A TWO-WAREHOUSE SUPPLY CHAIN NETWORK DESIGN AND OPTIMIZATION WITH CROSS-ROUTE COSTS AND BUDGET, MAXIMUM FLOW AND CAPACITY CONSTRAINTS

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ABSTRACT

Supply chain optimization techniques for modelling the behavior of manufacturing supply chains have been used for long in order to allow better planning, minimize total cost and improve efficiency. In this paper, a systematic approach is presented for the facility placement, optimal production planning and product transportation across network arcs. An optimization formulation is developed for the determination of production size, locations of network nodes and optimal supply chain. The objective function considered the minimization of transportation cost, production cost and the operational costs for the facilities. The incorporation of budget constraint, delivery mode, cross-route costs, maximum flow by a shipping firm, production capacity of the plants, stocking capacity of owned and rented warehouses and traffic factors on the supply routes in the mathematical model further broadened the problem. A case study is solved to analyze how the model performs with the changing network characteristics.

KEYWORDS: *Cross-route costs, Network design, Supply chain, Traffic factor, Two-warehouse.*

INTRODUCTION

The framework of supply chain network gives fundamental structure to supply chain operations. The system is a fundamental component in the intensity of a firm and a noteworthy area of capital investment. Issues talked about by R. H. Ballou[1] are identified with the advancement of better models and the requirement for looking at few models for network design. A supply chain is a coordinated system of suppliers, manufacturing plants and transportation routes which are sorted out to procure crude materials, transformation of crude materials to completed items and afterward to distribute the completed items to clients[2]. I. M. Bowling et al.[3] studied a numerical programming model for the ideal arrangement of conveyed bio-refineries. The model could decide the measure of each item sent to every facility and the quantity of items and sub-items that must be created for every facility to decide the most extreme aggregate net benefit considering the transportation, working and capital expenses for the facilities. G. Dikos et al.[4] presented supply chain network planning and enhancement in Heracles general cement company. The target of Heracles was to continue with full coordination and synchronization of supply chain planning and improvement and the venture asset arranging framework, and additionally the generation of every interconnected outputs and reports. A. Nagurney et al.[5] considered the outline of supply chain network on account of basic needs as may happen in crises, disasters and assaults influencing national security. The created model caught a solitary association that tries to make the required items at a few assembling plants, stored and distributed to the demand points. The aftereffect of the model gave the optimal capacity enhancements and volumes of item streams to minimize the aggregate cost subject to the requests being fulfilled under demand uncertainty. F. Altiparmak et al.[6] proposed a steady-state genetic algorithm for the single-source multi-item multi-stage supply chain network planning issue. Exploratory review demonstrated that the steady-state genetic algorithm discovered preferred heuristic arrangements over the other heuristic methodologies and achieved the great heuristic arrangements with extremely modest calculation time when compared with CPLEX. E.P. Schulz et al.[7] formulated a multi-period mixed integer nonlinear supply chain model for a petrochemical complex. The model included creation, item conveyance, stock administration and choices, for example, singular generation levels for every item and in addition working conditions for each plant. F. Wang et al.[8] concentrated on a supply chain network design issue with natural concerns. The principle focus was the natural investments choices in the planning stage. A multi-objective optimization model was recommended that caught the trade-off between the aggregate cost and nature impact. An exhaustive arrangement of numerical

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tests was directed and the outcomes demonstrated that the proposed model can be connected as an effective tool in planning green supply chain. D. Bredstrom et al.[9] studied the supply chain issue of a substantial worldwide pulp maker with a few pulp factories. The organization utilized manual making arrangements for its supply chain, which included harvesting and transportation of pulp, generation planning and distribution of items to clients. In tests and examinations with today's manual planning, new vital strategies were found that fundamentally diminished the organization's supply chain costs. A. Othman et al.[10] presented a multi-period stochastic planning model for a supply chain network of a petroleum association working in an oil delivering nation under unverifiable economic situations. The proposed supply chain network made out of all exercises identified with unrefined petroleum generation, handling and distribution. H. M. Bidhandi et al.[11] proposed a mixed whole number linear programming model for solving supply chain framework issues in deterministic, multi-item, single-period settings. The model coordinated location and capacity decisions for suppliers, plants and stockrooms choice, product range assignment and production streams. S. R. Yadav et al.[12] introduced the algorithm portfolio idea to solve a combinatorial optimization issue relating to a supply chain. A. T. Gumus et al.[13] built up a coordinated supply chain configuration model and a supply chain network design configuration case was inspected for a multinational organization in liquor free beverage sector. A three-echelon inventory network system was considered under demand instability and the coordinated neuro-fuzzy and mixed whole number linear programming methodology was connected to the system to understand the plan viably. A. Nagurney[14] proposed a structure for supply chain network design and redesign that took into account the optimal levels of capacity and operational product streams related with supply chain exercises of assembling, stockpiling and circulation at negligible aggregate cost and subject to the satisfaction of product demands. K. Govindan et al.[15] proposed a multi-objective optimization model by coordinating sustainability in decision-making on circulation in a perishable food supply chain network.

