An Integrated Decision Making Model for Supplier Selection and Network Optimization

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ABSTRACT

Increase in product flow to manufacturers due to government regulations and customers' environmental awareness has required an effective product recovery network design which known as the closed loop supply chain (CLSC). An effective CSLC management needs strategic decision-making regarding supplier selection and order allocations beside network design. Therefore, this paper aims to optimize supplier selection, order allocation and CLSC network configuration, simultaneously. In this study, a CLSC network managing by a company that includes manufacturer, distributor, retailer, collection and recovery centers is examined. This research proposes an integrated approach to select the best suppliers using AHP and COPRAS methods and optimize CLSC network configuration. It is modeled as a mixed-integer linear programming model that maximize total profit of CLSC and importance weights of suppliers.

INTRODUCTION

The supply chain constitutes all stages from supplier to customer-from order to delivery. Various models of supply chain configuration could be considered based on chain link such as supplier, manufacturer, distributor, retailer, collection centers, recycling centers and disposal [1]. And the closed-loop supply chain is a two-sided situation of these stages. While forward flow focuses minimizing cost, reverse flow focuses on more environmental measurements such as the reliability of used components, ease of recovery, disassembly and disposal [2], [3]. Due to the increasing importance of these criteria in supply chain network design, relationships between suppliers and manufacturers need to be developed for a stable presence in the current competitive markets [4]. That is, supplier selection problem is an important issue in supply chain configuration.

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Supplier selection is a multi-criteria decision making problem which is composed of both qualitative and quantitative factors. Although several studies have been conducted for supplier selection in traditional network, supplier selection in the CLSC network is a new issue. There are some differences between the supplier selection in traditional and CLSC networks. The importance of certain criteria is higher in CLSC than in traditional networks. In order to the sustainable success under the pressure of global competition, supplier selection and order allocation should be handled simultaneously with the CLSC configuration [5].

In recent years, researchers have been interested in this condition in CLSC optimization. For example, Sasikumar and Haq 2011 [6] designed a multi-echelon, multi-product closed loop distribution supply chain (CLDSC) network with the selection process of best third-party reverse logistics provider (3PRLP). In this network, they used fuzzy VIKOR method for the selection of best 3PRLP and developed a mixed integer linear programming model to optimize the CLDSC network. Amin and Zhang [5] proposed an integrated model which has two phases. In the first phase, they designed a fuzzy method to evaluate suppliers in reverse logistic. In the second phase, they proposed a multi objective mixed-integer linear programming model to determine strategic (selection of suppliers and refurbishing sites) and tactical (optimal product flow in CLSC network) decisions.

Ghayebloo et al. [2] developed a bi-objective mixed integer programming model for a forward/reverse logistic network including three stages in the forward flow and two stages in the reverse flow and obtained Pareto optimal solutions that prove the trade-off between the profit and the greenness objectives. Moghaddam [7] presented a multi-objective optimization model for supplier selection and order allocation in a CLSC network and solved it by hybrid Monte Carlo simulation integrated with three different variants of goal programming method. Kafa et al. [8] presented a trade-off between sustainability criteria for both supplier and 3PRL provider selection. Therefore, proposed a multi-objective mixed-integer programming (MILP) model to configure CLSC network and to select the best partners.

Azadeh et al. [1] proposed a new integrated approach based on experimental design and computer simulation for supplier selection in a CLSC network design. Moreover, they used data envelopment analysis (DEA) to assess suppliers based on determined criteria and used Taguchi method to determine order quantities. Rezaee et al. [4] presented a multi-objective programming model based on the integrated simultaneous data envelopment analysis–Nash bargaining game for CLSC optimization, supplier selection and orders allocation considering quantity discount policy.

