An Optimization Model for Multi-period Multi-Product Multi-objective Production Planning

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Abstract-- **This paper presents a mixed integer linear programming (MILP) optimization model to solve the partner selection, and production planning problem in the design of manufacturing chains operating under a multi-product, multi echelon, multi-period and multi-objective manufacturing environment. The proposed manufacturing chain consists of a facility, three suppliers, three distributors and four customers. The performance of the developed model is illustrated by using a verification problem. Discussion of the results proved the accuracy of the model.**

Index Term-- **Production planning, location, allocation, MILP, modeling, multi-products, multi echelon, multi-objective and multi-periods.**

1. INRODUCTION

Production planning affects profit of the factory and service level of the customers. So it is very important to give the production planning process more attention to assure high profit and service level.

Chandra and Fisher (1994) [1] attempted to solve the problem of coordinating the production and distribution functions for a single-plant, multi-commodity, multi-period manufacturing environment. The study assumed that products are produced and stored in the plant until they are delivered to the customers using a fleet of trucks. Results of computational experiments clearly showed that planning production and routing simultaneously could lead to a cost saving of up to 20%.

Chang, and Park (2002) [2] considered the multi-product single-period supply network design problem. The supply network was decomposed into an inbound network, a production–distribution network and an outbound network, and a heuristic based on Lagrangian Relaxation was used to design each sub-network.

Yan, Yu, and Cheng (2003) [3] proposed a strategic production–distribution model which included multiple suppliers, producers, distribution centers and customers for manufacturing multiple products in a single period.

Kouvelis et al. (2004) [4] presented a mixed integer program to investigate global production network design for a single product. A two-stage production process is analyzed for the introduction of a new product in different markets. Their work clearly demonstrates the importance of including tariffs and regional trading rules into global supply chain design, since they have a significant impact on the network structure. According to their key findings, increased trade tariffs favor gradual decentralization of production processes.

Altiparmak, Gen, Lin, and Paksoy (2006) [5] formulated a mixed integer nonlinear model for a multi-objective supply chain network designed for a single product of a plastic company. A solution procedure based on genetic algorithms was developed to solve the problem.

Sha and Che (2006) [6] studied the design of a complex supply chain network. The overall objective was to maximize the preference of servicing the demand and minimize the number of partners involved. A multi-phase mathematical approach based on Genetic Algorithms, Analytical Hierarchy Process and Multi-Attribute Utility Theory was proposed to solve the problem. However, their studies only considered single product and single period demand from the customer, and did not consider the structure of the product.

Huebner (2007) [7] developed a strategic production network design model to maximize the NPV of cash flows before tax. The model optimizes the production and distribution plan and determines the plant location, product allocations and capacity changes. Based on the special problem structure of a global chemicals company, a single sourcing assumption between different supply chain echelons is introduced. Thus, the model covers duty drawbacks for re-exports after one production level and requires modifications to allow duty drawbacks across a higher number of production stages and multiple supplies from several sub-assemblies.

Tsiakis and Papageorgiou (2008) [8] suggested a deterministic mixed-integer problem for designing a global production network including production plants, distribution centers and different customer zones. Although multiple products are considered, only one common duty rate for all products is taken into account. Due to the strategic focus of the paper, decisions on where to open production plants and distribution centers, the allocation of products to plants and the assignment of distribution centers to plants and customer zones to distribution centers are incorporated.

Zapfel et al. (2010) [9] used a genetic algorithm to generate the final integrated production distribution plan. In the study, the product structures were represented by (1) a one-level BOM in the inbound sub-network and (2) a two-level BOM in the production–distribution sub-network. Items were arranged in a fixed level of the BOM. Manufacturing plants were grouped according to the BOM structure, with each group producing items located at the same level of the BOM. However, the approach is no longer effective when the BOM structure is complex, for example, a more than two-level BOM with the same item existing in different levels.

Mula, Peidro, and Diaz-Madronero (2010) [10] presented a review of using mathematical programming models for supply chain design, and highlighted that it is essential to integrate the suppliers' nodes into the supply chain optimization models.

Indeed, local effectiveness is far from automatically inducing the global efficiency of the whole multi-stage manufacturing chain.

Hence, formulating integrated cost-effective partner selection and production and distribution decisions is a challenge for manufacturing chain designers, especially when the products have complicated structures.

Mezghani et al. (2012) [11] developed a Goal Programming formulation within an imprecise environment and explicitly introduce the manager's preferences into the aggregate planning model.

Margaretha Gansterer (2015) [12] presented a comprehensive hierarchical production planning (HPP) framework, to investigate the impact of aggregate planning in a make-to-order (MTO) environment. The planning problem is formulated as a linear mathematical model and solved to optimality by a standard optimization engine. The performance of the system is evaluated based on service and inventory levels. Real world data coming from the automotive supplier industry is used to define four demand scenarios.

In this study, a mixed integer linear programming (MILP) optimization model to solve the partner selection, and production planning problem in the design of manufacturing chains operating under a multi-product, multi echelon, multi-period and multi-objective manufacturing environment is developed for the purpose of production planning in a factory to maximize the profit of the factory and the overall service level of the customers. The factory has three approved suppliers and has three distributors to serve four customers as shown in figure 1.