In this paper, an optimization model is introduced to quickly and effectively design the channel route network. The main contribution is the development of an integrated approach to address the major factors of a supply chain network such as: minimizing the number of production and stocking facilities, maximum number of products that can be assigned to shipping firm for delivery across network arcs, transportation type, budget constraint, multi-product flow, cross-route costs, traffic factor and the two-warehouse issues. The objective of the problem is to assign products to network nodes for production and stocking, optimal flow of products across network arcs, selection of route with less hurdles, increase the number of products assigned to a given shipping firm so as to minimize the total cost less than the allocated budget and satisfy the total customer demand. A case study is solved to clarify the proposed model.

The rest of the article is organized as follows. In Section 2, issue portrayal is presented. In Section 3, an integer mathematical formulation is presented to solve a problem. In Section 4, a case study of a local paper mill is tested on a network designed for product flow across the two-stage supply chain network. Section 5 is used for results and discussion. Section 6 includes conclusion and suggested areas for further research.

PROBLEM DESCRIPTION

In this broad supply chain network design and optimization problem, the focus is on the location and capacity allocation of production facilities and

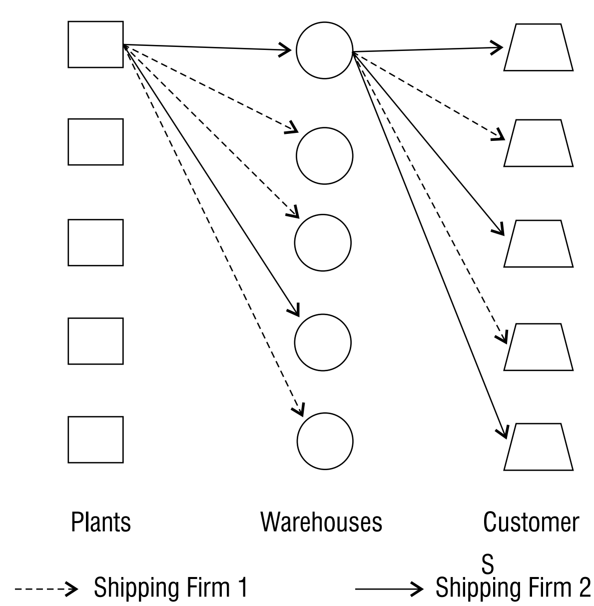

Fig. 1 Two-stage fully flexible supply chain network

warehouses. Customers are then assigned to the selected warehouses. A supply chain is considered in which production facilities send products to warehouses that supply markets as shown in Fig. 1. Location and capacity allocation decisions have to be made for both factories and warehouses.

The following conditions are assumed in the transportation model.

1. Three-stage supply chain network is considered.
2. Fully flexible supply chain network is considered.
3. Supply chain network optimization problem is considered.
4. Total cost should be less than or equal to the allocated budget.
5. Two-warehouse (rented and owned) location problem is considered.
6. The product flow ranges are considered same for all shipping firms.
7. Customer demands are known in advance for each type of product.
8. Multi-product supply chain network for product distribution is considered.
9. Inflow of products to a warehouse should be greater than or equal to outflow from the warehouse.
10. Traffic factor is considered 1 for a supply route with no hurdles and it decreases with the increase in hurdles on the supply route. A closed supply route has traffic factor equal to zero.
11. Total number of products assigned to a shipping firm across all routes of the supply chain network should be less than or equal to the maximum number of products that a shipping firm can transport in a given time horizon.
12. The number of products stocked in a warehouse should be less than or equal to the stocking capacity of the warehouse.
13. Product outflow from a production plant should be less than or equal to the production capacity of the production plant.

