Determination of Material Flows in a Multi-echelon Assembly Supply Chain

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Abstract

This study aims to minimize the total cost of a four-echelon supply chain including suppliers, an assembler, distributers, and retailers. The total cost consists of purchasing raw materials from the suppliers by the assembler, assembling the final product, materials transportation from the suppliers to the assembler, product transportation from the assembler to the distributors, product transportation from the distributors to the retailers, and product holding and stock-out in the distribution centers. To this end, having modeled the problem addressed, a numerical example including ten suppliers, an assembler, three distributors and eight retailers in the chain is solved for four periods of time. Then the model is solved by a simulated annealing-based heuristic and LINGO. Finally, a set of 30 numerical problems of small and large sizes are developed and solved. The results indicate that simulated annealing-based heuristic provides near optimal solutions.

Key words: Multi-echelon; Supply chain; Cost minimization; Simulated annealing.

1. Introduction

Nowadays, due to the globalization of markets, the inventory issues have changed. Multinational companies store their products in the countries where maximal financial benefits can be gained. Moreover, as products are distributed to customers in different countries, supply chain issues have attracted the attention of researchers and practitioners.

A supply chain network (SCN) has a number of components including raw material suppliers, basic part manufacturing units, component suppliers, inventory service providers, assemblers, distributors, retailers and customers. Each group of these components, for example, raw material suppliers, is called an echelon. The goal of SCN design is to develop a network that meets the objectives set by the decision makers (DMs) such as cost minimization and service level maximization.

In this paper, a model for choosing a SCN is proposed. The model involves the supply of various components or modules from a set of suppliers and the allocation of finished products to warehouses or distribution centers. This scenario reflects a situation in manufacturing in which products require obtaining materials or components from many sources. The applicability of the model is studied designing a numerical analysis based on the model of the problem.

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2. Literature Review

A number of studies have addressed various issues of SCN design. Several of these studies including those on supplier selection are reviewed because one of the major outputs of the model proposed in this research is on supplier selection and order allocation. One of the earliest publications on the use of supply chain is a paper by Weber and Current (1993) where the authors analyzed the selection of suppliers with respect to minimizing the total purchase cost. Erenguc et al. (1999) reviewed the mathematical models used in the production and distribution planning. Categorizes a supply chain into the three stages of supplier stage, plant stage and distribution stage, they reviewed various optimization treatments used at the last two stages. In another study, Sabri and Beamon (2000) reviewed SCN design concluding that researches in the field focus on both deterministic and stochastic supply chains with the former being more strategic and the latter more operational. The authors also developed a cost minimization model for the simultaneous analysis of strategic and operational aspects in a supply chain through first analyzing the strategic aspect and then using its output in the operational aspect to develop a minimum cost solution. Providing a different categorization, Geunes and Pardalos (2003) classified the supply chain related models according to strategic, operational and tactical decision making. However, they did not consider multiple objective models. Jayaraman (1999) used a model to analyze a capacitated facility location and allocation. Weber et al. (2000) proposed a method for suppliers' selection involving developing supplier order quantity solutions using a SA method and evaluating these solutions using data envelopment analysis (DEA). Proposing the idea that supply chain design should be considered in terms of cooperating systems involved in networks, Chandra and Kumar (2001) developed two single-objective linear models for SCN design: (1) a decomposition model identifying common constraints and (2) a dynamic process flow model using the flow of components in a network. Liao and Rittscher (2007) provided an extension of Weber and Current's (1993) model for supplier selection with regard to supplier flexibility arguing that when the nature of demand is stochastic, it is necessary to evaluate suppliers based on quantity and time flexibility. Steuer (1986) said that moving from one set of results to another set of results regarding the stated objectives may result in obtaining better solutions to the problem as Goicoechea et al. (1982) maintained. Studying the process of operation allocation and material handling system, Sujono and Lashkari (2007) stated that methods like goal programming yield good results in this area. Nijkamp et al (1990) and Karpak et al. (1999) suggested using a visual interactive linear programming model for supplier selection, and considered suppliers' quality in service providing as an objective function. Cohon (1978) and Deb (2001) believed that this type of visual method helps the DMs to understand the implications of their choice. Korpela et al. (2002) developed an analytic hierarchy process (AHP) model for SCN design as they suggested that the traditional approach of cost or profit based optimization is not sufficient anymore for supply chain design. Their model which solves the production allocation problem by maximizing the strategic importance of customers and their preferences can help with tactical decision-making in a SCN. In the same vein, Zhou et al. (2003) proposed a bi-criteria model for the allocation of customers to warehouses. Aiming to minimize costs, they used a genetic algorithm to arrive at the solution. Spitter and Hurkens (2005) also developed a linear programming model for supply chain operation planning with capacity constraints for assembly. The model addresses the complexity of incorporating lead times and multi period capacity consumption in a capacitated assembly condition. Using a fuzzy quality function deployment (QFD) setting where linguistic preferences on a Likert scale were converted to quantitative terms, Erol and Ferrel (2003) solved the problem of maximizing total value chain of supply chain operation and concluded that such a method is able to use both qualitative and quantitative data. Similar models are presented by Benayoun et al. (1971), Costa and Climaco (1999), Duckstein (1982), and Magretta et al. (1998). Moreover, another similar model using the total cost and total user satisfaction as two objectives for analysis was developed by Erol and Ferrel (2004). Guillen et al. (2005) set the objective of maximizing the net present value in a stochastic supply chain setting to choose numbers, location and capacities of plants and warehouses. They concluded that generating different configurations of SCN could help DMs to determine the best design according to their objectives. Last but not least, Demirtas and Ustun (2006) developed a model to minimize defect rates from the supplier.

