ICIC Express Letters
Volume **11**, Number **2**, February **2017**
 ISSN 1881-803X
pp. 465–473

A ROBUST SUPPLY CHAIN NETWORK DESIGN WITH SUPPLY AND DELIVERY DISTANCE LIMITS

Jianling Chen

School of Traffic and Logistics Engineering
Shandong Jiaotong University
No. 5, Jiaoxiao Road, Tianqiao District, Jinan 250023, P. R. China
chenjl@sdjtu.edu.cn

Received July 2016; accepted October 2016

Abstract. *This paper presents a robust supply chain network design model involving multi-product, multi-period and multi-echelon 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 with multiple criteria evaluation, the optimal objective is the weighted sum of total cost, variance of total cost and penalty cost of inventory shortage. Limits of supply and delivery distance are incorporated in the proposed model. The supply limits include two parts, where the minimum supply quantity from an arbitrary supplier to its customers is regulated, and the demand from a downstream node may be satisfied by at least two upstream suppliers. The delivery distance limit is regulated that a distribution center's distribution radius should be proportional to its capacity. Several important conclusions are drawn through numerical sample tests. First, the proposed method ensures a robust supply chain network with an ability of risk mitigation. Second, a reasonable distribution radius limit in a DC is beneficial for intensive logistics management. Finally, 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, Delivery distance, Supply

1. **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. 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 (DCs) to meet the demand of customers. These suppliers, factories and DCs 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 [1,2]. However, the real supply chain network runs under complex and dynamic environment. Uncertainty of demand, process/manufacturing and supply may occur at any time in supply chain [3,4]. For example, the customer's demand may be uncertain due to the affection of season, price and police, etc. Therefore, a great deal of efforts have focused on SCND under uncertainty. The uncertainty in supply chain may be stochastic, which is generally described with the type of fixed or variable possibility distributions [5]. In recent researches, scenario approach has been used to represent uncertainty through setting up different scenarios which represent realizations of uncertain parameters [6,7]. Emergent and destructive natural disasters such as earthquake, and fire, and social crisis such as fight, and 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, how to keep robustness of supply chain network, is therefore becoming the focus of industries and scholars. Chen and Zhao [8] numerated the risks possibly existing in supply chain network and evaluated their effects by means of Extenics method. Mulvey et al. [9] 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. Later, Yu and Li [10] simplified the formulation of this model in order to reduce the computational effort. Leung et al. [11] proposed a robust optimization model to solve multi-site production planning problem with uncertain demand. Similarly, Pan and Nagi [12] developed a robust optimization model for a supply chain network with a single product and multi-period production. Tian et al. [13] described the robustness of SCND by means of regret method. In recent years, substantial studies have proved the important role of contracts in design process. Huang et al. [14] studied the effects of buy back contract and operational strategies on robust coordination of supply chain network. Tabrizi and Karimi [15] investigated the role of contracts in uncertain environments. There are reasons to believe that contracts are contributive to building a robust supply chain network in uncertainty environment.

The main contributions of our study include three points. (1) Capacity is selected as a design variable in DC location in order to meet the fluctuating demand under dynamic environment. (2) 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. (3) The DC's delivery distance is set up to be proportional to its capacity. This consideration is expected to improve the capacity utilization of DCs.

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

2. **Problem Descriptions.** It is assumed that a supply chain network includes four types of nodes, namely, supplier, factory, DC and retailer, as shown in Figure 1. These nodes are randomly scattered in geology. A company owns M factories in total. Each factory can produce I kinds of products with T periods. To produce these products, R kinds of the raw materials are needed. They can be provided by L suppliers. The products are transported from these factories to several DCs, and then from DCs to K retailers. There are J candidates of DCs. The demands of these retailers are uncertain due to the reasons of season, marketing and technology, etc. Each retailer's demand should be satisfied to the possible. Otherwise, a commercial loss may be generated.