MATHEMATICAL MODEL

In general, the fully flexible supply chain network problem is used to determine the optimum quantity of products shipped from production facilities to the demand points and to find the best delivery routes for the delivery of products to fulfill the customer demands that minimizes the total shipping cost. Before presenting the problem formulation, the following notations are introduced:

Indices:

c index of shipping firm $c=1,2,\dots,a$

d index of discount range $d=1,2,\dots,b$

e index of product grade $e=1,2,\dots,p$

f index of production node $f=1,2,\dots,q$

g index of warehouse node $g=1,2,\dots,r$

h index of retailer node $h=1,2,\dots,s$

Parameters:

B Allocated budget for the supply chain for a specific time horizon

C_{fg} cost per unit per mile from supply node f to destination node g

C_{gh} cost per unit per mile from supply node g to destination node h

D_{fg} distance in miles from a supply node f to destination node g

D_{gh} distance in miles from a supply node g to destination node h

F_{ef} operating cost of locating a production facility at location f to produce product e

F_{eg} operating cost of locating a stocking facility at location g to stock product e

Gf fixed cost of a production facility at location f

G_g fixed cost of a stocking facility at location g

K_{ef} capacity of the production facility f to produce product e

K_{eg} capacity of the stocking facility g to stock product $_e$

P_{cd} percent discount offered by shipping frim c for discount rang d

R_{eh} number of products of grade e required at the demand point h

T_{fg} traffic factor value on the route from supply node f to demand node g

T_{gh} traffic factor value on the route from supply node g to demand node h

W_{ef} working days per month of the production facility f to produce product e

H_{ef} production time per day of production facility f to produce product e

M_c Percent discount or extra charge by a shipping firm c

l_d^c lower bound on flow by shipping firm c for discount range d

u_d^c upper bound on flow by shipping firm c for discount range d

r_f^e production rate at plant f for product of grade e

t_f^e production time at plant f for product of grade e

DECISION VARIABLES:

X_{efg}^{cd} number of products of grade e shipped from production node f to stocking node g by the shipping firm c in a discount range d

X_{egh}^{cd} number of products of grade e shipped from stocking node g to demand node h by the shipping firm c in a discount range d

Y_{ef} 1 if production facility producing product e is located at location f, otherwise 0

Y_{eg} 1 if stocking facility stocking product e is located at location g, otherwise 0

z_d^c 1 if total flow of products shipped by firm c is in the range d, otherwise 0

The problem is formulated as the following integer program:

MINIMIZE:

$$Z=\sum_{f=1}^{q}G_f+\sum_{g=1}^{r}G_g+\sum_{e=1}^{p}\sum_{f=1}^{q}F_{ef}Y_{ef}+\sum_{e=1}^{p}\sum_{g=1}^{r}F_{eg}Y_{eg}+\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{f=1}^{q}\sum_{g=1}^{r}\frac{D_{fg}}{T_{fg}}C_{fg}X_{efg}^{cd}(1-P_{cd})(1\pm M_c)+$$
$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{g=1}^{r}\sum_{h=1}^{s}\frac{D_{gh}}{T_{gh}}C_{gh}X_{egh}^{cd}(1-P_{cd})(1\pm M_c)$$

The objective function being the total transportation cost of the supply chain network is required to be minimized subject to the following constraints:

$$\sum_{e=1}^{p}\sum_{f=1}^{q}F_{ef}Y_{ef}+\sum_{e=1}^{p}\sum_{g=1}^{r}F_{eg}Y_{eg}+$$
$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{f=1}^{q}\sum_{g=1}^{r}\frac{D_{fg}}{T_{fg}}C_{fg}X_{efg}^{cd}(1-P_{cd})(1\pm M_c)+\forall c\in a,d\in b,e\in p,f\in q,g\in r,h\in s \tag{1}$$
$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{g=1}^{r}\sum_{h=1}^{s}\frac{D_{gh}}{T_{gh}}C_{gh}X_{egh}^{cd}(1-P_{cd})(1\pm M_c)\le B$$

$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{g=1}^{r}X_{egh}^{cd}\ge R_{eh}\forall e\in p,h\in s \tag{2}$$

$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{f=1}^{q}X_{efg}^{cd}-\sum_{c=1}^{p}\sum_{d=1}^{r}\sum_{e=1}\sum_{h=1}^{s}X_{egh}^{cd}\ge 0\forall g\in r \tag{3}$$

$$\sum_{e=1}^{p}\sum_{f=1}^{q}\sum_{g=1}^{r}X_{efg}^{cd}+\sum_{e=1}^{p}\sum_{g=1}^{r}\sum_{h=1}^{s}X_{egh}^{cd}\ge l_d^c z_d^c\forall c\in a,d\in b \tag{4}$$

$$\sum_{e=1}^{p}\sum_{f=1}^{q}\sum_{g=1}^{r}X_{efg}^{cd}+\sum_{e=1}^{p}\sum_{g=1}^{r}\sum_{h=1}^{s}X_{egh}^{cd}\le u_d^c z_d^c\forall c\in a,d\in b \tag{5}$$