The review of supply chain models above shows the importance of objectives while designing a SCN. As the literature also emphasizes the involvement of DMs in the design of a SCN, it is better to use methods that can help DMs to understand solutions to the problems in different stages of solution searching. This type of interactive solution searching generates one solution at a time and facilitates a pre-informed decision making. Various objectives that could be considered for strategic decision making on a SCN are: (1) increasing service levels, (2) decreasing warehouse costs, (3) decreasing total fixed and variable costs, (4) decreasing the lead time (order processing and supply lead time), (5) consolidating the supplier base, (6) increasing the supplier reliability, (7) increasing capacity utilization and, (8) increasing total quality of supply. Additional objectives recommended by Weber and Current (1993) include the minimization of orders from unstable regions and minimization of delivery distance (or time). With regard to the issue of objectives, Pokharel (2007) developed a model of SCN with three objective functions and solved it using the interactive multiple objectives decision making techniques. Kang and Kim (2009) also developed a two-level supply chain in which a supplier serves a group of retailers in a given geographic region and determines a replenishment plan for each retailer using the information on the demands of final customers and inventory levels of the retailers. They tried to minimize the costs including vehicle cost, retailer – dependent material handling cost, and inventory holding cost of the whole supply chain. More recently, Sankar Sana (2010) constructed an integrated production–inventory model in order to obtain the production rate and raw material order size maximizing the expected profit. They made an attempt to consider a few business strategies as well. Park et al. (2010) dealt with a single-sourcing network design problem for a three-level supply chain consisting of suppliers, distribution centers (DC's) and retailers, where risk-pooling strategy and DC-to-supplier dependent lead times were the focus of attention. In doing so, they aimed to minimize the system-wide location, transportation, and inventory costs. Georgiadis et al. (2010) proposed a detailed mathematical formulation for the problem of designing supply chain networks comprising multi-product production facilities with shared production resources, warehouses, distribution centers and customer zones and operating under time varying demand uncertainty. They were able to illustrate the efficiency and applicability of their model in which networks involve complex interactions. Finally, Sadjady and Davoudpour (2011) addressed the design problem of a two-echelon supply chain network in deterministic, single-period, multi-commodity contexts. In order to minimize the total costs of transportation, lead-times, and inventory holding costs for products, as well as opening and operating costs for facilities, they formulated the problem as a mixed integer programming model.

3. Modeling

In the present paper, a simulated SCN design model is proposed. This supply chain consists of four echelons. At the first stage of the model, there are suppliers that provide raw materials for an assembler. The assembler receives raw materials from the suppliers in order to make the final product and deliver it to the third echelon of the chain in which the distributors are. The distributors play the role of suppliers for the retailers (the forth echelon) that deliver the product to the end users. Figure 1 illustrates the supply chain.

In this model, the suppliers are divided into different groups with each group being capable of providing just one type of raw materials for the assembler.

As each final product is assembled by one unit of each type of raw material, there is at least one supplier from each group of suppliers in the supply chain. For example, suppose that the final product is the refrigerator and its raw materials are compressor, lid, cabinet and foam, with the consumption coefficient of one unit.

The following assumptions should be considered in modeling this problem:

The supply chain only produces one type of product.

Only one unit from each raw material is needed to assemble the final product.

Customers' demands are definite and certain.

Assembling the final product has no wastages.

The cost of transportation between two elements of the chain is directly related to the quantity of the transported product.

