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A Multi-Objective Model for Supply Chain Network Design under Stochastic Demand

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***Abstract*—**In this article, the design of a Supply Chain Network (SCN) consisting of several suppliers, production plants, distribution centers and retailers, is considered. Demands of retailers are considered stochastic parameters, so we generate amounts of data via simulation to extract a few demand scenarios. Then a mixed integer two-stage programming model is developed to optimize simultaneously two objectives: (1) minimization the fixed and variable cost, (2) maximization the service level. A weighting method is utilized to solve this two objective problem and a numerical example is made to show the performance of the model.

***Keywords*—**Mixed Integer Programming, Multi-objective Optimization, Stochastic Demand, Supply Chain Design, Two Stage Programming

I. Introduction

ONE of the important factors that has a significant impact in supply chain responsiveness and costs concerns with network design decision which is typically a strategic decision [3]. When customers demand are stochastic variables in supply chain network (SCN) design problem, the most important issue is to find the network configuration that can simultaneously achieve the objectives of minimization total cost comprised of the costs of manufacturers and distributors, and maximization retailers service level.

Supply chains performance measures are classified as qualitative and quantitative. Customer satisfaction, flexibility, and effective risk management can be categorized as qualitative factors. Quantitative factors are also categorized by: (1) objectives that are based directly on cost or profit such as cost minimization, profit maximization, etc. and (2) objectives that are based on some measure of customer responsiveness such as customer response time minimization, lead time minimization, etc. [7].

However, the SCMN problem is usually involving trade-offs among different goals. In this study, we developed a mixed integer two-stage programming model to design a supply chain network via optimizing multi objective functions. We considered two objectives for SCM problem: (1) minimization of total fixed costs for establishing manufacturers and distribution centers and the expected value of production costs and distribution costs, (2) maximization of the customer service level.

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II. Literature review

There are many studies in supply chain design concerning deterministic parameters such as [10] and [17]. However, in real life problems, there are so many operational and commercial uncertainties such as costumer demand, product price, operational costs, facility capacities, and so forth. Moreover these uncertainties can occur in both strategic and tactical level. In tactical level planning, for example, distribution of raw materials and final products, there are several papers like [22] and [20]. Also in strategic level there are so many papers related to location decisions of supply chain components which can be found in a comprehensive review by [18]. Moreover, in strategic level, supply chain network design papers are reviewed by [21].

In this scope, some papers just deals with one stochastic parameters like demand [15], While others consider more than one stochastic parameter like [6] that simultaneously consider production cost, delivery cost, and demand as stochastic parameters. [8] used Two Stage Approach (TSA) for modeling an uncapacitated Location problem. [15] modeled a distribution problem with stochastic demand by TSA then used network recourse decomposition method as a solution technique, although, they didn't analyze responses variability according to demand and other parameters characteristics. [9] Consider network design problem with capacity constraint and their model is MILP and its objective is to minimize the operational and strategic costs. They use Benders algorithm to solve the problem and claim that the network is robust.

[5] Review the production and distribution problems. They emphasize on large scale logistics models and point their defects. [4] Mention the importance of uncertainty considerations in large scale logistics systems and they focus on MILP models and its solution approaches.

[16] Design a multiple products and multiple layers network. The first stage variable is an integer and the second stage variable is continuous. They utilize two models and techniques to solve the problem. Firstly, "Wait and see" analysis and then TSA is used. [14] Also designs a multi product and multi echelon network. In their model the consumers and production location is given and the goal is to locate the ware houses and distribution centers in order to minimize the total strategic and operational costs in which they use MILP model.

[1] Present a two stage model deciding about production topology, facility capacity, product selection, and product allocation. Its objective function is maximizing the selling profit by subtracting operational and investment costs. In their paper they consider demand, product price, raw material procurement and production cost as stochastic parameters.

And their solution approach is based on branch and fix coordination algorithm.

[19] presents a Two Stage model to design a large scale network. The objective is to determine the location of facilities and deciding about that which machine in each facility should participate in production process in order to minimizing the objective function. The solution method is based on benders algorithm that is mixed with SAA method to solve the model. In their paper two real large scale problems results is presented. [13] model a single product and single period location allocation problem by Two Stage approach and solve it by Lagrangian method.