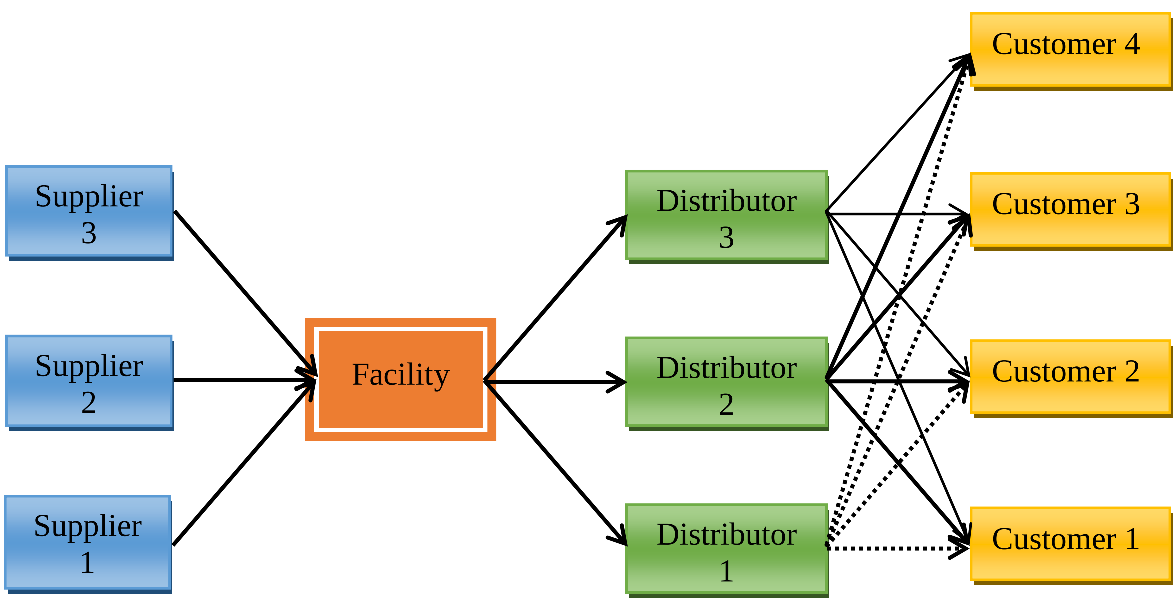

Fig. 1. Facility, suppliers, distributors and customer network.

2. MODEL DESCRIPTION

The proposed model assumes a set of customer locations with known and time varying demands and a set of candidate suppliers of known, limited and time varying capacity, and distributor's locations of known, limited and time varying capacity. It optimizes locations of the suppliers, distributors and customers and allocate the shipment between them to maximize the profit and overall customer service level taking their capacities, inventory and shortage penalty and other costs into consideration.

The problem is formulated as a mixed integer linear programming (MILP). The model is solved using Xpress-MP software which uses Mosel language in programming [13].

The flow of material and product are assumed as shown in figure 2. Where suppliers are responsible for supplying of raw materials to the facility. Facility is responsible for manufacturing of the three products and supplying some of them to the distributors and storing the rest for the next periods; if it is profitable. Distributors are responsible for the distribution of products to the customers and/or storing some of them for the next periods, and customers' nodes may represent one customer, a retailer, or a group of customers and retailers.

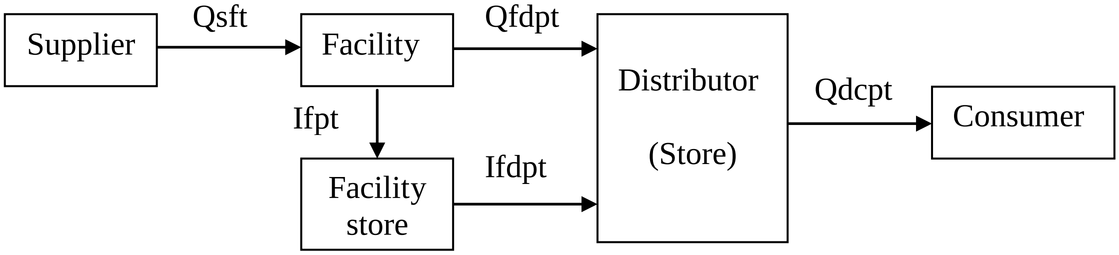

Fig. 2. Model flow.