The cost of ordering between two elements of the chain is zero.

The cost of shortage is considered at the end of each period, which is relative to the units of shortage in the distributor centers.

The cost of holding is considered for the remaining products at the end of period in the distributor centers.

All customers' demands must be met at the end of the final period.

The parameters of this problem and the decision variables are presented in Table 1 and Table 2, respectively.

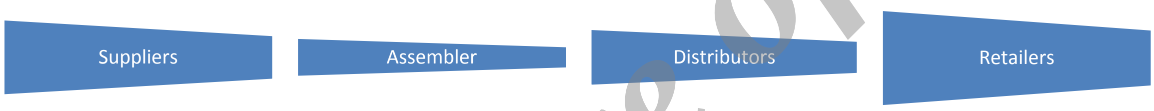

Fig. 1. The schema of the four-echelon supply chain

Table 1
Parameters of the model

Symbol	Parameter
T	Number of periods
J	Number of raw materials used in manufacturing one unit of the final product
S	Number of suppliers
D	Number of distributors
R	Number of retailers
TS_{js}	Transmission cost of one unit of raw material of type j from supplier S to the assembler
CH_{js}	Cost of buying one unit of raw material of type j from supplier S
AE	Cost of assembling one unit of all the raw material of type j and manufacturing a unit of final product
TD_d	Cost of the transmission of one unit of final product from the assembler to distributer d
TR_{dr}	Cost of the transmission of one unit of final product from distributer d to retailer r
BC	Cost of the maintenance of one product unit at the end of a period
PC	Cost of the shortage of one product unit at the distributor's place
ES_{js}	Capacity of supplier S for piece (raw material) j (maximum flow of product that can be supplied by supplier S, that is a constant amount during all periods)
EA	maximum flow of product from assembler to distributors, that is a constant amount during all periods
K_d	The sum total of retailers covered by distributor d (they are provided by distributor d)
MR_{rt}	Demand of retailer r in period t from the related distributor
Z	Total cost

Table 2
Decision making variables

Symbol	Variable
y_t	The amount of product manufactured by the assembler in period t
FS_{jst}	Flow of raw material j from supplier S to the assembler in period t
FD_{dt}	Flow between the assembler and distributor d
FR_{drt}	Flow of final product from distributor d to retailer r in period t
PD_{dt}	Reserved product in the place of distributor d in period t
BD_{dt}	Remaining product in the place of distributor d in period t

3.1. Objective Function

Since in this problem all demands are to be met, and the total income of the chain is constant, minimizing the total cost of the chain is important. The costs include the cost of buying raw materials, the cost of assembling, the cost of holding remaining products, the cost of shortage, and the cost of material and final product transportation among different echelons of the supply chain.

First, we form the cost function of buying the raw material and transporting them to the assembler as in Eq. (1)

$$\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{j=1}^{J}\left(TS_{js}+CH_{js}\right)*FS_{jst} \qquad (1)$$

Then the cost of assembling the raw materials by the assembler is as follows (Eq. 2):

$$\sum_{t=1}^{T} AE * y_t \qquad (2)$$

And the cost of transporting the final product to the distributors and then the retailers is gained by Eq. (3)

$$\sum_{t=1}^{T}\sum_{d=1}^{D} TD_d * FD_{dt} + \sum_{t=1}^{T}\sum_{d=1}^{D}\sum_{r\in k_d} TR_{dr} * FR_{drt} \qquad (3)$$

The cost of holding the remaining products and that of shortage are obtained from Eq. (4)

$$\sum_{t=1}^{T}\sum_{d=1}^{D}(BC * BD_{dt}) + \sum_{t=1}^{T}\sum_{d=1}^{D}(PC * PD_{dt}) \qquad (4)$$

Thus, the objective function to minimize the total cost is as follows:

$$Z = \sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{j=1}^{J}\left(TS_{js}+CH_{js}\right)*FS_{jst} + \sum_{t=1}^{T} AE * y_t + \sum_{t=1}^{T}\sum_{d=1}^{D} TD_d * FD_{dt} + \sum_{t=1}^{T}\sum_{d=1}^{D}\sum_{r\in k_d} TR_{dr} * FR_{drt} +$$

$$\sum_{t=1}^{T}\sum_{d=1}^{D}(BC * BD_{dt}) + \sum_{t=1}^{T}\sum_{d=1}^{D}(PC * PD_{dt}) \qquad (5)$$

3.2. Constraints

Constraints of the problem include the capacity constraint of suppliers, the capacity constraint of assemblers, constraints that indicate the amount of shortage or inventory surplus at the end of the periods for the distributors, and constraints on the equilibrium of flows among different echelons of the chain. Some of these constraints are calculated as follows.

