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A HEURISTIC TO MINIMIZE TOTAL COST IN A MULTI PRODUCT SUPPLY CHAIN NETWORK

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Abstract

In this paper, the distribution planning model for the supply chain network having multi product demand is studied. The supply chain is traditionally characterized by a forward flow of materials and backward flow of information. In today's competitive environment it is required to minimize the cost of the whole supply chain network. Here we have considered the different products which are manufactured at factories are delivered to customers through the distribution centers. The objective function is to minimize the total cost consisting of production cost, transportation cost, inventory holding cost and replenishment cost. A mixed integer linear programming model is generated in GAMS to find out the optimum cost. For practical purpose a heuristic is generated and the heuristic results are compared with the optimum solution. In the heuristic the original model is segmented due to the time periods.

1. Introduction

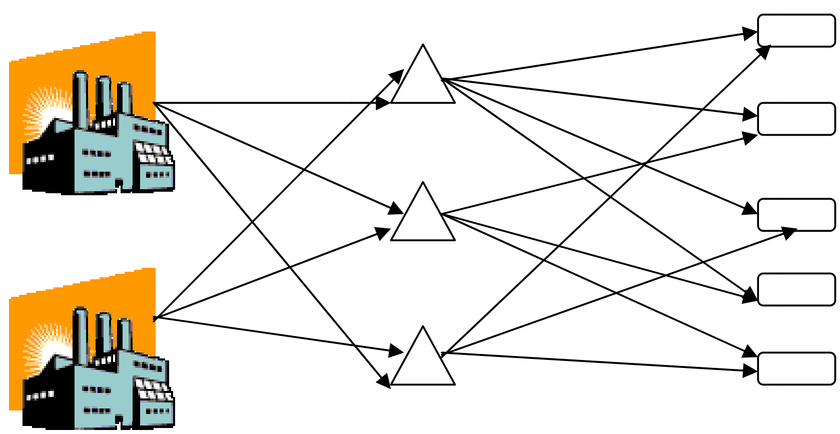
The modeling and analysis of production-distribution systems as a supply chain network is an active area of research. For the purposes of this paper, we use the definition of a supply chain provided by Ganeshan and Harrison (1995) as a network of facilities that performs the functions of procurement of materials, and transformation of these materials into intermediate and finished products. A similar definition has been given by Bhaskaran and Leung, (1997), who describe the manufacturing supply chain as an integrative approach used to manage the inter-related flows of products and information among suppliers, manufactures, distributors, retailers and customers.

At its highest level, a supply chain is comprised of two inter-related and integrated processes:

1. The Production Planning and Inventory Control processes, and
2. The Distribution and Logistics processes.

The production planning and inventory control process encompasses the manufacturing and storage sub-processes, and their interfaces. The distribution and logistics process determines the transport of products from the plant warehouse to retailers. These products may be transported to retailers directly, or may first be moved to distribution centers, which, in turn, transport the products to retailers.

This paper addresses both the above mentioned processes in a supply chain. The proposed model solves a supply chain problem composed of multiple plants producing multiple products that are transported to multiple distribution centers and thereon to customers as shown in Figure 1. This type of supply chain model is typical in many industries.



Plants distribution centers customers

Fig. 1. Structure of a supply chain network

At the operational level, supply chain models can be classified into three categories (Kang, Lee and Lee, 2008). The first category is the product distribution model, in which production scheduling and distribution planning is studied from production facilities to wholesalers or customer as in Barnes-Schuster, Bassok, and Anupindi (2006), Chan, Chung, and Wadhwa (2005) and Lee and Kim (2002). The second category of models consists of location allocation routing models, in which the location of facilities such as plant and stock points, and allocation and transportation route of customers are studied as in Conde (2007), Doong, Lai, and Wu (2007), Zhou, Min and Gen (2002). The third category consists of inventory transportation models that deal with inventory control of stock points and transportation planning from manufacturer or wholesaler to retailer and customer as in Qu, Bookbinder, and Iyogun (1999), Yano (1992) and Yokoyama (1995). In this paper, we propose an integrated multi period, multi product production and distribution model in a supply chain network to satisfy the retailer's demand in each of the future time periods for a specified planning horizon.We propose a Mixed Integer Linear Programming (MILP) formulation for the above supply chain network problem, and also a heuristic that can be useful for solving larger problems. The problem is formulated as a MILP model that minimizes the total cost of production, distribution, inventory holding and replenishment costs, subject to inventory balance constraints and side constraints for production time available at the plants. The proposed heuristic that can be useful for solving large real-life problems proceeds as follows: The problem is broken into time periods, and each of these problems for the single time period is solved sequentially and finally integrated to obtain the solution for the model with full time horizon. The paper is organized as follows. In Section 2, we present a brief review of the relevant literature. In Section 3, a mathematical model formulation is proposed. A heuristic for determining the product flow route and replenishment plan of stock point is suggested in Section 4. An illustrative example is solved in Section 5. Finally, Section 6 concludes the paper with a summary of results and discussions.

