Supply Chain Network Design Optimization Model for Multi-period Multi-product

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Abstract-- **Supply chain management (SCM) is the management of the flow of goods and services. It includes the movement and storage of raw materials, inventory, and finished goods from point of origin to point of consumption.**

In this paper, the supply chain network is mathematically modeled in a mixed integer linear programming (MILP) form considering multi-product, multi-period, multi-echelons and associated cost elements. The model represent both location and allocation decisions of the supply chain which maximizes the total profit.

Model outputs have proved its ability to design multi-product, multi-period, multi-echelons networks. In general, the results have shown the effect of customers' demands from each product in each period in the quantities of material delivered from each supplier too each facility, the quantities of each product delivered from each facility and facility store to each distributor, the inventory of each product in each facility and distributor, the quantities of each type of product delivered from each distributor to each customer in each period. The model has been verified through a detailed example and the implementation of the proposed model has been demonstrated using some numerical example.

Index Term-- **Supply chain Management (SCM), supply chain network design, location, allocation, MILP, modeling, multi-products, multi echelon and multi-periods.**

1. INRODUCTION

Supply chain network design affects its performance and profit. So it is very important to give the design process more attention to assure good performance and profit.

Imran Maqsood, et al. (2005) [1] proposed an interval-parameter fuzzy two-stage stochastic programming (IFTSP) method for the planning of water-resources-management systems under uncertainty.

Tjendera Santoso, et al. (2005) [2] proposed a stochastic programming model and solution algorithm for solving supply chain network design problems of a realistic scale. their solution methodology integrates a recently proposed sampling strategy, the sample average approximation (SAA) scheme, with an accelerated benders decomposition algorithm to quickly compute high quality solutions to large-scale stochastic supply chain design problems with a huge (potentially infinite) number of scenarios.

M. El-Sayed, et al. (2010) [3] developed a multi-period multi-echelon forward–reverse logistics network design under risk model. The proposed network structure consists of three echelons in the forward direction, (suppliers, facilities and distribution centers) and two echelons, in the reverse direction (disassembly, and redistribution centers), first customer zones in which the demands are stochastic and second customer zones in which the demand is assumed to be deterministic, but it may also assumed to be stochastic. The problem is formulated in a stochastic mixed integer linear programming (SMILP) decision making form as a multi-stage stochastic program to maximize the total expected profit.

Fan Wang, et al. (2011) [4] studded a supply chain network design problem with environmental concerns. They are interested in the environmental investments decisions in the design phase and proposed a multi-objective optimization model that captures the trade-off between the total cost and the environment influence.

Jiang Wu and Jingfeng Li 2014 [5] studied dynamic facility location and supply chain planning through minimizing the costs of facility location, path selection and transportation of coal under demand uncertainty. The proposed model dynamically incorporates possible changes in transportation network, facility investment costs, operating cost and changes in facility location.

Ruiqing Xia and Hiroaki Matsukawa 2014 [6] investigated a supplier-retailer supply chain that experiences disruptions in supplier during the planning horizon. There might be multiple options to supply a raw material, to manufacture or assemble the product, and to transport the product to the customer. While determine what suppliers, parts, processes, and transportation modes to select at each stage in the supply chain, options disruption must be considered.

Farzaneh Adabi and Hashem Omrani 2014 [7] presented a supply chain management by considering efficiency in the system considering two objective functions where the first one maximizes the efficiency of the supply chain and the second one minimizes the cost of facility layout as well as production of different products. The study has been formulated as a mixed integer programming.

Kyoung Jong Park 2014 [8] proposed a method to optimize a supply chain network for yacht service that maximizes values for service users / customers, and profits for service providers. This paper used the Cash to Cash cycle (C2C cycle) to optimize a yacht service supply chain network inclusive of design, research, manufacture, and leisure service. A Supply Chain Network Optimization for Yacht Service is developed using an evolutionary algorithm and C2C Cycle of deterministic Environment.

In this paper, a location allocation model is developed for the purpose of designing the multi echelon supply chain network for multi-product and multi period to maximize the Total profit of the supply chain network. The proposed supply chain structure consists of three echelons (three suppliers, three facilities and three distributors) to serve four customers as shown in figure 1.

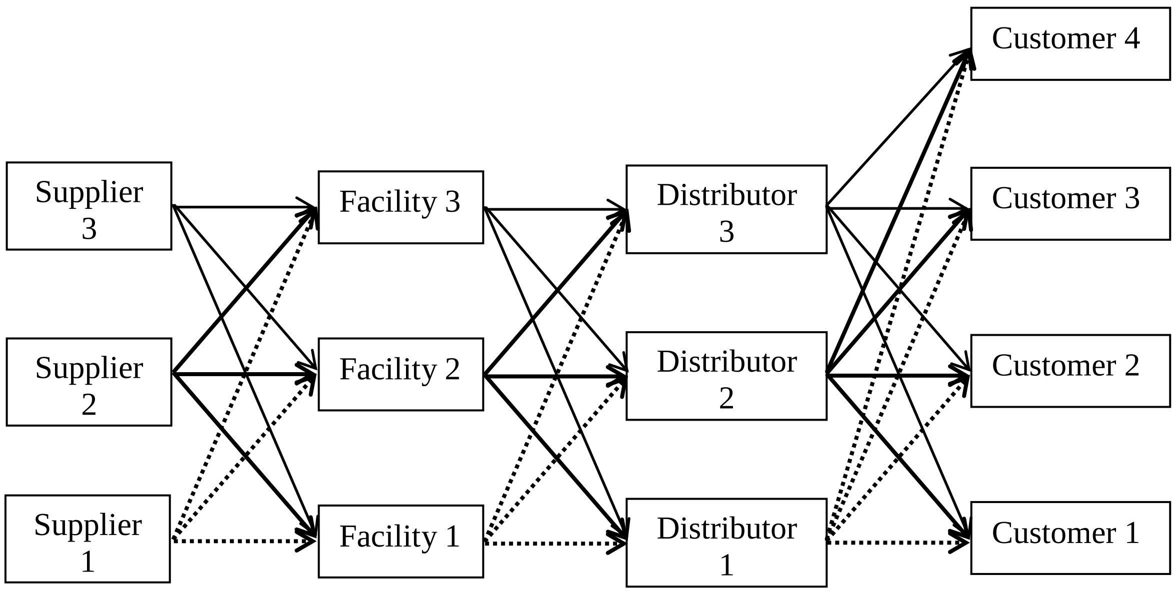

Fig. 1. The proposed supply chain network.

2. MODEL DESCRIPTION

The proposed model assumes a set of customer locations with known demands and a set of candidate suppliers, facilities, and distributor's locations. It optimizes locations of the suppliers, facilities, distributors and customers and allocate the shipment between them to maximize the Total profit taking their capacities and costs into consideration.

The problem is formulated as a mixed integer linear programming (MILP). The model is solved using XpressMP software which uses Mosel language in programming [9].

The flow of material and product through supply chain nodes are assumed as shown in figure 2.

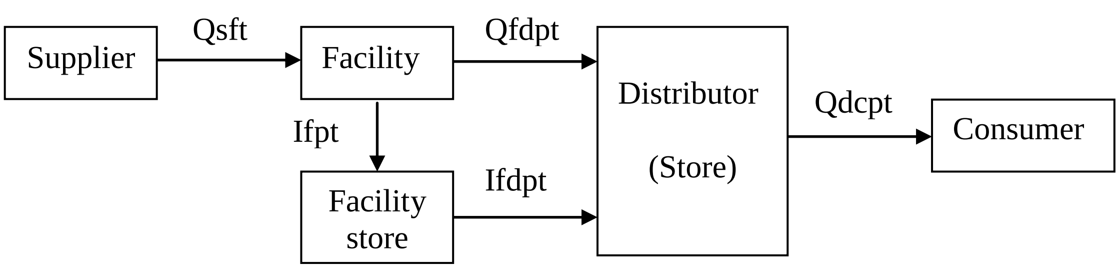

Fig. 2. Model flow.