The model considers fixed costs for all nodes, materials costs, transportation costs, manufacturing costs, non-utilized capacity costs for the facility, 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-objectives, where it maximizes Profit of the facility and the Overall Service Level of each of the four customers.
2. Overall Service Level is assumed as the ratio of the total quantities delivered to each customer and the total demand in all periods from all products.
3. Overall Service Level may be manipulated as an objective and as an input to study its effect on the profit
4. The model is multi-product, where actions and flow of materials take place for multi-product.
5. Products weights are different.
6. The model is multi-period, where actions and flow of materials take place in multi-periods.
7. Customers' locations are fixed and known.
8. Customers' demands are known for all product in all periods.
9. The locations of suppliers, facility, and distributors are known.
10. 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.
11. Capacity of each supplier, facility, and distributor locations are known for each period.
12. The shortage cost depends on the shortage quantity for each product and time.
13. The holding cost depends on the, weight of product and residual inventory at the end of each period for each product.
14. The transportation cost depends on the transported quantities, weight of product and the linear distance between locations.
15. The manufacturing cost depends on the manufacturing hours for each product and manufacturing cost per hours
16. The material cost is different for each product depending on its weight.
17. 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*.
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 contracting supplier *s*,
F_f: fixed cost of the facility,
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 the facility.
D_{fd}: distance between the facility 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 the facility Raw Material Store in period t.
$CAPH_{ft}$: capacity in manufacturing hours of the facility in period *t*,
$CAPFS_{ft}$: storing capacity of the facility 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 in period *t*,
MH_p: Manufacturing hours for product (p)

NUCCf: non utilized manufacturing capacity cost per hour of the facility,
$SCPU_p$: shortage cost per unit per period,
HF_p: holding cost per unit per period at facility 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 the facility and distributor *d* for product *p*.
TCperkm: transportation cost per unit per kilometer.

DECISION VARIABLES

L_s: binary variable equal to 1 if a supplier *s* is contracted 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 the facility.
Li_{fd}: binary variable equal to 1 if a transportation link is activated between the facility 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 the facility in period *t*,
Q_{fdpt}: number of batches transported from the facility to distributor *d* for product p in period *t*,
I_{fpt}: number of batches transported from the facility to its store for product p in period *t*,
I_{fdpt}: number of batches transported from store of the facility 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 the facility for product p.
R_{dpt}: residual inventory of the period *t* at distributor *d* for product p.
OSL_c: Overall Service Level of customer c.

4.1. Objective function.

The objectives of the model are to maximize both the profit of the facility and the Overall Service Levels of the four customers.

$$\text{Overall Service Level}_c = \sum_{d\in D}\sum_{p\in P}\sum_{t\in T} Q_{dcpt} \Big/ \sum_{p\in P}\sum_{t\in T} DEMAND_{cpt} \quad (1)$$

Profit = Total revenue – Total cost

4.1.1. Total revenue

$$\text{Total revenue} = \sum_{d\in D}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{dcpt}\, B_{dp}\, P_{pct} \quad (2)$$

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

$$\text{Fixed costs} = \sum_{s\in S} F_s L_s + Ff + \sum_{d\in D} F_d L_d \quad (3)$$

4.1.2.2. Material cost

$$\text{Material cost} = \sum_{s\in S}\sum_{t\in T} Q_{sft}\, B_s\, MatCost_{st} \quad (4)$$

4.1.2.3. Manufacturing costs

$$\text{Manufacturing costs} = \sum_{d\in D}\sum_{p\in P}\sum_{t\in T} Q_{fdpt}\, B_{fp}\, MH_p\, Mc_{ft} + \sum_{p\in P}\sum_{t\in 2\ldots T} I_{fpt}\, B_{fp}\, MH_p\, Mc_{ft} \quad (5)$$

4.1.2.4. Non-Utilized capacity cost (for the facility)

$$(\sum_{p\in P}\sum_{t\in T}((\mathrm{CAPH}_{ft})\,\mathrm{L}_f-\sum_{d\in D}(\mathrm{Q}_{fdpt}\,\mathrm{B}_{fp}\,\mathrm{MH}_p)-\sum_{d\in D}(\mathrm{I}_{fpt}\,\mathrm{B}_{fp}\,\mathrm{MH}_p))NUCC_f) \quad (6)$$

4.1.2.5. Shortage cost (for distributor)

$$\sum_{p\in P}(\sum_{c\in C}(\sum_{t\in T}(\sum_{1}^{t}\mathrm{DEMAND}_{cpt}-\sum_{1}^{t}\sum_{d\in D}\mathrm{Q}_{dcpt}\,\mathrm{B}_{dp})))\,\mathrm{SCPU}_p \quad (7)$$

4.1.2.6. Transportation costs

$$\sum_{t\in T}\sum_{s\in S}\mathrm{Q}_{sft}\,\mathrm{B}_s\,\mathrm{T}_s\,\mathrm{DS}_{sf}+\sum_{p\in P}(\sum_{t\in T}\sum_{d\in D}\mathrm{Q}_{fdpt}\,\mathrm{B}_{fp}\,\mathrm{W}_p\mathrm{T}_f\,\mathrm{D}_{fd}+\sum_{t=2}^{T}\sum_{d\in D}\mathrm{I}_{fdpt}\,\mathrm{B}_{fp}\mathrm{W}_p\mathrm{T}_f\,\mathrm{D}_{fd}+$$
$$\sum_{d\in D}\sum_{c\in C}\sum_{t\in T}\mathrm{Q}_{dcpt}\,\mathrm{B}_{dp}\,\mathrm{W}_p\mathrm{T}_d\,\mathrm{D}_{dc}) \quad (8)$$

