Optimization of Shortest Path of Multiple Transportation Model Based on Cost Analyses

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Abstract **— In transportation process, normally there are several modes to deliver goods and sometimes there is cross-transportation or multimodal transport mode. Meanwhile, in the transportation process, transportation costs, time and risks vary with timeframe. Due to the characteristics of transportation network, transportation costs and transit time will vary with different starting time. Transportation costs can be divided into fixed costs, road transportation costs and transit fees considering multiple influence factors and various options, for instance, railway, airline and waterline. This article illustrates in detail that optimization of shortest path of multiple transportations based on cost analyses and this mode has been verified by genetic algorithm.**

Keywords - multimodal transport; route optimization; shortest path; genetic algorithm

I. INTRODUCTION

With the development of E-Commerce, there is an increasing booming of orders. Single transportation is far less able to meet internet consumers' need, especially during the rapid development of offshore E-Commerce. Offshore E-Commerce logistics are normally required two or more modes of transportation from starting points to its destinations which is multiple transportation. In multiple transportation process, optimization of shortest path are most likely decided by the type of goods, transportation distance, clients need, reliability and flexibility of transportation services and transportation infrastructure.

Due to the increasing needs of multiple transportation, scholars have paid a lot of attention to the multiple transportation mode. There were various theories regarding this matter. Among those, Angelica Lozano (2001) has studied shortest path in multiple transportation mode and verified by sequential algorithm. A straight path under multiple transportation mode has been fully studied by Dezhi Zhang (2002).Other scholars, such as Modesti, Sciomachen (1998) and Angelicalozano, Giovanni Storchi (2002) have all been researched on shortest path of multiple transportation. However, those researches have not taken internet into account.

In reality, time factor has some impact on the targets considered during transportation, such as time, cost, etc. About the subject of the shortest circuit under the time-varying condition, it's mainly concentrated in obtaining the shortest circuit of the shortest transport time under the condition of single mode of transportation. Elise, d. m., Hani s.m., (1998) studied the shortest circuit in the shortest time random time-varying network , proposed and compared two different algorithm .Elise, d. m., Hani s.m (2003) put forward some principles of comparing different paths under random time-varying network. Athanasiso z., Dimit rios k. and Hani, s. m. (1997) analyzed the application of considering the shortest circuit of the shortest time under the condition of the time-varying in intelligent transportation system. Daniele p. (2000) studied the shortest circuit considering the shortest time under the condition of discrete random time-varying hypergraph network, and gave a solution. Elise, d. m. (2001) studied the shortest circuit of the minimum expected travel time under the condition of the time-varying random networks, and gave a algorithm to solve the minimum expected travel time. Sathaporn Opasanon, Elise Miller - Hooks (2006) studied the shortest circuit problem of multi-rules under the condition of the time-varying stochastic network, and gave a solving algorithm. Zhang Jianyong etc. (2002) started from the principle of minimizing the total cost, and set up a kind of optimal allocation model of multimodal transport network, in order to analyze the reasonable organization pattern of the multimodal transport system from the point of quantitation. Wang tao, etc. (2005) put forward a transportation mode combination optimization model after analyzing the transportation characteristics of various modes of transportation, and gave a solving algorithm. Wang Yunpeng etc. (2005) studied the multimodal transport process based on extended Petri net. Michel Beuthe (2001) studied the subject of transportation optimization of minimum cost in the multimodal transportation network composed of road - railway - inland marine etc. 10 categories of goods. Liu Cheng etc. (2005) studied the parallel genetic algorithms of the logistics distribution vehicle routing problem with soft time Windows. Wei zhong etc. (2006) put forward the shortest time path transportation cost model. Herminia I.C alvete (2007) studied the vehicle routing problem with soft time Windows, and put forward the goal programming method for solving the problems. Sun Huacan (2008) put forward the concept of reasonable path, and set up an optimization model of combined transportation path containing the path-rationality constraint, and pointed out that except the transportation benefit maximization, the factors of reasonable sequence of change and the change number must be considered when choosing and optimize a combined transport route.

The studies above have studied systematically various combinations of shortest path and multiple-transportation. The key of multi-networking model is considered from various levels. However, it has its own limitation, some models only considered time, transportation costs or service as conditions. None of the studies have considered various time which also have impact on transportation costs or the influence of transportation volume. Some studied even neglected exchange goods and deliver time with the assumption that transportation volume cannot be divided. In reality, if transportation point has demand on specific goods and volume will change as well. Some research prefer to consider best transportation path as shortest path while in the contrary the choices which have been made are based on fastest way or lowest transportation costs, normally not based on the shortest path. Thus, this paper have analyzed fully optimization of shortest path of multiple transportation model based on costs analyze. The costs refer to the lowest fee under a certain transport time, and those two elements are used to construct this multiple transportation model. In this article, this model will be explained in detail in order to enhance efficiency, reduce transportation fee and optimize transportation path.