The model considers fixed costs for all nodes, materials costs, transportation costs, manufacturing costs, non-utilized capacity costs for facilities, holding costs for facility and distributors' stores and shortage costs.

3. MODEL ASSUMPTIONS AND LIMITATIONS

The following assumptions are considered:

1. The model is multi-product, where actions and flow of materials take place for multi-product.
2. Products weights are different.
3. The model is multi-period, where actions and flow of materials take place in multi-periods.
4. Customers' locations are fixed and known.
5. Customers' demands are known for all product in all periods.

6. The potential locations of suppliers, facilities, and distributors are known.
7. Costs parameters (fixed costs, material costs, manufacturing costs, non-utilized capacity costs, shortage costs, transportation costs, and inventory holding costs) are known for each location, each product at each period.
8. Capacity of each supplier, facility, and distributor locations are known for each period.
9. The shortage cost depends on the shortage quantity for each product and time.
10. The holding cost depends on the, weight of product and residual inventory at the end of each period for each product.
11. The transportation cost depends on the transported quantities, weight of product and the linear distance between locations.
12. The manufacturing cost depends on the manufacturing hours for each product and manufacturing cost per hours
13. The material cost is different for each product depending on its weight.
14. Integer number of batches is transported.

4. MODEL FORMULATION

The model involves the following sets, parameters and variables:

Sets:

S: potential number of suppliers, indexed by *s*.
F: potential number of facilities, indexed by *f*.
D: potential number of distributors, indexed by *d*.
C: potential number of first customers, indexed by *c*.
T: number of periods, indexed by *t*.
P: number of product, indexed by *p*.

Parameters:

F_s: fixed cost of opening supplier *s*,
F_f: fixed cost of opening facility *f*,
F_d: fixed cost of opening distributor *d*,
$DEMAND_{cpt}$: demand of customer *c* from product *p* in period *t*,
P_{pct}: unit price of product p at customer *c* in period *t*,
W_p : product weight.
MH_p: manufacturing hours for product.
D_{sf}: distance between supplier *s* and facility *f*.
D_{fd}: distance between facility *f* and distributor *d*.
D_{dc}: distance between distributor *d* and customer *c*.
CAP_{st}: capacity of supplier *s* in period *t* (kg),
$CAPM_{ft}$: capacity of facility f Raw Material Store in period t.
$CAPH_{ft}$: capacity in manufacturing hours of facility *f* in period *t*,
$CAPFS_{ft}$: storing capacity of facility *f* in period *t* ,
CAP_{dt}: capacity of distributor *d* in period *t* (kg),
MatCost: material cost per unit supplied by supplier *s* in period *t*,
MC_{ft}: manufacturing cost per hour for facility *f* in period *t*,
MH_p: Manufacturing hours for product (p)
NUCCf: non utilized manufacturing capacity cost per hour of facility *f*,
$SCPU_p$: shortage cost per unit per period,
HF_p: holding cost per unit per period at facility *f* store (kg),
HD_p: holding cost per unit per period at distributor *d* store (kg),
B_s: batch size from supplier s
B_{fp}& B_{dp}: batch size from facility *f* for product and distributor *d* for product.
TCperkm: transportation cost per unit per kilometer.
M: Big number
S: Small number

Decision Variables:

L_s: binary variable equal to 1 if a supplier *s* is opened and equal to 0 otherwise.
L_f: binary variable equal to 1 if a facility *f* is opened and equal to 0 otherwise.
L_d: binary variable equal to 1 if a distributor *d* is opened and equal to 0 otherwise.
Li_{sf}: binary variable equal to 1 if a transportation link is activated between supplier *s* and facility *f*.
Li_{fd}: binary variable equal to 1 if a transportation link is activated between facility *f* and distributor *d*.
Li_{dc}: binary variable equal to 1 if a transportation link is activated between distributor *d* and customer *c*.
Q_{sft}: number of batches transported from supplier *s* to facility *f* in period *t*,
Q_{fdpt}: number of batches transported from facility *f* to distributor *d* for product p in period *t*,
I_{fpt}: number of batches transported from facility *f* to its store for product p in period *t*,
I_{fdpt}: number of batches transported from store of facility *f* to distributor *d* for product p in period *t*,
Q_{dcpt}: number of batches transported from distributor *d* to customer *c* for product p in period *t*,
R_{fpt}: residual inventory of the period *t* at store of facility *f* for product p.
R_{dpt}: residual inventory of the period *t* at distributor *d* for product p.

4.1. Objective function.

The objective of the model is to maximize the total profit of the supply chain network.

Total profit = Total income – Total cost

4.1.1. Total income

$$\text{Total income} = \sum_{d\in D}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{dcpt}\, B_{dp}\, P_{pct}$$

4.1.2. Total cost

Total cost = fixed costs + material costs + manufacturing costs + non-utilized capacity costs + shortage costs + transportation costs + inventory holding costs.

4.1.2.1. Fixed costs

$$\text{Fixed costs} = \sum_{s\in S} F_s L_s + \sum_{f\in F} F_f L_f + \sum_{d\in D} F_d L_d \quad (2)$$

4.1.2.2. Material cost

$$\text{Material cost} = \sum_{s\in S}\sum_{f\in F}\sum_{t\in T} Q_{sft}\, B_s\, MatCost_{st}$$

4.1.2.3. Manufacturing costs

$$\text{Manufacturing costs} = \sum_{f\in F}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T} Q_{fdpt}\, B_{fp}\, MH_p Mc_{ft} + \sum_{f\in F}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T} I_{fpt}\, B_{fp}\, MH_p Mc_{ft} \quad (4)$$

4.1.2.4. Non-Utilized capacity cost (for facilities)

$$\sum_{f\in F}\Big(\sum_{p\in P}\sum_{t\in T}((CAPH_{ft})\, L_f - \sum_{d\in D}(Q_{fdpt}\, B_{fp} MH_p) - \sum_{d\in D}(I_{ffpt}\, B_{fp} MH_p))NUCC_f\Big) \quad (5)$$

4.1.2.5. Shortage cost (for distributor)

$$\sum_{p\in P}\Big(\sum_{c\in C}\Big(\sum_{t\in T}\Big(\sum_{1}^{t} DEMAND_{cpt} - \sum_{1}^{t}\sum_{d\in D} Q_{dcpt}\, B_{dp}\Big)\Big)\Big) SCPU_p \quad (6)$$

4.1.2.6. Transportation costs

$$\sum_{t\in T}\sum_{s\in S}\sum_{f\in F} Q_{sft}\, B_s\, T_s\, DS_{sf} + \sum_{p\in P}\Big(\sum_{t\in T}\sum_{f\in F}\sum_{d\in D} Q_{fdpt}\, B_{fp}\, W_p T_f\, D_{fd} + \sum_{t\in T}\sum_{f\in F}\sum_{d\in D} I_{fdpt}\, B_{fp} W_p T_f\, D_{fd}(1+s) + \sum_{d\in D}\sum_{c\in C}\sum_{t\in T} Q_{dcpt}\, B_{dp}\, W_p T_d\, D_{dc}\Big) \quad (7)$$

4.1.2.7. Inventory holding costs

$$\sum_{p\in P}\Big(\sum_{f\in F}\sum_{t\in T} R_{fpt}\, W_p\, HF_f + \sum_{d\in D}\sum_{t\in T} R_{dpt}\, W_p\, HD_d\Big) \quad (8)$$

4.2. Constraints

4.2.1. Balance constraints:

$$\sum_{s\in S} Q_{sft} B_s = \sum_{d\in D}\sum_{p\in P} Q_{fdpt} B_{fp} W_p + I_{fpt} B_{fp} W_p, \forall t\in T, \forall f\in F \quad (9)$$

$$I_{fpt} B_{fp} + R_{fp(t-1)} B_{fp} = R_{fpt} B_{fp} + \sum_{d\in D} I_{fdpt} B_{fp}, \forall t\in T, \forall f\in F, \forall p\in P \quad (10)$$

$$\sum_{p\in P}\sum_{f\in F}(Q_{fdpt} + I_{fdpt}) B_{fp} + R_{dp(t-1)} B_{dp} = R_{dpt} B_{dp} + \sum_{p\in P}\sum_{c\in C} Q_{dcpt} B_{dp}, \forall t\in 2\to T, \forall d\in D \quad (11)$$

$$\sum_{d\in D} Q_{dcpt} B_{dp} \le DEMAND_{cpt} + \sum_{1\to t} DEMAND_{cp(t-1)} - \sum_{d\in D} Q_{dcp(t-1)} B_{dp}, \forall t\in T, \forall c\in C, \forall p\in P \quad (12)$$

Constraint (9) ensures that the amount of materials entering to each facility from all suppliers equal the sum of the exiting form it to each store and distributor.