2. Literature Review

Williams (1981) presents seven heuristic algorithms for scheduling production and distribution operations in supply chain networks, comparing them with each other and with a dynamic programming model. The objective is to determine minimum cost production and production distribution schedule, satisfying the product demand, in a given distribution network. It is assumed that the demand rate is constant and that processing is instantaneous, with no delivery lags between facilities. Cohen and Lee (1988) use three different cost based sub-models: material control sub-model, production sub-model, and distribution sub-model to develop a model for establishing a material requirement policy for all materials for every shop in the supply chain production system. Newhart, et. al. (1993) design an optimal supply chain using a two phase approach. The first phase is a combination of a mathematical program and heuristic model, with the objective of minimizing the number of distinct product types held in inventory throughout the supply chain. The second phase is a spreadsheet-based inventory model, which determines the minimum amount of safety stock required to absorb demand and lead time fluctuations. Arntzen, et. al. (1995) develop a mixed integer programming model, called GSCM (Global Supply Chain Model), that can accommodate multiple products, facilities, stages (echelons), time periods, and transportation modes.Beamon (1998) provides a focused review of literature in the area of multi shop supply chain design and analysis and suggest four categories: deterministic analytic models, economic models, and simulation models. Ross (2000) suggested the method to reconfigure an existing distribution network by mapping simulated annealing heuristics to minimize operation cost of the depot and vehicles. Jararaman and Ross (2003) have suggested the extension of the problem discussed in Ross (2000), in which the supply chain consists of single manufacturing plant, multiple distribution centers and retailers. Syarif, Yun, and Gen (2002) have dealt with the configuration problem of the supply chain network using genetic algorithm. Vergara, Khouja, and Michalewicz (2002) used the evolutionary algorithm to solve the problem minimizing total cost in replenishment plan from suppliers. The chromosome in the evolutionary algorithm was represented by a sequence of replenishment plan, in which performances were shown significantly good through the computational experiment. Random local search and genetic algorithm were employed in the heuristics as Yokoyama (2002) has shown.Some other heuristic methods are actively adopted in this problem such as relaxation technique, decomposition, dispatching rule based approach. Barbarosoğlu and Özgür (1999) developed a mixed integer mathematical model for the integrated production–distribution model, and used Lagrangian relaxation and subgradient optimization to decouple the imbedded distribution and production sub-problems, and coordination of them, respectively. Vidal and Goetschalckx (2001) focused on the transportation planning of supply chain to minimize the transportation costs and international taxes. Through the relaxation, they developed the heuristic using sequenced linear programming. Qu et al. (1999) have studied the supply chain problem by decomposing into modified periodic review and traveling salesman problem to control inventory–transportation system.Simpson and Erengüc (1998) have addressed the multiple stage distribution channels including production stage, in which production and distribution planning are integrated. Lee and Kim (2002), developed and integrated multi-period, multi-product, multi-shop production and distribution model in supply chain. They proposed a hybrid approach combining the analytic and simulation model. Kang, Lee and Lee (2008) developed a mixed integer programming formulation and heuristics for practical use. Table 1 gives the summary of literatures available and categorised them.

	Model Type			Performance Measure			Type of Solution		
Author(s)	Production distribution	Location allocation routing	Inventory transportation	Cost	Customer Responsiveness	Activity time	Heuristic	Metaheuristic	Optimum
Arntzen, et. al. (1995)				✓		✓			
Barbarosoğlu and Özgür (1999)	✓			✓			✓		
Cohen and Lee (1988)			✓	✓					
Jararaman and Ross (2003)	✓	✓		✓			✓		
Lee, Kang and Lee (2008)	✓			✓			✓		
Lee and Kim (2002)	✓			✓					✓
Newhart, et. al. (1993)			✓	✓	✓		✓		
Qu, et. al. (1999)			✓						
Ross (2000)	✓	✓		✓			✓		

Simpson and Erengüc (1998)	✓			✓			✓		
Syarif, Yun and Gen (2002)		✓		✓				✓	
Vergara, Khouja and Michalewicz (2002)	✓			✓					✓
Vidal and Getschalckx (2001)			✓	✓			✓		
William (1981)	✓			✓			✓		
Yokoyama (2002)			✓	✓				✓	
This Paper	**X**			**X**	**X**		**X**		**X**

Table 1: Summary of Literatures

3. Mathematical Formulation

The supply chain model under study is diagrammatically represented in figure 2. It shows its entities, cost, type of model and some other characteristics. It is considered as consisting of two stage connected flow networks. In the first stage, several plants producing different kinds of products are supplied to multiple distribution centers which are capable of keeping inventory. In the second stage, these distribution centers supply stock to different customers. Customer demand is deterministic and *a priori* known for each time period in a planning horizon. This demand has to be met in every time period. Every product is transported from the plants to the customers via Distribution Centers (DCs). The transportation time from factories to distribution center and to the customers is assumed to be negligible. So, the demand in a period can be satisfied from the transport in the same period. Manufacturing capacity of the factory is assumed to be of reasonable size to cater to the total demand.