In literature, little portion of papers consider multiple objective models in stochastic environment and in supply chain network design problems. [12] utilize a multi-stage model and its objective functions are minimizing risk and maximizing profit. In their paper a new approach based on Moreau-Yosida regularization is used to solve the model. [2] consider demand, distribution cost, stock out cost, capacity expansion cost are stochastic. They use three objective functions to provide a robust model. The first objective function is the traditional total cost of investment, distribution, stock out, and capacity expansion. The second objective function is minimizing the variance of total cost, and ultimately the third one is minimizing the financial risk.

In this paper we are trying our best to model a supply chain network with stochastic demand by utilizing Two Stage programming and also multi objective concept. The first objective is minimizing total cost of allocating facilities and the second objective is maximizing service level.

III. Model Formulation

In this section we intend to construct the model of the mentioned problem. The main assumptions of the provided model are: (a) The formulation is a single period, multi product model, (b) the operational costs and the capacity of the facilities are deterministic parameters, (c) the customers' demands are all stochastic parameters, normally distributed with mean equals to their deterministic parameters and standard deviation equals to the fraction of their mean, (d) capacity of each facility is limited. You can see the parameters and variables of the model in the following:

Indexes

C: Set of commodities indexed by c
D: Set of candidate distributers indexed by d
K: Set of raw materials indexed by k
L: Set of suppliers indexed by l
M: Set of candidate manufacturers indexed by m
R: Set of retailers indexed by r
S: Set of scenarios indexed by s

Parameters

b^{kc}: Demand of retailer r for commodity c under scenario s
CL_l^k : Maximum capacity of supplier l to provide raw material l
CM_m^c: Maximum capacity of manufacturer m to produce commodity c
CD_d^c : Maximum capacity of distributer d to deliver commodity c
FCD_d : Fixed cost of distributing commodity from distribution center d
FCM_m: Fixed cost of production in manufacturer m
FCD_d^c : Fixed cost of distributing commodity c from distribution center d
FCM_m^c : Fixed cost of producing commodity c in manufacturer m
H_r^{cs}: Demand of retailer r for commodity c under scenario s
p^s: Probability of scenario s
RL_l: Maximum available resource for supplier l
RM_m: Maximum available resource for manufacturer m
RD_d: Maximum available resource for distributer d
RL_l^k : Resource usage of supplier l for providing raw material k
RM_m^c : Resource usage of manufacturer m for producing commodity c
RD_d^c : Resource usage of distributer d for distributing commodity c
ULM_{lm}^k : Unit cost of providing raw material k to manufacturer$m$from supplier l
UMD_{md}^c : Unit cost of providing commodity c to distributer$d$from manufacturer m
UDR_{dr}^c: Unit cost of providing commodity$c$to retailer$r$from distributer$d$
ε: A short number near the zero
M: A large number near the infinite number
N: Number of commodity types

Variables

xlm_{lm}^{ks}: Amount of raw material k provided by supplier l to manufacturer m under scenario s
xmd_{md}^{cs} : Amount of commodity c provided by manufacturer m to distributer d under scenario s
xdr_{dr}^{cs}: Amount of commodity c provided by distributer d to retailer r under scenario s
yd_d: Binary variable equals to 1 when distribution center d distribute at least one commodity
ym_m: Binary variable equals to 1 when manufacturer m produce at least one commodity
yd_d^c: Binary variable equals to 1 when distribution center d distribute commodity c
ym_m^c: Binary variable equals to 1 when manufacturer m produce commodity c
t_r^{cs}: Binary variable equals to 1 when demand is satisfied
γ: Satisfaction level