$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{g=1}^{r}X_{efg}^{cd}\le K_{ef}Y_{ef}\forall f\in q \tag{6}$$

$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{f=1}^{q}X_{efg}^{cd}\le K_{eg}Y_{eg}\forall g\in r \tag{7}$$

$$\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{e=1}^{p}\sum_{h=1}^{s}X_{egh}^{cd}\le K_{eg}Y_{eg}\forall g\in r \tag{8}$$

$$t_f^e=r_f^e\sum_{c=1}^{a}\sum_{d=1}^{b}\sum_{g=1}^{r}X_{efg}^{cd}\forall e\in p,f\in q \tag{9}$$

$$K_{ef} = \frac{W_{ef} H_{ef}}{r_f^e} \forall e \in p, f \in q \quad (10)$$

$$X_{efg}^{cd}, X_{egh}^{cd} \geq 0, integers \ \forall c \in a, d \in b, e \in p, f \in q, g \in r, h \in s \quad (11)$$

$$\sum_{d=1}^{b} z_d^c \leq 1 \forall c \in a \quad (12)$$

$$z_d^c \in \{0,1\} \forall c \in a, d \in b \quad (13)$$

$$Y_{ef}, Y_{eg} \in \{0,1\} \forall e \in p, f \in q, g \in r \quad (14)$$

Simplex method for linear programming is used to solve the problem. The objective of the problem minimizes the fixed, operating and production costs of the production facilities, fixed and operating cost of the stocking facilities and total shipping cost of the network priced according to the cost per unit per mile times the corresponding distance divided by the traffic factor value times one minus the discount offered for a given range of products by a shipping firm times discount or extra charge applied by a shipping firm.

The first constraint states that the total customer demand must be satisfied within the allocated budget for the supply chain. The second constraint enforces that the customer demand for a specific product must be satisfied at a demand location. The third constraint specifies that the total inflow of a specific product to a warehouse must be greater than or equal to the total outflow of that product from the warehouse. The fourth constraint requires that the total flow of products across all routes and all stages of the supply chain network by a shipping firm in a given range is either zero or satisfies the lower bounds of the range whereas the fifth constraint shows that the total flow of products across all routes and all stages of the supply chain network by a shipping firm in a given range is either zero or satisfies the upper bounds of the range. The sixth constraint ensures that the number of products shipped from a production plant to warehouses cannot exceed the production capacity of the plant while the seventh constraint requires that the number of products shipped from production plants for stocking in a warehouse should be less than or equal to the stocking capacity of a warehouse. The eighth constraint enforces that the product outflow from a warehouse should not exceed the stocking capacity of the warehouse. The ninth equation states that the production time in a plant to produce a product is equal to the production rate times the number of products produced. The tenth equation states that the capacity of a production plant is equal to the total production time in a specific time horizon divided by the production rate to produce a product while the eleventh constraint ensures that the number of products shipped from production facilities to warehouses or from warehouses to demand locations in the supply chain network is both greater than or equal zero and integers. The twelfth constraint specifies that the movement of products on all arcs of the network by a shipping firm corresponds to exactly one flow range whereas the thirteenth constraint enforces that z_r^c is equal to 1 if total flow of products shipped by firm *a* is in the range *b*, else 0. And the last constraint states that each production facility to produce a specific product is either open or close.

