4PL Routing Problem on fuzzy Time Varying Networks

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Abstract
Based on the time varying networks, the traveling condition is affected by many uncertain factors like weather and human beings. In this paper, a fourth party logistics routing problem on fuzzy time varying networks is proposed, where the third party logistics' transportation time is dependent on the departure time. A fuzzy program model is built on the uncertain theory. A genetic algorithm with fuzzy simulation method is used to solve the problem. The numerical analysis is presented and the results show that the model presented here is practical in the real world.
Key words: *fourth party logistics; fourth party logistics routing problem; genetic algorithm; fuzzy time varying networks; credibility theory*

1 Introduction
The Fourth-Party Logistics (4PL)' concept was proposed by Accenture [1], which focuses on how to organize multiple Third Party Logistics (3PLs) to work together. Many studies have been conducted on 4PL, such as its historical inevitability, advantages, and development prerequisites [2, 3], and the optimization of operational problems like the routing problem in 4PL (4PLRP) [4, 5].

The routing problem is one of the most important issues in the logistics. When studying the routing problem in 4PL, the researchers found that it is more difficult than studying the routing problem in 3PL because more issues, such as the selection of 3PL providers, cost and time factors, and the capacity and reputation of 3PL providers, should be considered. In recent years, the 4PLRP has attracted increasing attention from researchers. For example, Huang et al. [4] presented 4PL routing problem (4PLRP) model with uncertain delivery time. Cui et al. [5] proposed 4PLRP model with fuzzy duration time and cost discount. Liu et al. [6] considered the resource allocation and activity scheduling for 4PL. Chen et al. [7] built a fuzzy integer goal programming for 4PLRP.

These researches make a big contribution for the 4PLRP. For describing the uncertainty on the route, the time parameters were assumed to be stochastic or fuzzy. But in the real-life situation, the transportation time of a 3PL in the network depends on the departure time. In some optimal researches, they used time varying network to depict it, which could reflect the influence of time period to the cost and transportation speed[8-10]. However, in practice, the transportation speed will also fluctuate with the time period. Using the time varying network can only characterize multi certain information pieces, rather than dynamic, uncertain ones.

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Considering the above two aspects， In this paper, the fuzzy time varying time is used to depict the uncertainty on the route. Firstly, a description of fuzzy time varying network is given, and a fuzzy programming model on the fuzzy time varying network is established. Then, a Genetic Algorithm with fuzzy simulation is proposed to the model. Furthermore, the numerical analysis is used to analysis the problem. The results show that the proposed method is effective and efficient.

2 Problem Description

2.1 Problem Description

A 4PLRP on the fuzzy time varying network is defined as follows:

Assumed that a 4PL company undertakes a logistics task from v_1 to v_n and the cities between them ($v_2 \ldots v_n$) are the transferring nodes. If there is any business between any two cities, an edge will be added and the two cities are connected. Each city has the properties of cost and time. Since there may be several 3PL companies that could provide service between the two connected cities, there may be multiple edges between them. Each edge also has properties of cost and time. Then the whole logistics network of 4PL can be described as a multi-graph (see Fig.1).

The multi-graph depicted above is defined by $G(V,E)$, where $|V| = n$ is the number of cities, and E is the number of edges.

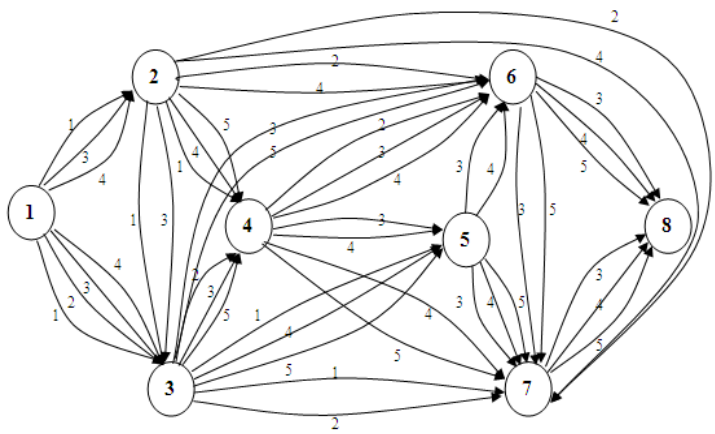

Fig. 1 – The Multi-graph of the 4PLRP

The parameters and decision variables are described as follows:

Parameters

r	the number of 3PL suppliers for 4PL
$\dot{T}_{ijk}(t)$	the kth 3PL supplier's fuzzy traveling time from node i to node j when it arrived at i on the tth day
T_i	the staying time of node i
$T_i^{'}$	the translation time of node i
C_{ijk}	the cost of the kth 3PL supplier from node i to node j
C_i	the staying cost of node i
$C_i^{'}$	the translation cost of node i
b_i	the number of goods received by node i, which is defined as

$$b_i = \begin{cases} -1, & if \text{ i } is\ the\ source\ node \\ 1, & if \text{ i } is\ the\ destination\ node \\ 0, & otherwise \end{cases}$$

TV	the number of time periods
$VTime$	the time interval at each time period
$Time_{ijk}(q)$	the time of the kth 3PL supplier arrived at the tth day from node i to node j when arrived node i at the [q,q+1) period($i, j = 1,2,\ldots,n$, $k = 1,2,\ldots,r$, $q = 1,2,\ldots,TV$)

For the fuzzy varying time considered in this paper, the time $\tilde{T}_{ijk}(t)$ is computed as follows:

If 3PL arrived i at t and $t/VTime \in [q, q+1)$, then $T_{ijk}(t) = Time_{ijk}(q)$

Decision variables

$x_{ijk}(t)$	1 if the kth edge from node i to node j (i, j =1, 2, . . . , n; k = 1,2,. . . , r) is selected at t ; 0 otherwise
$y_i(t)$	1 if node i undertakes the task at t; 0 otherwise
$z_i(t)$	1 if transfer the 3PL supplier on the node i at t; 0 otherwise

2.2 Formulation of the Problem

The objective of this problem is to find a route with minimum cost and time. The mathematical model can be described as follows:

$$\min\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{r}\tilde{T}_{ijk}(t)x_{ijk}(t) + \sum_{i=1}^{n}T_i y_i(t) + \sum_{i=1}^{n}T'_i\, z_i(t)\right) \quad k \in \{1,2,\ldots,r\} \tag{1}$$

s.t.

$$\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{r}C_{ijk}x_{ijk}(t) + \sum_{i=1}^{n}C_i y_i(t) + \sum_{i=1}^{n}C'_i\, z_i(t) \le C \tag{2}$$

$$\sum_{i=1}^{n}x_{ijk}(t) - \sum_{i=1}^{n}x_{jik}(t) = b_j,\ j \in \{1,2,\ldots,n\},\ k \in \{1,2,\ldots,r\} \tag{3}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{r}x_{ijk}(t) = y_j(t), \quad j \in \{1,2,\ldots,n\} \tag{4}$$

$$\sum_{j=1}^{n}\sum_{k=1}^{r}x_{ijk}(t) = y_i(t), \quad i \in \{1,2,\ldots,n-1\} \tag{5}$$

$$x_{ijk}(t), y_i(t), z_i(t) = 0 \text{ or } 1, \quad i, j \in \{1,2,\ldots,n\}, k \in \{1,2,\ldots,r\} \tag{6}$$

In the model, Eq. (1) is the objective function for minimize the sum of time on the route; Eq. (2) is a constraint to ensure the cost used on the route is not more than C ; Eq. (3) maintains a balance of the network flow; Eq. (4) and Eq.(5) ensure that the selected nodes and edges are made up of the route; Eq.(6) defines x, y and z respectively as 0-1decision variables.

In the above model, the objective function (1) contains fuzzy parameters. We use credibility theory to describe it as follows:

$$\min\left(\bar{T}\right) \tag{7}$$

$$Cr\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{r}\tilde{T}_{ijk}(t)x_{ijk}(t)+\sum_{i=1}^{n}T_i y_i(t)+\sum_{i=1}^{n}T'_i\, z_i(t)\le \bar{T}\right)\ge \alpha \tag{8}$$

Which means that the credibility that the time needed on the route is not more than the time $\bar{T}$ required by the customer is not less than a, where a is a defined confidence level ($0\le\alpha\le 1$). And the objective is change to be minimize $\bar{T}$.