We construct a two-stage multi-objective mixed-integer linear programming for our problem in which the first objective is minimizing the costs related to supply chain facilities and the second one is maximizing the customer satisfaction level. These two objectives and the constraint can be shown as following:

$$\begin{aligned} minimize & \sum_{m\in M} FCM_m ym_m + \sum_{d\in D} FCD_d yd_d \\ &+ \sum_{m\in M}\sum_{c\in C} MFC_m^c ym_m^c + \sum_{d\in D}\sum_{c\in C} DFC_d^c yd_d^c \\ &+ E_S\Bigg(\sum_{l\in L}\sum_{m\in M}\sum_{k\in K} ULM_{lm}^k xlm_{lm}^{ks} \\ &+ \sum_{m\in M}\sum_{d\in D}\sum_{c\in C} UMD_{md}^c xmd_{md}^{cs} \\ &+ \sum_{d\in D}\sum_{r\in R}\sum_{c\in C} UDR_{dr}^c xdr_{dr}^{cs}\Bigg) \qquad (1) \end{aligned}$$

$$maximize\ \ \gamma \qquad (2)$$

S.t.

$$\sum_{l\in L} xlm_{lm}^{ks} - \sum_{c\in C}\sum_{d\in D} b^{kc} xmd_{md}^{cs} = 0 \qquad \forall m,k,s \qquad (3)$$

$$\sum_{m\in M} xmd_{md}^{cs} - \sum_{r\in R} xdc_{dr}^{cs} = 0 \qquad \forall d,c,s \qquad (4)$$

$$\sum_{k\in K}\sum_{m\in M} RL_l^k xlm_{lm}^{ks} \le RL_l \qquad \forall l,s \qquad (5)$$

$$\sum_{c\in C}\sum_{d\in D} RM_m^c xmd_{md}^{cs} \le RM_m ym_m \qquad \forall m,s \qquad (6)$$

$$\sum_{c\in C}\sum_{r\in R} RD_d^c xdr_{dr}^{cs} \le RD_d yd_d \qquad \forall d,s \qquad (7)$$

$$\sum_{m\in M} xlm_{lm}^{ks} \le CL_l^k \qquad \forall l,k,s \qquad (8)$$

$$\sum_{d\in D} xmd_{md}^{cs} \le CM_m^c ym_m^c \qquad \forall m,c,s \qquad (9)$$

$$\sum_{r\in R} xdr_{dr}^{cs} \le CD_d^c yd_d^c \qquad \forall d,c,s \qquad (10)$$

$$\sum_{m\in M} \frac{RM_m}{RM_m^c} ym_m^c \ge \sum_{r\in R}\left(\sum_{s\in S} p^s H_r^{cs}\right) \qquad \forall c \qquad (11)$$

$$\sum_{d\in D} \frac{RD_d}{RD_d^c} yd_d^c \ge \sum_{r\in R}\left(\sum_{s\in S} p^s H_r^{cs}\right) \qquad \forall c \qquad (12)$$

$$\sum_{d\in D} xdr_{dr}^{cs} - H_r^{cs} < Mt_r^{cs} \qquad \forall r,c,s \qquad (13)$$

$$\sum_{d\in D} xdr_{dr}^{cs} - H_r^{cs} \ge M(t_r^{cs} - 1) \qquad \forall r,c,s \qquad (14)$$

$$\sum_{c\in C} t_r^{cs}/N \ge \gamma \qquad \forall r,s \qquad (15)$$

$$ym_m^c \le ym_m \qquad \forall m,c \qquad (16)$$

$$yd_d^c \le yd_d \qquad \forall d,c \qquad (17)$$

$$xlm_{lm}^{ks}, xmd_{md}^{cs}, xdr_{dr}^{cs}, \gamma \ge 0 \quad \forall l,m,d,r,c,k,s \quad (18)$$

$$ym_m, yd_d, ym_m^c, yd_d^c, t_r^{cs} \in \{0,1\} \quad \forall m,d,r,c,s \quad (19)$$

Objective (1) minimizes the sum of total fixed cost and expected total variable cost. Objective (2) maximizes the satisfaction level. Constraints (3) ensure that the total amount of raw material $k$delivered to manufacturer m is equal to the total amount required byall commodities made at this manufacturer, while constraints (4) ensure that all commodities that enter a given distributer also leave that distributer. Constraints (5)-(7) express that the resources used in each supplier, manufacturer and distributer should be less than their maximum total available resources, while constraints (8)-(10) guarantee that the total raw materials or commodities which exit from suppliers, manufacturers or distributers should be less than their capacities. Constraints (11) and (12) ensure that the total capacity of the opened facilities is greater than the total demand. Constraints (13) and (14) are sensors for demand fulfillment. In other words, if demand was satisfied, sensor t_r^{cs} would be 1, otherwise it would be 0. So by constraint (15) the average number of sensors which were 1 should be more than satisfaction level. Finally the constraints (16) and (17) ensure that when a facility did not opened, that would not provide any raw material or commodity.