PROBLEM DEFINITION

The problem is related to a CLSC network managed by a firm with manufacturer, distributor, retailer, collection and recovery centers. CLSC network design based on the discussed problem is given in Figure 1. The firm meets demands of the customers in the form of new and remanufactured products and evaluate returned products at the same time. Thus, it needs to choose the right suppliers for supplying new parts from the outside and evaluate reusable parts from the inside to minimize cost, increase quality and be environment-friendly.

Herein, a two-stage integrated approach is proposed for selecting the best suppliers using a hybrid multi-criteria decision-making method and optimizing CLSC network
configuration. At the first stage, AHP is used to calculate the relative weights of supplier selection criteria and then COPRAS is used for ranking (weights) of suppliers. At the second stage, the weights of the criteria and suppliers are incorporated into the proposed model with other formulations. The weights of supplier are used as coefficients order quantities between suppliers so that the sum of the purchasing value is maximized.

It is modeled as a mixed-integer linear programming model that maximize total profit of CLSC and value of purchasing for suppliers.

Some assumptions made for developed model are as follows:

1) There is only one product and it is completely modular.
2) The model is designed for a single period.
3) There is no difference between a new product with remanufactured product and it can meet demand for the same price.
4) There is no provision for quantity discount in this model.
5) The production capacity is sufficient for all product requirements.
6) All cost and sales price information is known.
7) The demand of customers is certain and fulfilled.
8) The quantity of returned products at collection center is known.
9) Returned products contains all parts including useless parts.
10) There aren’t stock and stock out.

Figure 1. Representational Closed Loop Supply Chain Network.

Mathematical Model

INDICES

\( i \): Set of suppliers \((i = 1, 2, \ldots, I)\)
\( j \): Set of parts \((j = 1, 2, \ldots, J)\)

PARAMETERS

\( m \): Manufacturing cost of the product
\( p_{ij} \): Purchasing cost of the part \( j \) from the supplier \( i \)
\( de \): Disassembly cost of returned product in recovery center
\( h \): Purchasing cost of returned product from customer  
\( t_{aij} \): Unit transportation cost of new part \( j \) from supplier \( i \) to manufacturer  
\( t_{bj} \): Unit transportation cost of reusable part \( j \) from recovery center to manufacturer  
\( tc \): Unit transportation cost of product from manufacturer to distributor  
\( td \): Unit transportation cost of product from distributor to retailer  
\( te \): Unit transportation cost of product from retailer to customer  
\( tf \): Unit transportation cost of product from customer to collection center  
\( tg \): Unit transportation cost of product from collection center to recovery center  
\( th_{ij} \): Unit transportation cost of the part \( j \) from recovery center to disposal  
\( r_{ij} \): Refurbishing cost of the part \( j \)  
\( e_{ij} \): Disposal cost of the part \( j \)  
\( nu_{ij} \): Number of part \( j \) required to manufacture a product  
\( D \): Total product demand of customer  
\( S \): Sales price of new product to customer  
\( F \): Sales price of returned product to spot market  
\( G_{ij} \): Sales price of returned part \( j \) to recycling plant  
\( W_{i} \): The weight (lean priority value) of the supplier \( i \)  
\( \alpha \): The rate of returned product from collection center to recovery center  
\( \beta \): The rate of parts to be refurbished after disassembling  
\( \theta \): The rate of parts from recovery center to recycling plant  
\( l \): Maximum number of suppliers  
\( C_{i} \): Maximum capacity of the supplier \( i \)  
\( A_{i} \): Minimum purchase quantity from the supplier \( i \)  
\( N \): The amount of returned products

**DECISION VARIABLES**

\( X_{ij} \): The amount of new part \( j \) ordered from the supplier \( i \)  
\( Y_{ij} \): The amount of reusable part \( j \) recovered from the recovery center  
\( T_{ij} \): The amount of part \( j \) to be recycled  
\( Q_{ij} \): The amount of part \( j \) to be disposed  
\( Z \): The amount of products to be manufactured  
\( V \): The amount of products sent from the collection center to the recovery center  
\( K \): The amount of returned product sent from the collection center to the spot center  
\( b_{i} \): Binary variable, if supplier \( i \) is chosen 1, 0 otherwise

