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Competition in Supply Chain Network: Retailers' Risk Averseness Approach

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A B S T R A C T

This paper formulates a competitive supply chain network throughout a mixed integer linear programming problem, considering demand uncertainty and retailers risk averseness. That is, makes the model more realistic in comparison with the others. Employed conditional value at risk method through the data-driven approach, makes the model to be convex and sensitive to the risk averseness level. Finally, the model outputs and its results are illustrated through a numerical example.

Keywords: *Competitive supply chain, supply chain network equilibrium, risk averseness, conditional value at risk.*

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1. Introduction

Supply Chain Network (SCN) management, is proposed as a good idea to deal with today's competitive worldwide markets [1]. This paper formulates a single-objective mixed integer linear programming to formulate a Supply Chain Network Design (SCND) problem under uncertain demand in compliance with retailers' risk averseness. Wang et al. [2] and Jamshidi et al. [3] report a same idea; nevertheless, their approaches and the contributions are quite different. Wang et al.[2] formulated a deterministic model. Jamshidi et al. [3] pointed out a model considering the transportation modes and environmental respects.

A lot of researchers report the classical SCND from linear deterministic models to non-linear stochastic ones which are reviewed by Wang et al. [2], Pan and Nagi [1] and Fahimnia et al. [4]. Some more recent researches are done by Lou and Dai [5], Baghalian and Rezapour [6] and Fahimnia, Farahani [7]. Much more recent research is presented by Liu and Papageorgiou [8] which analyze the global SCND problem via a multi-objective MILP

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model, and Hashim et al. [9] that adopt a bi-level programming to the problem using fuzzy logic.

The SCND makes three levels of decision across sourcing, fabrication, distribution and utilization of the SC: 1) strategic decisions, 2) tactical decisions, and 3) operational decisions. Our research is familiar with the second and the third class. However, it reflects the effects of the SC downstream risk-averseness, using the Conditional Value at Risk (CVaR) method. On the other hands, Xiao and Yang [10] and Rezapour and Farahani [11] lay stress on recently evolution in Competitive Supply Chains (CSCs). Despite some relevant real-life examples which are introduced by Xiao and Yang [10] and Farahani et al. [12], there are few researchers that investigate the CSCs. In general, here are three types of competition: 1) competition among potential candidates in the same tier [13], 2) competition among potential candidates in different tiers [14], and 3) SCs competition [10]. Our research is familiar with the first class which leads to Supply Chain Network Equilibrium (SCNE) problem as a major area of recently SC researches [15].

In this paper, not only the classical SCND problem is considered, but the competition between retailers in the last tire of the network is discussed based on their risk averseness level. Formulating the SCND problem based on the retailers' competition in order to achieve all of the market capacity, is the main contribution of the paper. The initial objective function covers the fixed production, alliance, and transportation costs. Reformulation of the constraint, which is including the uncertain demand, makes the model to be analytically solvable.

The rest of the paper is as follows: The literature review will be presented in section 2 and the problem description will be discussed in section 3. Model formulation and solution approach will be pointed out in section 4. Computational results and sensitivity analysis will be clearly presented in section 5 and finally, the conclusions will be presented in section 6.

2. Literature Review

The SCNE problem that is first studied by Samuelson [16], has already been an important issue due to independent decisions which are made by SCN members to maximize their own outcomes [17]. Dong et al. [18] investigated the SCNE problem, considering the stochastic demand contrary to Nagurney et al. [19] which designed their model based on deterministic demand. Older information about the SCNE problem are available in the book by Nagurney and Dong [20]. Dong et al. [18] extended the model to SCNE model with random demand with known probability distribution function. Nagurney et al. [21] proposed their model as the first multi-echelon SCNE model, considering both demand and supply side risk simultaneously in electronic commerce. The first multi-echelon SCNE under uncertain demand was formulated by Dong et al. [22], and subsequently, Hamdouch [23], and Liu and Nagurney [15] suggested the dynamic multi-tiered SCNE. Qiang et al. [24] formulated the closed-loop SCNE model under uncertain environment. The sensitivity of the SCNE problem to the risk attitude parameter is previously investigated by Xiao and Yang [10]. Our research and [10], and [17] has a same methodology through its attention to the risk averseness parameter; however the approaches and contributions of these researches are quite dissimilar. This research contrary to the Xiao and Yang [10] that is, investigate the competition of two SCs, formulate the competition among potential members in the same echelon. Gui-tao et al. [17] considers the risk averseness of the manufacturer, whereas the proposed model is based on the demand side of the SC. To the best our knowledge, this is the first research to introduce these approaches simultaneously in the SCNE problem as the CSCs modeling issues.