The problem for supply chain managers is to design a robust supply chain network in order to resist uncertainty. It is charactered with multi-echelon, multi-product and multi-period. Therefore, the following questions need to be answered:

(1) How to select the right suppliers when both procurement and supply risk are considered? (2) How to determine the right locations and capacities of DCs? (3) How to

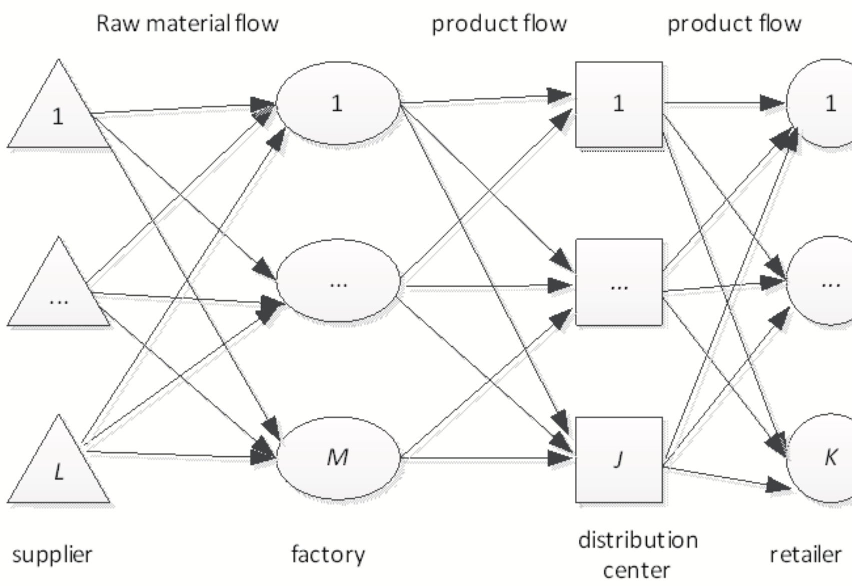

FIGURE 1. An illustration of a manufacturing supply chain network

determine a reasonable delivery distance for a DC? (4) How to make supply plan, production plan and delivery plan with the minimal cost?

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

(1) The retailers' demands can be described as a series of scenarios. The probabilities of these scenarios happening 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 DCs immediately once they are finished from production line. (4) The fixed production cost, variable production cost and holding cost are various with different periods and scenarios.

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 DCs. From the geological view, a DC's delivery scope can be represented with its distribution radius. The larger a DC's distribution radius is, the more retailers it may serve. On the other hand, only with enough capacity, can a DC serve more retailers. Therefore, the DC's distribution radius is defined to be proportional to its capacity.

3. Robust SCND Model with Supply and Delivery Distance Constraints.

3.1. **Parameters and variables definition.** t, ξ, m, l, k, r, i are indices of periods, scenarios, factories, suppliers, retailers, products and raw materials, respectively. θ_ξ is the adjusted variable; p_ξ is the probability that scenario ξ happens; D_{tik}^{ξ} is retailer k's demand; β represents the service level; λ is the weight assigned to cost variability; ω is the penalty weight due to inventory shortage; B_{irm} is the parameter of material conversion; CAP_{rl} is the material supply capacity of supplier l; CAP_j and CAP_0 are the capacity and benchmark of DC j; R_d is the benchmark of delivery radius; S_l, G_j, C_{rl}^{R}, C_{tim}^{FM}, C_{tim}^{VM}, c_{rlm}, c_{ijk} and CI_{tij} are variables of costs; d_{lm}, d_{mj} and d_{jk} are variables of distances; $q_{lm}^{\min}$, $q_{rlm}^{\min}$, $Q_{mj}^{\min}$, $Q_{jk}^{\min}$ are variables of supply limits; $p_{im}^{\min}$ and $p_{im}^{\max}$ are variables of production limits; η_{ij} is the turnover of product i at DC j; $CD_j^{\min}$ and $CD_j^{\max}$ are the capability limits of DC j, respectively. M_a is a large enough positive integer. X_l, Z_j, X_{lm}, y_{mj}, z_{jk} and w_{tim} are 0-1 binary variables. CD_j is the design capacity of DC j; q_{trlm}, Q_{timj}, Q_{tijk}^{ξ}

are the quantity of product flow. p_{tim} is the quantity of product i made by factory m; δ_{tik}^{ξ} is the unfulfilled demand from retailer k.