II. CONSTRUCTION OF MULTIPLE TRANSPORTATION MODEL

A. Net Point

There are many points where goods can change their transportation method in multiple transportation models. Those points were called net points. Ground rules of changing transportation are as follow:

If there are more than one ways to transfer transportation methods, then connect the two points with lines. One line is equal to one transportation method.

If there is one point that goods could be transfer there, then separate them with nodes. Each way starts and ends with new nodes. This way is named nodes transportation methods.

As can be seen, transportation net is as follow. There are two lines between O and A, refer to highway transportation and railway transportation. Due to transfer at point A, it is divided point A into 4 nudes.

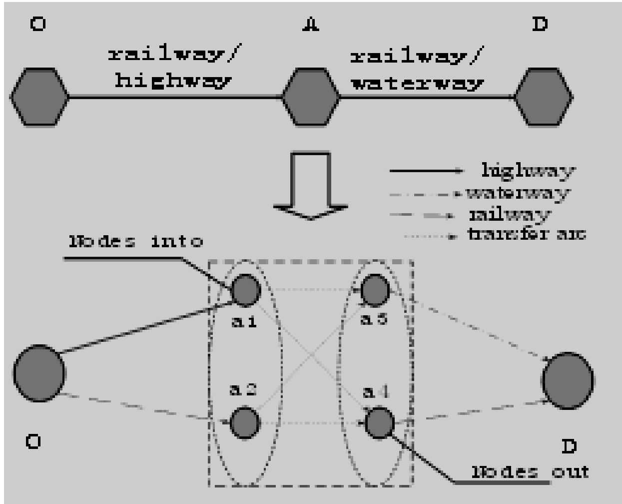

Fig.1 Transformation Of Multimodal Transport Network

B. Model Hypothesis

(1) If the distance between OD is not divided, then there could be one transportation methods between OD.

(2) There is neither adding nor reducing goods during transportation process, or at nodes.

C. Explanations of Symbols

For multimodal transport network $G=(V,E)$, among them, V is the point set of multimodal transport network; $i \in V$ is a node in network; E is the set of multimodal transport network edge; $e \in E$ is an edge in multimodal transport network; M is collection for a batch of goods, $m \in M$ is one kind of these goods; F_m is fixed cost when transporting the goods “m” (RMB); K is the transit transportation mode for selection; $(K,1) \in K$ is a transit way; $t_{i,i+1}^{k}$ is the time required to adopt the mode of transportation k between the nodes i and $i+1$ (min); $c(m,k)$ is the transportation costs when shipping goods “m” with “k” method (RMB); s_i^{kl} is the transiting time at point “i” converting from method “k” to method “l” (min); $c(k,l,m)$ is the transmitting cost of goods “m” from method “k” to “l” (RMB); T is required delivery deadline (min); P_v is a set of multimodal transport midpoint.

$$x_{i,i+1}^{k}=\begin{Bmatrix} 1, choose\ \mathrm{mod}e\ k\ between\ i\ and\ i+1 \\ 0, other \end{Bmatrix}$$

$$y_i^{kl}=\begin{Bmatrix} 1, transportation\ \mathrm{mod}e\ k\ turn\ to\ l\ at\ node\ i \\ 0, other \end{Bmatrix}$$

III. OPTIMIZATION MODEL OF MULTIPLE-TRANSPORTATION

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In reality of multiple transportation process, some points of transmitting have barely occurred (For instance, from airline to water transportation). Therefore, it is taken by nudes. At nudes, it could only select from backup option. Based on those conditions, a multiple transportation model has been established. The exact model is:

$$\min Z = \sum_m F_m + \sum_i \sum_m \sum_k x_{i,i+1}^k c(m,k) + \sum_i \sum_m \sum_k \sum_l y_i^{kl} c(k,l,m) \quad (1)$$

s.t.