Constraint (10) ensures that the sum of the flow entering to each facility store and the residual inventory from the previous period is equal to the sum of the exiting to each distributor store and the residual inventory of the existing period for each product.

Constraint (11) ensures that the sum of the flow entering to each distributor, distributor store and the residual inventory from the previous period equal the sum of the exiting to each customer and the residual inventory of the existing period for each product.

Constraint (12) ensures that the sum of the flow entering to each customer does not exceed the sum of the existing period demand and the previous accumulated shortages for each product.

4.2.2. Capacity constraints:

$$\sum_{f \in F} Q_{sft} B_s \le CAP_{st} L_s, \forall t \in T, \forall s \in S \tag{13}$$

$$\sum_{s \in S} Q_{sft} B_s \le CAPM_{ft} L_f, \forall t \in T, \forall f \in F \tag{14}$$

$$(\sum_{d \in D} Q_{fdpt} B_{fp} + \sum_{d \in D} I_{ffpt} B_{fp}) MH_p \le CAPH_{ft} L_f, \forall t \in T, \forall f \in F, \forall p \in P \tag{15}$$

$$\sum_{p \in P} R_{fpt} B_{fp} W_p \le CAPFS_{ft} L_f, \forall t \in T, \forall f \in F \tag{16}$$

$$\sum_{f \in F} (Q_{fdpt} + I_{fdpt}) B_{fp} W_p + \sum_{t \in T} R_{dpt-1} B_{fp} W_p \le CAP_{dt} L_d, \forall t \in T, \forall d \in D, \forall p \in P \tag{17}$$

Constraint (13) ensures that the sum of the flow exiting from each supplier to all facilities does not exceed the supplier capacity at each period.

Constraint (14) ensures that the sum of the material flow entering to each facility from all suppliers does not exceed the facility capacity of material at each period.

Constraint (15) ensures that the sum of manufacturing hours for all products manufactured in facility f to be delivered to its store and each distributor does not exceed the manufacturing capacity hours of it at each period.

Constraint (16) ensures that the residual inventory at each facility store does not exceed its capacity at each period.

Constraint (17) ensures that the sum of the residual inventory at each distributor from the previous periods and the flow entering at the existing period from the facilities and its stores does not exceed this distributor capacity at each period for each product.

4.2.3. Linking (contracts)-Shipping constraints:

$$Li_{sf} \le \sum_{t \in T} Q_{sft}, \forall s \in S, \forall f \in F \tag{18}$$

$$Li_{fd} \le \sum_{t \in T} (Q_{fdpt} + I_{fdpt}), \forall f \in F, \forall d \in D, \forall p \in P \tag{19}$$

$$Li_{dc} \leq \sum_{t \in T} Q_{dcpt}, \forall d \in D, \forall c \in C, \forall p \in P \quad (20)$$

Constraints (18-20) ensure that there are no links between any locations without actual shipments during any period.

4.2.4. Shipping-Linking constraints:

$$\sum_{t \in T} Q_{sft} \leq M\, Li_{sf}, \forall f \in F, \forall s \in S \quad (21)$$

$$\sum_{t \in T} (Q_{dcpt} + I_{fdpt}) \leq M\, Li_{fd}, \forall f \in F, \forall d \in D, \forall p \in P \quad (22)$$

$$\sum_{t \in T} Q_{dctp} \leq M\, Li_{dc}, \forall d \in D, \forall c \in C, \forall p \in P \quad (23)$$

Constraints (21-23) ensure that there is no shipping between any non linked locations.

4.2.5. Maximum number of activated locations constraints:

$$\sum_{s \in S} L_s \leq S \quad (24)$$

$$\sum_{f \in F} L_f \leq F \quad (25)$$

$$\sum_{d \in D} L_d \leq D \quad (26)$$

Constraints (24-26) limit the number of activated locations, where the sum of binary decision variables, which indicate the number of activated locations, is less than the maximum limit of activated locations (taken equal to the potential number of locations).

5. MODEL VERIFICATION

5.1 MODEL INPUTS

The model has been verified through the following case study where the input parameters are considered as showing in table I.

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Table I
Verification model parameters

Parameter	Value	Parameter	Value
Number of suppliers	3	Material Cost per unit weight	10
Number of facilities	3	Manufacturing Cost per hour	10
Number of Distributors	3	Manufacturing hours for product (1)	1
Number of Customers	4	Manufacturing hours for product (2)	2
Number of products	3	Manufacturing hours for product (3)	3
Fixed costs for supplier & distributor	20000	Transportation cost per kilometer per unit	0.001
Fixed costs for facility	50000	Facility holding cost	2
Weight of Product (1) Kg	1	Distributor holding cost	2
Weight of Product (2) Kg	2	Capacity of each suppliers in each periods	4000
Weight of Product (3) Kg	3	Supplier batch size	10
Price of Product (1)	100	Facility Batch size for product p	5
Price of Product (2)	150	Distributor Batch size for product p	1
Price of Product (3)	200	Capacity of each Facility Raw Material Store in each periods	4000
Customers Demands for product (1) for all customers in all periods	300	Facility capacity in hours	6000
Customers Demands for product (2) for all customers in all periods	500	Capacity of each Facility Store in each periods	2000
Customers Demands for product (3) for all customers in all periods	700	Capacity of each Distributor Store in each periods	4000

5.2 MODEL RESULTS

The results of the model are as shown in the following tables 2, 3, and 4:

Table II
Number of batches transferred between suppliers, facilities, facilities stores and distributors

	F1	F2	F3
S1	S1F1	S1F2	S1F3
	400	0	0
	400	0	0
	400	0	0
S2	S2F1	S2F2	S2F3
	0	400	0
	0	400	0
	0	400	0
S3	S3F1	S3F2	S3F3
	0	0	400
	0	0	400
	0	0	400

	D1			D2			D3		
F1	F1D1			F1D2			F1D3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	120	163	118	0	0	0	0	0	0
	60	100	180	0	0	0	0	0	0
	120	130	140	0	0	0	0	0	0
F2	F2D1			F2D2			F2D3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	60	130	160	0	0	0
	0	0	0	120	199	94	0	0	0
	0	0	0	0	73	218	0	0	0
F3	F3D1			F3D2			F3D3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	0	0	0	60	100	180
	0	0	0	0	0	0	59	105	177
	0	0	0	0	0	0	121	200	93

	D1			D2			D3		
FS3	FS1D1			FS1D2			FS1D3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0
FS3	FS2D1			FS2D2			FS2D3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0
FS3	FS3D1			FS3D2			FS3D3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0

Table III
Number of batches transferred from distributors to customers

	C1			C2			C3			C4		
D1	D1C1			D1C2			D1C3			D1C4		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	300	500	590	300	315	0	0	0	0	0	0	0
	300	500	810	0	0	90	0	0	0	0	0	0
	300	500	700	300	150	0	0	0	0	0	0	0
D2	D2C1			D2C2			D2C3			D2C4		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	0	150	700	300	500	100	0	0	0
	0	0	0	300	520	470	300	475	0	0	0	0
	0	0	0	0	365	840	0	0	250	0	0	0
D3	D3C1			D3C2			D3C3			D3C4		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
	0	0	0	0	0	0	0	0	400	300	500	500
	0	0	0	0	0	0	0	25	885	295	500	0
	0	0	0	0	0	0	300	500	465	305	500	0