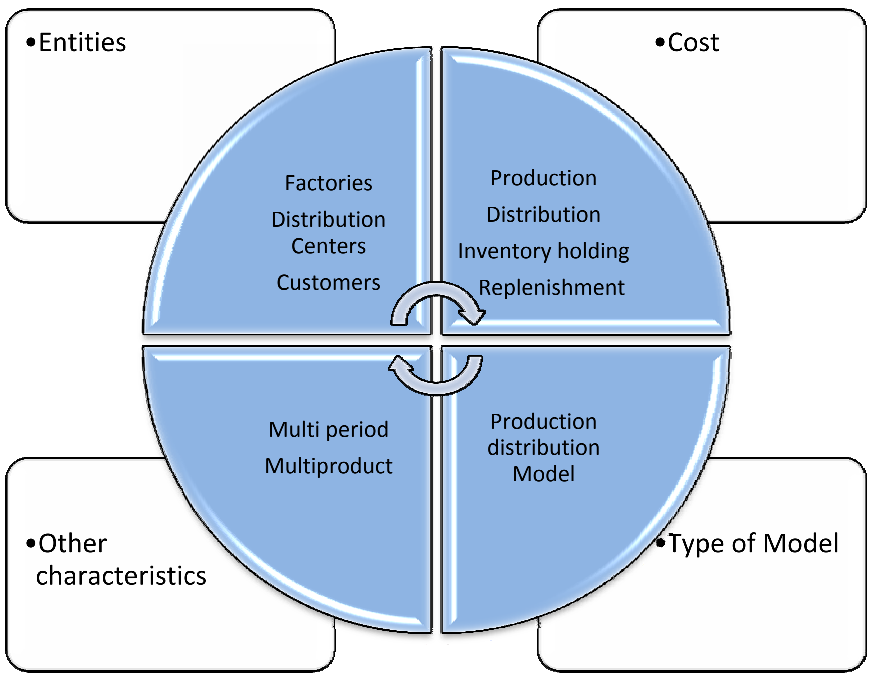


Fig 2: Supply chain model under study

Decisions on order quantities are based on the quantity of product that can be stored in the plant and the safety stock levels at the plants and distribution centers. At each plant, the maximum stock level is fixed but a Distribution Center is assumed to have unlimited capacity to store the product. A fixed replenishment cost at the specific stock point is charged whenever order is placed by the Distribution Center. Inventory holding cost is proportional to the quantity and the time length of inventory being kept. Transportation cost is also proportional to the total quantity of items transported. It may differ according to the route on which the products move. The objective is to minimize the sum of production cost, inventory holding cost, replenishment cost associated with stock points, and transportation cost of delivering products from factory to customer.

Index

i = index for manufactured products

j = index for manufacturing plant

k = index for distribution center

c = customer index

t = time period index

Given data

$Trans_{jk}$ = unit transportation cost from plant j to DC k

TC_{kc} = unit transportation cost from DC k to customer c

$Prodcost_{ij}$ = unit production cost for product i in plant j

H_{ij} = unit holding cost of product i at plant j

SS_{ij} = Safety stock of product i at plant j

B_{ij} = maximum stock of product i at plant j

D_{ict} = Demand of product i for customer c in period t

W_{ik} = unit holding cost of product i at DC k

YY_{ik} = intial stock of product i in DC k

$istockp_{ij}$ = intial stock of product i in plant j

SDC_{ik} = safety stock of product i at DC k

U_{jt} = production time available in plant j at period t

R_{kt} = Replenishment cost of DC k at period t

PT_i = production time required for one unit of product i

Decision variables

P_{ijt} = number of units of product i produced in plant j at period t

Qty_{ijkt} = number of units of product i transported from plant j to DC k at period t

QC_{ikct} = number of units of product i transported from DC k to customer c at period t

