Improved Allocation Model of Logistics Service Supply Chain Capability Based on NSGA-II: A Case of Tobacco Group Company

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Abstract

This study built a multi-objective distribution model and used evolutionary algorithms to solve allocation problem of multi-logistics service capabilities. The model we proposed was improved by introducing decreasing marginal cost function rather than fixed unit cost. The multi-objective optimization model of capability allocation was established with the objective constraints of minimizing service integrators’ procurement cost and penalty cost as well as maximizing service providers’ satisfaction. The tobacco group company has a typical two-stage logistics system to provide various logistics service capabilities. Hence we adopted elitist non-domination sorting genetic algorithm (NSGA-II) to solve the non-linear multi-objective problem with initial parameters from a practical tobacco company. Our study claims that the increase of demand uncertainty will have significant influence on both logistics service integrator and provider. Moreover, we find that NSGA-II can solve the multi-objective programming problem effectively.

Keywords: Logistics service capability allocation, NSGA-II, Service supply chain

1. Introduction

Logistics service chain is a typical service supply chain. With the rapid development of logistics service industry, logistics service supply chain becomes stronger. The framework of such supply chain is customer demand → logistics service integrator → logistics service provider, among which, logistics service integrator is the core actor for it directly faces customers, and allocate customer orders among logistics service providers [1].

Generally speaking, logistics service integrator usually have many functional logistics service providers. When integrator collects customer demand, it will allocate the orders among logistics service providers, and such process is called capability allocation process. Rational and effective order allocation is important to the stability of the whole supply chain [2]. When there are various service providers, service integrator cannot simply consider its own maximization of procurement cost, but also the degree of satisfaction of service providers to the integrator’s allocation, as well as the matching problem of different logistics capability [3].

Prior researches usually assume the unit cost of logistics service is fixed, this is not generally the case. Therefore, this study introduces decreasing marginal cost function, and constructs objectives which aims at simultaneously minimizing procurement cost and penalty cost of logistics service integrators as well as maximizing the degree of satisfaction of logistics service providers. This is a multi-objective logistics capability allocation model with random demand. The framework of our model is as Figure 1.
After investigation and survey, we find that tobacco group company has two logistics parts: industrial logistics and commercial logistics. Its commercial logistics is a very typical multi-stage logistics service system. The tobacco group itself acts as the logistics service integrator, who does not contact to market directly. Through its order allocation, the various logistics service providers could offer services to market. Hence our study adopts tobacco group company as a practical case of the proposed model and solution.

2. Theoretical Foundation

For both logistics service providers and integrators, logistics cost relates closely to the enterprise profit level and competitiveness. Hence discussion of logistics cost is significant to improve the performance of logistics service supply chain [4]. Logistics cost mainly include transportation cost, storage cost, package cost, loading cost, logistics information cost, and so forth [5].

\[ C(X) \]

Figure 2. Concave cost function (Logarithmic form) of logistics service provider

In this study, we think logistics service provider would firstly have certain cost input, such as human resource input and device input, then it is able to build up own logistics service capability and cooperate with service integrator. That is to say, although there is no order for service provider allocated from service integrator, the cost of provider should not be zero. Meanwhile, due to the economy of scale, the marginal cost of logistics service provider is decreasing with acquired order increases. Therefore, based on the study of [6], we set the cost function of logistics service provider to be as shown in Figure 2.

Elitist non-dominated sorting genetic algorithm (NSGA-II) is an improvement of NSGA,
which are both developed from genetic algorithms and one of the best evolutionary algorithms. The rapid non-dominated sorting algorithm of NSGA-II can reduce algorithmic complexity and computing time effectively. Meanwhile, NSGA-II adopts crowdedness and crowded comparison operator, thus requires no share parameters. Moreover, the introducing of elitist strategy can help the algorithm to expand the sampling space during optimizing process, and to combine parent and offspring population. The multi-generation of population compete with each other to produce the next generation of population, then the offspring population become better. Hence we use NSGA-II to solve the multi-objective problem.

### 3. Allocation Model of Multi-logistics Service Capabilities

Assume there are $M$ types of logistics service capabilities. The demand of $j$th logistics service capability is $R_j^j$; the interval of $j$th logistics service capability provided by $i$th logistics service provider is $[\omega_{ij}^j, \omega_{ij}^+]$, and $\sum_{i=1}^{N} \omega_{ij}^j \leq R_j \leq \sum_{i=1}^{N} \omega_{ij}^+$. Assume the service capabilities of different service providers are independently. Next we set the decreasing marginal cost function to be $f(x) = b\ln(ax + 1) = cx$, which is concave. Then the cost function of $i$th logistics service provider is $C_i(x) = \sum_{j=1}^{M} b_j \ln(a_j x_j + 1)$, and the cost function image of logistics service integrator is as Fig. 2.