4.1.2.7. Inventory holding costs

$$\sum_{p\in P}(\sum_{t\in T}\mathrm{R}_{fpt}\,\mathrm{W}_p\,\mathrm{HF}_f+\sum_{d\in D}\sum_{t\in T}\mathrm{R}_{dpt}\,\mathrm{W}_p\,\mathrm{HD}_d) \quad (9)$$

4.2. Constraints

4.2.1. Balance constraints:

$$\sum_{s\in S}Q_{sft}B_s=\sum_{d\in D}\sum_{p\in P}Q_{fdpt}B_{fp}W_p+I_{fpt}B_{fp}W_p,\forall t\in T \quad (10)$$

$$I_{fpt}B_{fp}+R_{fp(t-1)}B_{fp}=R_{fpt}B_{fp}+\sum_{d\in D}I_{fdpt}B_{fp},\forall t\in T,\forall p\in P \quad (11)$$

$$\sum_{p\in P}(Q_{fdpt}+I_{fdpt})B_{fp}+R_{dp(t-1)}B_{dp}=R_{dpt}B_{dp}+\sum_{p\in P}\sum_{c\in C}Q_{dcpt}B_{dp},\forall t\in 2\to T,\forall d\in D \quad (12)$$

$$\sum_{d\in D}Q_{dcpt}B_{dp}\le \mathrm{DEMAND}_{cpt}+\sum_{1\to t}\mathrm{DEMAND}_{cp(t-1)}-\sum_{d\in D}Q_{dcp(t-1)}B_{dp},\forall t\in T,\forall c\in C,\forall p\in P \quad (13)$$

Constraint (10) ensures that the amount of materials entering to the facility from all suppliers equal the sum of the exiting form it to each store and distributor.

Constraint (11) ensures that the sum of the flow entering to 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 (12) 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 (13) 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:

$$Q_{sft}\,B_s \le CAP_{st}\,L_s,\forall t\in T,\forall s\in S \tag{14}$$

$$\sum_{s\in S} Q_{sft}\,B_s \le CAPM_{ft}\,L_f,\forall t\in T \tag{15}$$

$$(\sum_{d\in D} Q_{fdpt}\,B_{fp}+\sum_{d\in D} I_{fpt}\,B_{fp})\,MH_p \le CAPH_{ft}\,L_f,\forall t\in T,\forall p\in P \tag{16}$$

$$\sum_{p\in P} R_{fpt}B_{fp}W_p \le CAPFS_{ft}\,L_f,\forall t\in T \tag{17}$$

$$(Q_{fdpt}+I_{fdpt})\,B_{fp}W_p+\sum_{t\in T} R_{dpt\text{-}1}\,B_{fp}W_p \le CAP_{dt}\,L_d,\forall t\in T,\forall d\in D,\forall p\in P \tag{18}$$

Constraint (14) ensures that the sum of the flow exiting from each supplier to facility does not exceed the supplier capacity at each period.

Constraint (15) ensures that the sum of the material flow entering to facility from all suppliers does not exceed the facility capacity of material at each period.

Constraint (16) ensures that the sum of manufacturing hours for all products manufactured in the facility to be delivered to its store and each distributor does not exceed the manufacturing capacity hours of it at each period.

Constraint (17) ensures that the residual inventory at facility store does not exceed its capacity at each period.

Constraint (18) 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 facility and its store does not exceed this distributor capacity at each period for each product.

4.2.3. Linking (contracts)-Shipping constraints:

$$Li_{sf} \le \sum_{t\in T} Q_{sft},\forall s\in S \tag{19}$$

$$Li_{fd} \le \sum_{t\in T}(Q_{fdpt}+I_{fdpt}),\forall d\in D,\forall p\in P \tag{20}$$

$$Li_{dc} \le \sum_{t\in T} Q_{dcpt},\forall d\in D,\forall c\in C,\forall p\in P \tag{21}$$

Constraints (19-21) ensure that there are no links between any locations without actual shipments during any period.

4.2.4. Shipping-Linking constraints:

$$\sum_{t\in T} Q_{sft} \le M\,Li_{sf},\forall s\in S \tag{22}$$

$$\sum_{t\in T}(Q_{dcpt}+I_{fdpt}) \le M\,Li_{fd},\forall d\in D,\forall p\in P \tag{23}$$

$$\sum_{t\in T} Q_{dctp} \le M\,Li_{dc},\forall d\in D,\forall c\in C,\forall p\in P \tag{24}$$

Constraints (22-24) ensure that there is no shipping between any non-linked locations.

4.2.5. Maximum number of activated locations constraints:

$$\sum_{s \in S} L_s \leq S \qquad (25)$$

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

Constraints (25-26) 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 consider as showing in table 1.