The capacity constraint of the assemblers is gained from Eq. (6)

$$\sum_{d=1}^{D} FD_{dt} \le EA; \forall t = 1, \ldots, T \qquad (6)$$

The capacity constraint of the suppliers is as Eq. (7)

$$FS_{jst} \le ES_{js} \quad \forall j = 1, \ldots J, \forall s = 1, \ldots S, \forall t = 1, \ldots T \qquad (7)$$

And regarding the equilibrium, we can use Eq. (8)-(9)

$$\sum_{s=1}^{S} FS_{1st} = \sum_{s=1}^{S} FS_{2st} = \sum_{s=1}^{S} FS_{3st} = \cdots = \qquad (8)$$

$$\sum_{s=1}^{S} FS_{Jst} = Y_t; \forall\, t = 1, \ldots, T$$

$$\sum_{d=1}^{D} FD_{dt} = Y_t; \forall t = 1, \ldots T \qquad (9)$$

For each distributor, the amount of input flow in period t plus the remaining amount of product at period (t-1) minus the reserved amount of product (shortage amount) in period (t-1) would be equal to the sum of the total demands received by the distributor in period t and the remaining product at the end of period t minus the amount of reserved product at period t. This is presented in Eq. (10)

$$FD_{dt} + BD_{d(t-1)} - PD_{d(t-1)} = \sum_{r\in k_d} MR_{drt} + BD_{dt} - PD_{dt}$$

$$\forall\, t = 1,2, \ldots, (T-1), \forall d = 1,2, \ldots, D \qquad (10)$$

assuming that:

$$BD_0 = PD_0 = BD_T = PD_T = 0$$

On the other hand, the output flow from each distributor at period t is equal to the minimum of the sum of total input amount to the distributor at period t and the remaining amount of product at period (t-1) and the sum of demands received by the distributor at period t and the reserved amount of product at period (t-1) as given by Eq. (11)

$$FR_{drt} = \sum_{r\epsilon k_d} \min\{FD_{dt} + BD_{d(t-1)}, \sum_{r\epsilon k_d} MR_{drt} + PD_{d(t-1)}\} \quad (11)$$

Note that for the last period, Eq. (11) will turn to Eq. (12) with respect to the aforementioned assumption.

$$\sum_{r\epsilon k_d} FR_{drt} = \sum_{r\epsilon k_d} MR_{drt} + PD_{d(t-1)} \quad (12)$$

4. Solving the Problem

In this section, in order to solve the defined problem, we design a numerical example and solve it by a Simulated Annealing (SA) based heuristic.

4.1. Problem Definition

We consider a refrigerator making company as an assembler whose required materials are supplied by a number of different suppliers. Keeping the problem simple, we assume that the suppliers are to deliver just four main original parts to the assembler (see Table3).

Table 3
Original parts of the refrigerator required by the assembler

NO.	Original Equipment (OE)
1	Engine
2	Frame (Cabinet)
3	Cooling system
4	Electronic items

The company is assumed to be able to manufacture at most 100 units of refrigerators because of the constraints on the quantity of laborers and working area. Since owners of the company are going to select their suppliers among a few competent ones, they consider the prices offered by the suppliers as given in Table 4.

This assembler company is supposed to have three distribution centers in three major cities of the country so that the distribution centers would satisfy the requirements of a number of retailers located in the neighboring provinces. Each retailer as a customer is assigned to just one distribution center. The monthly demands of the retailers for a four-month time period as well as the assignment to the centers are shown in Table 5.

Other required data are provided in Tables 6-8.

Table 4
Costs of buying from different suppliers

Supplier NO.	Required OE	Unit price	Transmission price of the unit	capacity
1	Engine	100	2	60
2	Engine	99	3	50
3	Frame (Cabinet)	60	5	20
4	Frame (Cabinet)	59	5	50
5	Frame (Cabinet)	58	6	70
6	Cooling system	80	2	50
7	Cooling system	81	2	80
8	Electronic items	30	1	30
9	Electronic items	31	1	40
10	Electronic items	29	1	50

Table 5
Retailers' demands in different periods

Number of retailers	Assigned distributor	retailers' demand in different periods				Total demand
1	1	10	12	12	10	44
2	1	8	8	9	9	34
3	1	15	12	12	10	49
4	2	15	18	18	20	71
5	2	4	5	5	4	18
6	3	18	15	15	14	62
7	3	12	13	14	15	54
8	3	20	10	18	5	53
Total demand		102	93	103	87	382