3.2. **Formulations.** The first term in (1) is total cost including fixed cost (2), raw material cost (3), variable production cost (4), transportation cost (5) and inventory holding cost (6). The second term in (1) is the variance of total cost which measures solution robustness. The third term in (1) is the penalty (7) for the unfilled demand which represents the model's robustness.

$$\begin{aligned} &\min \left[TCF + TCR + TCM + \sum_{\xi} p_{\xi}(TCT^{\xi} + TCI^{\xi}) \right] \\ &+\lambda \sum_{\xi} p_{\xi} \left[(TCT^{\xi} + TCI^{\xi}) - (TCT + TCI) + 2\theta_{\xi} \right] + TCSH \end{aligned} \tag{1}$$

$$TCF = \sum_{l} S_l X_l + \sum_{j} G_j Z_j + \sum_{t}\sum_{i}\sum_{m} C_{tim}^{FM} w_{tim} \tag{2}$$

$$TCR = \sum_{t}\sum_{r}\sum_{l}\sum_{m} C_{rl}^{R} q_{trlm} \tag{3}$$

$$TCM = \sum_{t}\sum_{i}\sum_{m} C_{tim}^{VM} p_{tim} \tag{4}$$

$$\begin{aligned} TCT = &\sum_{t}\sum_{r}\sum_{l}\sum_{m} q_{trlm} c_{lm} d_{lm} + \sum_{t}\sum_{i}\sum_{m}\sum_{j} Q_{timj} c_{mj} d_{mj} \\ &+ \sum_{t}\sum_{\xi}\sum_{i}\sum_{j}\sum_{k} p_{\xi} Q_{tijk}^{\xi} c_{ijk} d_{jk} \end{aligned} \tag{5}$$

$$TCI = \sum_{t}\sum_{\xi}\sum_{i}\sum_{j} p_{\xi} CI_{tij} \left(\sum_{m} Q_{timj} - \sum_{k} Q_{tijk}^{\xi} \right) \tag{6}$$

$$TCSH = \omega \sum_{t}\sum_{\xi}\sum_{i}\sum_{k} p_{\xi} \delta_{tik}^{\xi} \tag{7}$$

$$X_l \geq x_{lm}, \quad \forall l, m \tag{8}$$

$$Z_j \geq y_{mj}, \quad \forall m, j \tag{9}$$

$$Z_j \geq z_{jk}, \quad \forall j, k \tag{10}$$

$$\sum_{m} w_{tim} \geq 1, \quad \forall i \tag{11}$$

$$\sum_{i} w_{tim} \geq 1, \quad \forall m \tag{12}$$

$$\sum_{l} x_{lm} \geq 2, \quad \forall m \tag{13}$$

$$z_{jk} d_{jk} \leq R_d * CAP_j / CAP_0 \quad \forall j, k \tag{14}$$

$$q_{trlm} \leq M_a * x_{lm}, \quad \forall t, l, r, m \tag{15}$$

$$Q_{timj} \leq M_a * y_{mj}, \quad \forall t, i, m, j \tag{16}$$

$$Q_{tijk}^{\xi} \leq M_a * z_{jk}, \quad \forall t, i, j, k, \xi \tag{17}$$

$$\sum_{r} q_{trlm} \geq q_{lm}^{\min} x_{lm}, \quad \forall t, l, m \tag{18}$$

$$q_{trlm} \geq q_{rlm}^{\min} x_{lm}, \quad \forall t, l, r, m \tag{19}$$

$$\sum_{i} Q_{timj} \geq Q_{mj}^{\min} y_{mj}, \quad \forall t, m, j \tag{20}$$

$$\sum_i Q^{\xi}_{tijk} \geq Q^{\min}_{jk} z_{jk}, \quad \forall t, j, k, \xi \tag{21}$$