The resulted network design is shown in figure 3

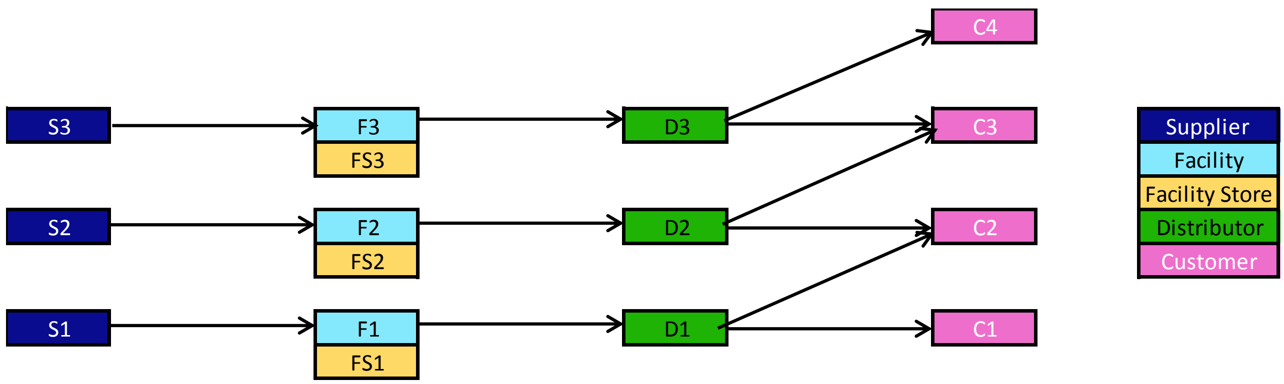

Fig. 3. Supply chain network of verification model

Table IV
Results of total revenue, total cost and total profit

Total Revenue	2620000	Non Utilized Cost	-180000
Fixed Cost	-270000	Shortage Cost	-48000
Material Cost	-360000	Transportation Costs	-1,523
Manufacturing Cost	-360000	Inventory Holding Cost	0
Total Profit		1,400,477	

5.3 MODEL RESULTS ANALYSIS

Tables V to VIII show the quantities received by each customer from each product at each period and the amounts of shortages.

Table V
Number of each Product received in each periods and the shortage for Customer 1

Period	Customer 1								
	Product 1			Product 2			Product 3		
	Demand	Received	Shortage	Demand	Received	Shortage	Demand	Received	Shortage
1	300	300	0	500	500	0	700	590	110
2	300	300	0	500	500	0	700	810	-110
3	300	300	0	500	500	0	700	700	0
	Total Shortage		0	Total Shortage		0	Total Shortage		0

Table VI
Number of each Product received in each periods and the shortage for Customer 2

Period	Customer 2								
	Product 1			Product 2			Product 3		
	Demand	Received	Shortage	Demand	Received	Shortage	Demand	Received	Shortage
1	300	300	0	500	465	35	700	700	0
2	300	300	0	500	520	-20	700	560	140
3	300	300	0	500	515	-15	700	840	-140
	Total Shortage		0	Total Shortage		0	Total Shortage		0

Table VII
Number of each Product received in each periods and the shortage for Customer 3

Period	Customer 3								
	Product 1			Product 2			Product 3		
	Demand	Received	Shortage	Demand	Received	Shortage	Demand	Received	Shortage
1	300	300	0	500	500	0	700	500	200
2	300	300	0	500	500	0	700	885	-185
3	300	300	0	500	500	0	700	715	-15
	Total Shortage		0	Total Shortage		0	Total Shortage		0

Table VIII
Number of each Product received in each periods and the shortage for Customer 4

Period	Customer 4								
	Product 1			Product 2			Product 3		
	Demand	Received	Shortage	Demand	Received	Shortage	Demand	Received	Shortage
1	300	300	0	500	500	0	700	500	200
2	300	295	5	500	500	0	700	0	700
3	300	305	-5	500	500	0	700	0	700
	Total Shortage		0	Total Shortage		0	Total Shortage		1600

Table IX
the total required quantities, materials, manufacturing hours to satisfy all customers in each period

Required	Product 1	Product 2	Product 3	Total required	Total capacity	Total shortage
Quantity	4*300=1200	4*500=2000	4*700=2800	N/A	N/A	N/A
Material weight	1*1200=1200	2*2000=4000	3*2800=8400	13600	12000	1600
Manufacturing hours	1*1200=1200	2*2000=4000	3*2800=8400	13600	18000	No

Since the material required (13600) exceeds the suppliers capacities (12000), suppliers will deliver the maximum quantity of material (full capacity) to facilities and consequently there will be shortage in supplied material (13600-12000=1600 Kg / period)

Since the manufacturing capacity of facilities exceeds the required, the facilities can manufacture the required quantities but they will be limited to manufacture the quantities supplied by suppliers

Table X
shortages of all products in all periods for all customers

Period	Customer 1			Customer 2			Customer 3			Customer 4			Shortage weight (Kg)
	P 1	P 2	P 3	P 1	P 2	P 3	P 1	P 2	P 3	P 1	P 2	P 3	
1	0	0	110	0	35	0	0	0	200	0	0	200	1600
2	0	0	-110	0	-20	140	0	0	-185	5	0	700	1600
3	0	0	0	0	-15	-140	0	0	-15	-5	0	700	1600
Total	0	0	0	0	0	0	0	0	0	0	0	1600	4800

Tables X shows that the total weight of shortages is 1600 Kg /period due to lack of material supplied and shortage of 1600 units at customer 4 from product 3 which is logical because of customer 4 is the farthest customer for all distributors.

Tables 10 also shows that the model decided to give the fourth customer 500 units with only 200 units shortage in period 1 to reduce the total shortage cost where it depends on the number of shortage units and periods.

Table IV show that there is no holding cost because that the total demands exceeds the capacities in all periods which means there is no reasons to hold any product in any period.

6. RESULTS AND DISCUSSIONS

The model performance is analyzed through the flowing eight cases

6.1 Case 1

The demand of this case and the total revenue, costs and total profit are shown in table 11.

Table XI
Model inputs and outputs of case 1

Model Inputs		Model Outputs	
Customer's Demands for product 1	300	First Sales	1620000
		Fixed Cost	-180000
		Material Cost	-216000
Customer's Demands for product 2	300	Manufacturing Cost	-216000
		Non Utilized Cost	-144000
		Shortage Cost	0
Customer's Demands for product 3	300	Transportation Costs	-1091
		Inventory Holding Cost	0
		Total Profit	862909

RESULTS DISCUSSIONS

As shown in figure 4 it is noticed that the required weight(7200 Kg) is less than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network can satisfy all demands without any shortage nor holding as shown in table XI with opening two suppliers as shown in figure 5.