Due to the uncertainty of customer demand, we assume $R_j$ to be a random variable which obeys normal distribution $N(\mu_j, \sigma_j^2)$. Then we build a programming model with chance constraint [8]:

$$\sum_{i=1}^{N} x_{ij} \geq R_j = \alpha$$

It represents that the probability of the total capability provided by $j$th logistics service provider that could satisfy customer demand is $\alpha$. We use the expected value of random variable to replace the random variable, then we get the equivalent model:

$$\sum_{i=1}^{N} x_{ij} = \mu_j + \phi^{-1}(\alpha)\sigma_j$$

Considering the degree of satisfaction of logistics service provider to the order allocation of service integrator, we assume the degree of satisfaction of $i$th logistics service provider to the allocated $j$th logistics service capability (say $x_{ij}$) to be $d_{ij}$. Then we have:

$$d_{ij} = \begin{cases} \frac{\omega_{ij}^j}{x_{ij}}, & x_{ij} > w_{ij}^+ \\ d_{ij}^0 + \frac{x_{ij} - w_{ij}^+}{w_{ij}^+ - w_{ij}^-}(1 - d_{ij}^0), & w_{ij}^- \leq x_{ij} \leq w_{ij}^+ \\ \frac{x_{ij}}{w_{ij}^-}d_{ij}^0, & 0 \leq x_{ij} \leq w_{ij}^- \\ \end{cases}$$

(1)

Where $d_{ij}^0$ indicates the initial degree of satisfaction when $x_{ij}$ equals $w_{ij}^-$. When $0 \leq x_{ij} \leq w_{ij}^-$, the degree of satisfaction is $\frac{x_{ij}}{w_{ij}^-}d_{ij}^0$; while $x_{ij} = w_{ij}^-$, the degree of satisfaction is $d_{ij}^0$; when $w_{ij}^- \leq x_{ij} \leq w_{ij}^+$, the degree of satisfaction becomes $d_{ij}^0 + \frac{x_{ij} - w_{ij}^-}{w_{ij}^+ - w_{ij}^-}(1 - d_{ij}^0)$; and when $x_{ij} = w_{ij}^+$, the degree of satisfaction is 1.

In particular, when $x_{ij} > w_{ij}^+$, because of the powerful position of service integrator, service
provider will have to meet the allocation designed by integrator. Now for $i$th provider, although it meets the requirement of integrator, its degree of satisfaction is lower than 1. The specific functional image is as Figure 3.

**Figure 3.** Functional image of the degree of satisfaction of $i$th logistics service provider

It is certain that the degree of satisfaction of service provider who is allocated comprehensive service order (i.e. containing multi-logistics capacities) is different from provider who only gets unique service order. Assume the weight of service provider’s preference to unique and comprehensive capability is $\varepsilon_1$ and $\varepsilon_2$ respectively, and $\varepsilon_1 + \varepsilon_2 = 1$. The values of $\varepsilon_1$ and $\varepsilon_2$ are acquired from interview. Assume the preference of $i$th logistics service provider to $j$th logistics service capability is $\lambda_{ij}$ and $\sum_{j=1}^{M} \lambda_{ij} = 1$. Then the degree of satisfaction of $i$th logistics service provider to the eventual order allocation is $d_i = \varepsilon_1 \sum_{j=1}^{M} \lambda_{ij} d_j + \varepsilon_2 (\frac{1}{M} \sum_{j=1}^{M} d_j)$. The former item indicates the degree of satisfaction on unique logistics capability, and the latter item indicates the comprehensive logistics capability.

The importance of service providers varies, so service integrator will have preference to some cooperated service providers. We use $\beta_{ij}$ to measure the preference of integrator to the $j$th service capability provided by $i$th provider, and $\sum_{j=1}^{M} \beta_{ij} = 1$. On the other hand, during the cooperation of service integrator and providers, if the provider is dissatisfied with the allocated service capability, it will cause penalty cost to the service integrator. Such penalty cost includes decreasing service quality, closing the cooperation, and so on. The deeper the cooperation is, the larger the penalty cost will be. Therefore, we set a penalty function $\delta$, and $\delta$ is related to both the penalty coefficient (say $k_i$ and $0 < k_i \leq 1$) of $i$th service provider and the allocation result of $i$th service provider. While $\delta$ is in proportion to $k_i$ and in inverse proportion to degree of dissatisfaction (i.e. $1 - d_i$).

