**LOGISTICS PATH OPTIMIZATION BASED ON COGNITIVE PSYCHOLOGY AND CONSUMERS’ PSYCHOLOGICAL PREFERENCE OF WAIT TIME**

**Jian Li***

**Abstract**

Currently, the logistics path planning often falls short of the consumers’ preference of wait time. Based on cognitive psychology, this paper aims to optimize the logistics path from the perspective of consumers’ psychological preference of wait time. Starting with the traditional ant colony algorithm, a hybrid ant colony algorithm was designed, which chooses the path randomly, and determines the logistics path in a manner similar to roulette selection. The logistics path was optimized by means of cumulative foreground model. Through simulation experiment, the hybrid ant colony algorithm was found to effectively optimize logistics path; the cost of logistics transportation does not need to be optimized if the consumers have a high psychological preference for wait time; the pheromone volatilization factor between nodes has a positive correlation with path selection speed and the satisfaction of consumers’ psychological preference. The research findings provide a new reference for optimizing logistics path in the light of cognitive psychology and consumer preferences.

**Key words:** Logistics Path, Wait Time, Psychological Preference, Hybrid Ant Colony Algorithm.

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**INTRODUCTION**

Along with the improvement of production and management technology, the competition between enterprises has become increasingly fierce, and the focus of competition has shifted from production to non-production field. Enterprises have attached more importance to the logistics activities such as transportation, packaging, and loading and unloading (Ashutosh & Banwet, 2015). Also, the logistics supply chain management model has evolved from the traditional vertical management model to the horizontal management model. Therefore, the optimization of the logistics path is an important factor for the competitiveness of enterprises (Yu, Yue, Lu et al., 2018). At present, the logistics industry has increasingly become the mainstream business model, but most third-party logistics enterprises or suppliers simply transport the goods that customers demand. Such mode of transportation wastes the utilization of the overall resources and decreases the profit margin of the logistics industry gradually (Szczesny & König, 2015, Kazakov, Lempert, & Bukharov, 2013). Nowadays, the terms such as third-party logistics (3PL) and fourth-party logistics (4PL) are emerging one after another. In reality, it’s the logistics providers with leadership strength who integrate the entire logistics supply chain, and then the whole resources. Currently, 4PL grows the fastest (Schneider, Gschwind, & Vigo, 2018).

Consumers’ psychological preference of wait time is the most direct factor to evaluate logistics transportation. From the perspective of consumers’ cognitive psychology, the longer wait time consumers can withstand, the more reasonable the optimization of logistics path is, but different consumers have different
psychological preferences of wait time, which causes great difficulties in optimizing the logistics path (Cho, Lee, Cho et al., 2016; Wells & Martin, 2017). Aimed at improving the overall competitiveness of the supply chain, logistics path optimization is a series of activities to meet the needs of users and reduce the wait time of consumers by coordinating the physical flow, information flow and capital flow together with each enterprise on the supply chain (Almeida, 2014). In order to meet the consumer’s psychological preference of wait time, logistics path optimization first needs to optimize the time sequence, synchronize the logistics path optimization and the logistics service provider optimization, and then make selection according to the consumer’s cognitive psychology and bearing status of psychological preference (Shih, 2012). Based on the theory of cognitive psychology, this paper aims to optimize the logistics path using the 4PL logistics supply chain approach from the perspective of consumers’ psychological preference of wait time.

PATH OPTIMIZATION PROBLEM MODEL AND ITS ALGORITHM DESIGN

At present, there are four main operation modes of logistics, including collaborative operation mode, integrated operation mode, industry innovation operation mode and dynamic alliance operation mode. Among them, the dynamic alliance operation mode can provide various and individualized services according to consumers’ psychological preference of wait time, and the path information of each logistics in the supply chain communicate with each other, so as to truly achieve a wide range of resource integration, reduce cost operation and maximize profits (Jalali & Abadi, 2017). Figure 1 shows the specific dynamic alliance operation mode. The ant colony system is a commonly used path optimization model. The commonly used ant colony system algorithm and the max-min ant colony system algorithm are prone to stagnation and slow convergence. In view of this, combined with the advantages of traditional ant colony algorithm, a hybrid ant colony algorithm was proposed, which chooses the path randomly, and determine the logistics path in the similar way to the roulette selection method (Reusche, Rösler, Henriques et al., 2011). Figure 2 shows a seven-node logistics path distribution map; it’s assumed that C and T are the logistics costs and transit times required for passing the nodes respectively; two nodes contain multiple transportation paths, and the logistics cost and transit time required for different transportation paths between the same nodes are different; the i, j and k respectively represent the starting point, the end point of the logistics transportation, and the path selection between the nodes. Then, the minimum time spent on logistics transportation is expressed as:

