate a candidate move (from X_0 to the candidate solution X_n) using one of the four moves randomly.

Mov1: Randomly, one of the opened distribution centers (a_j) is closed and all of the customers are reallocated among the remaining opened distribution centers. If the remaining capacities of the opened distribution centers are not enough for the customers of a_j then we randomly select an open distribution center and increase its capacity level to one higher level, finally, by using the heuristic algorithm (H_1), we assign the opened distribution centers to the suppliers. The procedure of mov1 is as follows:

Step 1. Select an open distribution center randomly (a_j). Let D_j be the set of customers that assigned to a_j.

Step 2. Select a customer (K) from D_j, randomly.

Step 3. Determine the opened distribution centers that have enough remaining capacity for demand of customer k. Let O_k be the opened distribution centers which have enough remaining capacity.

Step 4. If O_k is empty, (we can not find the opened distribution center that have enough remaining capacity) then go to Step 5, otherwise go to step 8.

Step 5. If all of the opened distribution centers have the highest capacity level. Then stop and exit from this move and select a move randomly for generating a candidate move, otherwise go to Step 6.

Step 6. Randomly select one of the opened distribution centers.

Step 7. If this distribution center has the highest capacity level then go to Step 6 for selecting another open distribution center, otherwise increase its capacity level to one higher level and assign customer k to this distribution center and go to Step 9.

Step 8. Select a distribution center from O_k randomly and assign customer k to this distribution center.

Step 9. Delete the customer k from D_j.

Step 10. Is D_j empty? If yes, close a_j and stop, otherwise go to Step 2.

In Step 5 of the mov1 by the time mov1 is not performed as many number as max-mov1, we give up mov1 and we do not apply mov1 during the algorithm, note that max-mov1 is as an input for the heuristic method. In fact, mov1 is terminated when a max-mov1 number of moves are not performed based on Step 5.

We apply the heuristic algorithm (H_1) at the end of the each move for all of the opened distribution centers. Because in Step 2 of the heuristic algorithm, we select the opened distribution centers randomly, so we use this heuristic algorithm (H_1) at the end of the each move for all of the distribution centers for changing the selection of the opened distribution centers.

Mov2: In this move we select two open distribution centers randomly, (a_i, a_j), and exchange a_i and a_j. Finally, we use the heuristic algorithm (H_1) for all of the opened distribution centers for assigning the opened distribution centers to the suppliers. In this move capacities of a_i and a_j are checked for serving the customers.

Mov3: One of the opened distribution centers (a_i) is closed randomly, and a closed distribution center (a_j) is opened randomly and one of the capacity levels is selected for a_j randomly. Then we assign all of the customers corresponding to the eliminated distribution center (a_i) to the new opened distribution center (a_j), and we use the heuristic algorithm (H_1) for all of the opened distribution centers for assigning the opened distribution centers to the suppliers. In this move the capacity of a_j is checked for serving the customers.

Mov4: Select two open distribution centers, randomly, (v_i, v_j). Then randomly select a customer (c_i) in v_i and a customer (c_j) in v_j and exchange c_i and c_j. Finally, we use the heuristic algorithm (H_1) for all of the opened distribution centers for assigning the opened distribution centers to the suppliers. In this move we must check the capacities of distribution centers.

4 Computational results

The computational experiments described in this section were designed to evaluate the performance of our overall solution procedure with respect to a series of test problems. It was coded in visual basic 6 and run on a Pentium 4 with 2.8 GB processor.

The demand requirements of the customers were drawn from a uniform distribution between 200 and 800, and we use the following parameters:

c_{jk} Is uniformly drawn from [2, 4]
u_k Is uniformly drawn from [1, 6]
t_{jk} Is uniformly drawn from [1, 15]
$S = 2$.

Four capacity levels are used for the capacities of the potential distribution centers. If we let D represents total demand requirements ($D = \sum_{k\in K} D_k$) and $|J|$ be the number of potential distribution centers and a_j is a random number between 0.8 and 1.2 for each distribution center. Then we define for each distribution center: $cap(j) = \left[a_j \times \frac{D}{|J|}\right]$, ($[A]$ is the integer part of A), so the different capacities of the potential distribution center are computed as follows.

$$b_j^1 = cap(j),\ b_j^2 = 1.5 \times cap(j),\ b_j^3 = 2 \times cap(j),\ b_j^4 = 2.5 \times cap(j)$$

Fixed set up costs of locating and operating distribution centers are as follows. Let k_j for each distribution center were drawn from a uniform distribution between 4500 and 5500. Then fixed set up cost for distribution center j is computed as follows.

$$F_j^1 = [0.65 \times k_j],\ F_j^2 = [0.9 \times k_j],\ F_j^3 = [1.1 \times k_j],\ F_j^4 = [1.35 \times k_j]$$

The capacity of each supplier is computed as follows: $V_i = \left[r_i \times \frac{D}{|I|}\right]$, in which r_i is a random number between 0.8 and 1.2 for each supplier and I is the number of suppliers. We use four segments for shipping goods from the suppliers to the distribution centers for each instance.

Our goal in this section is to find out (1) performance of the heuristic algorithm, and (2) the benefit of considering capacity levels for the distribution centers.

4.1 Performance of the hybrid algorithm

4.1.1 Comparison of optimal solution and hybrid algorithm

For evaluating the proposed heuristic, fourteen problems are solved by LINGO.8 software (tab. 1). Parameter tuning is a matter of serious concern for any optimization problem as it induces good performances. The parameters affect the working of the hybrid algorithm, drastically. For each problem, the tuning of the parameters is done by carrying out random experiments. It can be seen that the solutions of the proposed hybrid algorithm are optimal (or near optimal) in different problems (Tab. 1). The average CPU time are less than or equal to 181 seconds for proposed hybrid algorithm (CPU times are in the seconds). However, the maximal average CPU time for obtaining the optimal solutions is equal to 10511 seconds, and for instance 12 to 14 by a 3 hours time limit, LINGO can not find the optimal solution, and the hybrid algorithm in this instance is better than the best solutions that are obtained by LINGO.