CASE STUDY

A local paper mill at Peshawar city produces master paper reels of different grades. Customer demands are for master reels of standard width. There are two production plants at Peshawar and customers within Peshawar and at the nearby cities. The production plant 1 has production rates of 1.5 hr/product and 1.0 hr/product for products A and B respectively. The cost per product at production plant 1 is \$20/product and \$40/product while producing product A and B respectively. Similarly, the production plant 2 produces only product A with production rate of 1.4 hr/product and \$20/product cost rate. The plant production time per day is 20 hours and is same for both production facilities. In rare cases, the production time per day is greater than 20 hours but almost remains 20 hours per day. The production days per month for both the plants are 25 days. Hence, the monthly production capacity of production facility 1 is 333 and 500 units of product A and B respectively. Similarly, the monthly production capacity of facility 2 is 357 products of product A only. The operating cost of production facility 1 for each product (A and B) is \$1000 and \$1200 to produce product A at production facility 2. The operating cost of the owned warehouse at node 3 is \$500 each for stocking product A and B. Similarly, the operating cost of the rented warehouse at node 4 is \$400 each for stocking product A and B. The fixed costs of production facilities 1 and 2 are \$500 and \$600, respectively. The fixed costs of warehouses at nodes 3 and 4 are \$500 and \$800 for the given time horizon. The stocking capacities per month of warehouses at nodes 3 and 4 are 500 and 400 for products of grade A and B respectively. The monthly demand from customer at node 5 is 300 paper reels of grade A and 150 paper reels of grade B. Similarly, the monthly demand from customer at node 6 is 180 paper reels of grade A and 200 paper reels of grade B. No extra charge on delivery is applied while shipping the products across network arcs i.e., the product delivery is normal. The production plant-warehouse and warehouse-retailer distances, traffic factor values on the supply routes and shipping costs are summarized in Table 1. The distances in miles, traffic factor values and cost per unit per mile are given in second, fourth and sixth columns of Table 1 respectively.

Table 1. Distances, traffic factor values and shipping costs

D_{fg}	Distance (miles)	T_{fg}	Traffic factor	C_{fg}	$ per unit per mile
D_{13}	40	T_{13}	0.90	C_{13}	2.0
D_{14}	15	T_{14}	0.90	C_{14}	2.0
D_{23}	04	T_{23}	0.90	C_{23}	2.0
D_{24}	28	T_{24}	1.00	C_{24}	1.5
D_{35}	57	T_{35}	1.00	C_{35}	1.5
D_{36}	19	T_{36}	0.85	C_{36}	2.1
D_{45}	33	T_{45}	1.00	C_{45}	2.1
D_{46}	45	T_{46}	1.00	C_{46}	2.0

Two shipping firms may involve in the delivery of customer demands. In Table 2, the discounts offered for different flow ranges by the shipping firms are shown. There is 2% discount from shipping firm 1, if it is assigned less than 500 units of product-flow across all routes in total. If the total flow assigned to shipping firm 1 is 500 or more but less than 1000, there is 5% discount on product-flow across all routes in total. The discounts offered for the same ranges of product flow by shipping firm B, are 3 and 6%, respectively. In this case study, the two different product flow ranges are same for both the firms. This is only for simplicity and these ranges may differ from one another for the shipping firms.

Table 2. Discounts offered for different flow ranges

S. No.	Range	Shipping Firm 1	Shipping Firm 2
1	0-449	2%	3%
2	500-1000	5%	6%

The problem is solved with the information gave by the paper production factories and delivery firms as appeared in the above tables using lp_solve version 5.5.2.0 for 32-bit OS, 2.00 GB of RAM with 64-bit REAL variables and Intel® Core™ i3 CPU 2.53 GHz processor. There are total 6 nodes in the network and 8 arcs. The model includes 30 constraints and 67 variables with a goal to reduce the over-all cost. Time to

Table 3. Mathematical model outputs

Decision Variable	Value
X_{A23}^{12}	357
X_{B46}^{22}	200
X_{B14}^{12}	180
X_{A36}^{22}	180
X_{A35}^{22}	177
X_{B14}^{22}	170
X_{B45}^{22}	150
X_{A12}^{12}	123
X_{A12}^{12}	123
Y_{A1}	1
Y_{B1}	1
Y_{A2}	1
Y_{A3}	1
Y_{A4}	1
Y_{B4}	1
Z_1^2	1
Z_2^2	1
Objective value	$101806
Allocated budget	$111000

load information was 0.01 seconds; presolve utilized 0.06 seconds, 0.20 seconds in simplex solver, altogether 0.27 seconds. In Table 3, the yields of the mathematical model are appeared and every other value of not recorded variables is equivalent to zero.

The outputs show that both the shipping firms are involved in the movement of paper reels across the different arcs of the supply chain network and satisfies the upper and lower bounds. The flow of paper reels follows the cheapest way between a pair of nodes and the customer demand at each node is satisfied. The total cost $101806 comprises of production costs of the required products, fixed costs of the production and stocking facilities, operating costs and shipping costs.

In Fig. 2, the supply of paper reels across network arcs is shown. Shipping firm 1 transports 660 master reels only from production facilities to warehouses in the second range at 5% discount. Shipping firm 2 transports 1000 master reels from production facilities to warehouses and also from warehouses to demand points in the second range at 6% discount. The total customer demand is fulfilled from stocking facilities 3 and 4.