Table 6
Costs of transporting one unit of refrigerator from the assembler to the distribution centers

Distribution NO.	Cost of transportation to the distribution centers	Capacity of the distributor in each period
1	10	32
2	10	22
3	10	48

Table 7
Costs of transporting one unit of refrigerator from the distributors to the retailers

	Distributor 1	Distributor 2	Distributor 3
Retailer 1	15	-	-
Retailer 2	14	-	-
Retailer 3	14	-	-
Retailer 4	-	16	-
Retailer 5	-	16	-
Retailer 6	-	-	17
Retailer 7	-	-	18
Retailer 8	-	-	18

Table 8
General information of the problem

Parameter	Value
Cost of assembling one unit of refrigerator	15
Cost of holding one unit of refrigerator at the end of a period	20
Cost of the shortage of one unit of refrigerator at the end of a period	30

Based on all the information above, the supply chain can be illustrated as follows in Figure 2.

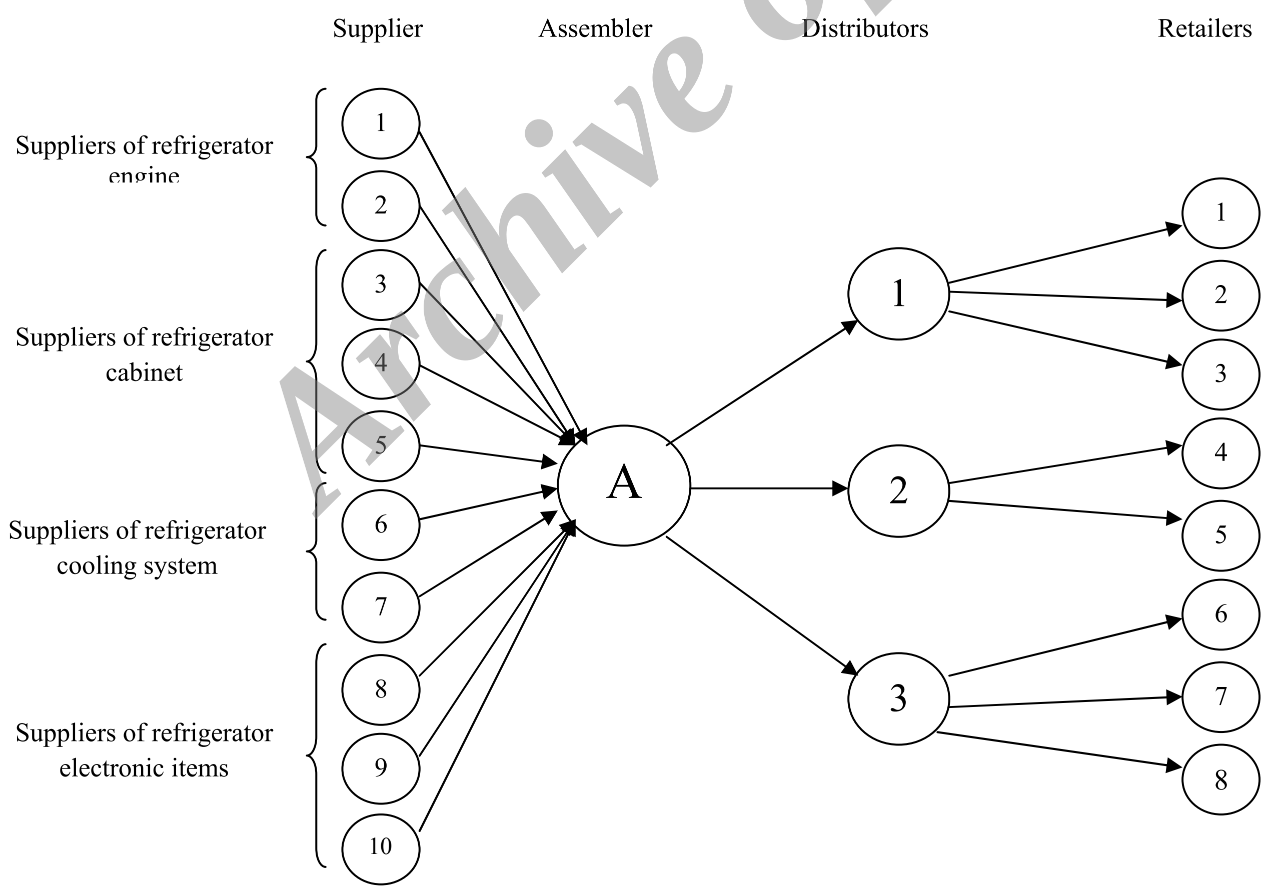

Fig. 2. The schema of the supply chain

4.2.1. Solving the problem using LINGO

The problem is solved by LINGO, and its results are reported in Table 9.