**OBJECTIVE FUNCTIONS**

maximize \( Z = \left[ S \times Z + F \times K + \sum_{j} G_{ij} T_{ij} \right] - \left[ \left( \sum_{i} \sum_{j} p_{ij} X_{ij} + m \times Z + d \times V + h \times N + \sum_{j} r_{ij} Y_{ij} + \sum_{j} e_{ij} Q_{ij} \right) + \left( \sum_{i} \sum_{j} t_{aij} X_{ij} + \sum_{j} t_{bj} Y_{ij} + Z \times (t_{c} + t_{d} + t_{e}) + N \times t_{f} + V \times t_{g} + \sum_{j} t_{h_{ij}} Q_{ij} \right) \right] + \left[ \sum_{i} \sum_{j} W_{i} X_{ij} \right]. \)  \( (1) \)

**CONSTRAINTS**

\( Z = D, \)  \( (2) \)
\[
\sum_i X_{ij} + Y_j = nu_j * Z \\
\forall j,
\]
\[
N * \alpha = V,
\]
\[
N * (1 - \alpha) = K
\]
\[
nu_j * V * \beta = Y_j \\
\forall j,
\]
\[
nu_j * V * \theta = T_j \\
\forall j,
\]
\[
nu_j * V * (1 - (\beta + \theta)) = Q_j \\
\forall j,
\]
\[
\sum_i b_i \leq l,
\]
\[
A_i * b_i \leq \sum_j X_{ij} \leq C_i * b_i \\
\forall i,
\]
\[
X_{ij}, Y_j, Q_j, T_j, Z, V, K \geq 0 \\
\forall i, j,
\]
\[
b_i = 0, 1 \\
\forall i.
\]

Objective function is to maximize the total profit, that is, the model maximizes the total revenue while minimizing the total cost. For this reason, the objective function is calculated as the difference between total revenue and total cost, and it consists of three main parts. The first part of the objective function maximizes the total revenue; Company can perform three different sales for the new products, used products and used parts as revenue. The second part the objective function minimizes the total cost; The company is accepted to five different costs including the total purchasing cost, total manufacturing costs, the total refurbishing cost, the total disposal cost and total transportation cost. The last part of the objective function maximizes the total value of purchasing.

Constraint (2) is the demand constraint which ensures that the total demand is satisfied. The constraints between (3) and (8) are the balance constraints. that is, the amount of the input and the amount of the output are to be equal to each other. Constraint (9) represent the limitation of the number of suppliers. Constraints (10) represent minimum purchasing quantity from suppliers and maximum capacity of suppliers. The remaining constraints (11) and (12) are the sign (non-negativity and binary) constraints of the decision variables.

**Illustrative Example**

In the case study, 5 potential suppliers will be evaluated according to four main criteria for supplying five different type parts to a firm. The purchasing criteria are Cost, Quality, Delivery and Environmental Performance. The pair wise comparison decision matrix is created in Table I using the 1-9 significance scale recommended by Saaty for comparisons of the criteria. Weights of the criteria are found by the AHP method using the pair wise comparison matrix. The evaluation of alternative suppliers by the decision maker on criteria are given in Tables III. Ranking (weights) of the suppliers are found by the COPRAS method by using decision matrix and weights of criteria (as shown in Tables IV). To perform optimal order allocation, weights of the
suppliers based on the results of COPRAS are used as coefficients in the last part of the objective function.

