Fuzzy Scheduling of Logistics Production and Distribution under Uncertain Environments using Particle Swarm Optimization

Xing Liu1∗, Hai Liu

1 School of Management Tianjin University
Tianjin University
Tianjin City, China
2School of Business Zhengzhou University
Zhengzhou University
Henan Province, China

Abstract — In this paper we attempt to integrate production scheduling and distribution routing problems to minimize the total cost of the supply chain under uncertain environments. The particle swarm optimization method is used to select the location of the distribution center, combining it with the tabu search algorithm to solve vehicle distribution route problem. Especially, the location of each particle is encoded as a floating point number. Each particle consists of a two row matrix, the first row represents the location of distribution center and the second row the link between distribution center and customer. The experiment results show that this scheme can solve production-distribution problems in the global sense efficiently. In the future, convergence speed and accuracy based on particle swarm optimization will be studied to reduce running time of the proposed algorithm, and its performance will be compared with other intelligent computing techniques.

Keywords- Logistics Production-distribution; Particle Swarm Optimization; Fuzzy Scheduling, Uncertain Environment.

I. INTRODUCTION

The production and distribution problems in supply chain is a hotspot of academic research at home and abroad, the goal of which is to integrate production scheduling and distribution routing problem to minimize the total cost of supply chain[1]. How to effectively integrate members of the supply chain and correctly determine production, distribution and vehicle routing, increasingly attracts the attention of the industry. Optimization of enterprise supply chain is helpful to improve operational efficiency, reduce costs, improve customer satisfaction, and enhance the competitiveness of enterprises[2]. Improving the level of the supply chain must abandon the pattern that studies each stage separately. In the decision-making of integrated supply chain, the location allocation problems and vehicle routing problem are two aspects which attract more attention in the theory and practice[3]. On the basis of the two models and other logistic decision model, the location routing problem is generated. In the decision of facility position, transportation cost should be considered at the same time. For many customers and many facilities, through the establishment of location routing problem model, the optimal number of facilities, capacity and the optimal transportation plan and route arrangement, supply chain cost can be reduced. Location routing problem is one of the most concerns under supply chain production-distribution system. Location routing problem model is a special kind of location selection model, the basic idea of which is to consider distribution route optimization of vehicles as well as the location optimization of distribution centres. A typical location routing problem model can be described as follows. The number of customers, the location, and the demand is known. A company delivers the goods to the customers from one or more distribution centres, and there exists several number of distribution centre location for selection. Each customer gets goods only from a distribution centre.

Hall[3] divided the vehicle distribution service into independent subnets, which is composed of single goods collection centre, multiple single goods source and multiple terminals. The heuristic algorithm can be used to determine optimal path for each goods source and each terminal of each subnet. This algorithm can guarantee enough precision and is very suitable for large scale practical problems. Armacost[4] has carried on the detailed classification research in view of network planning scheme of air express mail delivery. Karen R[5] establishes express package distribution model based on minimizing the total cost. A fuzzy evaluation method of integrated logistics service networks was proposed by Zhao Zhiyan[6]. A framework for transportation decision making in an integrated supply chain was proposed by Stank TP[7]. Optimal production allocation and distribution supply chain networks was proposed by Tsiakis P[8]. A multi-agent system to solve the production-distribution planning problem for a supply chain was proposed by Kazemi A[9]. Meta-heuristic approach with memory and evolution for a multi-product production/distribution system design problem was proposed by Keskin BB[10]. An agent-based framework for building decision support system in supply chain management was proposed by Kazemi A[11]. Formulating ordering policies in a supply chain by genetic algorithm was given by Chan CCH[12]. Optimizing delivery lead time-inventory placement in a two-stage production-distribution system was written by Barnes-Schuster D[13]. Multicriterion genetic optimization for due date assigned distribution network problems was proposed by Chan FTS[14]. Hybrid genetic algorithm for multi-time period production-
distribution planning was proposed by Gen M[15]. Multi-
item dynamic production-distribution planning in process
industries with diverging finishing stages was proposed by
Rzik N[16]. Dynamic programming decision path encoding
of genetic algorithms for production allocation problems was
proposed by Hua C. Y[17]. Adopting co-evolution and
constraint-satisfaction concept on genetic algorithms to solve
supply chain network design problems was proposed by
Ying-Hua C[18]. The balanced allocation of customers to
multiple distribution centres in the supply chain network was
proposed by Zhou G[19]. To sum up, study of positioning
problem of the path is comparatively mature both at home
and abroad, but the study of fuzzy customer requirements is
relatively few. Location-path problem in the research is a
three layers of the supply chain system with a single factory,
multiple distribution centres and customers. It is assumed
that the factory has no inventory, products are shipped to the
distribution centres, each distribution centre can serve
multiple customers, and each customer can only be supplied
by a distribution centre. The production capacity is infinite
and transport capacity is limited. Then mathematical model
is set up and the main research goal is to minimize operation
cost and transport cost of the distribution centre.