Table 9
Results obtained from Lingo

Y_1	100	Y_2	98	Y_3	100	Y_4	87
FS_{111}	60	FS_{112}	60	FS_{113}	60	FS_{114}	60
FS_{121}	40	FS_{122}	38	FS_{123}	40	FS_{124}	27
FS_{231}	0	FS_{232}	0	FS_{233}	0	FS_{234}	0
FS_{241}	50	FS_{242}	50	FS_{243}	50	FS_{244}	50
FS_{251}	50	FS_{252}	48	FS_{253}	50	FS_{254}	37
FS_{361}	50	FS_{362}	50	FS_{363}	50	FS_{364}	50
FS_{371}	50	FS_{372}	48	FS_{373}	50	FS_{374}	37
FS_{481}	30	FS_{482}	30	FS_{483}	30	FS_{484}	30
FS_{491}	20	FS_{492}	18	FS_{493}	20	FS_{494}	7
FS_{4101}	50	FS_{4102}	50	FS_{4103}	50	FS_{4104}	50
FD_{11}	31	FD_{12}	34	FD_{13}	33	FD_{14}	29
FD_{21}	19	FD_{22}	23	FD_{23}	23	FD_{24}	24
FD_{31}	50	FD_{32}	41	FD_{33}	44	FD_{d4}	34
FR_{111}	0	FR_{112}	0	FR_{113}	0	FR_{114}	0
FR_{121}	0	FR_{122}	0	FR_{123}	0	FR_{124}	0
FR_{131}	31	FR_{132}	17	FR_{133}	16	FR_{134}	14
FR_{241}	0	FR_{242}	0	FR_{243}	0	FR_{244}	0
FR_{251}	19	FR_{252}	23	FR_{253}	23	FR_{254}	24
FR_{361}	50	FR_{362}	38	FR_{363}	47	FR_{364}	34
FR_{371}	0	FR_{372}	0	FR_{373}	0	FR_{374}	0
FR_{381}	0	FR_{382}	0	FR_{383}	0	FR_{384}	0

Other variables' values in each period are presented in Table 10.

Table10
The shortage and surplus in the place of distributors

PD_{11}	2	PD_{12}	0	PD_{13}	0	PD_{13}	0
PD_{21}	0	PD_{22}	0	PD_{23}	0	PD_{23}	0
PD_{31}	0	PD_{32}	0	PD_{33}	0	PD_{33}	0
BD_{11}	0	BD_{12}	0	BD_{13}	0	BD_{13}	0
BD_{21}	0	BD_{22}	0	BD_{23}	0	BD_{23}	0
BD_{31}	0	BD_{32}	3	BD_{33}	0	BD_{33}	0

The optimum value of the objective function turns out to be 21,507.

4.2.2. Solving the problem using SA

The problem defined in the previous section is nonlinear and thus difficult to solve, therefore we design a SA based heuristic to solve it. In this heuristic, we have a few notations including primal temperature (T_0), final temperature (T_f), temperature coefficient (α), number of the inner loop (N), number of temperature changes (i) , number of the inner loop(n), and the fitness function (F).

The heuristic is programmed using MATLAB. Two important points should be considered in applying the SA based heuristic: (1) Generating the initial solution and (2) generating the neighborhood solution. In order to generate the initial solution, we assume that the assembler works with the maximum capacity. The fitness function is also considered the same as the object function. The values of the heuristic parameters determined through trial and error turn out to be T0=2000, Tf = 5, α=0.9, n=100.
The proposed heuristic includes the following steps:
Step 1: Initiate T0, Tf, α, N, i=0, n=0
Step 2: A primal solution W0 is generated; Wn =W0; the value of F is calculated and Ti = T0
Step 3: A neighborhood solution for Wn is generated and ΔF is calculated by Eq. (13)

$$\Delta F = F(W_n) - F(W_{n+1}) \quad (13)$$

Step 4: If $\Delta F \leq 0$, the solution W_{n+1} is replaced with the previous solution, otherwise $p = e^{-\frac{\Delta F}{T_i}}$ is calculated and a random number (z) in (0, 1) is generated. If z<p, the solution W_{n+1} is replaced with the previous solution, otherwise the previous solution is selected and n=n+1.
Step 5: repeat steps 3 and 4 until n<=N.
Step6: i =i+1, $T_i = \alpha T_{i-1}$ and repeat step 3 to 6 until $T_i => T_f$
To generate the neighbor solution, we select one of the following ways:

- Reducing one unit from product in one period and adding one unit to another period
- Reducing one unit from supplied raw material from one supplier and adding one unit to another supplier
- Reducing one unit of product flow to one distributor in a period and adding one unit to another period
- Reducing one unit of product flow to one retailer and increasing one unit to another retailer

The problem is solved by the heuristic. The results are reported in Table 11.
The optimum value for the objective function of the problem turns out to be 21,875 by the heuristic.