Inv_plant_{ijt} = Inventory units of product i in plant j at period t

Inv_DC_{ikt} = Inventory units of product i in DC k at period t

DV_{kt} = 1, if DC k places an order in period t

0, otherwise

Proposed Model

Minimize

$$\sum_j^m \sum_i^n \sum_t^T Prodcost_{ij} P_{ijt} + \sum_j^m \sum_i^n \sum_t^T H_{ij} Inv_{plant_{ijt}} \quad \sum_i^n \sum_k^K \sum_t^T W_{ik} Inv_{DC_{ikt}} + \sum_j^m \sum_i^n \sum_k^K \sum_t^T Trans_{jk}\, Qty_{ijkt} + \sum_i^n \sum_k^K \sum_c^C \sum_t^T TC_{kc}\, QC_{ikct} + \sum_k^K \sum_t^T R_{kt} DV_{kt} \tag{1}$$

Subject to

1. $Inv\_plant_{ijt} = Inv\_plant_{ij(t-1)} + P_{ijt} - \sum_k^K Qty_{ijkt} + istockp_{ijt}$ $\forall$i, j, t (2)

2. $P_{ijt} + Inv\_plant_{ij(t-1)} + istockp_{ijt} \geq \sum_k^K Qty_{ijkt}$ $\forall$i, j, t (3)

3. $Inv\_DC_{ikt} = Inv\_DC_{ik(t-1)} + YY_{ikt} + \sum_j^m Qty_{ijkt} - \sum_c^C QC_{ikct}$ $\forall$i, k, t(4)

4. $SS_{ij} \leq Inv\_plant_{ijt} \leq B_{ij}$ $\forall$i, j, t (5)

5. $SDC_{ik} \leq Inv\_DC_{ikt}$ $\forall$i, k, t (6)

6. $\sum_i^n PT_i P_{ijt} \leq U_{jt}$ $\forall$j, t (7)

7. $\sum_k^K QC_{ikct} = D_{ict}$ $\forall$i, c, t (8)

8. $\sum_i^n \sum_j^m Qty_{ijkt} \leq BigM * DV_{kt}$ $\forall$k, t (9)

9. $DV_{kt} \epsilon \{0,1\}$ $\forall$k, t (10)

10. $\sum_i^n \sum_j^m Qty_{ijkt} \geq 0$ $\forall$k, t (11)

11. $\sum_i^n \sum_k^K QC_{ikct} \geq 0$ $\forall$k, t (12)

Equation (1) is the objective function that represents the sum of production cost for each manufacturing plant, replenishment cost for each distribution center, inventory holding cost for each stock point (including plants) and transportation cost for the flow quantity delivered from plant to customer. Constraints (2) to (4) are balance equations. Capacity constraints on the factory and distribution centers are shown in constraints (5) and (6).

Production time constraints for each plant are shown in constraint (7). Constraints (8) force the customer demands quantity to be met to be met in each time period. This constraint ensures that there is no backlog or stock out. Constraint (9) indicates that replenishment cost is incurred only when an order is placed for each distribution center, where *BigM* denotes a sufficiently large real number. No capacity constraint is assumed for the transportation links. Non negativity of decision variables is imposed through constraints (10) to (12) and ordering decisions are treated as binary variables through constraint (9).

4. Proposed Heuristic

The types of decisions made in our model are: (a) how much quantity of each product is to be produced in each plant in each time period, (b) choice of transportation routes, and (c) when and how much to order from upstream nodes in supply chain network. The proposed heuristic is constructed so that the original model for a single time period can be solved readily using optimization package. This is treated as an initial solution consisting of production plan in each plant, flow quantities along the links from plants to DCs and DCs to customers, inventory in each period at plants and DCs and the total optimized cost. This solution is then improved further using the heuristic described below.

For each link with positive flow from plant to DC, we compute the ratio of sum of production cost and inventory carrying cost (on hand stock – safety stock) at plant and DC, and the replenishment cost for DC. If the replenishment of the coming periods is combined with the present one then the replenishment cost can be reduced while the inventory holding cost and production cost for the same period will increase. If combining orders and keeping resultant inventories and producing the products in the same period is more beneficial with respect to cost, than placing orders separately in several periods, then an order is placed for the total amount of supplies during the corresponding periods. Thus, if the computed ratio is less than 1, then replenishment at the same time for the demand of several periods may be more beneficial than replenishing several times for demand of each period. Decision on whether to combine orders or not are made starting from the earliest time period and proceeding towards the last time period in the planning horizon.

The steps in the above heuristic are as follows:

Step0: Set time period t = 0

Step1: Set t = t+1

Step2: Update all the costs, customer demands and inventories for each stock point.

Step3: For the period t, find the solution of the segmented original problem (considering only single period)

Step4: For each link with positive transportation flow between plant and DC, compute the ratio of Production cost (for production required for that flow) plus the Inventory holding cost at plant and DC (excluding the safety stock) to the Replenishment cost at the DC. If the ratio is greater that 1 then go to Step 6.

