A Robust Supply Chain Network Design Considering Capacity, Supply and Delivery Distance Limits under Uncertain Demand

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Abstract — **This paper presents a robust supply chain network design considering capacity, supply and delivery distance limits under uncertain demand. It aims to form a systematic solution including facility location and capacity design, supply plan, production plan and delivery plan. The uncertainty of demand is described by means of scenario approach. Following a multiple criteria evaluation, the optimal objective is the weighted sum of total cost, variance of total cost and penalty cost of inventory shortage. The supply limits include two parts. One is that the minimum supply quantity from an arbitrary supplier to its customers is regulated. The other is that the demand from a downstream node may be satisfied by at least two upstream suppliers. The delivery distance limit is that the distribution center's distribution radius is set up to be proportional to its capacity. The main conclusions are drawn through numerical sample test as follows: i) the proposed method ensures a robust supply chain network with an ability of risk mitigation, ii) the distribution radius limit may be beneficial for intensive logistics organization without increasing the cost of supply chain, and iii) the trade-off between minimal inventory shortage and total supply chain cost should be reached by adjusting penalty weight.**

Keywords - supply chain network design, robust optimization, supply contracts, delivery distance, uncertain demand

I. INTRODUCTION

Nowadays, the various demands of customer, intensive competition and increasing application of information technology have posed a great challenge to companies. As a consequence, more and more companies put supply chain management on a strategic position in order to keep a core competence. Supply chain management integrates all the activities including procurement, manufacture, sale, finance and logistics management within and across companies into a cohesive and high-performance business pattern. It links channel partners such as suppliers, manufacturers and retailers together into a virtual organization, or in other words, a supply chain network.

Under the scene of globalization, a large company generally chooses to set up several factories or sub-companies at places where the labor and land cost are cheap. It has to find the right raw material suppliers for the need of production. It also needs to build many quick responsive distribution centers to meet the demand of customers. These suppliers, factories and distribution centers form a complicated network due to the supply and demand relations. So supply chain network design (SCND) needs to determine the number, location, capacity of nodes in supply chain network. In a dynamic market environment, it also inevitably involves planning on supply, production and distribution in order to achieve a balance between demand, resource and cost.

Early studies about SCND are mainly on deterministic facility location models[1]. Particularly, valuable efforts have been devoted on extensions of facility location model including capacity design, transportation and inventory decisions [2-4].However, the real supply chain network runs under complex and dynamic environment[5]. Many SCND parameters are actually uncertain variables. For example, the customer's demand may be uncertain due to the affection of season, price and police etc. So it is very critical to the rationality of SCND that how to describe demand uncertainty more close to reality. The uncertainty in supply chain may be stochastic. In Ji and Shao's study[6], the customer demand follows normal distribution and the costs in supply chain obey triangle distribution. In recent researches, scenario approach has been used to describe uncertainty through setting up different scenarios which represent realizations of uncertain parameters. Scenario can be represented through brainstorming meeting or expert reviews on plausible situations in supply chain, also be quantitatively generated through Monte Carlo Analysis method or other sample approximation methods, as discussed in Schütz and Sharma's papers[7-8].

Emergent and destructive natural disaster such as earthquake, fire, and social crisis such as fight, economic crisis may lead to serious disruption of supply chain network. Thus how to keep supply chain network still running well under uncertainty, in other words, with robustness of supply chain network, is therefore becoming the focus of industries and scholars. Chen[9] numerated the risks possibly existing in supply chain network and evaluates their effects by means of Extenics method. Mulvey and Vanderbei [10] proposed the concept of solution robustness and model robustness. They suggested a general robust optimization model based on these concepts. The optimal objective in their model includes expected value, variance and penalty of infeasibility. It is built based on a form of multi-criteria evaluation. Later, Yu and Li[11] simplified the formulation of this model in order to reduce the computational effort. Leung et al [12] proposed a robust optimization model to solve multi-site production planning problem with uncertain demand. Similarly, Pan and Nagi[13] developed a robust optimization model for a supply chain network with a single product and multi-period production. Tian[14] described the robustness of SCND by means of regret method. Huang X.Y and his colleagues [15-16] made a great deal of efforts on robust coordination of supply chain including buyback contract, H_∞ robust control and operational strategies.