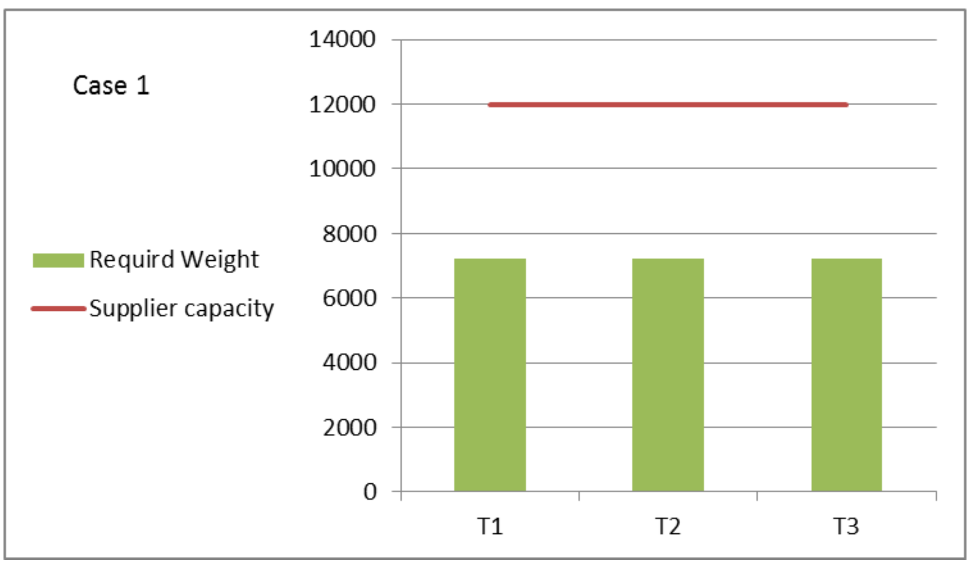

Fig. 4. Demand – Capacity relationship

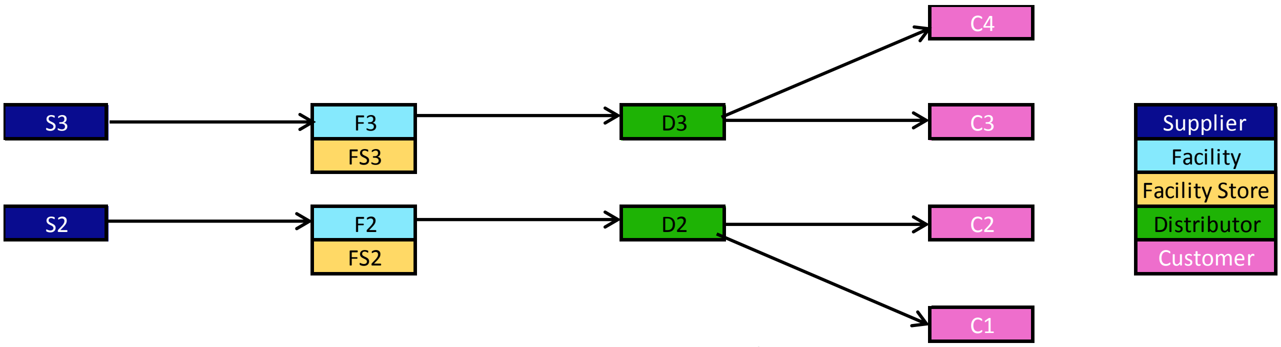

Fig. 5. Optimal network design for case 1

6.2 Case 2

The demand of this case and the total revenue, costs and total profit are shown in table XII.

Table XII

Model inputs and outputs of case 2

Model Inputs		Model Outputs	
Customer's Demands for product 1	300	Total Revenue	2460000
		Fixed Cost	-270000
		Material Cost	-336000
Customer's Demands for product 2	500	Manufacturing Cost	-336000
		Non Utilized Cost	-204000
		Shortage Cost	0
Customer's Demands for product 3	500	Transportation Costs	-1635
		Inventory Holding Cost	0
		Total Profit	1312365

RESULTS DISCUSSION

As shown in figure 6 it is noticed that the required weight(11200 Kg) is less than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network can satisfy all demands without any shortage nor holding as shown in table 12 with opening three suppliers as shown in figure 7.

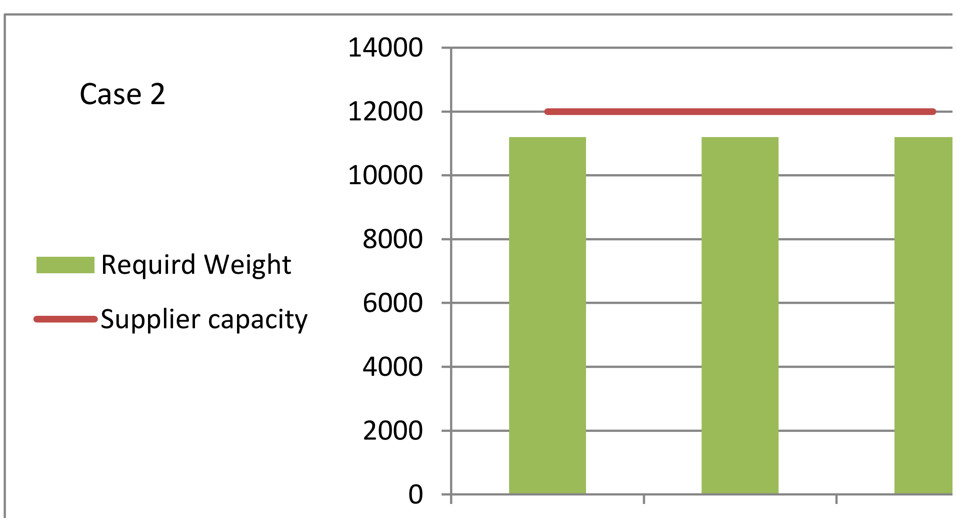

Fig. 6. Demand – Capacity relationship

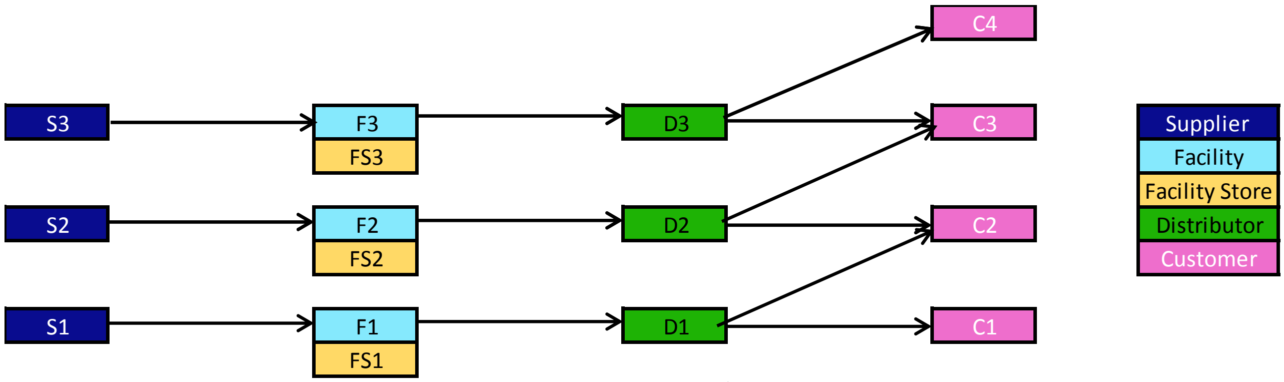

Fig. 7. Optimal network design for case 2

6.3 Case 3

The demand of this case and the total revenue, costs and total profit are shown in table 13.

Table XIII
Model inputs and outputs of case 3

Model Inputs		Model Outputs	
Customer's Demands for product 1	700	Total Revenue	2780000
		Fixed Cost	-270000
		Material Cost	-360000
Customer's Demands for product 2	500	Manufacturing Cost	-360000
		Non Utilized Cost	-180000
		Shortage Cost	-24000
Customer's Demands for product 3	500	Transportation Costs	-1670
		Inventory Holding Cost	0
		Total Profit	1584330

Results discussion

As shown in figure 8 it is noticed that the required weight(12800 Kg) is more than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network cannot satisfy all demands and it will be shortage as shown in table 13 with opening three suppliers as shown in figure 9.