Table 1. The pair wise comparisons among the criteria.

|          | Cost   | Quality | Delivery Time | Environmental Performance |
|----------|--------|---------|---------------|---------------------------|
| Cost     | 1.00   | 3.00    | 2.00          | 5.00                      |
| Quality  | 0.33   | 1.00    | 0.50          | 3.00                      |
| Delivery Time | 0.50 | 2.00    | 1.00          | 4.00                      |
| Environmental Performance | 0.20 | 0.33   | 0.25          | 1.00                      |

Table 2. The normalized matrix for the criteria.

|          | Cost   | Quality | Delivery Time | Environmental Performance |
|----------|--------|---------|---------------|---------------------------|
| Cost     | 0.49   | 0.47    | 0.53          | 0.38                      |
| Quality  | 0.16   | 0.16    | 0.13          | 0.23                      |
| Delivery Time | 0.25 | 0.32    | 0.27          | 0.31                      |
| Environmental Performance | 0.10 | 0.05   | 0.07          | 0.08                      |

After AHP analysis for determining criteria weights, it is observed that the weights of Cost: 0.47, Quality: 0.17, Delivery Time: 0.28 and Environmental Performance: 0.07.

\[ n_{max} = 4.07, \quad CI = 0.02, \quad RI = 0.02, \quad CR = 0.02. \]

CR \leq 0.1, the matrix is consistent.

Table 3. Decision matrix and weights of criteria.

| Suppliers | Cost ($) | Delivery Time (Day) | Quality (1-100 Score) | Environmental Performance (1-100 Score) |
|-----------|----------|---------------------|-----------------------|-----------------------------------------|
| Opt.      | min      | min                 | max                   | max                                     |
| 1         | 23.7     | 5.0                 | 70                    | 90                                      |
| 2         | 31.8     | 2.5                 | 90                    | 85                                      |
| 3         | 36.0     | 1.0                 | 95                    | 75                                      |
| 4         | 27.4     | 3.5                 | 76                    | 80                                      |
| 5         | 28.3     | 2.0                 | 82                    | 64                                      |
| Weights of criteria | 0.47 | 0.17 | 0.28 | 0.07 |

Table 4. The normalized decision matrix.

| Suppliers | Cost ($) | Delivery Time (Day) | Quality (1-100 Score) | Environmental Performance (1-100 Score) |
|-----------|----------|---------------------|-----------------------|-----------------------------------------|
| Opt.      | min      | min                 | max                   | max                                     |
| 1         | 0.16     | 0.36                | 0.17                  | 0.23                                    |
| 2         | 0.22     | 0.18                | 0.22                  | 0.22                                    |
| 3         | 0.24     | 0.07                | 0.23                  | 0.19                                    |
| 4         | 0.19     | 0.25                | 0.18                  | 0.20                                    |
| 5         | 0.19     | 0.14                | 0.20                  | 0.16                                    |

Table 5. Weighted normalized decision matrix.

| Suppliers | Cost ($) | Delivery Time (Day) | Quality (1-100 Score) | Environmental Performance (1-100 Score) |
|-----------|----------|---------------------|-----------------------|-----------------------------------------|
| Opt.      | min      | min                 | max                   | max                                     |
| 1         | 0.08     | 0.06                | 0.05                  | 0.02                                    |
| Suppliers | Si+ | Si- | Qi  | Pi  | Rank |
|-----------|-----|-----|-----|-----|------|
| 1         | 0.065 | 0.137 | **0.185** | 88  | 5    |
| 2         | 0.078 | 0.132 | **0.202** | 96  | 3    |
| 3         | 0.079 | 0.127 | **0.208** | 99  | 2    |
| 4         | 0.067 | 0.131 | **0.193** | 91  | 4    |
| 5         | 0.068 | 0.115 | **0.211** | 100 | 1    |

Table 7. The parameter values related suppliers.

| Suppliers | 1 | 2 | 3 | 4 | 5 |
|-----------|---|---|---|---|---|
| C_i       | 400 | 550 | 500 | 350 | 450 |
| A_i       | 100 | 50 | 150 | 75 | 50 |
| W_i       | 0.185 | 0.202 | 0.208 | 0.193 | 0.211 |

Table 8. The parameter values related parts.

