Design and algorithm of supply chain network model based on uncertain environment

Yulan Zheng*

School of Economics & Management, Fuzhou University, Fuzhou, Fujian, 350116, China

Received 1 July 2014, www.cmnt.lv

Abstract

Under the conditions of modern market economy and the increasing pressure of competition, a growing number of product life cycles are getting shorter, customer demand is constantly changing, this force the companies began to pay attention to their own internal management and supply chain management. Supply chain refers to the suppliers, manufacturers, distributors and end-users, and the network, which design both directions of material flow, information flow and capital flow [1]. In order to manage and use it better, People put network information technology in supply chain management, developed or purchased ERP implementation systems software, thus can share information between departments and enterprises. But problems have gradually exposed, faster access and processing does not produce a good decision automatically. So this paper under the premise of uncertainty, started studying supply chain's network model, establishing optimization model, design algorithms, therefore reducing the total costs, to avoid risks.

Keywords: uncertain environment, supply chain, model, design

1 Introduction

Supply chain management problem at first is the supply chain network design, to determine the configuration of supply chain and business processes that every level need to implement, is the primary concern, typical decision are as follows: supplier's selection, facilities' location, facilities' capacity, demand and supply distribution. Decision problem can be planned in two parts: Supplier's selection, facilities issues. If one of the issues optimized, it can have great benefits to the whole enterprise as a whole. If merchant, manufacturer and supplier in the supply chain can work together, manage and optimize the flow processes, inventory can be reduced, flexibility can increasing, so as to achieve the goal of low cost and high efficiency.

2 Effect of uncertainty environment on supply chain management

The source of uncertainty in supply and production processes is the initial supplies. Because material supply effects began to gradually pass to downstream members, and then expand the production assembly process and delivery time of the product, thereby indirectly affecting the customer's satisfaction to the product. Uncertainty of customer demand will step by step pass to upstream members along the supply chain, thus affecting the item's inventory and storage time, thus increased inventory costs. Sometimes customers demand uncertainty will cause serious impact on the enterprise, especially serious for some products, which difficult to keep and remodel frequent enterprise.

With the development of networks, production and market information's storage, analysis and delivered can quickly process. Supply chain information management is no longer limited by time or space, so that information can be shared directly between suppliers, manufacturers, distributors, customers, it greatly reduces bias caused by the layer-by-layer transmission of information zoom, Therefore, information possess a certain amount of certainty. Supply chain management is not only require information sharing, the supply of materials is necessary, if there is no matching system of logistics management, supply chain does not have an operating base, while not able to achieve e-commerce "business function".

So in a sense, supply chain management, aimed at preventing the identification of possible adverse consequences for supply chain performance, ensure that the uncertainty of the process can be reduced to a minimum to let material flow, increase flexibility, and reduce the cost of purchasing and supply and trading, through the optimization of the supply chain to improve the competitiveness of enterprises.

3 Design of supply chain network

Supply chain network design is strategic supply chain management issues. In the supply chain network, we can see all abstract as a directed graph consists of nodes and arcs. We are setting up a model that divided nodes into four categories: suppliers, manufacturers, distributors, and

***Corresponding author** e-mail:zylfzdx@163.com

customers demand points, arc is represented by the links between nodes, to represent business processes.

Supply chain network design's purpose is to identify products from raw materials to customer requirements points are complete channel architecture. Supply chain network design in this article need to solve the primary problem that considering the uncertainty of design parameters, to determine supply chain structure when meet constraints, and supply chain performance in parameter perturbation can remain stable enough, so as to avoid market risks.

Major constraints are:

1. supplier for all factory shipments cannot exceed the supplier's capacity;
2. factory shipments for all manufacturers cannot exceed factory capacity;
3. vendor shipments for customer demands cannot exceed manufacturers' capacity;
4. the total amount of goods from suppliers not less than the factory needs;
5. obtained from the factory cannot be less than the amount of cargo sellers demand;
6. obtained from the distribution centre cannot be less than the amount of goods to customer needs [1].

3.1 ESTABLISH MATHEMATICAL MODEL

Supply chain network design is a long-term strategic decision, because too few valid historical data can be used, it is difficult for policy makers using historical data to draw the exact value of the parameter, and it is difficult to determine the parameters of the probability distribution function, you can use scenario analysis to examine the uncertainties "to reproduce."