$$\sum_i p_{tim} * B_{imr} = \sum_l q_{trlm}, \quad \forall t, r, m \tag{22}$$

$$\sum_m q_{trlm} \leq CAP_{rl}, \quad \forall t, r, l \tag{23}$$

$$p_{tim} = \sum_j Q_{timj}, \quad \forall t, i, m \tag{24}$$

$$\sum_m Q_{timj} \geq \sum_k Q^{\xi}_{tijk}, \quad \forall t, i, j, \xi \tag{25}$$

$$\sum_j Q^{\xi}_{tijk} + \delta^{\xi}_{tik} = D^{\xi}_{tik}, \quad \forall t, i, k, \xi \tag{26}$$

$$\delta^{\xi}_{tik} \leq (1-\beta) D^{\xi}_{tik}, \quad \forall t, i, k, \xi \tag{27}$$

$$p^{\min}_{im} w_{im} \leq p_{tim} \leq p^{\max}_{im} w_{tim}, \quad \forall t, i, m \tag{28}$$

$$\sum_i \sum_k \eta_{ij} Q^{\xi}_{tijk} \leq CD_j, \quad \forall t, j, \xi \tag{29}$$

$$CD^{\min}_j Z_j \leq CD_j \leq CD^{\max}_j Z_j, \quad \forall j \tag{30}$$

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

$$p_{tim}, q_{trlm}, Q_{timj}, Q^{\xi}_{tijk}, CD_j, \delta^{\xi}_{tik}, \theta_{\xi} \geq 0, \quad \forall t, i, r, l, m, j, k, \xi \tag{32}$$

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

Constraints (8)-(10) ensure that a node cannot provide product or service to other nodes unless it includes 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 DC is proportionate to its capability. Constraints (15)-(17) indicate that no actual transportation occurs unless a supply-demand relation is built between two nodes. Constraints (18), (20) and (21) ensure that transportation volume should not be less than a minimal value due to the economical consideration. Constraint (19) implies that a minimal order quantity is required when a factory buys a certain kind of raw material from one of its suppliers. It may be helpful for keeping a long-last supply chain partnership. Constraint (22) is a balance equation for the raw materials. Constraint (23) ensures that the quantity of a raw material supplied by a supplier cannot exceed its capability. Constraints (24) and (25) are flow control equations for products. Constraint (26) indicates that a retailer's demand may be fully or partly satisfied by DCs. 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) and (30) represent the capacity limit of a DC. 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.

4. **Numerical Sample Tests.** The demand can be described with three scenarios, namely boom, fair and poor, with $\xi = 1, 2, 3$ and associated probabilities of 0.3, 0.5 and 0.2 respectively. Let $M = 2$, $I = 3$, $R = 4$, $L = 5$, $J = 5$, $K = 10$, $\beta = 0.95$, $\omega = 3$, $R_d = 60$, $CAP_0 = 1200$, and $B_{imr} = 1$, $\forall i, m, r$. Delivery distances between DCs and retailers and transportation distances between suppliers and factories are generated randomly within interval of $(0, 100)$. Other parameters are generated with reference to the industrial data. The model was solved with the mathematical programming software lingo12.0.

4.1. **Cost analysis.** The breakup of costs occurring under different scenarios is shown in Table 1. The expected total supply chain cost is 845689.1.