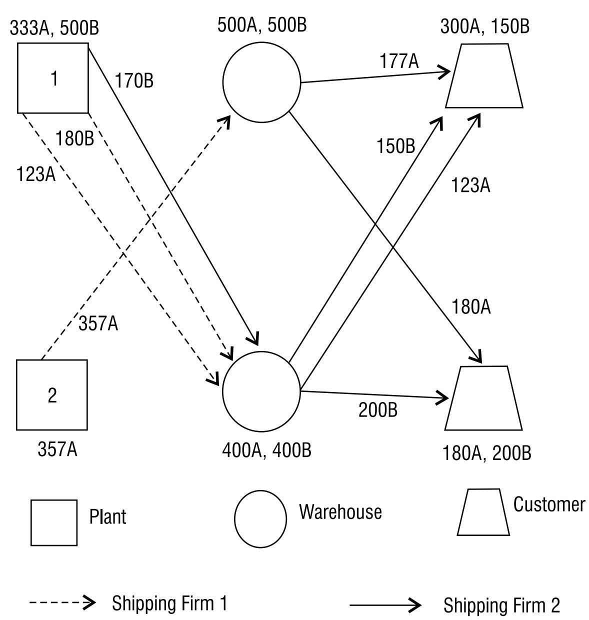

Fig. 2 Multi-product flow across network arcs

This is obvious that with the increase in customer demand, the shipping cost increases. In the case of total cost: the production cost, shipping cost and fixed costs of production facilities are added. Minimizing the number of production and stocking facilities to satisfy a total customer demand minimizes the total cost. There is no extra charge for normal delivery but the shipping frim charges or discounts by some percentage for urgent or late delivery respectively. This is observed that a route with more hurdles decreases the responsiveness and results in a tedious delivery of paper reels. In Pakistan, the delivery is affected by many factors such as road construction or repair, military and police check posts, political activity on a supply route, fog, traffic congestion, curves and slopes and passing through war affected zones etc. This is always preferred to select a route with no such hurdles i.e. maximum traffic factor value. A customer is assigned to a stocking facility based on the required grade of paper. A single facility may satisfy all the retailers even if it is closer to the retailers than other facilities. The more the paper reels assigned to a ground carrier for movement, more discount is availed and vice-versa, subject to time constraint for the maximum number of paper reels' shipping.

RESULTS AND DISCUSSION

The reason for this approach is making open/close choices of the paper generation and distribution centers, and determining the amount of item that streams from production plants to stockrooms and from stockrooms to clients with least cost. Shipping firms are chosen for the conveyance of items through the arcs of the supply chain network in light of the discounts offered for various flow ranges.

The model is run using lp_solve version 5.5.2.0 for analytical computations. The model outputs and results can be seen in Table 3. The quantity of products produced in the production plants that flows from the production plants to the demand nodes via warehouses is equal to the quantity of products demanded by the customers. As it is seen that both production facilities and both warehouses supply products, thus these facilities should be in progress in the process for the given time horizon. The shipping frim 2 offers higher discount for the range 2 than shipping firm 1, thus maximum quantity of products is shipped through shipping firm 2. Also, the quantity of products satisfies the upper and lower bounds of flow. The delivery is normal, so no extra charge is applied for urgent delivery nor discount is given by the carries for late delivery. The objective value is less than the allocated budget for the supply chain network.

CONCLUSION

In this paper, an integrated approach for planning of a supply chain network for the circulation of master paper reels is built up. The model uses cost minimization inside a framework enhancement point of view as the principle objective. The created structure can be connected in several circumstances in which the goal is to create and convey distinctive items at least total cost through distribution centers in order to fulfill the client request at different demand points. An expansion to the customary supply chain network design for item conveyance is presented, in which the transportation cost related with a supply route depends not just on the item stream over that route but on the item stream on other supply routes in the supply chain network as well. An optimized solution is presented with the incorporation of budget, maximum flow, production capacity and stocking capacity constraints. Issues such as delivery mode and traffic factors on the supply routes further widened the problem. It is shown that production capacity, stocking capacity, traffic factor, discount factor and delivery mode significantly affect the total cost.

Potential areas for further research include the generic model of the proposed approach and consolidation of service time choices keeping in mind the end goal to give the supply chain network issue a more refined look.

This research is a contribution to the literature of supply chain network systems with an emphasis on framework and optimization and item conveyance applications.

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