4.3. More Numerical Problems

In order to evaluate the performance of the model, we design a few more numerical problems and solve them. Moreover, we compare the results with each other. To provide the numerical examples, it is necessary to define the number of periods (T), the number of raw materials used in manufacturing one unit of find product (J), the number of suppliers (S), the number of distributors (D), and retailers (R). Having done so, 30 numerical problems of small and large size are designed and the results are obtained using LINGO which creates a local optimum and the SA based heuristic (see Table 12).

Table 11
Results obtained from the SA method

Y_1	85	Y_2	100	Y_3	100	Y_4	100
FS_{111}	60	FS_{112}	60	FS_{113}	60	FS_{114}	60
FS_{121}	25	FS_{122}	40	FS_{123}	40	FS_{124}	40
FS_{231}	20	FS_{232}	20	FS_{233}	20	FS_{234}	20
FS_{241}	50	FS_{242}	50	FS_{243}	50	FS_{244}	50
FS_{251}	15	FS_{252}	30	FS_{253}	30	FS_{254}	30
FS_{361}	50	FS_{362}	50	FS_{363}	50	FS_{364}	50
FS_{371}	35	FS_{372}	50	FS_{373}	50	FS_{374}	50
FS_{481}	30	FS_{482}	30	FS_{483}	30	FS_{484}	30
FS_{491}	40	FS_{492}	40	FS_{493}	40	FS_{494}	40
FS_{4101}	15	FS_{4102}	30	FS_{4103}	30	FS_{4104}	30
FD_{11}	16	FD_{12}	39	FD_{13}	30	FD_{14}	42
FD_{21}	19	FD_{22}	23	FD_{23}	23	FD_{24}	24
FD_{31}	50	FD_{32}	38	FD_{33}	47	FD_{d4}	34
FR_{111}	1	FR_{112}	21	FR_{113}	0	FR_{114}	0
FR_{121}	0	FR_{122}	6	FR_{123}	0	FR_{124}	0
FR_{131}	15	FR_{132}	12	FR_{133}	12	FR_{134}	21
FR_{241}	0	FR_{242}	0	FR_{243}	0	FR_{244}	0
FR_{251}	19	FR_{252}	23	FR_{253}	23	FR_{254}	24
FR_{361}	0	FR_{362}	0	FR_{363}	0	FR_{364}	0
FR_{371}	0	FR_{372}	0	FR_{373}	0	FR_{374}	0
FR_{381}	50	FR_{382}	38	FR_{383}	47	FR_{384}	34

Table12
Parameter values and results of the SA based heuristic and LINGO for the 30 numerical problems

Problem	T	J	S	D	R	Lingo Software	SA Method
1	1	2	5	5	5	15372	17342
2	1	5	5	5	5	16392	17456
3	2	5	7	5	5	15642	15432
4	2	5	10	5	5	14325	14546
5	3	5	7	5	5	16423	16235
6	4	5	7	7	5	17567	17642
7	5	8	10	7	10	19643	19725
8	5	8	12	10	10	18564	18492
9	5	10	12	10	10	19245	19345
10	7	10	12	10	10	21547	21539
11	7	10	15	10	10	19674	19780
12	10	10	15	10	10	24295	24352
13	10	10	15	10	15	23456	23420
14	10	10	15	15	15	20456	21364
15	12	10	15	10	15	25961	26154
16	15	10	20	10	20	64372	64592
17	15	15	20	10	20	79825	79345
18	15	20	20	10	20	91835	92185
19	20	30	40	20	30	169427	167315
20	20	30	45	20	35	174845	162354
21	20	35	40	30	40	235852	245301
22	25	40	60	40	50	325846	312981
23	30	40	60	40	50	465325	452369
24	30	40	100	60	80	759356	745692
25	25	50	100	60	80	598345	598946
26	30	50	80	50	80	1042356	945895
27	20	20	60	30	40	389324	395682
28	30	40	60	30	80	634285	621487
29	30	50	80	40	80	845627	724689
30	35	50	100	60	80	12345862	985746

5. Conclusion

The results of two one-sample k-s tests and the histograms run through SPSS16 for the first 15 numerical problems (as small size problems) and the second 15 numerical problems (as large size problems) using LINGO and the heuristic are illustrated in Figures 3-6.