| Parts | 1 | 2 | 3 | 4 | 5 |
|-------|---|---|---|---|---|
| p_{ij} suppliers | | | | | |
| 1 | 11.5 | 8 | 14 | 6.8 | 10 |
| 2 | 11.3 | 8.3 | 13.3 | 7 | 11.8 |
| 3 | 12 | 9.2 | 12.5 | 6.2 | 10.2 |
| 4 | 10.7 | 8.5 | 13.5 | 6.5 | 10.5 |
| 5 | 10 | 7 | 10 | 4.1 | 8.3 |
| t_{aij} suppliers | | | | | |
| 1 | 3 | 3 | 3 | 3 | 3 |
| 2 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 |
| 3 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 |
| 4 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| 5 | 4 | 4 | 4 | 4 | 4 |
| t_{bj} | 0.08 | 0.03 | 0.15 | 0.04 | 0.07 |
| t_{hj} | 0.08 | 0.01 | 0.05 | 0.03 | 0.04 |
| r_{j} | 1.5 | 2 | 0.5 | 1 | 2 |
| e_{j} | 0.02 | 0.01 | 0.05 | 0.03 | 0.015 |
| n_{uj} | 1 | 2 | 1 | 4 | 1 |
| G_{j} | 5 | 2 | 4 | 1 | 3 |

It is assumed that \( m = 5, \) \( de = 6, \) \( tc = 0.10, \) \( td = 0.08, \) \( te = 0.12, \) \( tf = 0.15, \) \( tg = 0.07, \) \( l = 3, \) \( h = 20, \) \( S = 150, \) \( D = 1400, \) \( F = 50, \) \( N = 1000, \) \( \alpha = 0.6, \) \( \beta = 0.2, \) \( \theta = 0.5 \) Supplier quantitative information is given in Table VII and VIII.

**Solution**

Mixed integer linear programming model developed in accordance with these data was solved in GAMS/CPLEX 24.0 software package, the following results were obtained.

Objective value \( Z_{\text{max}} \) is 184841.25, and the value of \( X_{12} = 246.4, X_{15} = 153.6, X_{21} = 140.8, X_{22} = 35.2, X_{24} = 254, X_{53} = 140.8, X_{54} = 309.2, Z = 140, V = 600, K = 400, b_1 = 1, b_2 = 1, b_5 = 1.\)
Table 9. Other decision variable values.

| Parts | 1    | 2    | 3    | 4    | 5    |
|-------|------|------|------|------|------|
| \(Y_j\) | 13.2 | 26.4 | 13.2 | 52.8 | 14.4 |
| \(T_j\) | 33   | 66   | 33   | 132  | 36   |
| \(Q_j\) | 19.8 | 39.6 | 19.8 | 79.2 | 21.6 |

In this solution, no products were purchased from suppliers 3 and 4, because the supplier 3 has the highest purchasing and transportation costs and the weight of supplier 4 is lower than the others except supplier 1. Despite the fact that the weight of supplier 1 is lowest value, it has been chosen since it has the lowest cost and we want to minimize the total cost at the same time. So, the company will work towards its goals with suppliers 1, 2 and 5.

**CONCLUSIONS**

In this study, a mixed integer linear programming model was considered for supplier selection, order allocation and CLSC network configuration. The model meets demands of customer, maximizes value of purchasing for suppliers and profit consist of different sales revenues and total cost and determines how to evaluate all returned products. Thus, AHP and COPRAS methods were used for supplier selection and a mixed integer linear programming model was developed to find out the optimum solution of the problem. The proposed model was verified with the aid of a numerical example by solving in GAMS/CPLEX 24.0 software package.

For future research, the proposed model could be applied in business performed CLSC activities and developed on networks with multi-product, more product recovery options and fixed costs to be more realistic. Furthermore, uncertainties in product returns could be added as fuzzy to network structure. Additionally, Other than the AHP and COPRAS method used in this study, other multi-criteria decision making methods can be used in a fuzzy environment and compared in terms of suitability.
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