The paper is organized as follows. In the next section,
model of production-distribution is proposed. In Section 3,
production-distribution fuzzy scheduling based on particle
swarm optimization is proposed. In Section 4, the
performance of proposed algorithm is tested. At last, some
conclusions are given in section 5.

II. MODEL OF PRODUCTION-DISTRIBUTION

The researched production-distribution network has a
fixed location of plant, multiple distribution centres and
multiple fixed position of client area. Factory has no
inventory, after the products are produced, they are shipped
directly to the distribution centre. The factory production
capacity is infinite, and it may deliver goods to any of the
distribution centre. (2) The cost of distribution centre includes
fixed start-up costs. Distribution centres have capacity limits,
and each distribution centre can supply goods for multiple
customers. The number of available vehicles of each
distribution centre is known and the vehicle is the same type.
The vehicle cannot be used repeatedly and can not be
transferred to other distribution centre. The demand of
customer is fuzzy.

The directed weighted graph \( G \) is used to describe
vehicle routing problem. \( G=(V,A,C) \),
\( V=\{i \mid i=0,\ldots,n\} \) represents vertices set.
\( A=\{(i,j) \mid i,j \in V\} \) represents arc set which connect
each vertices. \( C=\{c_{ij} \mid (i,j) \in A\} \) represents weight
matrix and \( c_{ij} \) represents distance between customer \( i \) to
customer \( j \). Any vehicle can not surpass its permitted load,
each customer is only supplied by one vehicle and is only
served once. Each vehicle starts from warehouse and returns
to warehouse at last. \( s=\{r_i \mid i=1,2,\ldots,k\} \), \( r_i \) represents
one path of vehicle.

Each customer is served once, each path starts and ends
on the same distribution centre, and the total load capacity is
no more than capacity of vehicles. The total load of each
path should not exceed capacity of the distribution centre,
which is responsible for the path. The demand of customer
is uncertain. Production-distribution model of single factory-
multiple distribution centres-multiple customers are as
follows.

\[
c_{ij} \text{ represents transportation cost between } i \text{ and } j. \quad a_i \text{ represents transportation cost from factory to distribution}
\]

\[
centre i. \quad W_i \text{ represents the number of distribution centre } i. \quad S_i \text{ represents start-up cost of distribution centre } i. \quad d_{jk} \text{ represents demand of customer } j. \quad Q_i \text{ represents capacity}
\]

\[
of vehicle } k. \quad T \text{ represents start-up cost of vehicles from}
\]

distribution centre to customer. The targeted function is

\[
\min f=\sum_{i=1}^{n}(a_i+s_i)+\sum_{i=1}^{n}c_{ij}x_{ijk}+\sum_{i=1}^{n}\sum_{j=1}^{m}W_{ij}y_{ij} \\

(1)
\]

The constraints are as follows.

\[
\sum_{k=1}^{K}x_{ijk}=1, \quad \forall j \in J, \quad (2)
\]

\[
\text{pos} \left\{ \sum_{j=1}^{m}\sum_{k=1}^{K}d_{ijk}x_{ijk} \leq Q_{ij} \right\}, \quad \forall k \in K, \quad (3)
\]

\[
\text{pos} \left\{ \sum_{j=1}^{m}\sum_{k=1}^{K}T_{ijk}y_{ijk} \leq W_{ij} \right\}, \quad \forall i \in I, \quad (4)
\]

\[
\sum_{j \in V}x_{ijk}-\sum_{j \in V}x_{jik}=0, \quad \forall k \in K, \quad \forall i \in V, \quad (5)
\]

\[
\sum_{i \in S}x_{ijk} \leq 1, \quad \forall k \in K, \quad (6)
\]

\[
\sum_{i \in S}x_{ijk} \leq |S|-1, \quad \forall S \in J, \quad \forall k \in K, \quad (7)
\]

\[
x_{ijk} \in \{0,1\}, \quad \forall i \in V, \quad \forall j \in V, \quad \forall k \in K, \quad (8)
\]

\[
y_{ij} \in \{0,1\}, \quad \forall i \in I, \quad (9)
\]

The formula (1) represents that the sum of distribution
centre start-up cost, distribution cost of vehicles and start-up
cost of vehicles is smallest. Formula (2) ensures that each
customer belongs to one route and is only accessed once.