TABLE 1. The structure of costs under different scenarios

Scenario	TCF	TCR	TCM	TCT^{ξ}	TCI^{ξ}	$TCSH^{\xi}$
boom	24232.20	374813.20	74859.15	382738.50	0	1386.00
fair				367959.10	1459.28	285.00
poor				355525.10	2713.46	239.00

4.2. **Supplier selection, distribution center location and capacity design.** Suppliers 1, 2, 3 and 5 are selected as the channel partners in this supply chain network. Candidates of DC 1, 2, 3 and 5 are selected to build up with capacities of 3000, 1600, 1200 and 2400, respectively.

4.3. **Supply plan, production plan and distribution plan.** It can be seen from Table 2 that the production task in factory 1 is evidently larger than that in factory 2 in all periods. It is because production cost in factory 1 is more economical than in factory 2. From Table 3, it can be seen that suppliers 2, 3 and 5 provide raw materials to factory 1, while suppliers 1 and 2 provide raw materials to factory 2. From Table 4, it can be seen that factory 1 transports products to DC 1, 2 and 5, while factory 2 transports products to DC 1 and 3. In another view, due to the enough supply of products, DC 1 can give full play of its capacity to satisfy the demand of retailers. From Table 5, it can be found that both DC 1 and 5 serve more retailers than DC 2 and 3. It is because they have a large capacity and distribution radius than DC 2 and 5.

TABLE 2. Production plan

Factory	Product	Period			
		1	2	3	4
1	1	1500	1500	1500	1500
	2	1500	1500	1500	1500
	3	1500	1500	1500	1500
2	1	653	912	999	688
	2	608	900	978	623
	3	733	874	975	539

4.4. **Sensitive analysis.** A sensitive analysis on R_d is made in order to check the effect of distribution radius limit on the solution of supply chain network. The main findings are shown as follows. (1) Capacity utilization shows minor change with the distribution plan is truly affected by the magnitude of R_d. (2) The delivery volume and total numbers of retailers served by a DC change evidently with R_d, although the average delivery volume in a DC shows little change. (3) The optimal objective does not change with R_d. A right distribution radius should be made cautiously in practice. If the distribution radius is too

TABLE 3. Supply plan

Factory	Supplier	Period 1	Period 2	Period 3	Period 4
1	1	(0, 0, 0, 0)[a]	(0, 0, 0, 0)	(0, 0, 0, 0)	(0, 0, 0, 0)
	2	(2220, 986, 786, 900)	(2214, 294, 180, 900)	(1948, 180, 180, 900)	(2220, 1130, 930, 900)
	3	(180, 1114, 2400, 2000)	(186, 1806, 2400, 2000)	(452, 1920, 2400, 2000)	(180, 970, 2400, 2000)
	5	(2100, 2400, 1314, 1600)	(2100, 2400, 1920, 1600)	(2100, 2400, 1920, 1600)	(2100, 2400, 1170, 1600)
2	1	(1814, 180, 180, 694)	(2500, 180, 266, 1386)	(2500, 332, 532, 1652)	(1670, 180, 180, 550)
	2	(180, 1814, 1814, 1300)	(186, 2506, 2420, 1300)	(452, 2620, 2420, 1300)	(180, 1670, 1670, 1300)
	3	(0, 0, 0, 0)	(0, 0, 0 ,0)	(0, 0, 0, 0)	(0, 0, 0, 0)
	5	(0, 0, 0, 0)	(0, 0, 0, 0)	(0, 0, 0, 0)	(0, 0, 0, 0)

[a] numbers in ( ) represent the volume of raw material r_i sent to factory m by supplier l, respectively.