$$\sum_k x_{i,i+1}^k = 1 \quad \forall k \in K, \forall i \in V \quad (2)$$

$$\sum_k \sum_l y_i^{ki} = 1 \quad \forall k,l \in K, \forall i \in V \quad (3)$$

$$x_{i-1,1}^k + x_{i,i+1}^l \geq 2y_i^{kl} \quad \forall i \in V, \forall k,l \in K \quad (4)$$

$$\sum_i \sum_k x_{i,i+1}^k t_{i,i+1}^k + \sum_i \sum_k \sum_l y_i^{kl} s_i^{kl} \leq T \quad \forall i \in P_V, \forall k,l \in K \quad (5)$$

$$x_{i,i+1}^k \in \{0,1\} \quad \forall i \in V, \forall k \in K \quad (6)$$

$$y_i^{kl} \in \{0,1\} \quad \forall i \in V, \forall k,l \in K \quad (7)$$

$$\forall i \in V, k \in K, m \in M \quad (8)$$

In the model above, formula (1) represents the cost target function. Cost function is mainly composed with three parts: fixed costs, cost, transfer cost. Formula (2) represents the mode of transportation choice constraint. The constraint between two nodes can only use one mode of transportation. Formula (3) represents that transit operations can only transfer to one mode of transportation. Same node can only be transferred once. Formula (4) represents the mode of transportation before and after the corresponding constraints. If the transformation mode k turns to l at node i, then adopt mode k between node $i-1$ to i and adopt mode l between node i to $i+1$ .Formula (5) represents shipping deadline constraints. Formula (6) and formula (7) represent variable constraint logic. Formula (8) represents variable nonnegative constraints.

IV.TO SOLVE ALGORITHM

The nature of the model is to seek for the shortest path under those conditions. Current algorithm is able to transfer the questions to shortest path from O to D with limited and timeframe. However, it is rather difficult to have the best practice or the most satisfied solution. Thus, this paper constructs based K how to calculate the shortest path. The main thought is : Starting with Dijkstra algorithm to calculate the shortest time path to end destination, then find the second shortest time path, the third shortest time path and so on. Afterwards to search those options to find the best practice based inherit algorithm.

A. Finding All Paths within Deadline with the Dijkstra Algorithm

When using the Dijkstra algorithm to find out short circuit problem under the circumstance of time-varying, the symbol of each point is $[(\lambda_i, \varepsilon_i, v, T_i)]$, λ_i is the node before the node i . ε_i is the mode of transportation before the node i (1 represent railway ; 2 represent highway; 3 represent waterway; 4 represent airline; 5 represent transit); v represents the stage number; T_i represents the time it takes to reach node i ; S is defined as the set of fixed label point, $\bar{S}$ is defined as a temporary marking point set.

According to Dijkstra algorithm, the labels of the vertices in the network can be divided into two categories, fixed label and temporary marking label. The idea of this algorithm is keep changing temporary label to fixed index from the starting point. Find out the shortest path from the starting point to other points. The time of stage v reaching point i can be expressed as $T_i = T_{\lambda_i} + \sum_m T(m, \varepsilon_i)$. $T(m,\varepsilon_i)$ represents the transport time of goods m with transportation method ε_i .

The steps to find all paths within deadline with the Dijkstra algorithm are as follows:

Step 1 According to the actual physical network; we take the form of figure 1to split network node. There are no contraindications on alternative transit ways. So we get a weighted directed graph, the weight of each side represents a certain goods transportation time and transportation cost, the weight on transfer arc represents the transit time and transit fees.

Step 2 $v = 0, S^{(0)} = \{v_0\}$, v_0 represents the starting transport point of goods, let other points in the network into $\bar{S}$, and given that $T_{v0} = 0, T_{vi} = +\infty$, the starting point is $[(-,-,0,0)]$ in the network, label for other nodes is $[(-,-,0,+\infty)]$.

Step 3: Make $v = v+1$ .Modify and fix the temporary label points attached to the label and calculate the time of the temporary label points, which is $T_{v_i}^{\varepsilon+1} = \min\{T_{v_i}^{\varepsilon}, T_{v_s} + T(\varepsilon_{v_i})\}$. Among them, v_l represents temporary label; v_s represents a fixed number. Calculate value of temporary label node v_l and T_{v_l} . If the information in the temporary label is $T_{v_i} < T$, the label on that point need to be updated. If in one of the phases (except the first one), all the labels in the points connecting to the fixed index point set S are the initial labels, then are connected to the temporary label points depending on the fixed before the label information push, find the point $\varepsilon_i = 5$ to disable the point before the transfer arc, deleted from the fixed label set point S after all has the fixed point label, and the point is set to the initial label all the label information. And then from all points with temporary label, select the time value of minimum point, change the time minimum point to fixed label, and that point to be included in the fixed label point set S .

