Two-Stage and Robust Stochastic Optimization of Closed-Loop Supply Chain Network under Uncertainty

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Abstract: In this paper, a network of closed-loop supply chain is considered, including external supplier, production/recovery facilities, hybrid distribution/collection centers, disposal centers and customers. Generally, in the closed-loop chains production is done by the returned products, we can't achieve a correct analysis by considering one period. In many situations in the real world, we need to consider more than one period, therefore the studied model is assumed in the form of some multi-period and suppliers are used to supply the shortage of parts. In this paper, it is assumed that parameters of demand, quantity and quality of returns and variable costs are uncertain. To evaluate the uncertainty, two approaches of two-stage and robust stochastic optimization have been used. The results show that performance of robust optimization is better than the two-stage stochastic optimization under uncertainty.

Keywords: Robust Optimization, Two-stage Stochastic Optimization, Closed-loop Supply Chain, Uncertainty

Introduction: In recent years, closed-loop supply chain networks and reverse logistics have been highly regarded as being used to minimize waste and recycling of products. Since the process of collecting, retrieving, and re-manufacturing requires time, it does not provide a real result in a model in a single period. Therefore, in this paper, a multi-period closed-loop supply network model is developed. Also, in the first period, raw materials are supplied from foreign suppliers, but in subsequent periods, the recycled materials are also used in production, thus saving raw materials purchase costs.

Materials and Methods: A Mixed-Integer Linear Programming (MILP) model is proposed. Its objectives are to minimize the costs of establishing centers, shipping costs, purchasing, producing, maintaining, refining, and disposal, as well as costs associated with unused capacity penalties centers. The mathematical model of this paper is as follows:

$$Min \quad \text{FC+VC+PC} \tag{1}$$

s.t.

$$\sum_j U_{jkt} \geq d_{kt} \quad \forall k, t \tag{2}$$

$$\sum_j Q_{kjt} \geq r_{k(t-1)} d_{k(t-1)} \quad \forall k, t \tag{3}$$

$$\sum_i X_{ijt} - \sum_k U_{jkt} = 0 \quad \forall j, t \tag{4}$$

$$\sum_i V_{jit} - (1-s_t) \sum_k Q_{kjt} = 0 \quad \forall j,\ t > 1 \tag{5}$$

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$$\sum_{m} T_{jmt} - s_t \sum_{k} Q_{kjt} = 0 \quad \forall j,\ t > 1 \qquad (6)$$

$$\sum_{j} V_{jit} - \sum_{j} X_{ij(t-1)} \le 0 \quad \forall i,\ t > 1 \qquad (7)$$

$$\sum_{j} X_{ijt} \le cw_i W_i \quad \forall i, t \qquad (8)$$

$$\sum_{i} X_{ijt} \le cy_j Y_j \quad \forall j, t \qquad (9)$$

$$\sum_{k} Q_{kjt} \le cyr_j Y_j \quad \forall j,\ t > 1 \qquad (10)$$

$$\sum_{j} V_{jit} \le cwr_i W_i \quad \forall i,\ t > 1 \qquad (11)$$

$$\sum_{j} T_{jmt} \le cz_m Z_m \quad \forall m,\ t > 1 \qquad (12)$$

$$\sum_{j} X_{ijt} \le S_{it} \quad \forall i,\ t = 1 \qquad (13)$$

$$\sum_{j} X_{ijt} - \sum_{j} V_{jit} \le S_{it} \quad \forall i,\ t > 1 \qquad (14)$$

$$\mathrm{W}_i, \mathrm{Y}_j, \mathrm{Z}_m \in \{0,1\} \quad \forall i, j, m \qquad (15)$$

$$S_{it}, X_{ijt}, \mathrm{U}_{jkt}, \mathrm{V}_{jit}, \mathrm{Q}_{kjt}, \mathrm{T}_{jmt} \quad \forall i, j, k, m, t \qquad (16)$$

Constraint (2) shows the flow of customer demand. Constraints (3) ensures that returned products are collected from customers. Constraints (4) to (7) establish the flow equilibrium. Equations (8) to (12) are the capacity constraints of the production centers, the link centers are in forward and reverse, and disposal centers. Constraint (13) represents the flow of the number of pieces purchased from the supplier in the first period. Constraint (14) states that after the second period, the recycled parts will be produced and purchased from the supplier as needed. Constraints (15) and (16) represent the status of the decision variables.

Results and Discussion: In order to have an efficient logistics network, the uncertainty in demand, the quantity and quality of returning products and variable costs are considered in the model, which are solved by two methods of two-stage random planning. The EVPI and VSS indices have been used to compare the solutions used.

Conclusion: In this paper, a multi-cycle model of closed loop supply chain network including foreign suppliers, production / rehabilitation centers, distribution / collection centers, disposal centers and customers are presented. To evaluate the model under uncertainty, two-stage randomization and robust optimization methods presented by Mulvey et al (1995) have been used. The more scenarios are scattered, the responsiveness of the model is better than the two-stage model response, and it shows a better performance of the steady model.

References

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