\[ T_{\text{min}} = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} T_{ijk} x_{ijk} + \sum_{j=1}^{n} T_{j} y_{j} \] (1)

The hybrid ant colony algorithm is applied to optimize the logistics transportation path for reducing the wait time of consumers. The most important is the selection of the path and the update of the pheromone, and the ant uses the pheromone to select the path in the process of finding the optimal path. In this study, the pheromones were seen as the consumers’ wait time (John & Stanley, 2011). From the perspective of cognitive psychology, when the consumer’s psychological preference of wait time is greater, the logistics transporter can choose the path with the lowest logistics cost among many routes, which can both satisfy the wait time of consumers and obtain more benefits.
PATH OPTIMIZATION PROBLEM CONSIDERING CONSUMERS’ PSYCHOLOGICAL PREFERENCE OF WAIT TIME

Algorithm design

Influenced by behavioural factors and psychological effects, consumers' wait time under different psychological cognition and psychological preference also varies. Consumers' satisfaction with logistics enterprises directly affects the choice of logistics service providers, and consumers' psychology preferences directly affect their perception and decision-making about logistics services. In this paper, based on the uncertainty of transportation time, the cumulative prospect theory was applied to explore the 4PL path selection considering the consumer's psychological preference of wait time, and then give the calculation method of the foreground value for logistics transportation time according to the behaviour characteristics of the consumers’ psychological preference of wait time.

Assuming V is a value function, the objective function is the maximum value of the value function, and it’s expressed as:

Objective function: \( \max V \) \hspace{1cm} (2)

According to the cumulative prospect theory, a cumulative foreground model considering the consumers' psychological preference of wait time can be established.

Expected value model: \( \max E(t) = \int_{t_0}^{\infty} f(t)dt, r(t) = t_0 - t \) \hspace{1cm} (3)

Foreground model:
\[ \max u(t) = \int_{t_0}^{\infty} v(t)F(t)dt = \int_{t_0}^{\infty} v(t)f(t)dt \] \hspace{1cm} (4)

where, \( E(t) \) represents the set of edges; \( v(t) \) represents the value function; \( f(t) \) represents the density function.

The improved ant colony algorithm is expressed as:

\[ P_{ijk}(n) = \begin{cases} \tau_{ijk}(n)\omega |\eta_j|^\beta \theta_k(n) \\ \tau_{ijk}(n)\omega |\eta_j|^\beta \theta_k(n) \\ 0, \text{else} \end{cases} \] \hspace{1cm} (5)

where, \( \omega \) and \( \beta \) are parameter coefficients, respectively, and \( \tau \) and \( \eta \) represent the pheromone concentration and the information amount, respectively.

Algorithm analysis

The parameter choice of the algorithm has a great influence on the calculation results of the objective function. According to the number of nodes in the logistics chain, the hybrid ant colony algorithm can effectively solve the time consumed and the mean value. With the number of nodes and path selections between nodes less, the path selection shall be faster, and the stability of the shortest path shall be better. In real life, if the consumers' psychological preferences are different, the values of the parameters will also vary. Figure 3 shows the influence of each parameter choice on the path optimization results. It can be seen that the larger the values of \( \omega \), \( \beta \) and \( \eta \), the longer the wait time of the consumer; the larger the pheromone concentration \( \tau \) value, the easier it is to find the optimal path, and the shorter the wait time of the consumer. Figure 4 compares the cumulative foreground model selected in this paper with the existing expectation model and foreground mode. It can be seen from the figure that when the reference point \( t_0 \) is small, it is difficult for the three models to satisfy the consumer's psychological preference; with the increase of reference point \( t_0 \), the cumulative foreground model value is the smallest, indicating that the logistics path decision tends to be more conservative, and it is easier to make the most profitable logistics transportation path while satisfying the consumer's psychological preference of wait time.