Before we go to solving stage of the problem we should reminisce that the demands of the retailers are stochastic parameters. So we initially would produce data in a way and then we can get to the solution methodology. In the next section we explain the solution methodology by a numerical example.

III. Solution Methodology and Numerical Example

This part presents a simple numerical example to show the results of the model formulation. In this example the supply chain consist of 4 suppliers, 3 potential manufacturer, 3 potential distributer, 4 retailers, 3 different kinds of raw materials and 3 kinds of finished products. Our objective is to find the best configuration of the supply chain (manufacturer and distributer should be determined), and also decide about which commodities should be provided in selected manufacturers and distributers in a way that the cost is minimized and the service level will be maximized. At the beginning we should generate data for the demand of retailers on every product to get to the scenarios. For this purpose we generate 1000 series of data for each combination of r and c based on normal distribution with mean equals to their deterministic quantity and standard deviation equals to the fraction of their mean, and then extract 10 scenarios from these data.

To solve a multi-objective model, there are many solution strategies like the Weighting Method, the Constraint Method, Multi-objective Simplex Method, Fuzzy method and etc. We used the weighting method to solve our problem since the model is a mix integer programming (MIP). The model is solved for different combinations of objective weights and the pareto-optimal configuration of the supply chain facilities is determined. Also we decide that each manufacturer and each distributer provide which commodities. Designing the supply chain network, the decision maker should select his own weights for the cost and service level, and then he can distinguish which facilities are needed. We do the same procedure on proposed example. The results can be demonstrated as below:

1. For all combination of the $w(1)$ (cost weight) and $w(2)$ (service level weight) manufacturers 2 and 3, and distributers 1,2 were selected, so the supply chain network would consist of four suppliers, two manufactures (1,2), two distributers (2,3) and four retailers.
2. For each combination of the weights, the commodities that should be provided in selected manufactures and distributers are shown in Fig. 1.

W(1) <0.025 and 0.2<W(1)<0.25 and 0.45<W(1)<0.5 and 0.55<W(1)<0.6 and 0.65<W(1)<0.7 and 0.9<W(1)<0.975	0.025<W(1) <0.1 and 0.3<W(1)<0.45 and 0.5<W(1)<0.55 and 0.6<W(1)<0.65 and 0.75<W(1)<0.9	0.1<W(1) <0.15 and 0.25<W(1)<0.3 and 0.7<W(1)<0.75	0.15<W(1) <0.2 and 0.975<W(1)<1
M2: Commodity 1 M3: Commodities 1,2,3 D1: Commodities 1,3 D2: Commodities 1,2	M2: Commodities 1,2 M3: Commodities 2,3 D1: Commodities 2,3 D2: Commodities 1,2	M2: Commodity 1 M3: Commodities 1,2,3 D1: Commodities 1,2,3 D2: Commodity 1	M2: Commodities 1,2 M3: Commodities 1,3 D1: Commodities 1,3 D2: Commodities 1,2

Fig. 1 Types of commodities which should be provided by selected manufactures and distributers

IV. Conclusion

In this study, a mixed integer two-stage programming model is developed to design a supply chain network by optimizing two different objectives. We considered two objectives: (1) minimization of total fixed and variable cost of plants and distribution centers, (2) maximization of the customer service level, and used the developed model to determine from which manufacturers and distributors, and also how much amounts should be provided to answer retailers' stochastic demand.