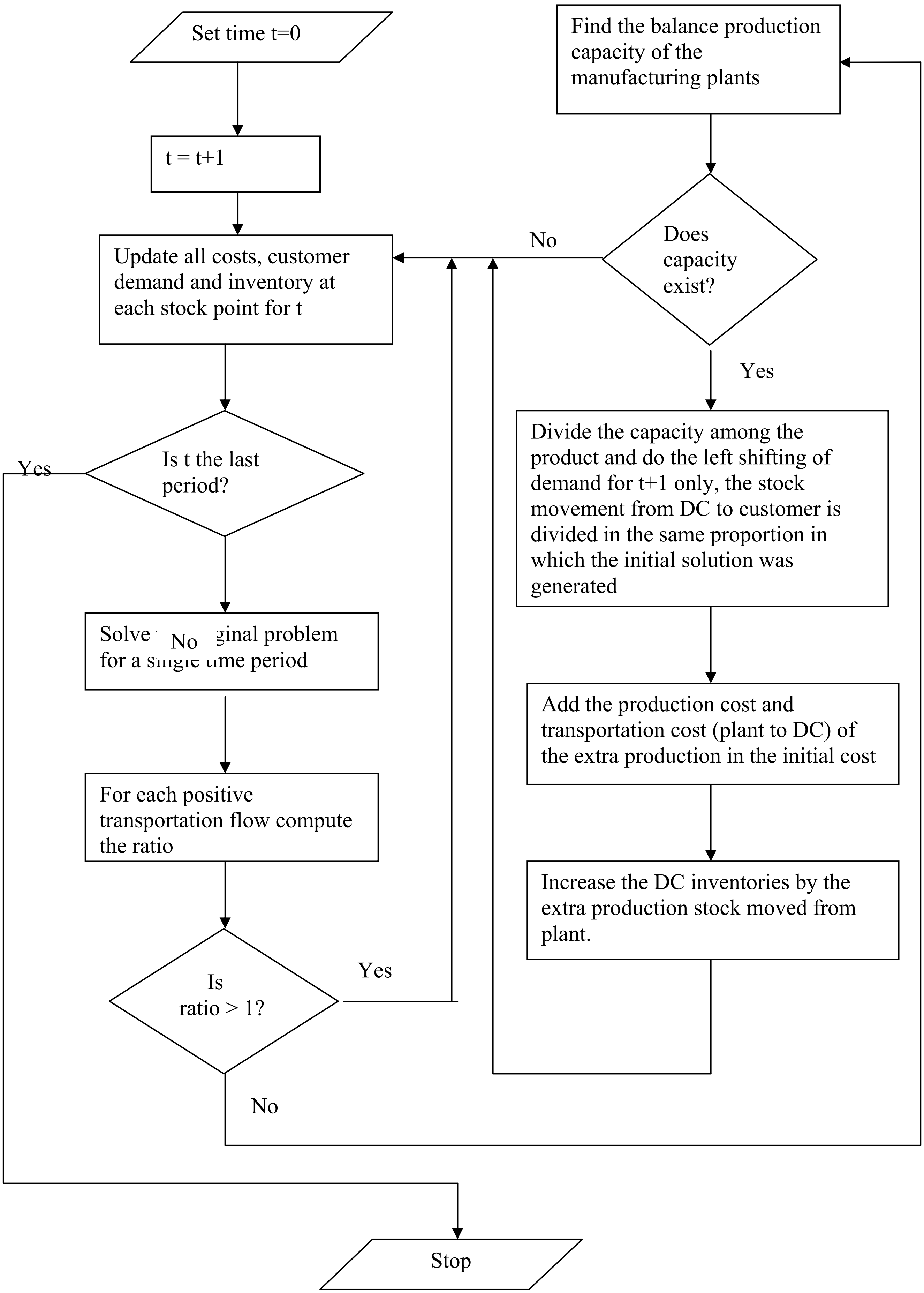
Otherwise the ratio is less than 1. Find out the balance capacity of the respective plant. If the balance capacity is zero then go to Step 2.

Otherwise there is a positive balance capacity at the plant. Divide the capacity among all products in the same ratio in which the initial production plan is generated for the corresponding period. Using this balance production capacity left shift the demand for only the next period (t+1) to production in period t. The transportation flow of the extra production from plant to DC and DC to customer will be divided in the same proportion in which the initial production for the corresponding period was considered. Go to Step5.

Step5: Add the production cost and transportation cost (from plant to DC only) of the extra production calculated in Step 4 to the cost evaluated in Step3. When we need to solve the model for the next period the inventory of each stock point will be increased according to the extra production distributed among each DC.

Step 6: If t is the last period, Stop, otherwise go to Step1 and repeat the process.

The above mentioned steps are shown as a flowchart in figure 3.