SIMULATION EXPERIMENTS AND ANALYSIS

Parameter analysis of hybrid ant colony algorithm

The analysis was conducted according to the seven-node logistics path distribution diagram given in Figure 2. Figure 5 shows the basic data of nodes for the seven-node 4PL logistics path problem. There are many parameters affecting the optimization of logistics path, including the parameters of the hybrid ant colony algorithm itself such as the information heuristic factor, expectation heuristic factor and pheromone volatilization factor. This experiment was repeated 100 times, to obtain the optimal solution. Figure 6 shows the influence of each impact factor on time, in which the influence of information heuristic factor and expected...
heuristic factor on time does not show obvious regularity; with the increase of pheromone volatilization factor, the time gradually decreases, mainly because the higher pheromone volatilization can lead to faster path selection and shorter time spent, thereby more satisfying the consumer’s psychological preferences.

**Figure 3. The influence of each parameter on the path optimization results**

(a) $\omega$ influence

(b) $\beta$ influence

(c) $\tau$ influence

(d) $\eta$ influence

**Figure 4. The comparison between the cumulative foreground model and the other two models**
**Analysis of consumer wait time**

It’s assumed that the consumer’s wait time is $T_m$, and the expected cost is $C_m$. If the expected cost is 50, the actual cost of the delivery path must be less than 50. Figure 7 shows the optimal solution and time corresponding to the consumer wait time. It can be seen that when the wait time of the consumer is short, the optimal solution is negative, indicating that the delivery time required by the consumer cannot...
be reached; as the wait time of the consumer increases, the optimal solution gradually increases, and there will be more logistics path schemes; also, when the wait time of the consumer is larger, the alternative logistics transportation scheme is increased, and the delivery time is reduced, forming a mutually inspiring manner. Assuming $T_m=65$, the selected logistics path selection with different expected costs was observed. Figure 8 shows the optimal solution and time corresponding to the expected logistics cost of the consumer. It can be seen that the optimal solution and time are increased with the increase of expected logistics transportation cost; when the expected logistics transportation cost is increased to 50, the optimal solution is constant, that is, the logistics path optimization scheme is determined, and the transportation cost can no longer be the influencing factor of the logistics route optimization choice. Table 1 lists the optimal logistics paths for different models. The selected optimal logistics paths are the same using the expected value model and the cumulative foreground model (1-3-6-7), and the optimal logistics path when using the foreground model is (1-3-4-7).

Table 1. The optimal logistics path corresponding to different models

<table>
<thead>
<tr>
<th>Model</th>
<th>Logistics optimal path</th>
</tr>
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<tbody>
<tr>
<td>Expected value model</td>
<td>1-3-6-7</td>
</tr>
<tr>
<td>Cumulative foreground model</td>
<td>1-3-6-7</td>
</tr>
<tr>
<td>Foreground model</td>
<td>1-3-4-7</td>
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Figure 7. The optimal solution and time corresponding to the consumer wait time

CONCLUSIONS

Based on the theory of cognitive psychology, this paper adopts the 4PL logistics supply chain approach from the perspective of consumers’ psychological preference of wait time, and optimizes the logistics path. The specific conclusions are as follows:

(1) Consumers’ satisfaction with logistics enterprises directly affects the choice of logistics service providers, and consumers’ psychological preferences directly affect their perception and decision-making on logistics services. If the consumer’s psychological preference of wait time is greater, the logistics transporter can choose the path with the lowest logistics cost among the many routes, which can satisfy the wait time of consumers and also obtain more benefits;

(2) If the number of nodes and the number of path selections between nodes are less, the path selection shall be faster and the stability of the shortest path shall be higher. Moreover, with different consumer’s psychological preference, the value of the parameter will also vary; with the larger pheromone concentration value, it shall be easier to find the optimal path, and has shorter wait time of the consumer;

(3) When the wait time of the consumer is short, the optimal solution is negative; with the wait time of the consumer increasing, the optimal solution also gradually increases, and there will be more logistics path schemes; with the expected logistics transportation cost...
increasing, the optimal solution and the time also increase; when the expected logistics transportation cost is increase to 50, the transportation cost can no longer be the influencing factor of the logistics route optimization.

REFERENCES