According to our knowledge, few studies focus to disclose the effect of supply contracts, capacity design and delivery distance on capacity utilization for a logistics facility under uncertain demand. That is the reason to motivate us to work on this study. The main contributions in this study are generalized into three points:

First, capacity is selected as a design variable in distribution center location in order to meet the fluctuating demand under dynamic environment;

Second, supply contracts are designed as follows: one is that the minimum supply quantity from an arbitrary supplier to its customers is regulated; the other is that a manufacturer is suggested to choose at least two suppliers in order to avoid supply chain disruption under single-source procurement;

Third, the distribution center's delivery distance is set up to be proportional to its capacity. This consideration is expected to improve the capacity utilization of distribution centers.

The rest of the paper is organized as follows. In section 2, a robust supply chain network design problem characterized with multiple raw materials and products under uncertain demand is described. In section 3, a model including facility location, capacity design, production plan and delivery plan with considerations of supply and distribution distance limits is proposed. In section 4, the effectiveness and efficiency of the proposed model with a numerical sample are tested. Finally, the remarks are concluded in the last section.

II. PROBLEM DESCRIPTIONS

It is assumed that a supply chain network includes four types of nodes, namely, supplier, factory, distribution center and retailer, as shown in Fig. 1. These nodes are randomly scattered in geology. A company owns *M* factories in total. Each factory can produce I kinds of products. To produce these products, *R* kinds of the raw materials needed. They can be provided by *L* suppliers. The products are transported from these factories to several distribution centers, and then from distribution centers to *K* retailers. There are *J* distribution centers to be available. The demands of these retailers are uncertain due to seasonal and market reasons etc. Each retailer's demand should be satisfied to the possible. Otherwise, a commercial loss may be generated.

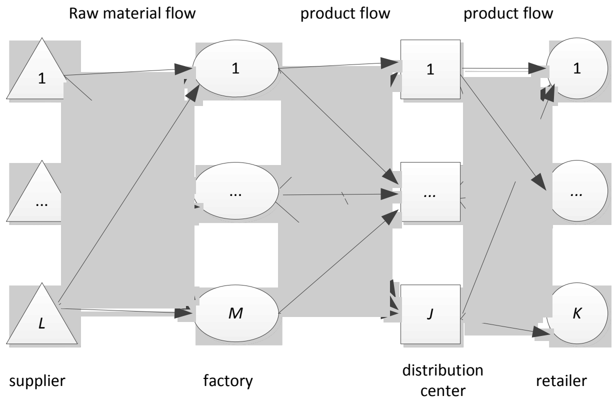

Fig. 1 An illustration of a manufacturing supply chain network

The SCND solution needs to solve the following problems:

(1)How to select the right suppliers if supply chain manager try to avoid the risk of supply?

(2)How to determine the right locations and capacities of the distribution centers?

(3)How to determine the maximal delivery distance of a distribution center?

(4)How to arrange for the supply plan, production plan and delivery plan with the cost as little as possible?

For the convenience to solve the problem, the following assumptions are suggested.

(1)Retailers' demands are uncertain. They are described by means of the scenario method. The probabilities of these scenarios happen are evaluated on the basis of historical records of sales.

(2)The whole process from raw material supply to product delivery is considered as a period.

(3)Products are transported to distribution centers immediately once they are finished from production line.

(4)The holding cost in distribution center fluctuates with the demand.

To avoid the risk of supply chain disruption, a resilient strategy is adopted. It is regulated that the demand from a downstream node may be satisfied by dual or more upstream suppliers. For example, a factory may purchase raw materials from two or more suppliers rather than from a single-source and the demand from a retailer may be satisfied by more than one distribution centers. From the geological view, a distribution center's delivery scope can be represented with its distribution radius. The larger a distribution center's distribution radius is, the more retailers it may serve. On the other hand, only with enough capacity, can a distribution center serve more retailers. Therefore, the distribution center's distribution radius is set up to be proportional to its capacity.