First of all, the basic premise of establishing mathematical model is:

1. Indirect costs incurred by the supplier product can be obtained by using the activity-based costing method: $\varpi = \sum_t \sum_f \tau_t u_f x_{tf}$, t is vendor performance evaluation index number; f is cost driver number; u_f is the unit cost of cost drivers; τ_t is number of supplier performance index; x_{tf} is number of cost driver caused by supplier performance index.
2. Every customer area can only get delivery services from one seller. Through these premises, we can completely define the following method:

a) The main sources of uncertainty--customer demand and costs;

b) Parameter uncertainty--different value ranges;

c) Combine the value ranges of different situations, judge the rationality and form various scenarios;

d) Equal probability distribution of each scenario.

Based on the principle of "first divide later combine" we respectively established supplier selection and decision-making model (Table 1), after consolidation we set up supply chain network design model based on robust optimization theories.

TABLE 1 Supplier selection and decision-making model

Collection		Index number		Design variable		Controlled variable	
I	Supplier collection	i	SupplierNumber, i∈I	X_{im}	Whether choose supplier i provide raw material m; Yes: $X_{im}=1$; No: $X_{im}=0$	G^s_{ijm}	Number of raw material m that supplier i purchased from manufacturer j under the s scenery
J	Manufacturer collection	j	Manufacturer number, j∈J	Y_j	Whether establish manufacturer; Yes: $Y_j=1$; No: $Y_j=0$	Q^s_{jpk}	Volume of product p from manufacturer j to marketing centre k under s scenery
K	Marketing centre collection	k	Marketing centre number, k∈K	Z_k	Whether set up marketing centre k; Yes: $Z_k=1$; No: $Z_k=0$	R^s_{knp}	Volume of product p from marketing centre k to customer n under s scenery
N	Customer area collection	n	Customer area number, n∈N	XY_{kn}	Whether marketing centre k provide product for customer area n; Yes: $XY_{kn}=1$ No: $XY_{kn}=0$		
M	Raw material collection	m	Raw material number, m∈M	FC_j	Capacity of manufacturer j		
P	Product collection	p	Product number, p∈P	DC_k	Capacity of marketing centre		
S	Possible scenarios collection	s	Scenarios number, s∈S				

3.2 INTEGRATE SUPPLY CHAIN NETWORK DESIGN MODEL

After establishing a sub-model, we began to integrate supply chain network design model, before establishing model we have to defined first: $\forall s \in S$, ξ_s is the supplier's chosen raw material costs and facilities decision cost' summation, then: $\xi_s = \xi^s_{VS} + \xi^s_{FL}$. For each specific scenario s, the parameter of the model is determined, here supply chain network design problems are common problems of the deterministic optimization problem, for every deterministic optimization problems, their numerical are differences, the rest of the structure is the same,

$\forall s \in S$, the objective function value is ξ_s^* after optimizing.

Make the parameter $\omega > 0$, if variable $x = \{X_{im}, Y_j Z_k XY_{kn} FC_j DC_k\}$ is the feasible solution to all the deterministic optimization problems ND_s, then the objective function value to ND_s is $\xi_s(x)$.

Only if $\forall s \in S$, $\frac{\xi_s(x) - \xi_s^*}{\xi_s^*} \le \omega$, x is robust solution to supply chain network design problem.

$\forall s \in S$, left in the equation above is known as the relatively regretted, absolutely regretted is determined by $\xi_s(x) - \xi_s^*$, relatively regretted and absolutely regretted can change with each other by multiply or division the constant ξ_s^*.

When the probability of each scenario is different, you can define different regret limited coefficients ω.

From the above definition, we can know there can be more robust solutions of supply chain network design, and robust optimization is aimed at finding best robust solutions. Therefore, we can establish integrate robust optimization model (ROM) for supply chain network design ρ_s – probability of S scenery, ω – regret limited coefficients.

$$Min \xi = \sum_s \rho_s \xi_s,$$

$$\begin{aligned} \xi_s = &\sum_i \sum_m \varpi_{im}^s X_{im} + \sum_j v_j^s Y_j + \sum_k w_k^s Z_k + \\ &\sum_i \sum_j \sum_m (\alpha_{im}^s + \mu_{ijm}^s) G_{ijm}^s + \sum_j \sum_k \sum_p (\beta_{jp}^s + \eta_{jkp}^s) Q_{jkp}^s + \\ &\sum_k \sum_n \sum_p (\gamma_{kp}^s + \lambda_{knp}^s) R_{knp}^s + \sum_j \theta_j^s FC_j + \sum_k \sigma_k^s DC_k, \end{aligned} \quad (1)$$

s.t.