Set time t=0
t = t+1
Update all costs, customer demand and inventory at each stock point for t
Is t the last period?
Yes
No
Solve
ginal problem
for a
time period
For each positive transportation flow compute the ratio
Is ratio > 1?
Yes
No
Find the balance production capacity of the manufacturing plants
Does capacity exist?
No
Yes
Divide the capacity among the product and do the left shifting of demand for t+1 only, the stock movement from DC to customer is divided in the same proportion in which the initial solution was generated
Add the production cost and transportation cost (plant to DC) of the extra production in the initial cost
Increase the DC inventories by the extra production stock moved from plant.
Stop

Fig 3. Flowchart for heuristic

5. Illustrative example

As an illustration of the proposed heuristic, we consider the cost minimization problem of an integrated production-distribution system in a supply chain network. The supply chain network consists of 2 manufacturing plants, 3 distribution center, 5 customers, 2 products and 3 time periods. The data which is used in the example is given in Appendix A. The MILP formulation for the problem and the data in Tables 1 to 9 (Appendix A) is solved using GAMS student version to get the optimum results shown in Table 10.

Table 10: Optimum Solution obtained using the GAMS model

Table 10(a): Production Quantities for Product 1

	Period 1	Period 2	Period 3
Plant 1	1400	1500	1100
Plant 2	1300	1100	1400

Table 10(b): Production Quantities for Product 2

	Period 1	Period 2	Period 3
Plant 1	1100	1000	1400
Plant 2	780	700	500

Table 10(c): Quantity of Product 1 transported from Plants to DCs

	Period 1	Period 2	Period 3
Plant 1 to DC1	890	900	400
Plant 1 to DC3	500	600	700
Plant 2 to DC1	10	0	0
Plant 2 to DC2	1300	1100	1400

Table 10(d): Quantity of Product 2 transported from Plants to DCs

	Period 1	Period 2	Period 3
Plant 1 to DC1	600	600	800
Plant 1 to DC2	0	200	300
Plant 2 to DC2	800	700	500

Table 10(e): Quantity of Product 1 transported from DCs to Customers

	Period 1	Period 2	Period 3
DC1 to Customer 2	500	500	200
DC1 to Customer 4	400	400	200
DC2 to Customer 1	500	500	800
DC2 to Customer 3	800	600	600
DC3 to Customer 5	500	600	700

Table 10(f): Quantity of Product 2 transported from DCs to Customers

	Period 1	Period 2	Period 3
DC1 to Customer 2	300	200	200
DC1 to Customer 4	300	400	600
DC2 to Customer 1	400	500	600
DC2 to Customer 3	400	400	200
DC2 to Customer 5	500	200	300

Table 10(g): Inventory of Products at Plants and DCs

	Period 1	Period 2	Period 3
Product 1 at Plant 1	20	20	20
Product 1 at Plant 2	20	20	20
Product 2 at Plant 1	20	20	20
Product 2 at Plant 2	20	20	20
Product 1 at DC1	50	50	50
Product 1 at DC2	50	50	50
Product 1 at DC3	50	50	50
Product 2 at DC1	50	50	50
Product 2 at DC2	50	50	50
Product 2 at DC3	50	50	50

Table 10(h): Ordering Decisions at DCs

	Period 1	Period 2	Period 3
DC1 places Order	1	1	1
DC2 places Order	1	1	1
DC3 places Order	1	1	1

The optimal value of objective function value, which is the minimum total cost, comes out to be 220,052 units. The same problem when solved with the proposed heuristic give the total cost value as 221,039 units. The output of the heuristic is shown in Table11.

Table11 Experiment result with the proposed heuristic method

Table 11(a): Production Quantities for Product 1

	Period 1	Period 2	Period 3
Plant 1	1400	957.5	600
Plant 2	1562.5	2500	780

Table 11(b): Production Quantities for Product 2

	Period 1	Period 2	Period 3
Plant 1	1100	1542.5	1900
Plant 2	937.5	0	0

Table 11(c): Quantity of Product 1 transported from Plants to DCs

	Period 1	Period 2	Period 3
Plant 1 to DC1	890	0	0
Plant 1 to DC2	0	357.5	0
Plant 1 to DC3	500	600	600
Plant 2 to DC1	12	1627	0
Plant 2 to DC2	1560.5	873	680
Plant 2 to DC3	0	0	100

Table 11(d): Quantity of Product 2 transported from Plants to DCs

	Period 1	Period 2	Period 3
Plant 1 to DC1	600	600	800
Plant 1 to DC2	0	0	800
Plant 1 to DC3	500	742.5	300
Plant 2 to DC2	957.5	200	0