3 Algorithm Design

In this section, the genetic algorithm designed in [5] is used to solve the problem formulated above, which is shown as follows.

3.1 Fuzzy simulation

In our problem model, the constraint in Eq. (2) contains fuzzy parameters. In this subsection, we use fuzzy simulation [31] to estimate it, which is given as follows:

Suppose x and y are two decision vectors, which are composed of $x_{ijk}(t)$ and $y_i(t)$ (i, j =1, 2, . . . , n; k = 1,2,. . . , r) respectively.

Let

$$f(x,y,\xi,\eta)=\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{r}\xi_{ijk}x_{ijk}(t)+\sum_{i=1}^{n}\eta_i y_i(t) \tag{9}$$

where ξ and η are fuzzy vectors composed of ξ_{ijk} and η_i (i, j $\in$ {1,2,…, n}; k $\in$ {1,2,…,r}) respectively. And we denote that $\mu_{\xi_{ijk}}$ is the membership function of ξ_{ijk}, and μ_{η_i} is the membership function of η_i, respectively.

In the following, we will show how to simulate the fuzzy function:

$$U:(x,y)\to \min\{\bar{f}\mid Cr\{f(x,y,\xi,\eta)\le \bar{f}\}\ge\alpha\} \tag{10}$$

where $0\le\alpha\le 1$.

Firstly, generate θ_{ijk}^{q} and σ_i^q from the ε-level sets of fuzzy variables ξ_{ijk} and η_i (i, j $\in$ {1,2,…, n}; k $\in$ {1,2,…,r}) respectively, where ε is a sufficiently small positive number, q = 1, 2,…,N, and N is a sufficiently large number. Set $\nu_q=\min_{i,j,k}\{\mu_{\xi_{ijk}}(\theta_{ijk}^{q})\}\wedge\min_{i}\{\mu_{\eta_i}(\sigma_i^q)\}$ (q =1,2,…,N). According to the concept of credibility measure [31], for any number r, we set

$$L(r)=\frac{1}{2}(\max_{1\le q\le N}\{\nu_q\mid f_q(x,y)\le r\}+\min_{1\le q\le N}\{1-\nu_q\mid f_q(x,y)>r\}) \tag{11}$$

It follows from monotonicity that we may employ bisection search to find the maximal value r such that $L(r)\ge\alpha$. This value is an estimation of $\bar{f}$. The process can be run as follows:

Step 1: Set s := 1.

Step 2: Generate θ_{ijk}^{q} and σ_i^q from the ε-level sets of fuzzy variables ξ_{ijk} and η_i (i, j $\in$ {1,2,…, n}; k $\in$ {1,2,…,r}) respectively, where e is a sufficiently small positive number, and q = 1, 2,…,N.

Step 3: Set $\nu_q = \min_{i,j,k}\{\mu_{\xi_{ijk}}(\theta_{ijk}^q)\} \wedge \min_i\{\mu_{\eta_i}(\sigma_i^q)\}$ for q =1,2,…,N.

Step 4: Find the minimal value r such that $L(r) \geq \alpha$.

Step 5: Set $\bar{f}$:= r.

3.2 The framework of genetic algorithm

Step 1: Initialize the adjacent matrix according to the model graph.
Step 2: Generate the initial population of PS individuals with fuzzy simulation, where PS denotes the population size.
Step 3: Calculate the time by time varying network.
Step 4: Select individuals by the roulette wheel selection scheme.
Step 5: Perform crossover operations on pairs of selected individuals with a crossover probability Pc.
Step 6: Update the capacity infeasible 3PL providers with feasible ones.
Step 7: Perform mutation operations to individuals with a mutation probability Pm.
Step 8: Calculate the fitness value of each solution and update the elitism if a better solution arises.
Step 9: Check whether the maximum allowable number of generations, denotAed NG, is reached. If not, go to Step 4; otherwise, go to Step 10.
Step 10: Stop the process and output the best solution.