Step 4 If the end of the goods has been fixed label, then stop counting, at this point can be launched by the end fall under the condition of time-varying shortest path, fixed label λ_i is in the front, and ε_i is the mode of transportation between that point and the former point, so we can get a path that contains transportation way and the road. If the end of the goods are not fixed label, then go to step 3.

Step 5 When getting the shortest time path, then find the sides of the shortest time path contained, respectively removed them from the weighted directed graph, so we get some atlas, then in accordance with steps 2 to 4 respectively, and then find out the shortest time path in each child figure.

Step 6 Then for each child figure to step 5, if the child figure does not exist in the third step in the figure label information that meet $T_{v_i} < T$, then stop calculation. So on, until finding all shortest time path that meet the shipping deadline.

B. *Using Genetic Algorithms K Shortest Path to Find Satisfactory Cost Path*

In this paper, genetic algorithms use symbol coding method, each chromosome locus symbols have expressed a mode of transport, each locus sequence corresponding to an arc on the given path. The number of arcs on the path minus is equal to the length of the chromosome number of nodes on a given path. For a given path, each chromosome and a hybrid mode of transport agents may be used in correspondence, this mode of transport and route will link up. Crossover algorithm uses single point crossover, and mutation operators are using the basic alleles specific implementation: the value of each allele at chromosome mutation probability mutate into symbols of other modes of transport. Select mode selection method based on the ratio of fitness through roulette ways, in addition to ensure the convergence of the algorithm, the algorithm embedded elitist strategy: if the current -generation algorithm produced the best individual so far worse than the best individual, then the individual with the best so far in the random replace a new group of individuals.

Algorithms shut down condition with the maximum number of generations, iterative algorithm terminates when the condition is not met.

Specific steps above K using genetic algorithms to find satisfactory cost path search path is :

Step 1 For a given path, genetic algorithms input various parameters : population size, maximum number of generations, as well as crossover and mutation probabilities ;

Step 2 initial population to calculate the fitness of all chromosomes in the population, statistical indicators initial population ;

Step 3 Select the group to perform the operation, to generate a matching pool ;

Step 4 crossover implementation: repeatedly perform the following operations until the new offspring chromosome number equal to the population size: ① two chromosomes randomly selected from a pool match ; ② elected to perform two chromosomes crossover operation according to the crossover probability ;

Step 5 mutation operation to achieve : the values of each of the alleles in the population of each chromosome mutation probability mutate according to ;

Step 6 Calculate the fitness of the population of all chromosomes, and statistical indicators at this population;

Step 7 Detect the shutdown condition: if the algorithm satisfies the shutdown condition, then go to step 8, otherwise go to step 3;

Step 8 For a given path of some of the best statistical indicators of transport and algorithms output algorithm to obtain the like.

V.THE EXAMPLE ANALYSIS

In order to verify the above model and algorithm, we use the transportation network as shown in figure 2 to analyze and verify the model and algorithm. The text represents transportation existing between those two nodes in figure 2. For example , between O and A , there are two transportations，railway and highway. The network shown in figure 2 includes four kinds of mode of transportation, highway, railway, waterway and aviation.

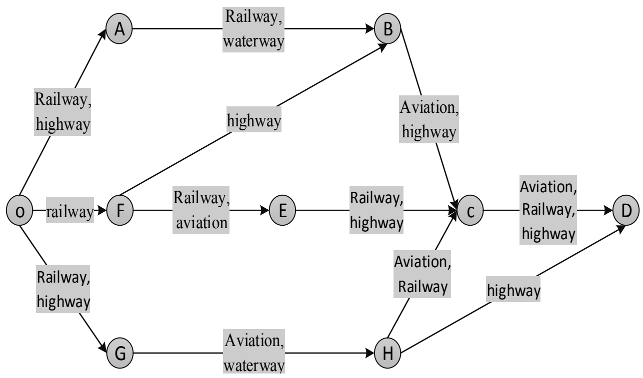

Fig.2 Initial Multimodal Transport Network

The network is as shown in figure 3 after the actual transport network nodes split. Each node is represented by one number for convenient analysis.