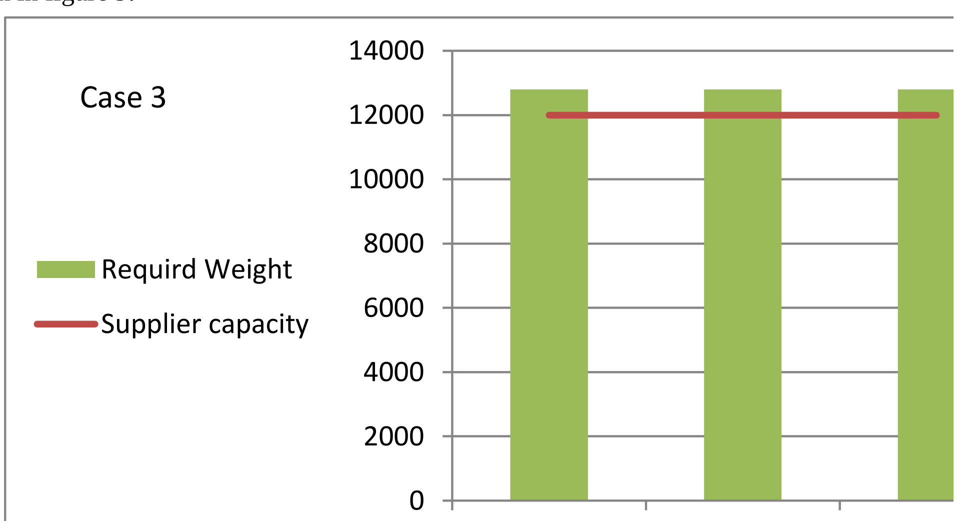

Fig. 8. Demand – Capacity relationship

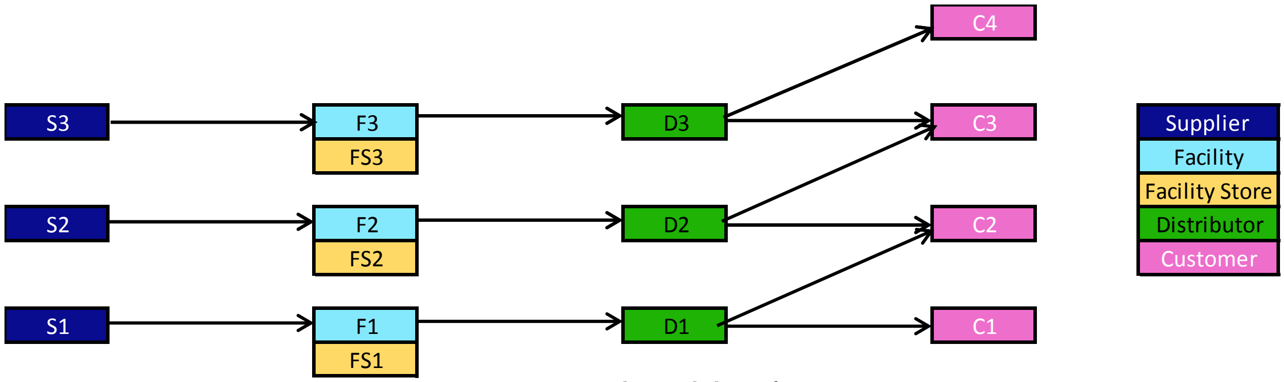

Fig. 9. Optimal network design for case 3

6.4 Case 4

The demand of this case and the total revenue, costs and total profit are shown in table 14.

Table XIV
Model inputs and outputs of case 4

Model Inputs		Model Outputs	
Customer's Demands for product 1	500	Total Revenue	2740000
		Fixed Cost	-270000
		Material Cost	-360000
Customer's Demands for product 2	700	Manufacturing Cost	-360000
		Non Utilized Cost	-180000
		Shortage Cost	-48000
Customer's Demands for product 3	500	Transportation Costs	-1535
		Inventory Holding Cost	0
		Total Profit	1520465

Results discussion:

As shown in figure 10 it is noticed that the required weight(13600 Kg) is more than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network cannot satisfy all demands and it will be shortage as shown in table 14 with opening three suppliers as shown in figure 11.

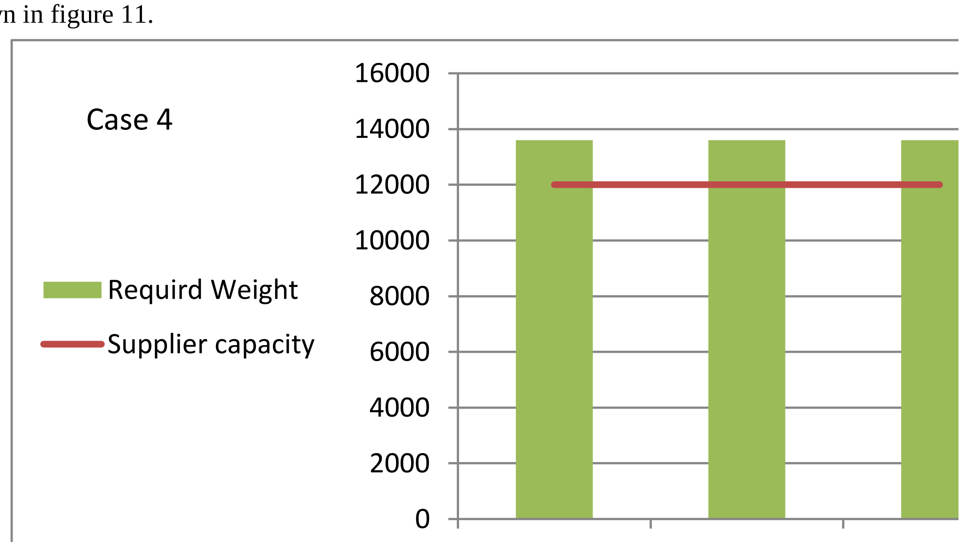

Fig. 10. Demand – Capacity relationship

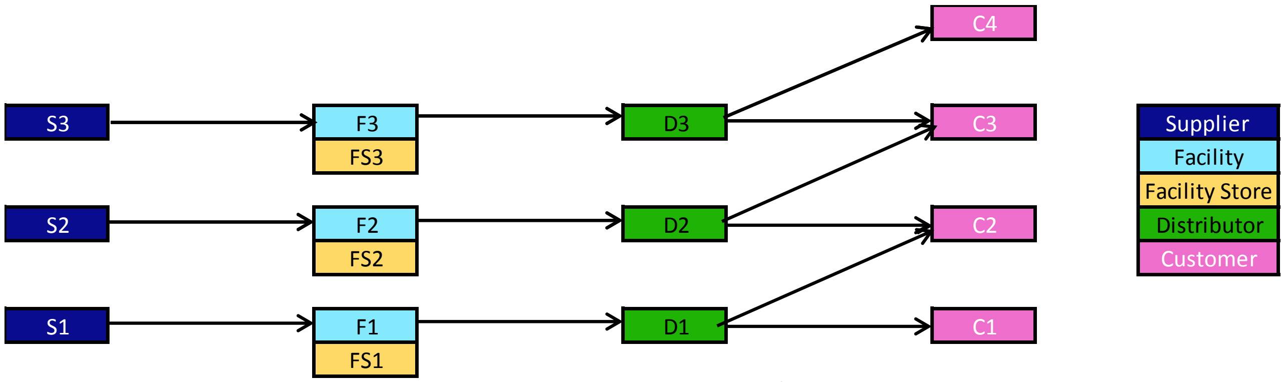

Fig. 11. Optimal network design for case 4

6.5 Case 5

The demand of this case and the total revenue, costs and total profit are shown in table XV.

Table XV
Model inputs and outputs of case 5

Model Inputs		Model Outputs	
Customer's Demands for product 1	500	Total Revenue	2700000
		Fixed Cost	-270000
		Material Cost	-360000
Customer's Demands for product 2	500	Manufacturing Cost	-400000
		Non Utilized Cost	-140000
		Shortage Cost	-72000
Customer's Demands for product 3	700	Transportation Costs	-1412
		Inventory Holding Cost	0
		Total Profit	1456588

Results discussion

As shown in figure 12 it is noticed that the required weight(14400 Kg) is more than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network cannot satisfy all demands and it will be shortage as shown in table 15 with opening three suppliers as shown in figure 13.