Finally, we build an improved allocation model of logistics service supply chain capabilities. The logistics service capability allocation of integrators to providers should satisfy the following objective: (1) Minimizing procurement cost of integrator; (2) Maximizing degree of satisfaction of provider; (3) Minimizing penalty cost of integrator. Then we get the multi-objective programming model as below:

$$
\begin{align*}
\min Z_1 &= \sum_{i=1}^{N} \sum_{j=1}^{M} c_{ij}(x_{ij}) \\
\max Z_2 &= \sum_{i=1}^{N} \beta_i (\varepsilon_1 \sum_{j=1}^{M} \lambda_{ij} d_j + \varepsilon_2 (\frac{1}{M} \sum_{j=1}^{M} d_j)) \\
\min Z_3 &= \sum_{i=1}^{N} \beta_i k_i (1 - d_i) = \sum_{i=1}^{N} \beta_i k_i (1 - \varepsilon_1 \sum_{j=1}^{M} \lambda_{ij} d_j - \varepsilon_2 (\frac{1}{M} \sum_{j=1}^{M} d_j))
\end{align*}
$$

(2)

4. Model Solution with NSGA-II
We adopt a tobacco group company as the case. The company has five logistics service providers, say A, B, C, D and E. The providers offer transportation and storage services. By survey, we have $D_1\sim N(200,16)$ and $D_2\sim N(130,16)$, where $D_1$ refers to the transportation demand and $D_2$ refers to the warehouse capability. We use Lingo 11.0 to solve the unknown parameters in the function of transportation and warehouse capability. The obtained function is displayed in Table 1.

### Table 1. Procurement cost function of transportation and warehouse capability of integrator

<table>
<thead>
<tr>
<th>Transportation capability</th>
<th>Procurement cost function</th>
<th>Warehouse capability</th>
<th>Procurement cost function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$C_{11} = 30.4251* \ln(1.2705x + 1)$</td>
<td>A</td>
<td>$C_{12} = 241.4642* \ln(0.2580x + 1)$</td>
</tr>
<tr>
<td>B</td>
<td>$C_{21} = 74.3082* \ln(0.0899x + 1)$</td>
<td>B</td>
<td>$C_{22} = 210.1765* \ln(0.1031x + 1)$</td>
</tr>
<tr>
<td>C</td>
<td>$C_{31} = 54.5732* \ln(0.1964x + 1)$</td>
<td>C</td>
<td>$C_{32} = 468.0072* \ln(0.0481x + 1)$</td>
</tr>
<tr>
<td>D</td>
<td>$C_{41} = 193.1689* \ln(0.0401x + 1)$</td>
<td>D</td>
<td>$C_{42} = 335.9261* \ln(0.0823x + 1)$</td>
</tr>
<tr>
<td>E</td>
<td>$C_{51} = 55.2790* \ln(0.5412x + 1)$</td>
<td>E</td>
<td>$C_{52} = 1014.1465* \ln(0.0136x + 1)$</td>
</tr>
</tbody>
</table>

The initial parameters are obtained through survey and first-hand data from a tobacco group company in China. We have designed relevant indices and collected answers within seven weeks, and spent one more week to ask experts to score the answers and statistics from both the tobacco group and logistics providers. Table 2 gives the initial values of parameters.

### Table 2. Initial values of parameters

<table>
<thead>
<tr>
<th>Service provider</th>
<th>TCI</th>
<th>WCI</th>
<th>TCP</th>
<th>WCP</th>
<th>WSCC</th>
<th>WSUC</th>
<th>WSP</th>
<th>K</th>
<th>ISTC</th>
<th>ISWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>[50,70]</td>
<td>[20,40]</td>
<td>0.54</td>
<td>0.46</td>
<td>0.40</td>
<td>0.58</td>
<td>0.22</td>
<td>0.55</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>B</td>
<td>[25,40]</td>
<td>[20,35]</td>
<td>0.56</td>
<td>0.39</td>
<td>0.50</td>
<td>0.50</td>
<td>0.14</td>
<td>0.30</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>C</td>
<td>[35,90]</td>
<td>[25,40]</td>
<td>0.51</td>
<td>0.47</td>
<td>0.20</td>
<td>0.78</td>
<td>0.30</td>
<td>0.60</td>
<td>0.15</td>
<td>0.30</td>
</tr>
<tr>
<td>D</td>
<td>[40,60]</td>
<td>[25,50]</td>
<td>0.40</td>
<td>0.57</td>
<td>0.60</td>
<td>0.40</td>
<td>0.17</td>
<td>0.40</td>
<td>0.30</td>
<td>0.20</td>
</tr>
<tr>
<td>E</td>
<td>[30,80]</td>
<td>[10,40]</td>
<td>0.54</td>
<td>0.44</td>
<td>0.65</td>
<td>0.35</td>
<td>0.22</td>
<td>0.50</td>
<td>0.25</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Note: TRI: transportation capability interval; WCI: warehouse capability interval; TCP: transportation capability preference; WCP: warehouse capability preference; WSCC: weight of satisfaction on comprehensive capability; WSUC: weight of satisfaction on unique capability; WSP: weight of service provider; K: penalty coefficient; ISTC: initial satisfaction of transportation capability; ISWC: initial satisfaction of warehouse capability.