$$\sum_j G_{ijm}^s \le cap_{im}^s X_{im}, \forall i, m, s, \quad (2)$$

$$\sum_j G_{ijm}^s \le cap_{im}^s X_{im}, \forall i, m, s, \quad (3)$$

$$\sum_j G_{ijm}^s \ge \sum_k \sum_p h_{mp}^s Q_{jkp}^s, \forall j, m, s, \quad (4)$$

$$\sum_j Q_{jkp}^s \ge \sum_n R_{knp}^s, \forall j, m, s, \quad (5)$$

$$\sum_k XY_{kn} = 1, \forall n, \quad (6)$$

$$R_{knp}^s \ge d_{np}^s XY_{kn}, \forall k, n, p, s, \quad (7)$$

$$\sum_k \sum_p a_{jp}^s Q_{jkp}^s \le FC_j, \forall j, s, \quad (8)$$

$$\sum_k \sum_p Q_{jkp}^s + \sum_n \sum_p d_{np}^s XY_{kn} \le DC_k, \forall k, s, \quad (9)$$

$$FC_j \le o Y_j, \forall j, \quad (10)$$

$$DC_k \le o Z_k, \forall k, \quad (11)$$

$$\xi_s - \xi_s^* \le \omega \xi_s^*, \forall s, \quad (12)$$

$$G_{ijm}^s, Q_{jkp}^s, R_{knp}^s \ge 0, \forall i, j, k, m, n, p, s, \quad (13)$$

$$X_{im}, Y_j, Z_k, X_{kn} \in \{0,1\}, \forall i, j, k, n, \quad (14)$$

$$FC_j, DC_k \ge 0, \forall j, k. \quad (15)$$

Equation (12) ensure a feasible solution of objective function value in a given situation does not exceed the area of optimization objective function value. Equations (13)-(15) are the variable value range constraint.

If we do not consider Equation (12), the above model would be transformed into a stochastic programming model SPM Equation (1) *s.t.* Equations (2)-(11) and (13)-(15).

4 Algorithm design

4.1 FEASIBILITY OF SOLVING MODEL

When $\omega \to +\infty$, ROM is stochastic programming model actually, and constraint condition become redundant constraints in the model, cish8i has a feasible answer, through optimize algorithm can get best answer. But for regrets limited coefficient you need to do feasibility analysis to ROM.

Move Equation (12), then:

$\xi_s \le (1-\omega)\xi_s^*$. Let $UB = \sum_s \rho_s (1-\omega) \xi_s^*$, therefore we can get the theorem: If ROM works, UB is its upper bound. Using this theorem, we can get following ROM feasibility test rules:

For a given heuristic, if we do not take into account Equation (12), the target value $\xi > UB$, the algorithm cannot get optimized ROM solution, satisfactory solutions even a feasible solution. Otherwise, feasible solution can be obtained, and satisfactory solutions even optimal solution.

4.2 DETERMINISTIC OPTIMIZATION PROBLEMS

Before solve ROM, first study the given scenery, then determine algorithm for optimization NDs.

$$\begin{aligned} Min \xi = &\sum_i \sum_m \varpi_{im}^s X_{im} + \sum_j v_j^s Y_j + \sum_k w_k^s Z_k + \\ &\sum_i \sum_j \sum_m (\alpha_{im}^s + \mu_{ijm}^s) G_{ijm}^s + \sum_j \sum_k \sum_p (\beta_{jp}^s + \eta_{jkp}^s) Q_{jkp}^s + \\ &\sum_k \sum_n \sum_p (\gamma_{kp}^s + \lambda_{knp}^s) R_{knp}^s + \sum_j \theta_j^s FC_j + \sum_k \sigma_k^s DC_k, \end{aligned}$$

s.t. Equations (2)-(11) and (13)-(15).

This kind of problem is theoretically can obtain exact solution, due to large scale and the computation time so they are unacceptable by us.