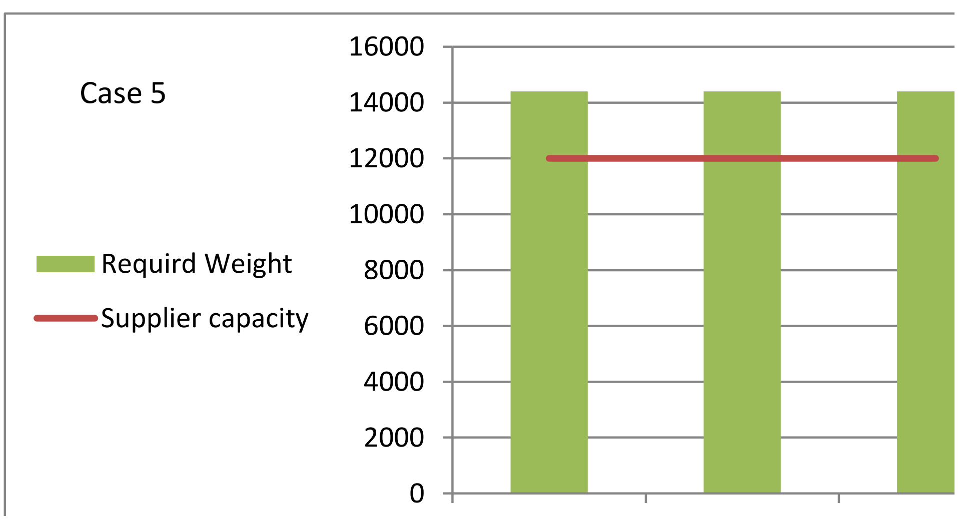

Fig. 12. Demand – Capacity relationship

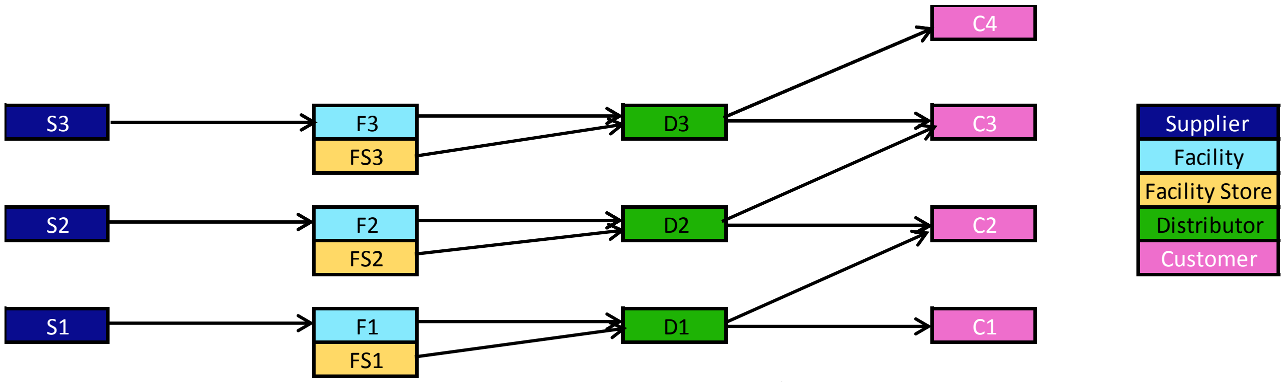

Fig. 13. Optimal network design for case 7

6.6 Case 6

The demand of this case and the total revenue, costs and total profit are shown in table 16.

Table XVI
Model inputs and outputs of case 6

Model Inputs		Model Outputs	
Customer's Demands for product 1	700	Total Revenue	2820000
		Fixed Cost	-270000
		Material Cost	-360000
Customer's Demands for product 2	700	Manufacturing Cost	-360000
		Non Utilized Cost	-180000
		Shortage Cost	-144000
Customer's Demands for product 3	700	Transportation Costs	-1363
		Inventory Holding Cost	0
		Total Profit	1504637

Results discussion:

As shown in figure 14 it is noticed that the required weight(16800 Kg) is more than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network cannot satisfy all demands and it will be shortage as shown in table 16 with opening three supplier as shown in figure 15.

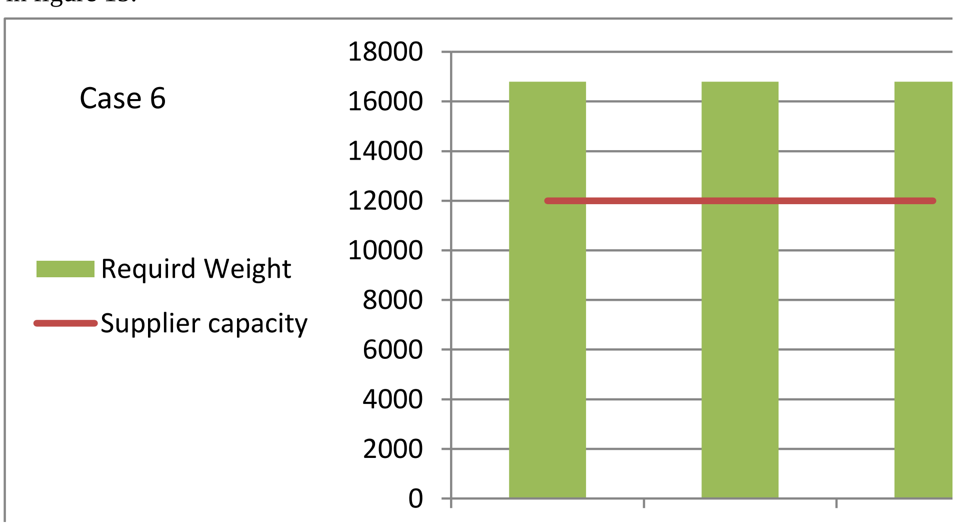

Fig. 14. Demand – Capacity relationship

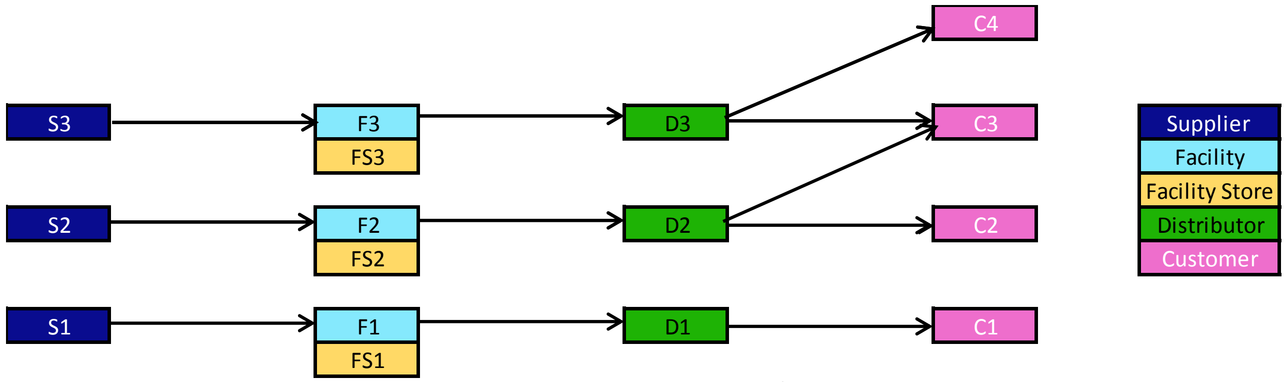

Fig. 15. Optimal network design for case 6

6.7 Case 7

The demand of this case and the total revenue, costs and total profit are shown in table 17.

Table 17: Model inputs and outputs of case 7

Model Inputs		Model Outputs	
Customer's Demands for product 1	700	Total Revenue	2700000
		Fixed Cost	-270000
		Material Cost	-360000
Customer's Demands for product 2	700	Manufacturing Cost	-380000
		Non Utilized Cost	-160000
		Shortage Cost	0
Customer's Demands for product 3	700	Transportation Costs	-1818
		Inventory Holding Cost	0
		Total Profit	1528182

Results discussion:

As shown in figure 16 it is noticed that the required weight(12000 Kg) is equal the suppliers capacities (3*4000 = 12000 Kg) in all periods the network can satisfy all demands without any shortage nor holding as shown in table 17 with opening three supplier as shown in figure 17.