Table I
Verification model parameters

Parameter	Value	Parameter	Value
Number of potential suppliers	3	Manufacturing hours for product 1	1
Number of facilities	1	Manufacturing hours for product 2	2
Number of potential Distributors	3	Manufacturing hours for product 3	3
Number of Customers	4	Transportation cost per kilometer per unit	0.001
Number of products	3	Facility holding cost	3
Fixed costs for supplier & distributor	20,000	Distributor holding cost	2
Fixed costs for facility	50,000	Capacity of each suppliers in each periods	4,000
Weight of Product 1 in Kg	1	Supplier batch size	10
Weight of Product 2 in Kg	2	Facility Batch size for product p	10
Weight of Product 3 in Kg	3	Distributor Batch size for product p	1
Price of Product 1	100	Capacity of Facility in hours	12,000
Price of Product 2	150	Capacity of Facility Store in each periods	2,000
Price of Product 3	200	Capacity of each Distributor Store in each periods	4,000
Material Cost per unit weight	10	Capacity of each Facility Raw Material Store in each periods	4,000
Manufacturing Cost per hour	10		

The demand patterns are assumed as the same for all customer as shown in the table 2.

Table II
Demand of each customer in all period for from product.

Period	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Product 1	200	300	400	500	600	700	700	600	500	400	300	200
Product 2	200	300	400	500	600	700	700	600	500	400	300	200
Product 3	200	300	400	500	600	700	700	600	500	400	300	200

5.2 MODEL OUTPUTS
The resulted optimal network is as shown in figure 3.

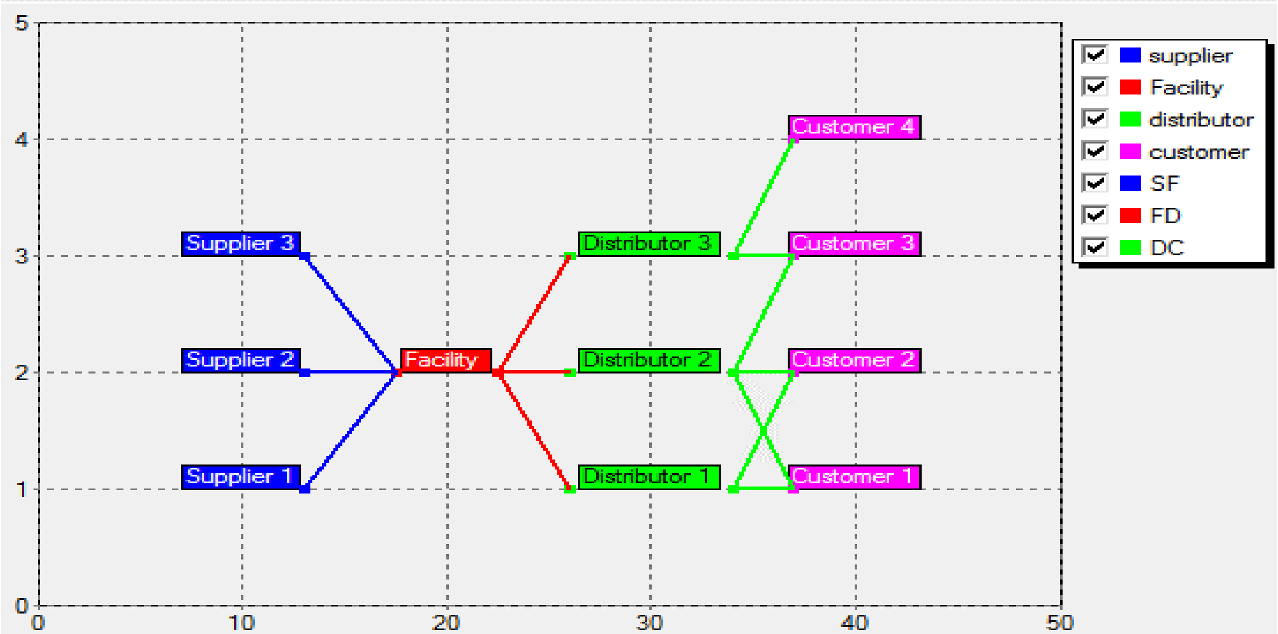

Fig. 3. The resulted optimal network.

Where the quantities of material supplied to the facility from suppliers are shown in table 3

Table III
Number of batches transferred from suppliers to the facility.

Period	1	2	3	4	5	6	7	8	9	10	11	12
Supplier 1	0	200	400	200	400	200	200	200	200	400	400	400
Supplier 2	400	400	400	400	400	400	400	400	400	400	400	400
Supplier 3	160	400	200	400	200	400	400	400	400	200	200	200

The number of batches transferred from the facility to distributors for each product in each period are shown in table 4

Table IV
Number of batches transferred from the facility to distributors.

Period	To distributor 1			To distributor 2			To distributor 3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
1	0	0	1	60	41	66	20	40	39
2	0	30	61	60	70	20	65	117	33
3	134	40	29	42	0	92	78	22	53
4	0	74	7	48	76	57	53	50	81
5	97	60	61	20	40	36	115	116	13
6	70	69	46	9	71	69	1	143	0
7	68	5	41	0	176	5	279	60	0
8	62	85	56	248	67	4	60	70	2
9	50	49	23	50	105	46	100	95	31
10	39	41	27	80	80	22	40	46	88
11	31	30	40	58	56	72	30	32	102
12	20	20	47	42	39	93	20	22	112

The number of batches transferred from the facility store to distributors for each product in each period are shown in table 5.