III. FORMULATIONS

A. Notations

Parameters and variables definition: *m* is the number of factories, *m*=1,…,*M; i* number of products, *i*=1,…,*I*; *r* is the number of raw materials, *r*=1,…,*R;l* is the number of suppliers, l=1,…,L; k is the number of retailers, k=1,…,K; j is the number of distribution centers, j=1,…,J; ξ is the number of scenarios, $\xi = 1,\ldots,S$; θ_ξ is the adjusted variable under scenario ξ ; p_ξ is the probability that scenario ξ happens; D_{ik}^{ξ} is retailer k's demand of product i under scenario ξ ;β is the service level of all retailers should promise; λ is the weight assigned to cost variability; ω is the penalty weight assigned to inventory shortage; B_{irm} is the quantity of raw material r that factory m uses to produce product I; CAP_{rl} is the maximize quantity of material r that supplier l may supply;CAP_0 is the reference capacity of distribution center; CAP_j is the capacity of distribution center j; R_d is the reference delivery radius of distribution center; S_l is the fixed cost of supplier l; G_j is the setup cost of distribution center j; C_{rl}^{R} is the unit cost of raw material r provided by supplier l; C_{im}^{FM} is the unit fixed cost that factory m produces product I; C_{im}^{VM} is the unit variable cost that factory m produces product I; c_{rlm} is the transportation rate shipping raw material r from supplier l to factory m; c_{imj} is the transportation rate shipping product i from factory m to distribution center j; c_{ijk} is the transportation rate shipping product i from distribution center j to retailer k; d_{lm} is the distance between supplier l and factory m; d_{mj} is the distance between factory m and distribution center j; d_{jk} is the distance between distribution center j and retailer k; CI_{ij} is the unit holding cost of product i at distribution center j ; $q_{lm}^{\min}$ is the lower supply limit from supplier l to factory m; $q_{rlm}^{\min}$ is the lower supply limit of raw material r from supplier l to factory m; $Q_{mj}^{\min}$ is the lower supply limit from factory m to distribution center j; $Q_{jk}^{\min}$ is the lower supply limit from distribution center j to retailer k; $p_{im}^{\min}$ is the minimal quantity of product i manufactured by factory m; $p_{im}^{\max}$ is the maximal quantity of product i manufactured by factory m ; η_{ij} is the turnover of product i at distribution j; $CD_j^{\min}$ is the lower limit of distribution center j's capability; $CD_j^{\max}$ is the upper limit of distribution center j's capability. M_a is an enough large positive integer.

Decision variables: X_l , Z_j , X_{lm} , y_{mj} , z_{jk} , w_{im} are 0-1 binary variables. CD_j is the design capacity of distribution center j; Q_{imj} is the quantity of product i shipped from factory m to distribution center j; Q_{ijk}^{ξ} is the quantity of product i delivered from distribution center j to retailer k under scenario ξ ; p_{im} is the quantity of product i made by factory m; q_{rlm} is the quantity of raw material r that supplier l supplies to factory m; δ_{ik}^{ξ} is retailer k's unfulfilled demand of product i under scenario ξ .

B. *Objective Functions*

Total fixed cost:

$$TCF = \sum_l S_l X_l + \sum_j G_j Z_j + \sum_i \sum_m C_{im}^{FM} w_{im} \quad (1)$$

Total raw material cost:

$$TCR = \sum_r \sum_l \sum_m C_{rl}^{R} q_{rlm} \quad (2)$$

Total variable production cost of factories：

$$TCM = \sum_i \sum_m C_{im}^{VM} p_{im} \quad (3)$$

Total transportation cost under scenario ξ :

$$TCT^{\xi} = \sum_r \sum_l \sum_m q_{rlm} c_{rlm} d_{lm} + \sum_i \sum_m \sum_j Q_{imj} c_{mj} d_{mj} + \sum_i \sum_j \sum_k Q_{ijk}^{\xi} c_{jk} d_{jk}, \xi \in \Omega$$

The expected total transportation cost:

$$TCT = \sum_r \sum_l \sum_m q_{rlm} c_{lm} d_{lm} + \sum_i \sum_m \sum_j Q_{imj} c_{mj} d_{mj} + \sum_\xi \sum_i \sum_j \sum_k p_\xi Q_{ijk}^{\xi} c_{ijk} d_{jk} \quad (4)$$

Total inventory holding cost under scenario ξ :

$$TCI^{\xi} = \sum_j \sum_i CI_{ij} (\sum_m Q_{imj} - \sum_k Q_{ijk}^{\xi}), \xi \in \Omega$$

The expected inventory holding cost:

$$TCI = \sum_\xi \sum_i \sum_j p_\xi CI_{ij} (\sum_m Q_{imj} - \sum_k Q_{ijk}^{\xi}) \quad (5)$$

Penalty cost for inventory shortage:

$$TCSH = \omega \sum_\xi \sum_i \sum_k p_\xi \delta_{ik}^{\xi} \quad (6)$$

The optimal objective function:

$$\min[TCF + TCR + TCM + \sum_\xi p_\xi (TCT^{\xi} + TCI^{\xi})] + \lambda \sum_\xi p_\xi [(TCT^{\xi} + TCI^{\xi}) - (TCT + TCI) + 2\theta_\xi] + TCSH$$

(7)

The first term in (7) is the total cost including fixed cost, raw material cost, production cost, transportation cost and inventory holding cost. The second term in (7) is the variance of total cost which measures solution robustness. The third term in (7) is the penalty for the unfilled demand which represents the model's robustness.