In addition, we set the population to be 100, the crossover rate to be 0.8 and mutational rate to be 0.3. The convergence rule is either no better individual appears 10 times in a row or the iterative time gets to 200.

Adopting NSGA-II to solve the allocation model of logistics service capabilities, we obtain 100 Pareto optimal solutions, which are displayed in Table 3.

### Table 3. 100 Pareto optimal solutions

<table>
<thead>
<tr>
<th>No.</th>
<th>PC</th>
<th>DS</th>
<th>KC</th>
<th>No.</th>
<th>PC</th>
<th>DS</th>
<th>KC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>219</td>
<td>0</td>
<td>11.7</td>
<td>35</td>
<td>1782</td>
<td>0.47</td>
<td>7.06</td>
</tr>
<tr>
<td>2</td>
<td>330</td>
<td>0.02</td>
<td>11.6</td>
<td>36</td>
<td>1989</td>
<td>0.55</td>
<td>5.98</td>
</tr>
<tr>
<td>3</td>
<td>139</td>
<td>0.02</td>
<td>11.5</td>
<td>37</td>
<td>3276</td>
<td>0.50</td>
<td>6.45</td>
</tr>
<tr>
<td>4</td>
<td>552</td>
<td>0.16</td>
<td>10.1</td>
<td>38</td>
<td>1426</td>
<td>0.50</td>
<td>6.42</td>
</tr>
<tr>
<td>5</td>
<td>771</td>
<td>0.16</td>
<td>10.1</td>
<td>39</td>
<td>1577</td>
<td>0.52</td>
<td>6.29</td>
</tr>
<tr>
<td>6</td>
<td>460</td>
<td>0.02</td>
<td>11.5</td>
<td>40</td>
<td>1500</td>
<td>0.50</td>
<td>6.4</td>
</tr>
<tr>
<td>7</td>
<td>666</td>
<td>0.05</td>
<td>11.2</td>
<td>41</td>
<td>1506</td>
<td>0.51</td>
<td>6.4</td>
</tr>
</tbody>
</table>
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Finally, we explore the influence of demand uncertainty on the logistics capability allocation by changing the demand variance of transportation capability. We set the transportation demand obeys normal distribution with mean equaling to 200. The variance $\sigma^2$ is set to be 4, 16, 36 and 64 respectively. The storage demand obeys $N(130, 16)$ and maintains. Every solution solved with NSGA-II produces 100 Pareto optimal values. Change $\sigma^2$ and choose the solution with minimum deviation of constraints, we gain the results as shown in Table 4.

<table>
<thead>
<tr>
<th>$\sigma^2$ = 4</th>
<th>$\sigma^2$ = 16</th>
<th>$\sigma^2$ = 36</th>
<th>$\sigma^2$ = 64</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total cost</strong></td>
<td>3747.0577</td>
<td>3817.9583</td>
<td>4537.5482</td>
</tr>
<tr>
<td><strong>Total degree of Satisfaction</strong></td>
<td>0.8535</td>
<td>0.8140</td>
<td>0.8100</td>
</tr>
<tr>
<td><strong>Strength of penalty</strong></td>
<td>3.1394</td>
<td>3.2822</td>
<td>3.3952</td>
</tr>
</tbody>
</table>

We can find that demand uncertainty will influence the procurement cost and penalty cost of service integrator as well as the total degree of satisfaction of service provider. With the increase of demand uncertainty, the procurement cost of service integrator will raise, and the degree of satisfaction of service provider will decline. Moreover, the service integrator will be less likely to meet the customer requirement of customers, thereby gets stronger penalty when fail in service.
5. Conclusion

This study builds a multi-objective distribution model and use NSGA-II to solve allocation problem of multi-logistics service capabilities. The model we proposed is improved by introducing decreasing marginal cost function rather than fixed unit cost. The tobacco group company is typical to be two-stage model to provide various logistics service capabilities. Hence we solve the non-linear multi-objective problem with initial parameters from a practical tobacco group company. Our study demonstrate that the increase of demand uncertainty will have significant influence on both logistics service integrator and provider. Moreover, we find that NSGA-II can solve the multi-objective programming problem effectively.

6. Acknowledgement

This work was supported by the National Science Foundation of China (Grant No. 71490723) and Innovation Program of Shanghai Municipal Education Commission (No. 12ZZ004).

7. References