Table V
Number of batches transferred from the facility store to distributors.

Period	To distributor 1			To distributor 2			To distributor 3		
	Product 1	P2	P3	Product 1	P2	P3	Product 1	P2	P3
2	0	0	1	0	0	12	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	8	0	0	0
5	0	0	0	0	21	50	5	0	3
6	0	0	0	6	0	1	0	0	0
7	0	0	0	0	0	11	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	1	0	0	0	0
10	0	0	0	0	0	31	0	0	1
11	0	0	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0

The number of batches transferred from distributors to customers for each product in each period are shown in table 6

Table VI
Number of batches transferred from distributors to customers.

Period		1	2	3	4	5	6	7	8	9	10	11	12
D1-C1	P1	0	0	395	500	600	700	680	620	500	390	310	200
	P2	0	300	400	500	600	690	50	850	490	410	300	200
	P3	0	300	165	500	600	460	410	560	230	270	410	470
D1-C2	P1	0	0	0	445	370	0	0	0	0	0	0	0
	P2	0	0	0	240	0	0	0	0	0	0	0	0
	P3	0	0	0	25	10	0	0	0	0	0	0	0
D1-C3	P1	0	0	0	0	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0	0	0	0	0
	P3	0	0	0	0	0	0	0	0	0	0	0	0
D1-C4	P1	0	0	0	0	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0	0	0	0	0
	P3	0	0	0	0	0	0	0	0	0	0	0	0
D2-C1	P1	200	300	5	0	0	0	0	0	0	0	0	0
	P2	200	0	0	0	0	10	400	0	0	0	0	0
	P3	200	0	235	0	0	0	0	0	0	1	0	0
D2-C2	P1	200	300	400	55	200	150	0	1880	500	400	300	200
	P2	200	300	400	260	600	700	679	51	1060	410	280	220
	P3	200	300	400	475	590	691	160	37	460	514	720	818
D2-C3	P1	200	0	1	439	0	0	0	600	0	400	280	220
	P2	0	0	10	500	10	0	681	619	0	390	280	170
	P3	12	268	273	187	270	9	0	3	0	15	0	112

D2-C4	P1	0	0	0	0	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0	0	0	0	0
	P3	0	0	0	0	0	0	0	0	0	0	0	0
D3-C1	P1	0	0	0	0	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0	0	0	0	0
	P3	0	0	0	0	0	0	0	0	0	0	0	0
D3-C2	P1	0	0	0	0	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0	0	0	0	0
	P3	0	0	0	0	0	0	0	0	0	0	0	0
D3-C3	P1	0	300	399	61	600	0	1400	0	500	0	0	0
	P2	200	300	390	0	590	700	0	0	500	10	20	30
	P3	188	32	127	313	160	0	0	14	310	890	1020	1120
D3-C4	P1	200	300	400	500	600	10	1390	600	500	400	300	200
	P2	200	300	400	500	570	730	600	700	450	450	300	190
	P3	200	300	400	500	0	0	0	6	0	0	0	0

The resulted Overall Service Level is shown in figure 4.

Fig. 4. The resulted Overall Service Level of the customers

Table VII represents the total revenue, costs and total profit values where figure 5 represent the cost share

Table VII
Cost/Revenue values.

Cost/Revenue	Value	Cost/Revenue	Value	Cost/Revenue	Value
Total Revenue	8,786,500	Material Cost	-1,156,000	Non-Utilized Cost	-201,600
Fixed Cost	-170,000	Manufacturing Cost	-1,238,400	Shortage Cost	-628,000
Transportation Costs	-106,002	Inventory Holding Cost	-25,000	Total Profit	5,261,498