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Formula (3) ensures possibility that meets the vehicle capacity is not less than $\lambda_1$. Formula (4) ensures possibility that meets the distribution centre capacity is not less than $\lambda_2$. Formula (5) and formula (6) ensures that each path starts and ends the same distribution centre. Formula (7) ensures the elimination of sub-paths. Formula (8) represents whether the vehicle goes through the path. Formula (9) represents whether the distribution is selected. Because formula (3) and formula (4) have fuzzy parameters $d_j = (\alpha, \beta, \gamma)$, so some actions should be carried.

Supposing the left capacity of vehicle is $\Delta W_k$, after vehicle $k$ distributes all customers. The left capacity of distribution centre is $\Delta W_k$, after distribution centre serves for all customers completely.

\[
\Delta Q_k = (\Delta Q_{k1}, \Delta Q_{k2}, \Delta Q_{k3})
\]

\[
\Delta W_k = (\Delta W_{k1}, \Delta W_{k2}, \Delta W_{k3})
\]

Constraints (3) and (4) are equivalent to the following inequation.

\[
pos(\Delta Q_k \geq 0) = \begin{cases} 
\Delta Q_{k3} > 0, \\
\frac{\Delta Q_{k3}}{\Delta Q_{k1} - \Delta Q_{k2}}, & \Delta Q_{k3} < 0 < \Delta Q_{k2} \\
0, & \Delta Q_{k3} \leq 0
\end{cases}
\]

\[
pos(\Delta W_k \geq 0) = \begin{cases} 
\Delta W_{k3} > 0, \\
\frac{\Delta W_{k3}}{\Delta W_{k1} - \Delta W_{k2}}, & \Delta W_{k3} < 0 < \Delta W_{k2} \\
0, & \Delta W_{k3} \leq 0
\end{cases}
\]

III. PRODUCTION-DISTRIBUTION FUZZY SCHEDULING

The initial value is produced by means of fuzzy c-means algorithm. The $n$ number of elements is separated into $c$ number of clustering. The weighted square sum between each data point and each clustering centre is

\[
J_{FCM} = \sum_{i=1}^{c} \sum_{j=1}^{m} (\mu_{ij})^m |x_j - y_i|^2
\]

$x_j$ represents the vector feature of the j-th customer, $v_i$ represents the i-th clustering centre, $\mu_{ij}$ represents membership of the j-th customer to the i-th clustering centre, and $m$ represents convergence parameter, which controls convergence speed. The membership degree is calculated by means of harmonic mean. The process of calculating initial solution is as follows.

Step1. Set the minimal error value of distance between initial clustering centre and the new centre.

Step2. Determine the initial number of clustering, which is determined by the total customer demand and capacity of each vehicle.

Step3. After determining $c$ number of clustering, $c$ number of average value is taken as initial centre of the clustering.

Step4. Calculate membership values between the current customers and clustering centres. Check the membership value of each customer to select the cluster with the highest membership value and this customer is assigned to this cluster. At this time, it is required to determine whether it conforms to constraint of the vehicle capacity. If it meets the constraint, the customer demand accumulates to the vehicle capacity in this cluster and turn to the next customer, until all of the customers belong to their corresponding clusters.

Step5. The vehicles of the full capacity are not considered, then determine whether there exists clustering centres. If there exists clustering centres, return to step 4. Otherwise, the update stops.

The continuous distribution centre location model is encoded and location of each particle is encoded with floating point number. Each particle consists of a two row of matrix, the first row represents the location of distribution centre and the second row represents distribution between distribution centre and customer. The initial location of distribution centre is $2m$ number of floating point number, which is $(x_i, y_i)$,

\[
\begin{pmatrix}
[x_{i1}, y_{i1}, x_{i2}, y_{i2}, \ldots, x_{im}, y_{im}]
\end{pmatrix},
\]

$i = 1, 2, \ldots, m$, $x_{ic} \leq x_i \leq x_{ic} + m$, $y_{ic} \leq y_i \leq y_{ic}$. $(x_{ic}, y_{ic})$ represents the coordinates at the starting point and $(x_{ic}, y_{ic})$ represents the coordinates at the end point.