4.3 ALGORITHM PROCESS

1) Initialize at first, then select 0-1 design variable's initial feasible solution x_{now}, Maximum number of iterations is *MN*, another number in the candidate collection *num*, initialization tabu list $TB=\phi$, tabu length $len=\sqrt{num}$. Make $bestsol_s=+\infty$, $step=0$.
2) Choose several *num* from x_{now} neighbourhood to form candidate collection $can(x_{now})$.
3) According to the supply chain structure for each neighbourhood, using all or nothing heuristic algorithm for flow distribution.
4) Let $\xi(x_{nb})=\xi_{CM}^{s}+\xi_{DM}^{s}, nb=1,2,...,num$. Computing objective function values of each neighbourhood in the collection.
5) Determine whether the current iteration satisfies the amnesty rule, if no, selected optimal solutions x_{nb} that not be tabu in the candidate collection, according to the principle of first-in first-out to update tabu list, $x_{now}=x_{nb}$, otherwise, choose another feasible solution x_{nb} in candidate collection as tabu object $x_{now}=x_{nb}$.
6) If $bestsol_s>\xi(x_{now})$, record the present optimal solutions $bestsol_s>\xi(x_{now})$, $x_{best}=x_{now}, beststep=step$
7) If $step-beststep\le NM$, $step=step+1$ then turn to the second item, if not, the algorithm finished.

5 Algorithm of ROM

To studying the feasibility of robust optimization model, we should study the stochastic programming model first.

ROM for studying the feasibility of the first to study the stochastic programming model. Actually, to obtain solution of stochastic programming model, it is only required to change the above 4th step of the algorithm: $\forall s\in S$. Let $\xi(x_{nb})=\xi_{CM}^{s}+\xi_{DM}^{s}$, $nb=1,2,...,num$, calculate $\xi(x_{nb})=\sum_{s}\rho_s\xi_s(x_{nb})$.

After solving the stochastic programming model, according to feasibility tests, if there is a feasible solution, use the following steps to solve it.

5.1 INITIALIZE

Select 0-1 design variable's initial feasible solution x_{now}, given two target value has not changed maximum number of iterations *MN* and another neighbourhood number in the candidate collection *num*, initialization tabu list $TB=\phi$, tabu length $len=\sqrt{num}$. $RS_{best}=+\infty$, $step=0$.

5.2 NODES' DEPLOYMENT

Choose several *num* from x_{now} neighbourhood to form candidate collection $can(x_{now})$.

5.3 FLOW DISTRIBUTION

According to the supply chain structure for each neighbourhood, use all or nothing heuristic algorithm for flow distribution.

5.4 UPDATED ROBUST OPTIMAL SOLUTION

$\forall s\in S$ let $\xi(x_{nb})=\xi_{CM}^{s}+\xi_{DM}^{s}$, $nb=1,2,...,num$, calculate $\xi(x_{nb})=\sum_{s}\rho_s\xi_s(x_{nb})$, judge whether there is feasible solution x_{nb}, makes the scene objective function values to meet robust constraints $\xi_s(x_{nb})\le(1+\omega)\xi_s^{*}$, if $\exists x_{nb}, RS_{best}>\xi(x_{nb})$, then $beststep=step$, record present optimal robust solutions $RS_{best}=\xi(x_{nb})$, $rx_{best}=x_{nb}$.

5.5 UPDATE TABU LIST

Determine whether the current iteration satisfies the amnesty rule, if not, elected optimal solution x_{nb} that not be tabu in the candidate collection, $x_{now}=x_{nb}$, otherwise, choose another feasible solution x_{nb} in candidate collection as tabu object $x_{now}=x_{nb}$.

5.6 TERMINATION CONDITIONS OF ALGORITHM

If $step-beststep\le NM$, $step=step+1$, then turn to second item, or this algorithm finished.

6 Application of ROM

Assume that the characters of study object are: $|N|=30, |I|=3, |J|=3, |K|=3, |M|=6, |P|=6$, scenery number is 10. Use robust optimization model and stochastic programming model to do supply chain network design, and then compare performance of optimized solution that is obtained.

Make every scenery's deterministic optimal objective function value is ξ_s^{*}, stochastic programming optimization objective function value corresponding to each scenery as ξ_s^{SP}, robust optimal solution corresponding to each target value for ξ_s^{RO}.