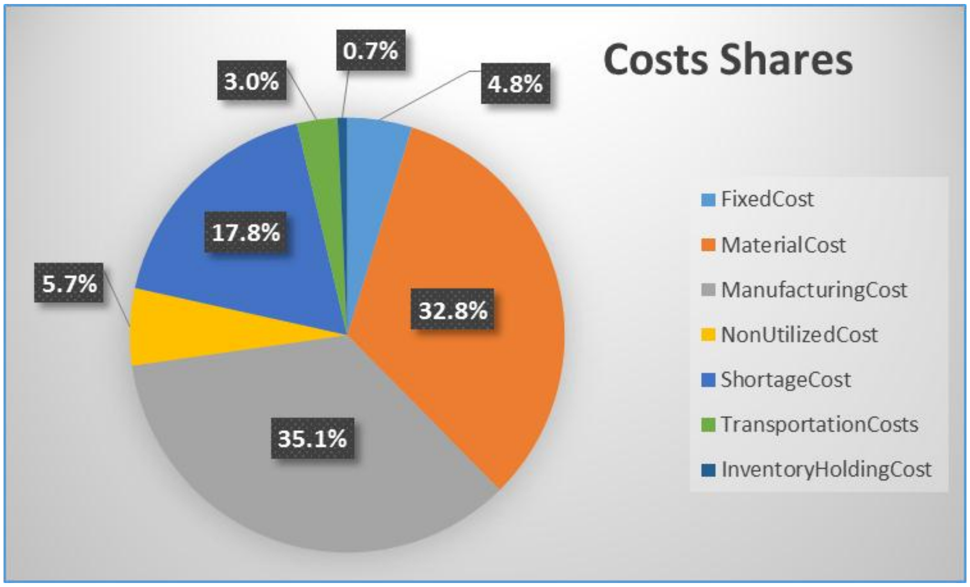

Fig. 5. Cost shares

5.3 RESULTS DISCUSSION

The relationship between the equivalent required manufacturing hours and manufacturing capacity in hours is shown in figure 6 in which it is noticed that the manufacturing capacity of the facility exceeds the equivalent required manufacturing hours in the first and last four periods. So there are some limitations regarding required hours.

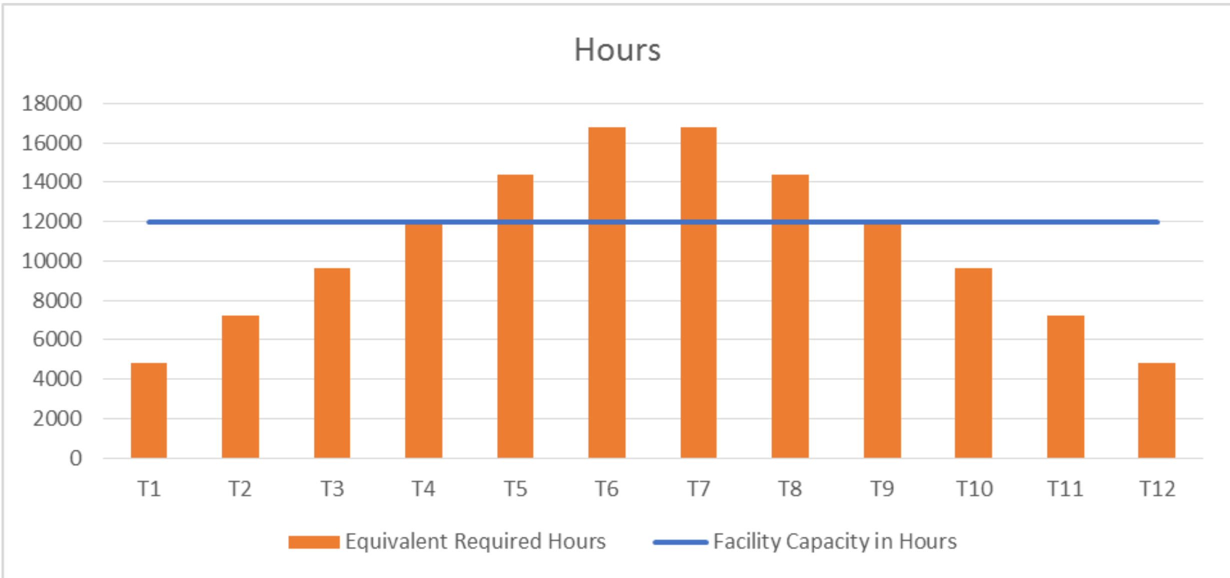

Fig. 6. relationship between the required manufacturing hours and manufacturing capacity in hours

Figure 7 in which the relationship between the equivalent required quantity of material, supplier capacity, facility RM store capacity and facility store capacity in kilograms it is noticed that the supplying capacity of the suppliers of 12000 kilograms exceeds facility RM store capacity of 10000 kilograms in all periods and both of them does not exceed the required weight in all periods. So there are some limitations regarding required weight.