2. Problem Description

In this paper several candidates are considered to supply a single product in a pre-defined production distribution sequence. Only one operation can be accomplished in each tier with only one selected member. The total formulated cost is defined as a summation of fixed alliances set-up cost, transportation cost, and manufacturing cost. In order to achieve more simplicity, holding and shortage costs are not assumed in the model without loss of generality. The SCN and consumer relationship is allowed in the last tier. That is, the demand uncertainty affects the SCN directly from this tier.

3. Problem Formulation and Solution Method

Following notation for the model formulation is described as follows:

$a \in A$	set of operations
$i \in I$	set of potential companies available for tier ***a***
$j \in J$	set of potential companies available for tier ***a+1***
$(i, j) \in \Gamma$	set of available alliances
N_a	number candidates in tier ***a***
$\eta_{i,a,j,a+1}$	fixed cost of linking candidate ***i*** in tier ***a*** to candidate ***j*** in tier ***a+1***
$\tau_{i,a,j,a+1}$	transportation unit cost from candidate ***i*** in tier ***a*** to candidate ***j*** in tier ***a+1***
$\xi_{i,a}$	unit processing cost at candidate ***i*** in tier ***a***
ψ	a very large number
α	risk averseness of the DM
$\tilde{d}$	uncertain demand
$x_{i,a,j,a+1}$	amount of product shipped from candidate ***i*** in tier ***a*** to candidate ***j*** in tier ***a+1***

$z_{i,a}$ amount of product manufactured at candidate ***i*** in tier ***a***

$y_{i,a,j,a+1} = \begin{cases} 1 & \text{if relation between member } i \text{ in tier } a \text{ and member } j \text{ in tier } a+1 \text{ is included} \\ 0 & \text{otherwise} \end{cases}$

$\omega_{i,a} = \begin{cases} 1 & \text{if candidate } i \text{ in tier } a \text{ is included in the chain} \\ 0 & \text{otherwise} \end{cases}$

The mixed integer linear programming formulation of the model is described through equations (1) to (12).

$$\Theta = \min \sum_{a=1}^{\varphi} \sum_{j=1}^{N_{a+1}} \sum_{i=1}^{N_a} \eta_{i,a,j,a+1} y_{i,a,j,a+1} + \sum_{a=1}^{\varphi} \sum_{i=1}^{N_a} \xi_{i,a} z_{i,a} + \sum_{a=1}^{\varphi} \sum_{j=1}^{N_{a+1}} \sum_{i=1}^{N_a} \tau_{i,a,j,a+1} x_{i,a,j,a+1} \tag{1}$$

Subject to:

$$\sum_{i=1}^{N_a} \omega_{i(a)} - 1 = 0, \qquad a \in A, \tag{2}$$

$$\omega_{i,a} \geq y_{i,a,j,a+1}, \qquad \forall (i,j) \in \Gamma, \;\; a \in A, \tag{3}$$

$$\omega_{j,a+1} \geq y_{i,a,j,a+1}, \qquad \forall (i,j) \in \Gamma, \;\; a \in A, \tag{4}$$

$$\omega_{i,a} + \omega_{j,a+1} \leq y_{i,a,j,a+1} + 1, \qquad \forall (i,j) \in \Gamma, \;\; a \in A, \tag{5}$$