TABLE 4. Transportation plan

Factory	DC	Period 1	Period 2	Period 3	Period 4
1	1	(750, 183, 1273)	(444, 655, 415)	(401, 362, 485)	(829, 920, 601)
	2	(180, 120, 0)	(283, 174, 129)	(217, 322, 313)	(180, 0, 120)
	3	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)
	5	(570, 1197, 227)	(773, 671, 956)	(882, 816, 702)	(491, 580, 770)
2	1	(0, 352, 442)	(519, 622, 345)	(742, 476, 534)	(198, 139, 313)
	2	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)
	3	(653, 256, 291)	(393, 278, 529)	(257, 502, 441)	(490, 484, 226)
	5	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)

big, it is hard to organize large-scale delivery due to more scattered destinations. From the standpoint of logistics, if the distribution radius is too small, the capacity utilization may be limited. Therefore, it is suggested that a DC's distribution radius should be proportional with its capacity.

The influence of ω on inventory shortage and the optimal objective is further investigated. It can be found that inventory shortage is restrained under fair scenario and poor scenario as ω rises. Meanwhile, the value of the optimal objective increases with ω. A trade-off between minimal inventory shortage and total supply chain cost can be reached by adjusting the value of ω.

5. **Conclusions.** In this study, a robust supply chain network design model under uncertain demand is proposed. It is featured with multi-product, multi-period and multi-echelon. The decisions include supplier selection, DC location and capacity design, supply plan, production plan and delivery plan. The supply contracts are introduced into our model. It is regulated 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 DC and every DC can deliver more than one products. A response strategy on route planning is also adopted. The delivery radius of a DC is defined to be relative with its capacity. Through the sensitive analysis, it is found that a reasonable distribution radius is beneficial for intensive logistics management. It is also 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.

Table 5. Distribution plan

Scenario	DC	Period	Retailer 1	2	3	4	5	6	7	8	9	10
boom	1	1	212	140	445	212	334	60	446	272	517	362
		2	485	247	330	555	242	60	233	60	508	280
		3	500	247	298	60	681	60	255	473	177	249
		4	623	60	234	467	597	373	60	192	60	334
	2	1	0	0	0	180	0	0	0	120	0	0
		2	0	0	0	99	0	0	0	487	0	0
		3	0	0	0	639	0	0	0	213	0	0
		4	0	0	0	129	0	0	0	171	0	0
	3	1	0	446	153	0	0	60	0	279	60	202
		2	0	60	159	0	0	468	0	155	163	195
		3	0	441	63	0	0	264	0	60	312	60
		4	0	131	322	0	0	220	0	238	60	229
	5	1	436	60	60	256	328	518	216	0	60	60
		2	247	411	244	60	471	181	479	0	60	247
		3	250	60	375	60	60	417	507	0	244	427
		4	60	399	60	60	60	60	568	0	523	60
fair	1	1	370	245	123	312	352	204	60	335	60	136
		2	238	60	392	333	223	159	435	60	327	546
		3	221	377	524	60	228	60	331	511	164	524
		4	363	238	147	389	469	60	60	412	399	186
	2	1	0	0	0	60	0	0	0	60	0	0
		2	0	0	0	303	0	0	0	283	0	0
		3	0	0	0	167	0	0	0	88	0	0
		4	0	0	0	60	0	0	0	60	0	0
	3	1	0	139	60	0	0	60	0	60	339	60
		2	0	238	60	0	0	60	0	358	310	60
		3	0	212	60	0	0	350	0	60	458	60
		4	0	101	60	0	0	60	0	60	60	293
	5	1	60	60	251	60	60	120	366	0	60	247
		2	434	396	231	60	462	475	222	0	60	60
		3	442	60	60	428	427	241	293	0	60	60
		4	162	208	333	60	60	427	480	0	60	60
poor	1	1	270	126	252	186	273	180	116	191	263	140
		2	386	60	293	393	525	60	534	64	150	125
		3	60	60	60	60	390	60	60	60	60	60
		4	281	60	60	214	348	123	125	144	60	138
	2	1	0	0	0	60	0	0	0	60	0	0
		2	0	0	0	145	0	0	0	441	0	0
		3	0	0	0	425	0	0	0	427	0	0
		4	0	0	0	120	0	0	0	60	0	0
	3	1	0	138	60	0	0	118	0	111	60	60
		2	0	60	118	0	0	466	0	101	60	395
		3	0	60	171	0	0	423	0	69	417	60
		4	0	60	298	0	0	155	0	229	321	137
	5	1	112	124	60	139	122	69	201	0	60	152
		2	205	474	199	60	60	60	60	0	389	60
		3	487	408	300	60	149	60	478	0	60	398
		4	121	327	60	63	60	133	273	0	60	133