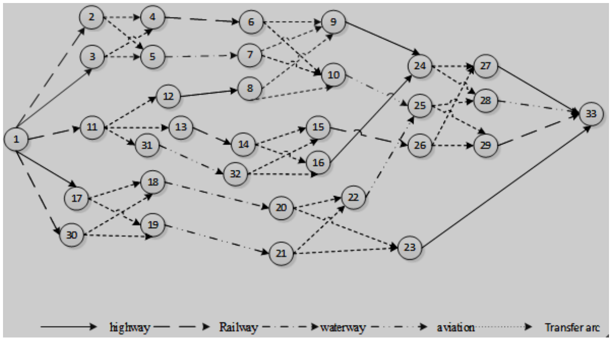

Fig.3 Multimodal Transport Network Diagram After Transformation

According to the actual situation of the cargo transport and experience, the transit alternative collections are {Railway-highway, highway-waterway, highway-aviation, waterways - highway}. So the transit way which is not in the above transit alternative collections can be disabled and deleted,so it can reduce the network size to a certain extent after the nodes are split. In this case, after some segment are deleted , the optimized network is as shown in figure 4.In the optimized network, arc weights indicate the transport time (s) and cost (RMB) between two nodes. And transit arc weights represent the transfer time/transfer cost. It is assumed that the transit time and the transit cost are 0 in the same mode of transportation in the transit node.

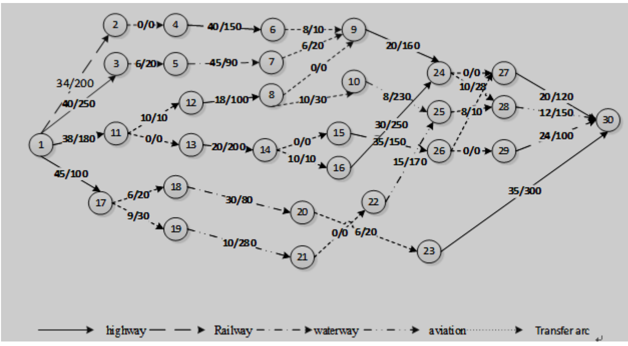

Fig.4 The Optimized Network

Suppose that there are a number of goods to be transported from O to D. According to the above conditions, assuming T=120min, according to the algorithm, firstly, we can obtain all paths within the time given which are shown as follows:

① 1→11→12→8→9→24→27→30
② 1→11→12→8→9→24→28→30
③ 1→11→12→8→10→25→28→30
④ 1→11→13→14→15→26→29→30
⑤ 1→11→13→14→16→24→27→30
⑥ 1→11→13→14→16→24→28→30
⑦ 1→17→19→21→22→25→28→30

With the path of the genetic algorithm to meet the shipping deadline set on the mode of transportation of combination to search to find satisfaction cost path. The parameters of genetic algorithm:

Population size: n=100;
The maximum number of generations: ger=400;
The crossover probability: pc=0.9;
Mutation probability: pm=0.01;

By using the MATLAB software to code genetic algorithm, we can obtain the satisfactory cost path within the time given (T=120min),the path is 1→11→12→8→9→24→27→30. So the original path is O → F → B → C → D, and the cost is 570 RMB, the transport time is 106min, Railway transport – road. In addition, we can also get the optimal cost paths within different limited time given, as shown in table I.

It can be seen from table I, when the deadline is 100 min, the mode of transportation should be railway to highway to aviation, which has the minimum cost, now, the transportation time is 96 min, but the cost is 700 RMB; When the deadline is 120 min, the mode of transportation should be railway to highway, which has the minimum cost, now, the transportation time is 106 min, but the cost is 570 RMB; If there is no deadline time, then the optimal path at this time is O→G→H→D , the mode of transportation is highway to waterway to highway, the minimum cost is 520 RMB, but the transportation time is 122 min.

TABLE I THE OPTIMAL COST PATHS WITHIN DIFFERENT LIMITED TIME GIVEN

Limited time/min	path	original path	time(min) and cost(yuan)	Transportation mode
100	1→11→12→8→10→25→28→30	O→F→B→C→D	96/700	railway→highway→aviation→aviation
120	1→11→12→8→9→24→27→30	O→F→B→C→D	106/570	railway→highway→highway→highway
unlimited	1→17→18→20→23→30	O→G→H→D	122/520	highway→waterway→highway

VI. CONCLUSIONS

In the multimodal transport，there are a variety of modes of transportation between the starting point and ending point. But through the network transformation, the transfer of multimodal transport network can be a reasonable representation. In practice, due to the special requirements of goods and the rationality of the transfer, It is in conformity with the actual demand to get the optimal path in the multimodal transport based on time costs or expenses cost. In the model built of this study, the restrictions on the optimal path under the condition of time-varying are considered. In the selecting of transfer mode, we delete the transfer modes that are impractical, that is to say, we can only choose from the alternative set, which can reduce the size of the network.Considering the constraints to the time limit, we established a cost oriented dynamic path optimization model of multimodal transport, and proposed the corresponding algorithms, finally, we proved the availability of the model through analysis on a case of multimodal transport network .

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