$$\omega_{i,a} \times \psi \geq \sum_{j=1}^{N_{a+1}} x_{i,a,j,a+1}, \qquad i \in I, \; a \in A, \tag{6}$$

$$\omega_{j,a+1} \times \psi \geq \sum_{i=1}^{N_a} x_{i,a,j,a+1}, \qquad j \in J \quad a \in A, \tag{7}$$

$$\sum_{j=1}^{N_{a+1}} x_{i,a,j,a+1} = z_{i,a}, \qquad i, \;\; a \in A, \tag{8}$$

$$\omega_{i,a} \times \tilde{d} \leq z_{i,a}, \qquad i \in I, \;\; a \in A, \tag{9}$$

$$x_{i,a,j,a+1} \geq 0, \qquad \forall (i,j) \in \Gamma, \;\; a \in A, \tag{10}$$

$$y_{i,a,j,a+1} \in \{0,1\}, \qquad \forall (i,j) \in \Gamma, \;\; a \in A, \tag{11}$$

$$\omega_{i,a} \in \{0,1\}, \qquad i \in I, \;\; a \in A. \tag{12}$$

The total cost of the network is included in Eq. (1). Constraints (2)-(5), enforce that the final network holds only one enterprise a tier. By Constraints (6) and (7), all of products are performed only through the final designed network which is balanced by Constraints (8) and.

Constraint (9) is to build the link between $z_{i,a}$ and $w_{i,a}$ while, the type of variables are defined by Constraints (10) to (12).

To deal with the uncertainty of demand, the DMs' risk averseness (α) is taking into account, Bertsimas and Brown [25] approach.

In this way, the conditional expectation $E[X \mid X \leq q_\alpha(X)]$ is considered, where $q_\alpha(X)$ is the $\alpha - quantile$ of the random variable X as presented in (13).

$$q_\alpha(X) = inf\{x \mid P(X \leq x) \geq \alpha\},\ \alpha \in (0,1) \tag{13}$$

The presented problem in this paper is minimization, so the cases with lowest cost are removed and the tail expectation $E[X \mid X \geq q_\alpha(X)]$ is considered. A nonparametric estimator of the $E[X \mid X \geq q_\alpha(X)]$ is presented in (14):

$$\hat{R}_\alpha = 1/N_\alpha \sum_{k=1}^{N_\alpha} X_{(k)}, \tag{14}$$

Where N is the number of in-hand realizations, N_α is the number of remaining cases after trimming to the decision makers risk averseness level $\alpha = (N_\alpha = [N(1-\alpha+\alpha)] \approx N(1-\alpha)$ and $X_{(k)}$ is thek-th smallest component of $(X_1, \ldots, X_N)$. In the presented problem, $X_{(k)}$ will be defined as the k-th greatest component.

The conditional expectation at the quantile level that is directly used by this research is defined by (15).

$$s_\alpha(X) = E[X] - E\left[X \mid X \leq q_\alpha(X)\right] \tag{15}$$

The $E[X \mid X \geq q_\alpha(X)]$ is finally referred as the Conditional Value-at-Risk (CVaR) which is, in this paper, employed to deal with the demand uncertainty. So, the reformulation of the constraints (12) is as follows:

$$z_{i(\varphi)} \geq \beta \left(\frac{1}{s_{1-\alpha}} \sum_{s=1}^{\lfloor s_{1-\alpha} \rfloor} d_{(s)} - \left(\frac{s_{1-\alpha} - \lfloor s_{1-\alpha} \rfloor}{\lfloor s_{1-\alpha} \rfloor} \right) d_{(\lceil s_{1-\alpha} \rceil)} \right) . w_{i(\varphi)}, \qquad i = 1, 2, \ldots, N_\varphi, \tag{16}$$

4. Computational results and sensitivity analysis

Figure 1 illustrates a 4 tiered network; each contains 3 potential companies, which is considered to numerically examining the model. Table 1, includes a numerical example, built to study the effectiveness of the model. The resulted problem can be solved by CPLEX 9.0 on a PC that has a 2.20GHz Intel(R) Core(TM)2 Duo CPU and 3.0G RAM. The results are shown in Table 2