In Tab. 2, we study the benefit of considering capacity levels on the capacity utilization. The results show that use of capacity levels for distribution centers increase the capacity utilization to a high level.

Table 1. Comparison of optimal solution and hybrid algorithm

NO.	# Customers	# DCs	#	Optimal Solution		Hybrid Algorithm		
				Suppliers Cost	CPU time	Cost	CPU time	Gap (%)
1	4	2	1	19125.6	12	19125.6	1	0.00
2	6	3	1	25892.1	28	25892.1	3	0.00
3	8	4	2	32978.4	54	32978.4	9	0.00
4	9	4	2	35026.4	132	35026.4	13	0.00
5	20	5	3	79226.1	487	79226.1	29	0.00
6	30	8	4	109213.4	695	110054.2	39	0.77
7	40	12	5	144786.7	847	146157.4	51	0.95
8	50	15	5	181912.5	1475	183792.7	67	1.03
9	60	17	6	211326.9	3524	213375.1	80	0.97
10	70	19	6	254975.9	6748	258138.6	94	1.24
11	80	21	7	292381.7	10511	296364.2	110	1.36
12	90	23	7	346759.7	3 hours limit	337882.6	127	
13	100	25	8	383674.1	3 hours limit	369734.2	146	
14	120	30	9	469526.4	3 hours limit	435186.4	181	

Gap: Gap from optimal solution (%).

Table 2. Impact of considering capacity level

NO.	# Customers	# DCs	# Suppliers	Cost	A.C.U
1	30	8	4	110054.2	90
2	40	12	5	146157.4	89
3	50	15	5	183792.7	91
4	60	17	6	213375.1	91
5	70	19	6	258138.6	92
6	80	21	7	296364.2	93
7	90	23	7	337882.6	93
8	100	25	8	369734.2	92
9	120	30	9	435186.4	94
10	150	35	10	520379.6	95
11	180	38	11	602347.3	94
12	200	40	12	667894.3	93
13	230	43	13	753846.5	94
14	250	45	14	821492.1	96
15	280	48	15	914263.4	96
16	300	50	16	996346.1	95

A.C.U: Average capacity utilization for the opened distribution centers (%).

4.1.2 Comparison of hybrid algorithm with sa algorithm and tabu search algorithm

In this section, we compare our hybrid algorithm with SA method and Tabu search method. The procedure for obtaining initial solution and candidate move, we use in SA method and tabu search method, are the same to the procedure of obtaining solution and candidate move in hybrid algorithm. In SA algorithm and Tabu search algorithm, for each problem, the tuning of the parameters is done by carrying out random experiments The comparison of hybrid algorith with SA algorithm and Tabu search are shown in Tab. 3. It can be seen that the solution quality in hybrid algorithm is better than the solution quality in SA algorithm and Tabu Search algorithm.

5 Conclusions

In this paper we have outlined an integrated supply chain design model which optimizes location, transportation and customer responsiveness decisions, simultaneously. Customer responsiveness was measured by the delivery delay cost.

Table 3. Comparison of hybrid algorithm with SA Algorithm and Tabu Search Algorithm

NO.	# Customers	# DCs	# Suppliers	Hybrid Algorithm		SA Algorithm		Tabu Algorithm	
				Cost	CPU Time	Cost	CPU Time	Cost	CPU Time
1	30	8	4	110054.2	39	111261.5	38	111749.8	38
2	40	12	5	146157.4	51	148796.3	49	149354.2	50
3	50	15	5	183792.7	67	186913.8	65	185324.7	66
4	60	17	6	213375.1	80	218423.8	77	220742.5	78
5	70	19	6	258138.6	94	264172.2	90	264496.4	92
6	80	21	7	296364.2	110	304865.3	103	307124.2	107
7	90	23	7	337882.6	127	344195.8	121	348238.6	124
8	100	25	8	369734.2	146	380146.8	139	383167.3	144
9	120	30	9	435186.4	181	451976.7	173	456139.8	176
10	150	35	10	520379.6	232	534716.8	224	538196.4	228
11	180	38	11	602347.3	283	622643.9	274	629829.5	280
12	200	40	12	667894.3	319	696597.2	309	704176.6	313
13	230	43	13	753846.5	373	785798.1	362	796248.7	368
14	250	45	14	821492.1	413	865254.3	402	879571.3	410
15	280	48	15	914263.4	468	969536.5	456	987342.1	464
16	300	50	16	996346.1	511	1054374	497	1075235	507

The goal of our model was to determine simultaneously the best sites for the distribution centers and determining capacity for distribution centers and the best strategy for distributing the product from the suppliers to the distribution centers and from distribution centers to the customers, and we used different capacity levels for distribution centers that make the problem more realistic and assignment of customers to the distribution centers more flexible and furthermore, we used piecewise linear transportation cost between suppliers and distribution centers for obtaining economics of scale.

A hybrid heuristic combining Tabu search with Simulated Annealing sharing the same tabu list was developed for solving the problem. We comprised the hybrid algorithm with the optimal solution, SA algorithm and Tabu search method. The results of extensive computational tests indicated that the hybrid algorithm is both effective and efficient for a wide variety of problem sizes. Also, we showed that consideration of considering capacity levels helps to achieve the capacity utilization to a high level. For future works it is interesting to consider the multi-period model.

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