C. *Constraints*

$$X_l \ge x_{lm}, \quad \forall l,m \quad (8)$$

$$Z_j \ge y_{mj}, \quad \forall m,j \quad (9)$$

$$Z_j \ge z_{jk}, \quad \forall j,k \quad (10)$$

$$\sum_m w_{im} \ge 1, \quad \forall i \quad (11)$$

$$\sum_i w_{im} \ge 1, \quad \forall m \quad (12)$$

$$\sum_l x_{lm} \ge 2, \quad \forall m \quad (13)$$

$$z_{jk} d_{jk} \le R_d * CAP_j / CAP_0 \quad \forall j,k \quad (14)$$

$$q_{rlm} \le M_a * x_{lm}, \quad \forall l,r,m \quad (15)$$

$$Q_{imj} \le M_a * y_{mj}, \quad \forall i,m,j \quad (16)$$

$$Q_{ijk}^{\xi} \le M_a * z_{jk}, \quad \forall i,j,k,\xi \tag{17}$$

$$q_{rlm} \ge q_{rlm}^{\min} x_{lm}, \quad \forall l,r,m \tag{18}$$

$$\sum_r q_{rlm} \ge q_{lm}^{\min} x_{lm}, \quad \forall l,m \tag{19}$$

$$\sum_i Q_{imj} \ge Q_{mj}^{\min} y_{mj}, \quad \forall m,j \tag{20}$$

$$\sum_i Q_{ijk}^{\xi} \ge Q_{jk}^{\min} z_{jk}, \quad \forall j,k,\xi \tag{21}$$

$$\sum_i p_{im} * B_{imr} = \sum_l q_{rlm}, \quad \forall r,m \tag{22}$$

$$\sum_m q_{rlm} \le CAP_{rl}, \quad \forall r,l \tag{23}$$

$$p_{im} = \sum_j Q_{imj}, \quad \forall i,m \tag{24}$$

$$\sum_m Q_{imj} \ge \sum_k Q_{ijk}^{\xi}, \quad \forall i,j,\xi \tag{25}$$

$$\sum_j Q_{ijk}^{\xi} + \delta_{ik}^{\xi} = D_{ik}^{\xi}, \quad \forall i,k,\xi \tag{26}$$

$$\delta_{ik}^{\xi} \le (1-\beta) D_{ik}^{\xi}, \quad \forall i,k,\xi \tag{27}$$

$$p_{im}^{\min} w_{im} \le p_{im} \le p_{im}^{\max} w_{im}, \quad \forall i,m \tag{28}$$

$$\sum_i \sum_k \eta_{ij} Q_{ijk}^{\xi} \le CD_j, \quad \forall j,\xi \tag{29}$$

$$CD_j^{\min} Z_j \le CD_j \le CD_j^{\max} Z_j, \quad \forall j \tag{30}$$

$$(TCT^{\xi} + TCI^{\xi}) - \sum_{\xi} p_{\xi}(TCT^{\xi} + TCI^{\xi}) + \theta_{\xi} \ge 0, \quad \forall \xi \tag{31}$$

$$p_{im}, q_{rlm}, Q_{imj}, Q_{ijk}^{\xi}, CD_j, \delta_{ik}^{\xi}, \theta_{\xi} \ge 0, \quad \forall i,r,l,m,j,k,\xi \tag{32}$$

$$X_l, Z_j, X_{lm}, y_{mj}, z_{jk}, w_{im} \square (0,1), \quad \forall i,l,m,j,k \tag{33}$$