Take the relative difference value between ξ_s^{SP} and ξ_s^{*}: $\varepsilon_{S-D}=\frac{\xi_s^{SP}\ \xi_s^{*}}{\xi_s^{*}}\times100\%$.

Relative difference value between ξ_s^{RO} and ξ_s^{*}:

$$\varepsilon_{R-D} = \frac{\xi_s^{RO} \xi_s^*}{\xi_s^*} \times 100\% .$$

Computed result:

TABLE 2 Comparison chart of robust optimization and stochastic programming solutions' performance

Stochastic programming	Robust optimization	Optimal objective values	Relative difference value	Relative difference value
ξ_s^{SP}	ξ_s^{RO}	ξ_s^*	ε_{S-D}	ε_{R-D}
5589027	565680	558474	0.1	1.29

Using the robust optimization model for design, system cost (the objective function value) for different scenarios, and if fluctuations are relatively stable, rendered as insensitive, implies that this determined supply chain network structure has less market risk. As a strategic supply chain network design, not only to establish the basis for subsequent development of enterprises, also involves saving a lot of fixed assets foe investment cost, of course, is also very necessary to reduce risks.

7 Conclusion

This chapter studied strategy-level of integration supply chain network design problem under uncertain environment, the aim is to take into account the uncertainty of design parameters, determine the selection of suppliers, factories and distributors' locations as well as the capacity, customer demand, and to make performance in supply chain networks have a good robust in the case of parameter perturbation. Through detailed analysis of the problem of supply chain network design, we established the integration of supply chain network design for robust optimization model and stochastic programming models.

In this algorithm design process, first of all, we analyses the feasibility of solving the model, and then to study the deterministic optimization problems. Proposed robust optimization model algorithm based on deterministic optimization model algorithm.

In the last example, we comparing difference in solving the objective function value between stochastic programming solutions and robust optimization solutions, evaluated performance of supply chain network that confirmed by robust optimization models. Calculations results not only show that the all or nothing algorithm of tabu search has good convergence properties, as well as its advantages in dealing with large scale problems, but also show that the robust optimization model for supply chain network design can effectively reduce market risk, which is essential for decision-making at the strategic level.

References

[1] Junfeng T 2005 Supply chain management optimization models and Algorithms under uncertainty PhD *Thesis of Southwest Jiaotong University (in Chinese)*

[2] New S J New 1996 A framework for analysing supply chain improvement *International Journal of Operations & Production Management* 16(4) 19-34

[3] Itoh T, Ishii H 2005 One Machine Scheduling Problem with Fuzzy Random Due-Dates *Fuzzy Optimization and Decision Making* **4**(1) 71-8

[4] Cao J, Zhou G G, Zhang D Y 2006 A Multi-plan synthetic evaluation method based upom AHP and fuzzy theory *Journal of Zhejiang University of Technology* **31**(4) 355-9 *(in Chinese)*

[5] Jjin X, Zhenfa Z 2004 An Analysis of Supplier's Competence Based on ANN Expert System *Industrial Engineering and Management* **2** 40-3

[6] Taylor (USA) 2006 Success to supply chain: Supply chain competition determine the success *China Market Press*

[7] Ferguson R B 2004 Modules cut supply chain risk *e-Week* **21**(3) 24

[8] Junyou J 2005 Analysis of Supply Chain Risk *Baocheng Technology* **2** 35-8 *(in Chinese)*

[9] Zhi L, Tao Y, Wen Y 2006 Supply chain risk analysis and decision-making model *Logistics Technology* **29**(130) 120-2 *(in Chinese)*

[10] Xiaoyu Z, Xiaoyuan H, Fuquan S 2005 Supply chain design method toward key suppliers and customers *Systems engineering* **23**(6) 34-8 *(in Chinese)*

[11] Nagurney A, Matsypura D 2005 Global supply chain network dynamics with multicriteria decision making under risk and uncertainty *Transportation Research Part E* **41**(6) 585-612

[12] Satyaveer S C, Jean M P 2005 Analysis of supply chain partnership with revenue sharing *International Journal of Production Economics* **97**(1) 44-51

[13] Jun P 2008 Design and Application of Supply Chain Optimization consider risk control *Hunan University (in Chinese)*

Author

Yulan Zheng, Fuzhou Province of China

Current position, grades: lecturer.
University studies: PhD degree will be earned in major of technology economy and management, Fuzhou University.
Scientific interest: technological innovation and management.