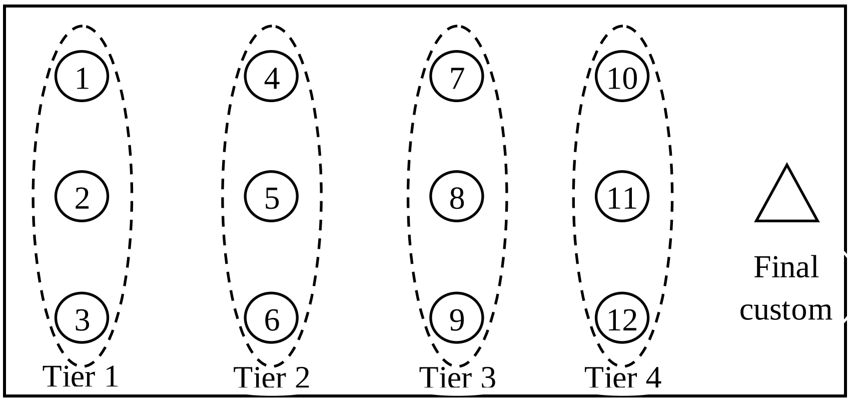

Fig 1. SCN for the example

Table 1. Data used in the problem

Data type	Range
Uncertain demand	Unif(50, 550)
Transportation unit cost	Unif(10, 15)
Fixed alliance cost	Unif(1000, 5000)
Production unit cost	Unif(20, 60)

Table 2. Results of computational study

α	$1-\alpha$	Located facilities
0.01	0.99	2-4-7-10
0.02	0.98	2-4-7-10
0.03	0.95	2-4-7-10
0.10	0.90	2-4-7-10 2-4-9-12
0.20	0.80	2-4-9-12
0.30	0.70	2-4-9-12
0.40	0.60	2-4-9-12
⋮	⋮	⋮

As one can see, the retailers' risk averseness has a significant impact on the network design. Table 2 shows the optimal designed network by changing the value of the alpha, as illustrated in Figure 2. Smaller value of the α makes the chain 2-4-7-10 to be optimal and by increasing the value of the retailers' risk averseness, this chain substituted with the chain 2-4-9-12. It means that by changing the value of alpha the competition between chains in the potential network makes the results to be deferent. In this network, the candidate 10 is more risk averse in comparison with the candidate 12 in the last tire of the network. Besides, the risk averseness of the retailers in the last tire, not only affect the selection of the candidates in the last tire, but it affects the candidate selection in other tires of the network.

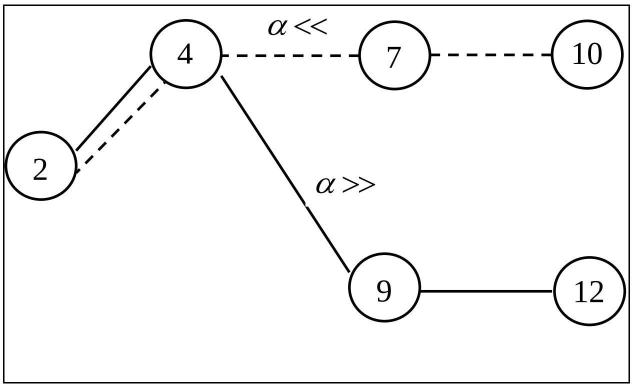

Fig 2. S Optimal network structure of SC in respect to alpha level

5. Conclusion

This paper investigates the multi-tiered single product supply chain network equilibrium problem using a mixed integer linear programming. We find that the level of retailers' risk averseness has a significant impact on the SCN design and make some competition in the whole network. Our numerical experiment simplifies the sensitivity analysis of the model to the parameter α . That is, the chain 2-4-7-10 is selected for the smaller values of the α and by increasing the value of the retailers' risk averseness, this chain substituted with the chain 2-4-9-12 .

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