Constraints (8)-(10) ensure that a node can't provide product or service to other nodes unless it is included a supply chain. Constraint (11) regulates that each product is produced by at least one factory. Constraint (12) indicates that each factory produces at least one product. Constraint (13) ensures that a factory has at least two suppliers. Constraint (14) regulates that the distribution distance of a distribution center is proportionate to its capability. Constraints (15)-(17) indicate that no actual transportation occurs unless a supply-demand relation is built between two nodes. Constraint (18) implies that a minimal order quantity is required when a factory buy a certain kind of raw material from one of its suppliers. It may be helpful for keeping a long-last supply chain partnership. Constraints (19)-(21) ensure that transportation volume should not be less than a minimal value due to the economical consideration. Constraint (22) is a balance equation for the raw materials. Constraint (23) ensures that the quantity of a raw material supplied by a supplier can't exceed its capability. Constraints (24)-(25) are flow control equations for products. Constraint (26) indicates that a retailer's demand maybe fully or partly satisfied by distribution centers. Constraint (27) ensures that the unfulfilled demand should not exceed the amount that the service level permits. Constraint (28) ensures that the amount of a certain product made by a factory should be within a reasonable scope. Constraints (29)-(30) represent the capacity limit of a distribution center. Constraint (31) represents the difference between total cost under scenario ξ and the expected total cost under all scenarios. Constraint (32) indicates non-negative variables limits. Constraint (33) specifies the binary decision variables.

IV. Numerrical Example Test

The retailer's demand can be described into three scenarios, namely boom, fair and poor, with =1, 2, 3 and associated probabilities of 0.3, 0.5 and 0.2 respectively. Let M=2, I=3, R=4, L=5, J=5, K=10, β=0.95, ω=3, R_d=60, CAP_0=1200, and B_{imr}=1, $\forall i,m,r$. Delivery distances between distribution centers and retailers and transportation distances between suppliers and factories are generated randomly within interval of (0,100); other parameters are set up with reference to the logistics industrial data. The model was solved with the commercial mathematical programming software lingo12.0, into which the global solver is inserted.

A. Solution of Roust SCND

Supplier 1, 2, 3 and 5 are selected as the channel partners in this supply chain network. The distribution center 1, 3 and 5 are set up with design capacities of 3000, 1200 and 2294, respectively. Production plan, supply plan, transportation plan and distribution plan are listed in table 1-table4.

TABLE I. Production Plan

Product, i	Factory, m	
	1	2
1	1500	653
2	1500	608
3	1500	733

TABLE II. Supply Plan

Factory, m	Raw Material, r	Supplier, l			
		1	2	3	5
1	1	0	2220	180	2100
	2	0	986	1114	2400
	3	0	786	2400	1314
	4	0	900	2000	1600
2	1	1814	180	0	0
	2	180	1814	0	0
	3	180	1814	0	0
	4	694	1300	0	0

TABLE III. TRANSPORTATION PLAN

Factory, *m*	**Product, *i***	**Distribution Center, *j***		
		1	**3**	**5**
1	1	740	0	760
	2	364	0	1136
	3	1102	0	398
2	1	0	653	0
	2	476	132	0
	3	318	415	0

From Table I, it can be seen that the production task in factory 1 is evidently larger than that in factory 2. It is because that production in factory 1 is more economical than in factory 2.

From Table II, it can be observed that supplier 2, 3 and 5 provide raw materials to factory 1, supplier 1 and 2 provide raw materials to factory 2.

From Table III, it can be found that factory 1 transports products to distribution center 1 and 5, factory 2 transports products to distribution center 1 and 3. In another view, only distribution center 1 owning the biggest capacity receives enough products from two factories, can it play enough roles.

From Table IV, it can be found that most of the retailers except retailer 7（under boom scenario）and retailer 9 (under all scenarios)receive products from at least two distribution centers. Distribution center 3 only delivers products to retailer 2, 3, 5 and 10 due to the relative lower limits of capacity and distribution radius.