Table 11(e): Quantity of Product 1 transported from DCs to Customers

	Period 1	Period 2	Period 3
DC1 to Customer 1	0	0	329
DC1 to Customer 2	500	500	200
DC1 to Customer 4	400	400	200
DC2 to Customer 1	500	500	471
DC2 to Customer 3	800	600	600
DC3 to Customer 5	500	600	700

Table 11(f): Quantity of Product 2 transported from DCs to Customers

	Period 1	Period 2	Period 3
DC1 to Customer 2	300	200	200
DC1 to Customer 4	300	400	600
DC2 to Customer 1	400	500	600
DC2 to Customer 3	400	400	200
DC3 to Customer 5	500	200	300

Table 11(g): Inventory of Products at Plants and DCs

	Period 1	Period 2	Period 3
Product 1 at Plant 1	20	20	20
Product 1 at Plant 2	20	20	20
Product 2 at Plant 1	20	20	20
Product 2 at Plant 2	20	20	20
Product 1 at DC1	52	779	50
Product 1 at DC2	310.5	441	50

Product 1 at DC3	50	50	50
Product 2 at DC1	50	50	50
Product 2 at DC2	207.5	50	50
Product 2 at DC3	50	50	50

Table 11(h): Ordering Decisions at DCs

	Period 1	Period 2	Period 3
DC1 places Order	1	1	1
DC2 places Order	1	1	1
DC3 places Order	1	1	1

6. Computational Results

There are total 4 cases solved in the same way and the final cost results is compared in Table12.

Table12: Comparison of the experimental results

Cases	Number of facilities			Results		% GAP
	Plant	DC	Customer	Optimum	Heuristic	
Case1	2	2	4	150599.40	158321.25	5.13
Case2	1	2	5	82577.00	86442.00	5.00
Case3	2	3	5	220052.00	221039.00	0.45
Case4	3	4	6	271271.50	271289.70	0.006

The gap between the optimum result and the proposed heuristic method is reducing as the facilities are increasing. This gives a scope to work on more cases to see whether the heuristic method is approaching to optimum result as we increase the number of facilities.

The figures below show the diagrammatic representation of solution through optimum method and heuristic.