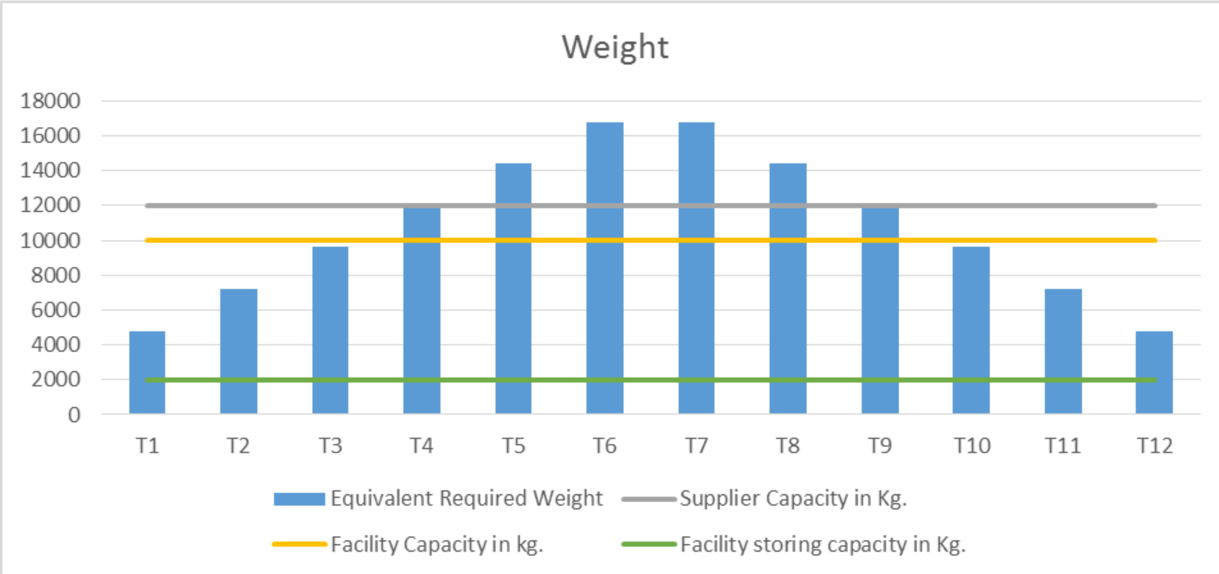

Fig. 7. relationship between the required weight and supplying capacity

And the relationship between the required weight, supplier capacity and the given weight is shown in figure 8 in which it is noticed that

In periods 1, 2 and 3 the supplied material is more than the required in the same period where the facility manufactures all supplied material, stored some of them for the next periods and send to customers what they need in this period.

In period 4 and 5 the required material is more than the supplied in the same period which is limited by the facility raw material store of 10,000 but the facility uses the stored products which are limited by the facility store of 2000 kilogram to satisfy customer's demands.

In period 6, 7, 8 and 9 the required material is more than the supplied in the same period which is limited by the facility raw material store of 10,000. So the facility manufacture is not able to satisfy customer's demands and there will be some shortages to be satisfied in the next periods if it is profitable.

In periods 10, 11 and 12 the supplied material is more than the required in the same period limited by the facility raw material store to satisfy the shortages occurred in the previous periods where the facility manufactures all supplied material and send them to customers to discover these shortages as possible.

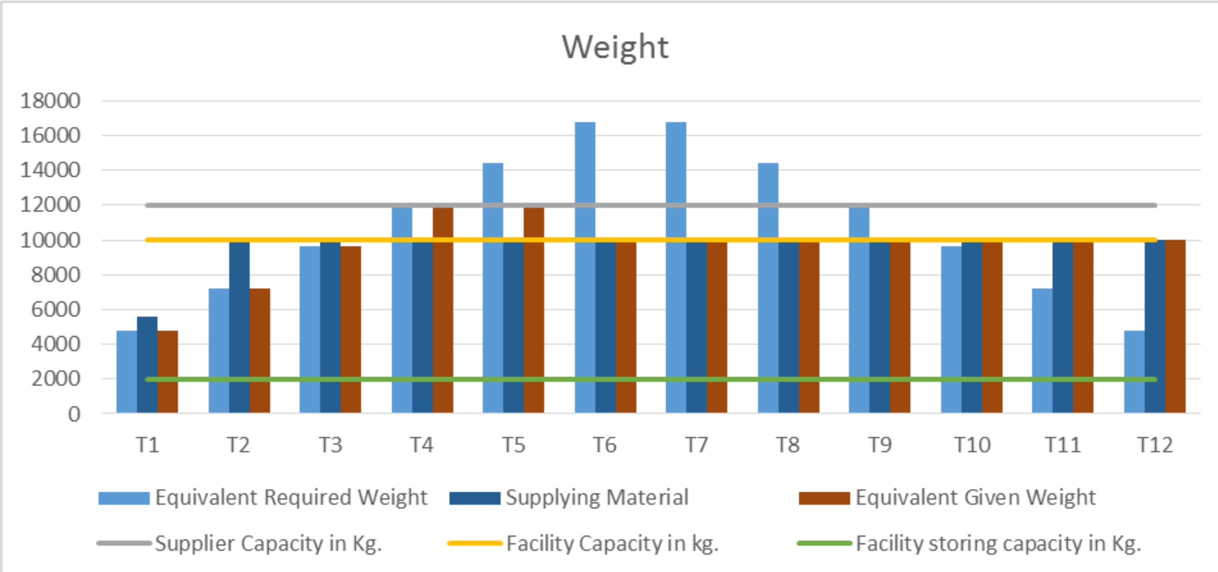

Fig. 8. relationship between the required weight, supplier capacity and the given weight

6. CONCLUSION AND FUTURE RECOMMENDATIONS

This model successfully tackled the problems of production planning for the following reasons:

1. The proposed model is verified through a general example with variable demand below and above the network capacities.
2. The proposed model is capable of optimizing multi-period, multi-echelon, multi-product and multi-objectives manufacturing network while considering inventory in both facility and distribution centres.
3. The model is capable of solving problems with a larger number of periods as compared to the numbers considered in the present work.

Future recommendations

a) In the present work, it is assumed that the customer's demands as known and deterministic values and it is recommended to tackle the problem of stochastic demand.

b) In the present work, it is assumed that the manufacturing network uses single item to manufacture multi- and it is recommended to tackle the problem of multi-items.

ACKNOWLEDGEMENTS

The author would like to thank FICO for their technical support.

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