TABLE IV. DISTRIBUTION PLAN

Scenario	Distribution center, *j*	Product *i*	Seller, *k*									
			1	2	3	4	5	6	7	8	9	10
boom	1	1	90	0	0	0	0	60	209	165	216	0
		2	0	8	0	0	207	0	0	220	203	202
		3	212	218	60	212	37	0	237	226	218	0
	3	1	0	228	200	0	224	0	0	0	0	1
		2	0	132	0	0	0	0	0	0	0	0
		3	0	0	53	0	134	0	0	0	0	228
	5	1	145	0	0	209	0	153	0	60	0	193
		2	201	60	221	13	198	216	0	0	0	0
		3	0	0	124	0	47	227	0	0	0	0
fair	1	1	0	60	100	108	60	83	0	20	152	157
		2	137	0	161	131	0	126	60	40	154	31
		3	149	0	53	133	0	115	0	0	146	0
	3	1	0	0	0	0	0	0	0	0	0	0
		2	0	132	0	0	0	0	0	0	0	0
		3	0	51	60	0	148	0	0	0	0	156
	5	1	144	93	50	60	77	60	143	130	0	0
		2	0	12	0	0	133	0	86	102	0	99
		3	0	96	10	0	0	0	137	155	0	0
poor	1	1	0	60	0	139	0	133	38	121	132	117
		2	60	0	60	57	138	124	103	130	114	54
		3	0	0	0	129	25	0	116	0	131	0
	3	1	0	0	0	0	0	0	0	0	0	0
		2	0	132	0	0	0	0	0	0	0	0
		3	0	124	60	0	110	0	0	0	0	121
	5	1	124	66	132	0	122	0	60	0	0	0
		2	86	6	51	60	0	0	0	0	0	60
		3	112	0	69	0	0	111	0	106	0	0

DOI 10.5013/IJSSST.a.17.38.15 ISSN: 1473-804x online, 1473-8031 print

TABLE V. SENSITIVE ANALYSIS OF DISTRIBUTION RADIUS

	Distribution center, *j*	R_d			
		50	**60**	**80**	**100**
Capacity	1	3000			
	3	1200			
	5	2294			
Amount delivered under the poor scenario	1	1981	1981	1981	1981
	3	496	547	360	547
	5	1216	1165	1352	1165
Retailers delivered under the poor scenario	1	1-10	1-10	1-10	1-10
	3	2,3,5,10	2,3,5,10	2,3,5,6,8,10	2,3,4,6,7,9,10
	5	1-10	1-8,10	1-10	1-10
Optimal objective		209177.8	209177.8	209177.8	209177.8