4 Numerical Experiments

The algorithm is coded in matlab 7.0 and run on a Core 2 2.83GHz computer. Run the algorithm 100 times and obtain the best solution (Best), the worst solution (Bad), the rate of finding the optimum (Rate). The 'Time' means the time taken by the algorithm running for one time(second), and the costs in the following are recorded by 100Yuan.
The parameters are set below:

$$Ps = 20, NG = 50, Pc = 0.4, Pm = 0.025$$

If the fuzzy time is depicted by the triangular number, the data of nodes and 3PL suppliers (edges) are shown as Table 1 and Table 2:

Table 1 The data of nodes

Node	Staying cost	Transit cost	Staying time	Transit time
1	1	2	0.5	1.5
2	2	3	0.5	0.6
3	2	3	0.5	0.6
4	5	10	1	1.2
5	3	5	3	4
6	4	6	1	2
7	2	4	1	1.5
8	1	3	1	1

Table 2 The initial data of 3PL suppliers

S	D	E	c	$Time_{ijk}^{L}(1)$	$Time_{ijk}^{m}(1)$	$Time_{ijk}^{U}(1)$	S	D	E	c	$Time_{ijk}^{L}(1)$	$Time_{ijk}^{m}(1)$	$Time_{ijk}^{U}(1)$
1	2	1	1	0.25	0.3	0.4	3	6	5	8	15	17	20
1	2	3	2	0.2	0.25	0.5	3	7	1	9	17	19	22
1	2	4	3	0.1	0.15	0.3	3	7	2	10	15	17	20
1	3	1	3	1.2	1.5	1.9	4	5	3	6	8	10	13
1	3	2	5	1	1.3	1.6	4	5	4	7	7	9	11
1	3	3	4	1	1.4	1.8	4	6	2	13	20	22	25
1	3	4	6	0.8	1.2	1.5	4	6	3	14	17	20	23
2	3	1	5	2	2.2	2.5	4	6	4	12	20	23	26
2	3	3	6	1.5	2	3	4	7	4	14	22	24	27
2	4	1	10	2	3	4	4	7	5	15	24	26	28
2	4	4	8	3	4	6	5	6	3	8	3	3.5	4
2	4	5	6	3	5	6	5	6	4	7	2.8	3.2	3.8
2	6	2	10	17	20	24	5	7	3	10	3.2	3.8	4.1
2	6	4	11	15	19	22	5	7	4	8	3.2	4.1	4.5
2	7	2	11	18	22	25	5	7	5	11	2.5	3.5	4.8
2	7	4	12	16	20	23	6	7	3	2	0.5	1.1	2
3	4	2	5	1	1.5	2	6	7	5	3	0.4	0.9	1.5
3	4	3	4	1.2	1.8	2	6	8	3	1	0.3	0.6	1
3	4	5	3	1.1	1.6	1.9	6	8	4	2	0.2	0.5	0.8
3	5	1	9	10	11	13	6	8	5	3	0.2	0.4	0.7
3	5	4	7	10	13	15	7	8	3	3	0.1	0.3	0.5
3	5	5	8	11	12	14	7	8	4	1	0.3	0.5	0.8
3	6	3	9	13	16	18	7	8	5	2	0.2	0.4	0.7

The first time section for the 3PL ($Time_{ijk}^{g}(1)$,where $g = L, M\ or\ U$) is shown in Table 2, and the others are generated randomly as follows：

```
for q=2:TV
    rand:=random[0,1];
    if rand>0.5
        Time^g_ijk(q) = Time^g_ijk(1) *（1+ random[0,1]）
    else
        Time^g_ijk(q) = Time^g_ijk(1) *（1- random[0,1]）
    end if
end for
```

If TV=50, VTime=2, PL=5, a =0.8, the optimal solution is:

path: [1 3 4 7 8]; PL: [4 5 4 4]

where the time is 12.2.

In the 4PL operation, it means that when they want to transport food from node1 to node8, the best choice is to undergo node3, node4 and node7 as two ports, and the indexed 3PL suppliers are 4,5,4,4 on the four chosen path finished the task respectively one by one.

5 Conclusion

In order to formulate the time varying uncertainty on the route, a 4PL routing problem on the fuzzy time varying networks was discussed. Firstly, a fuzzy integer programming model was built. Secondly, a genetic algorithm with fuzzy simulation was used to solve the problem. And the numerical results were given to show the transportation process on the 4PLRP.

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