The distribution path is represented by $z_q$. $z_q$ represents that the path between distribution centre $i$ and customer $j$ is selected. The particle speed consists of a two row of matrix, the first row of which is $2m$ number of floating point number, $v = [v_1, v_2, \ldots, v_{2m}]$.

The number of particles is $n$ and the dimension of searching space is $D$. $X_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ represents location of the i-th particle. $P_i = (p_{i1}, p_{i2}, \ldots, p_{id})$ or $P_{best}$ represents the historical best position. In the swarm
the historical best location of all particles is marked as $g_{best}$. $V_i = (v_{i1}, v_{i2}, \ldots, v_{id})$ represents the speed of particle $i$. Particle location and speed are adjusted according to (11) and (12) respectively.

$$v_{id} = v_{id}^{k-1} + c_1 \text{rand}(p_{id} - x_{id}^{k-1}) + c_2 \text{rand}(p_{gd} - x_{id}^{k-1})$$

$$x_{id}^k = x_{id}^{k-1} + v_{id}^k.$$  

(11) and (12)

$c_1$ and $c_2$ are constant. $w$ is inertia weight, $\text{rand}_i$ and $\text{rand}_d$ are random numbers belonging to $[0,1]$. $x_{id}^k$ represents the d-th dimension component of location vector of particle $i$ in the k-th iteration and $v_{id}^k$ represents the d-th dimension component of speed vector of particle $i$ in the k-th iteration. $p_{id}^k$ represents the d-th dimension component of individual best position $p_{best}$ of particle $i$. $p_{gd}$ represents the d-th dimension component of global best position $g_{best}$ of particle $i$. The location of distribution centre can be calculated by particle swarm optimization.

Step1. Initialize the speed and location of the particle.

Step2. Calculate fitness value of each particle in the swarm. Historical optimal value and historical optimal location corresponding to this particle are obtained. The individual with the best fitness value in the swarm is taken as the global optimal value.

$$f(z_i) = \sum_{i \in I} (a_i + S_i) y_{ij} \quad \text{fitness} = \frac{1}{f(z_i)}.$$  

Step3. Update the speed and location of all particles according to (11) and (12).

Step4. Calculate fitness value for each particle. The fitness values are compared with historical optimal value of the individual. If the fitness value is better than historical optimal value of the individual, the new location is taken as the new historical optimal value of this particle. Compare the individual optimal value with the global optimal value to determine the new global optimal value.

Step5. Determine whether it meets the stopping condition and output result. Otherwise, turn to step 3.

$$f(z_2) = \sum_{i \in I} \sum_{j \in C} \sum_{k \in K} c_{ij} x_{ijk} + \sum_{i \in I} \sum_{j \in C} \sum_{k \in K} T x_{ijk}$$

is a typical vehicle path problem, which can be solved by tabu search algorithm. The accepted solution after each iteration is taken as taboo object, which is put into the taboo table. After a fixed number of iteration, the algorithm stops.

IV. NUMERICAL EXAMPLES

There are four number of distribution centres, one enterprise, and twenty number of customers. The coordinates range of customers are generated randomly from (0, 0) to (100, 100). The demand is generated randomly from 0 to 100. The distance is Euclidean distance. $c_{ij} = 0.6 \text{ yuan} / \text{ km}$, $\lambda_1 = \lambda_2 = 0.95$. The maximum iteration number is 200. For the particle swarm optimization, $w = 1.6$, $c_1 = 1.7$, $c_2 = 1.7$, the maximum iteration number is 200. For the tabu search algorithm, taboo length is 8 and 50 number of adjacent areas of current solution are searched in each iteration. Fixed cost of establishing the distribution centre is shown in table I. The maximum capacity of each distribution centre is shown in table II. The location and demand of each customer is shown in table III and the location of each distribution centre is shown in table IV.

<table>
<thead>
<tr>
<th>distribution centre</th>
<th>$K_1$</th>
<th>$K_2$</th>
<th>$K_3$</th>
<th>$K_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>fixed cost</td>
<td>2500</td>
<td>2000</td>
<td>2500</td>
<td>3000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>distribution centre</th>
<th>$K_1$</th>
<th>$K_2$</th>
<th>$K_3$</th>
<th>$K_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>capacity(ton)</td>
<td>6500</td>
<td>6000</td>
<td>8000</td>
<td>7000</td>
</tr>
</tbody>
</table>
algorithm, particle swarm optimization and so on. Besides, genetic algorithm and other intelligent computing can be used to select the location of distribution centre, the result of which can be compared with the result of proposed scheme. In the future, convergence speed and accuracy based on particle swarm optimization will be studied.

REFERENCES