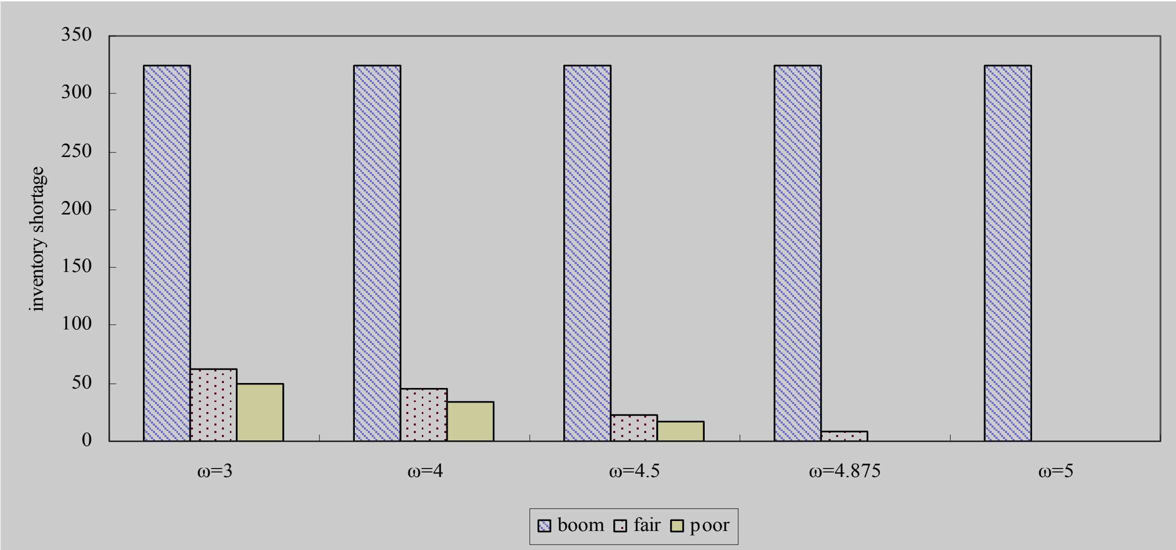

Fig.2 Influence of ω on Inventory Shortage

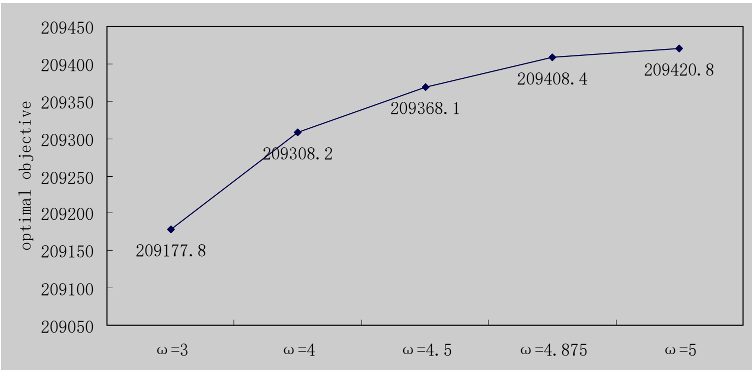

Fig.3 Influence of ω on Optimal Objective

B. *Sensitive Analysis*

A sensitive analysis by changing the value of R_d is made to check the effect of distribution radius limit on the solution of supply chain network. The results are shown in Table V. There are the following findings:

First, the magnitude of R_d affects the capacity utilization in a distribution center. Let U_c^{ξ} represents the capacity utilization of distribution center j under scenario ξ, and $U_c^{\xi} = \sum_k \sum_i Q_{ijk}^{\xi} / CD_j$. When R_d=50,60,80 and 100, under the poor scenario, the values of U_c^{ξ} for distribution center 1 are the same, namely 0.66; the values for distribution center 3 are 0.38,0.46,0.3 and 0.46, and the values for distribution center 5 are 0.53,0.51,0.59 and 0.51. The average values are 0.53, 0.54, 0.52 and 0.54 respectively. Second, it also strongly affects the delivery plan of a distribution center. Under the poor scenario, the numbers of retailers and total amount delivered by a distribution center changed evidently. Take distribution center 3 for example, by relaxing the limit of the distribution radius, the number of retailers served by distribution center 3 increases. The last but very interesting is the value of optimal objective doesn't change with R_d.

The effect of distribution radius limit can't therefore be neglected. A right distribution radius should be made cautiously. If the distribution radius is too big, more effort would be made to organize a delivery with scattered destinations. From the standpoint of logistics, it is not beneficial for intensive management. If the distribution radius is too small, the capacity utilization may be limited. Therefore, it is suggested that a distribution center's distribution radius should be proportional with its capacity. In this study, a trade-off is achieved when R_d=60. Thus, the distribution radius of distribution center 1, 3 and 5 are 150, 60,114.7 respectively.

It also can be seen that inventory shortage happens even under the poor scenario. It is because that the penalty effect is not evident if the value of ω is very small. So It is further investigated of the influence of ω on inventory shortage and the optimal objective. From Fig.**2**, it can be seen that inventory shortage is restrained under fair scenario and poor scenario as ω rises. In our case, the total capacity of factories is less than the total demands of retailers under boom scenario. Therefore, the inventory shortage always occurs under boom scenario. Finally it doesn't changes much better when ω exceeds 5. From Fig. 3, it can be seen that the value of the optimal objective increase with ω. A trade-off between minimal inventory shortage and total supply chain cost can be reached by adjusting the value of ω.

V. CONCLUSIONS

In this study, a robust supply chain network design model under uncertainty of demand is proposed. The optimal objective is designed based on multi-criteria evaluation. It includes three parts, namely total cost, variance of total cost and penalty cost. The decisions include supplier selection, distribution center location and capacity design, supply plan, production plan and delivery plan. The supply contracts are introduced into our model. It is regulated with a minimum supply quantity to ensure a sustainable cooperation between suppliers and demanders. A resilient strategy based on redundancy is used to reduce supply risks. The demand of raw materials from a factory can be provided by more than one supplier. Every supplier can provide more than one kind of raw materials. Similarly, the demand of products from a retailer can be satisfied by more than one distribution center and every distribution center can deliver more than one products. A response strategy considering rout planning is also adopted. The delivery radius of a distribution center is defined to be relative with its capacity. It may improve the delivery efficiency.

Through the sensitive analysis, it is found that a reasonable distribution radius may improve the capacity utilization in a distribution center and be helpful for intensive management. It is also investigated the effects of penalty weight for inventory shortage. It is found that increasing penalty weight is helpful for reducing inventory shortage and simultaneously increasing the total supply chain cost. Therefore, it is necessary to find a trade-off between minimal inventory shortage and total supply chain cost can be reached by adjusting penalty weight.

ACKNOWLEDGMENT

The author would like to thank the support received from Shandong Province Natural Science Foundation, PRC of China with Grant No. ZR2011GL006. The author is also grateful to Dr. Zhong-ping ZHAI and anonymous referees for their suggestions regarding the improvement of this article.

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