Acknowledgments. This study was supported by Shandong Province Natural Science Foundation (No. ZR2011GL006) and Shandong Province University Science & Technology Project (J13LN80), China.

REFERENCES

[1] R. Z. Farahani, S. Rezapour, T. Drezner et al., Competitive supply chain network design: An overview of classifications, models, solution techniques and applications, *Omega*, vol.45, no.2, pp.92-119, 2014.

[2] E. J. Lodree, C. D. Geiger and K. N. Ballard, Coordinating production and shipment decisions in a two-stage supply chain with time-sensitive demand, *Mathematical & Computer Modelling*, vol.51, nos.5-6, pp.632-648, 2010.

[3] A. Akbari and B. Karimi, A new robust optimization approach for integrated multi-echelon, multi-product, multi-period supply chain network design under process uncertainty, *The International Journal of Advanced Manufacturing Technology*, vol.79, no.1, pp.229-244, 2015.

[4] R. Babazadeh, J. Razmi and R. Ghodsi, Supply chain network design problem for a new market opportunity in an agile manufacturing system, *Journal of Intelligent Manufacturing*, pp.8-19, 2012.

[5] X. Bai and Y. Liu, Robust optimization of supply chain network design in fuzzy decision system, *Journal of Intelligent Manufacturing*, pp.1-19, 2014.

[6] P. Schütz, A. Tomasgard and S. Ahmed, Supply chain design under uncertainty using sample average approximation and dual decomposition, *European Journal of Operational Research*, vol.199, no.2, pp.409-419, 2009.

[7] S. Sharma, T. V. Mathew and S. V. Ukkusuri, Approximation techniques for transportation network design problem under demand uncertainty, *Journal of Computing in Civil Engineering*, vol.25, no.4, pp.316-329, 2011.

[8] J. Chen and Y. Zhao, Expandable matter-element risk analysis of automobile manufacturing supply chain, *Logistics Technology*, vol.32, no.3, pp.410-412,438, 2013.

[9] J. Mulvey, R. Vanderbei and S. Zenios, Robust optimization of large-scale systems, *Operations Research*, vol.43, no.2, pp.264-281, 1995.

[10] C. Yu and H. Li, A robust optimization model for stochastic logistic problems, *A Robust Optimization Model for Stochastic Logistic Problems*, vol.64, nos.1-3, pp.385-397, 2000.

[11] S. Leung, S. Tsang, W. Ng and Y. Wu, A robust optimization model for multi-site production planning problem in an uncertain environment, *European Journal of Operational Research*, vol.181, no.1, pp.224-238, 2007.

[12] F. Pan and R. Nagi, Robust supply chain design under uncertain demand in agile manufacturing, *Computers & Operations Research*, vol.37, no.4, pp.668-683, 2007.

[13] J. F. Tian, M. Yang and J. F. Yue, Research on supply chain network design model with regret value, *Journal of Industrial Engineering and Engineering Management*, vol.26, no.1, pp.48-55, 2012.

[14] R. Z. Qiu, X. Y. Huang and R. G. Ge, The robust coordination model of supply chain based on buyback contract, *Operations Research and Management Science*, vol.18, no.6, pp.59-64, 2009.

[15] M. Tabrizi and B. Karimi, Supply chain network design under uncertainty with new insights from contracts, *Journal of Zhejiang University: Science C*, vol.15, no.12, pp.1106-1122, 2014.