NPar Tests

One-Sample Kolmogorov-Smirnov Test

		VAR00001
N		30
Normal Parameters a,b	Mean	19379.533
	Std. Deviation	3340.6563
Most Extreme Differences	Absolute	.119
	Positive	.119
	Negative	-.087
Kolmogorov-Smirnov Z		.652
Asymp. Sig. (2-tailed)		.790

a. Test distribution is Normal.
b. Calculated from data.

Fig. 3. Results of the one-sample k-s test for the 15 small size problems

NPar Tests

One-Sample Kolmogorov-Smirnov Test

		VAR00002
N		30
Normal Parameters a,b	Mean	827235.38
	Std. Deviation	2196570.3
Most Extreme Differences	Absolute	.428
	Positive	.428
	Negative	-.364
Kolmogorov-Smirnov Z		2.342
Asymp. Sig. (2-tailed)		.000

a. Test distribution is Normal.
b. Calculated from data.

Fig. 4. Results of the one-sample k-s test for the 15 large size problems

Graph

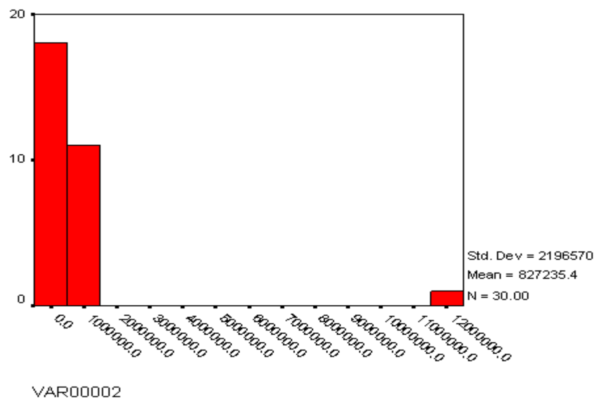

Fig. 5. Histogram of the 15 small size problems

Graph

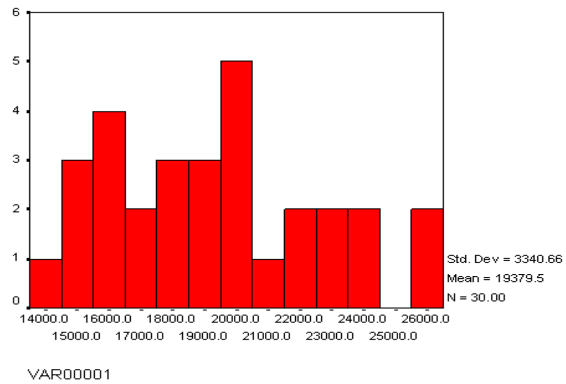

Fig. 6. Histogram of the 15 large size problems

T-Test

Group Statistics

	VAR00003	N	Mean	Std. Deviation	Std. Error Mean
VAR00001	1.00	15	19237.47	3453.9612	891.8089
	2.00	15	19521.60	3338.2650	861.9363

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00001	Equal variances assumed	.017	.899	-.229	28	.820	-284.1333	1240.2651	-2824.70	2256.4345
	Equal variances not assumed			-.229	27.968	.820	-284.1333	1240.2651	-2824.83	2256.5672

Fig. 7. Results of the independent samples T test for the 15 small size problems

NPar Tests

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
VAR00005 - VAR00004	Negative Ranks	5[a]	4.00	20.00
	Positive Ranks	10[b]	10.00	100.00
	Ties	0[c]		
	Total	15		

a. VAR00005 < VAR00004
b. VAR00005 > VAR00004
c. VAR00004 = VAR00005

Test Statistics[b]

	VAR00005 - VAR00004
Z	-2.272[a]
Asymp. Sig. (2-tailed)	.023

a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test

Fig. 8. Results of the Wilcoxon test for the 15 large size problems

Furthermore, for the 15 small size numerical problems, an independent samples T test shows that the average results of both methods with the confidence level of 95% are the same. But, for the 15 large size numerical problems, a Wilcoxon test, a non-parametric test for 2 related samples, reveals that the average results of SA considering the confidence level of 95% are lower than those obtained from LINGO (see Figures 7 and 8).

For further research, it is a good idea to model and solve the problem addressed in this study for multi-product cases.

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