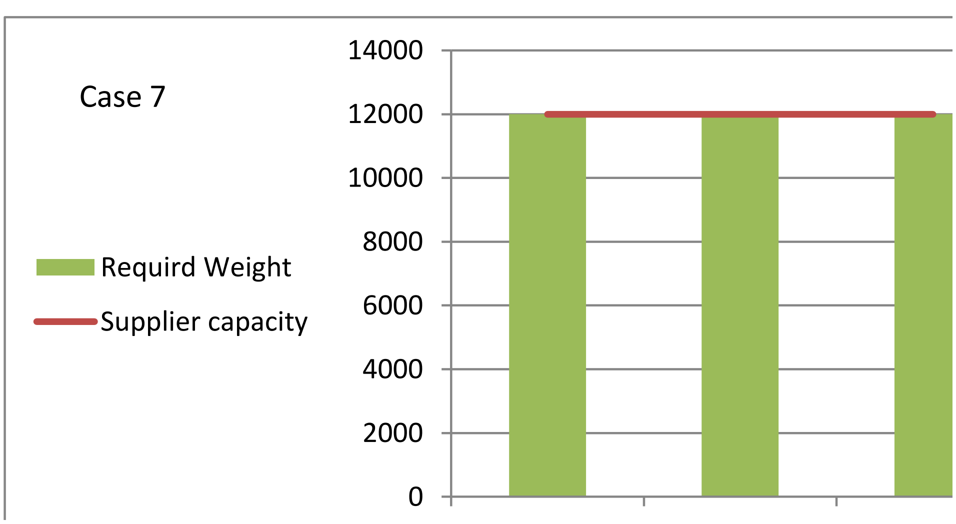

Fig. 16. Demand – Capacity relationship

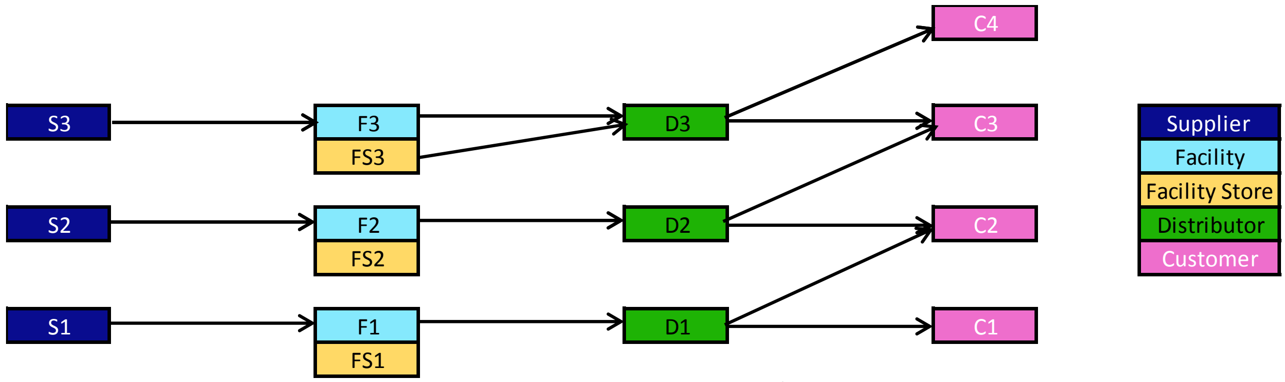

Fig. 17. Optimal network design for case 7

6.8 Case 8

The demand of this case and the total revenue, costs and total profit are shown in table 18.

Table XVIII
Model inputs and outputs of case 8

Model Inputs		Model Outputs	
Customer's Demands for product 1	300	Total Revenue	2620000
		Fixed Cost	-270000
		Material Cost	-360000
Customer's Demands for product 2	500	Manufacturing Cost	-360000
		Non Utilized Cost	-180000
		Shortage Cost	-48000
Customer's Demands for product 3	700	Transportation Costs	-1523
		Inventory Holding Cost	0
		Total Profit	1400477

Results discussion:

As shown in figure 18 it is noticed that the required weight(13600 Kg) is more than the suppliers capacities (3*4000 = 12000 Kg) in all periods the network cannot satisfy all demands and it will be shortage as shown in table 18 with opening three supplier as shown in figure 19.

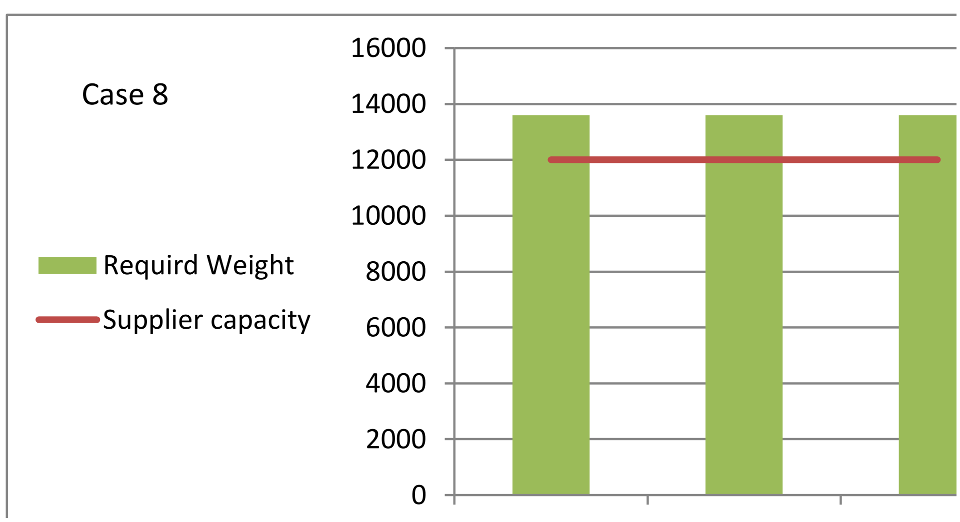

Fig. 18. Demand – Capacity relationship

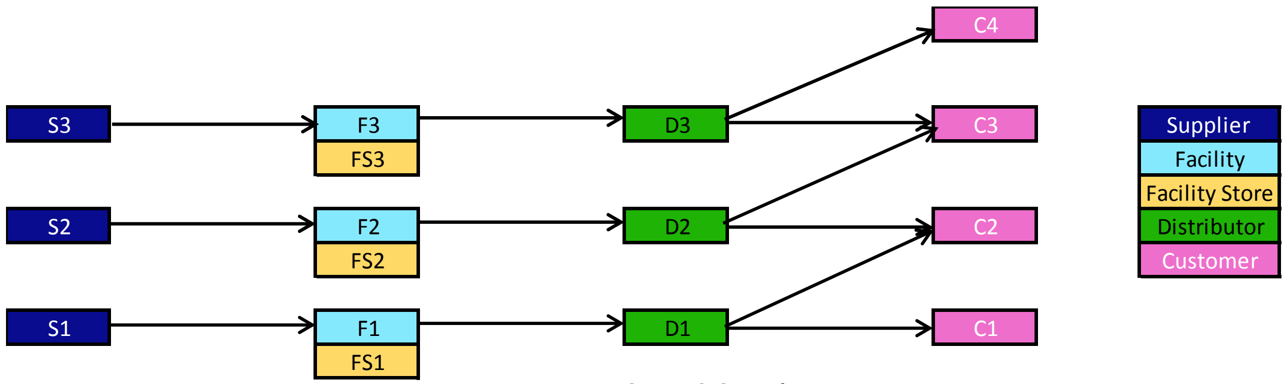

Fig. 19. Optimal network design for case 8

7. CONCLUSION

This proposed model successfully solved the problems of supply network design for the following reasons:

1. The proposed model can be used to design supply chain networks which produce multi-product for multi-period.
2. The proposed design model is capable of supply chain networks while considering inventory at the facility and distribution centres.
3. The proposed design model took into account different types of costs like non-utilised capacity cost for facilities, transportation cost between all nodes, holding cost of inventory in both facilities and distributers and shortage cost to enhance customers' satisfaction.
4. The model is eventually capable of solving problems with a larger number of periods as compared to the numbers considered in the present work.

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