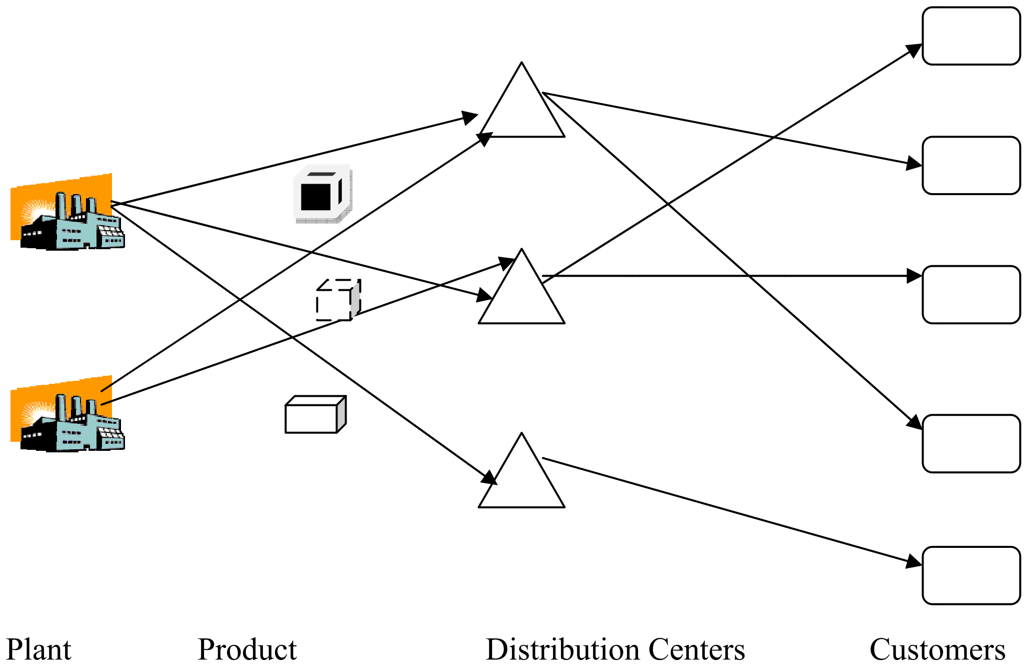


Fig 4. Solution by Optimum Method

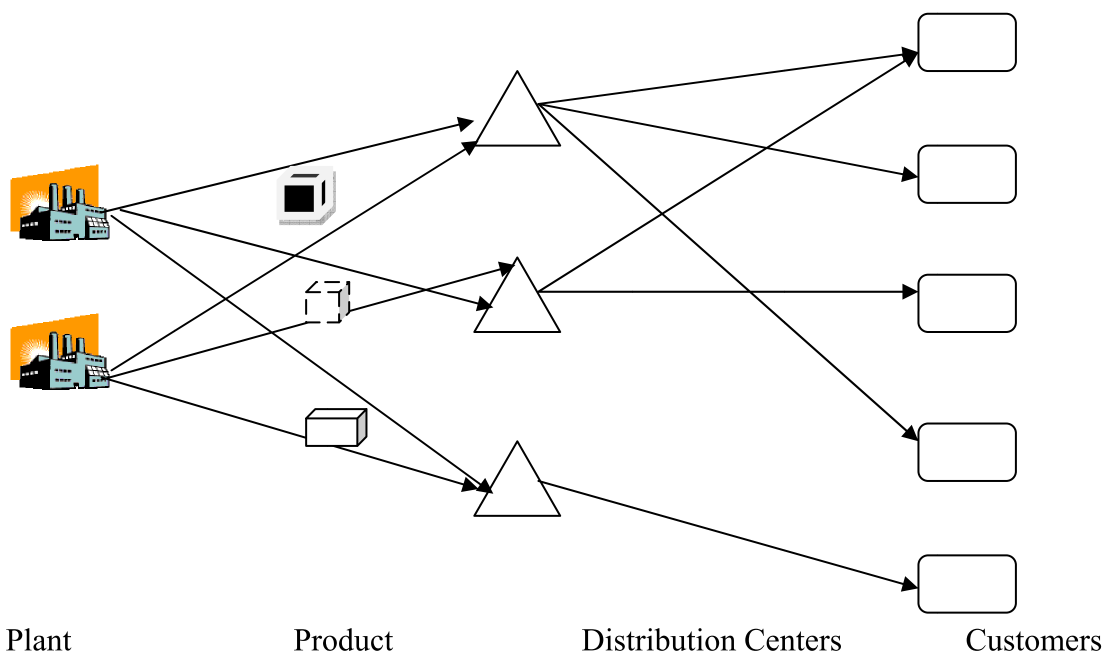


Fig 5. Solution by heuristic method

6. Conclusion and Discussion

In this paper, a mathematical formulation for the general structure of the supply chain network was suggested to minimize the sum of production cost, inventory holding cost, replenishment cost and transportation cost. We have assumed the capacity constraint at plants and multi products to be produced. For practical purpose a heuristic is suggested which works on the optimizing the original problem by considering single time period. There are 4 cases solved with both the method and heuristic results for these cases were compared with the optimum one. It is observed that the gap between the optimum result and heuristic result is reducing as the number of facilities was increased.

In this paper, we have not considered to optimize the network cost by considering supplier which supplies raw material to manufacturing plant, which would be interesting as research topic. Also we have not considered the space constraint in distribution center and that can also be added in the existing network.

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Appendix A

Table 1 (a): Demand for Product 1

	Period 1	Period 2	Period 3
Customer 1	500	500	800
Customer 2	500	500	200
Customer 3	800	600	600
Customer 4	400	400	200
Customer 5	500	600	700

Table 1 (b): Demand for Product 2

	Period 1	Period 2	Period 3
Customer 1	400	500	600
Customer 2	300	200	200
Customer 3	400	400	200
Customer 4	300	400	600
Customer 5	500	200	300

Table 2: Production time

	Hours per unit
Product 1	0.2
Product 2	0.2

Table3: Unit Production Cost

	Product 1	Product 2
Plant 1	0.3	0.3

Plant 2	0.4	0.4

Table 4: Production Time Available

	Period 1	Period 2	Period 3
Plant 1	500	500	500
Plant 2	500	500	500

Table5: Unit holding cost of product

	Product 1	Product 2
Plant 1	1	1
Plant 2	1	1
DC 1	0.5	0.5
DC 2	0.5	0.5
DC 3	0.5	0.5

Table 6: Replenishment cost of DC

	Period 1	Period 2	Period 3
DC 1	800	1000	1000
DC 2	1000	1000	1000
DC 3	600	600	600

Table 7: Safety stock of product

	Product 1	Product 2
Plant 1	20	20
Plant 2	20	20
DC 1	50	50
DC 2	50	50
DC 3	50	50

Table 8: Initial stock of product

	Product 1	Product 2
Plant 1	10	20
Plant 2	30	40
DC 1	50	50
DC 2	50	50
DC 3	50	50

Table 9(a) : Unit transportation cost from Plant to DC

	DC 1	DC 2	DC 3
Plant 1	9	9	9
Plant 2	9	9	9

Table 9(b) : Unit transportation cost from DC to Customers

	DC 1	DC 2	DC 3
Customer 1	10	7	12
Customer 2	7	10	12
Customer 3	10	7	12
Customer 4	7	10	12
Customer 5	10	10	5