References

[1] A. Alonso-Ayuso, L.F. Escudero, A. Garin, M.T. Ortuno, G. Perez, An approach for strategic supply chain planning under uncertainty based on stochastic 0–1 programming, J. Global Optim. 26 (2002) 97–124.

[2] A. Azaron, K.N. Brown, S.A. Tarim, M. Modarres, A multi-objective stochastic programming approach for supply chain design considering risk, Int. J. Production Economics 116 (2008) 129–138.

[3] Chopra, S., Meindl, P., 2004. Supply Chain Management: Strategy, Planning and Operation. Prentice Hall, Upper Saddle River, USA.

[4] C.J. Vidal, M. Goetschalckx, Modeling the effect of uncertainties on global logistics systems, J. Bus. Logist. 21 (1) (2000) 95–120.

[5] C. Vidal, M. Goetschalckx, Strategic production-distribution models: a critical review with emphasis on global supply chain models, Eur. J. Oper. Res. 98 (1997) 1–18.

[6] E.H. Sabri, B.M. Beamon, A multi-objective approach to simultaneous strategic and operational planning in supply chain design, Omega 28 (2000) 581–598.

[7] F. Altiparmak, M. Gen, L. Lin, T. Paksoy, 2006, A genetic algorithm approach for multi- objective optimization of supply chain Networks, Computers and Industrial Engineering 51, pp. 197-216.

[8] F.V. Louveaux, D. Peeters, A dual-based procedure for stochastic facility location, Oper. Res. 40 (1992) 564–573.

[9] G.J. Gutierrez, P. Kouvelis, A.A. Kurawala, A robustness approach to uncapacitated network design problems, Eur. J. Oper. Res. 94 (1996) 362–376.
[10] H. M. Bidhandi, R. Mohd. Yusuff, M. M. H. M. Ahmad, M. R. A. Bakar, Development of a new approach for deterministic supply chain network design, European Journal of Operational Research 198 (2009) 121–128.
[11] J. Xu, Q. Liuand R. Wang, A class of multi-objective supply chain networks optimal model under random fuzzy environment and its application to the industry of Chinese liquor, Information Sciences, Volume 178, Issue 8, 15 April 2008, Pages 2022-2043.
[12] M. Goh, J.I.S. Lim, F. Meng, A stochastic model for risk management in global supply chain networks, Eur. J. Oper. Res. 182 (2007) 164–173.
[13] P. Schütz, L. Stougie, A. Tomasgard, Stochastic facility location with general long-run costs and convex short-run costs, Computers & Operations Research, (2008) 2988-3000.
[14] P. Tsiakis, N. Shah, C.C. Pantelides, Design of multi echelon supply chain networks under demand uncertainty, Ind. Eng. Chem. Res. 40 (2001) 3585–3604.
[15] R.K.-M. Cheung, W.B. Powell, Models and algorithms for distribution problems with uncertain demands, Transport. Sci. 30 (1996) 43–59.
[16] S.A. MirHassani, C. Lucas, G. Mitra, E. Messina, C.A. Poojari, Computational solution of capacity planning models under uncertainty, Parallel Comput. 26(2000) 511–538.
[17] Sh. Rezapour , R. ZanjiraniFarahani, Strategic design of competing centralized supply chain networks for markets with deterministic demands, Advances in Engineering Software 41 (2010) 810–822.
[18] Snyder, L.V., 2006. Facility location under uncertainty: a review. IIE Transactions 38 (7), 537–554.
[19] T. Santoso, S. Ahmed, M. Goetschalckx, A. Shapiro, A stochastic programming approach for supply chain network design under uncertainty, Eur. J. Oper. Res. 167 (2005) 96–115.
[20] Van Landeghem, H., Vanmaele, H., 2002. Robust planning: a new paradigm for demand chain planning. Journal of Operation Management 20 (6), 769–783.
[21] W. Klibi, A. Martel, A. Guitouni, The design of robust value-creating supply chain networks: a critical review, Eur. J. Oper. Res. 203 (2) (2010) 283–293.
[22] Yu, C.-S., Li, H.-L., 2000. A robust optimization model for stochastic logistic problems. International Journal of Production Economics 64 (1–3), 385–397.