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THE METHOD TO SELECT THE TRANSPORT PATH BASED ON THE MULTIMODAL COST

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Abstract. To begin with, the current paper introduces the meaning of freight multimodal transport in order to select the best transport path in multimodal network. Secondly, the forming mechanism of freight multimodal transport cost has been illustrated. In addition to that the construction and the character of the freight multimodal cost have been analyzed carefully, and the mathematics model is set up so that to figure out the total cost of multimodal. Finally, a case of multimodal is given out and analyzed. The results indicate that the model and way to select the best multimodal path in the multimodal network are reasonable and effective.

Keywords: intermodal, intermodal cost, cost computing, transport path, intermodal network.

1. Introduction

Intermodal transport has grown over the past two decades in Europe and America. It also has been one of the most rapidly growing segments of the transportation industry in China resulted from the globalization of the marketplace. The intermodal transport has been developed very quickly in the north district, east district, south-center district, south-west district and north-west district of China. There are four main lines of intermodal transport: Beijing-Guangzhou railway, Beijing-Shanghai railway and highway, Jiangsu-Gansu railway and Changjiang River in China. It has become very important for intermodal transport operator to select an optimal path in intermodal transport network in China. Surprisingly, so far, there are few research papers on intermodal transport path. On the study of this issue, Chang (2008) take it as a multiobjective intermodal multicommodity flow problem (MMMFP) with time windows and concave cost, and used the relaxation and decomposition techniques to separate the original problem into smaller and easier subproblems. Verma and Verter (2010) set up a bi-objective optimization model to plan and manage intermodal shipments. Lozano and Storchi (2001) used the minimum cost network flow formulation to develop shortest paths for the origin–destination pairs, and used the shortest path approach within a local search heuristic. Otherwise, Min (1991) dealt with multiple objectives and on-time service requirements. Reddy and Kasilingam (1995) established a liner model at the condition of minimum total cost. Xie *et al.* (2006) used analytic hierarchy process (AHP) to select the optimal intermodal transport route. Zhong *et al.* (1996) gave out the shortest time path model of intermodal transport. He *et al.* (2007) established 0-1 integer programming model to select the modes of transport at the time and capacity constraints and designed a corresponding genetic algorithm to solve it. There is no unify understanding about cost computing of intermodal transport. Sondak *et al.* (1995) studied the principle of cost allocation. Caudle (1999) studied the method how to compute logistics cost in activity-based costing. Janic (2007) compared the cost of the intermodal transport with the cost of the road transport.

As mentioned above, several authors have developed intermodal path methods. The research gave out the ideal and method in path selection of intermodal transport, but most of the research was concentrated on program modal, they didn't study on forming mechanism, composition and characteristic of intermodal transport cost, they also did not answer of which the intermodal cost should compose and how to figure out the intermodal transport cost according to the forming mechanism of the intermodal transport cost. The mathematic models and the solution approach always are NP problems which they proposed and illustrated. The problem can not be solved with a local search heuristic algorithm. The operator and custom mainly take care of the intermodal cost. As some of intermodal cost can not be thought and figured out. Their research results are limit instructive for operator and custom to determine the intermodal transport program in practice. Cost computing of intermodal transport is the main decision basis for the selection of intermodal transport path and for the making an intermodal transport program. This paper illustrated the forming mechanism and analyzed the composition of intermodal transport cost. The gathering cost and the distributing cost are computed according to the service radius of intermodal station. Moreover, it is proved that there is linear function relation between the intermodal cost and intermodal quantity when the efficiency quota of intermodal transport is unchangeable.

In this paper a special focus is on the cost of intermodal transport. It has the following structure. The following Section is a literature review about the transport path, the next Section illustrate the meaning of intermodal transport. Section 3 analyzes the composition of intermodal transport cost. Section 4 describes the mechanism of intermodal transport and set up the formula to compute the intermodal transport cost. Section 5 uses an example to illustrate the proposed models and solution approaches. Section 6 concludes the paper.

2. The Meaning of Intermodal Transport

So far, there is no uniform definition of intermodal transport. In Continental North America and Europe it is called 'Intermodal Transport'. In 1993, the European Conference of Ministers of Transport defined intermodal transport as: 'movement of goods in one and the same loading unit or vehicle, which uses successive, various modes of transportation without any handling of the goods themselves during transfers between modes' (Terminology on Combined… 2006). In 1997, Nozick and Morlok (1997) put up that intermodal truck-rail service is comprised of the moving of trucks and containers on railcars between terminals, with movement by truck at each end. The European Conference of Ministers of Transport and United Nations have proposed a common definition, but no commonly accepted definition exists. Although experts have different views on the intermodal transport, the intermodal transport means the carriage of goods by at least two different modes of transport on the basis of an intermodal transport contract from a place at which the goods are taken in charge by the intermodal transport operator to another place designated for delivery, and there are three common characteristics about it: firstly, the intermodal transport involves at least two modes of transport; secondly, the intermodal transport is organized by at least two intermodal transport enterprises and they are responsible for their operations; thirdly, the intermodal transport has a synchronous schedule.

3. The Composition of Intermodal Transport Cost

Intermodal transport is performed with two or more different transport modes, it broke up the limit of single transport mode. Different transport mode share variety of transport resources and integrate together in greater space-time range in order to improve transport efficiency and reduce transport cost. It usually consists of three main parts: firstly, the freight is transported to departure freight station of intermodal transport from the door of shipper; secondly, the freight is taken over and transported by one transport mode and another transport mode, till the freight is transported to the freight destination station; thirdly, the freight is transferred and delivered to the consignee.

Intermodal transport is cooperative behavior between intermodal carriers. The cost caused by cooperative behavior must be taken into account when computing cost of intermodal transport. According to the meaning and mechanism of intermodal transport, the cost of intermodal transport should mainly consist of six parts:

$$C_{ly}\left(q,l,t\right)=C_{sj}+C_{xt}+C_{wl}+C_{zs}+C_{ss}\left(q,l,t\right)+C_{fx}, \quad (1)$$

where: q is the volume of intermodal transport; l is the distance of intermodal transport; t is the time of intermodal transport; $C_{ly}\left(q,l,t\right)$ is the cost of intermodal transport; C_{sj} is the design cost of intermodal transport; C_{xt} is the manage cost of intermodal transport; C_{wl} is the network usage cost of intermodal transport; C_{zs} is the special fixed cost of intermodal transport; $C_{ss}\left(q,l,t\right)$ is the operation cost of intermodal transport; C_{fx} is the random (risk) cost.

Design cost is mainly caused by investigation of market demand, discrimination of participant enterprises in intermodal transport, design of transport program and so on. Network usage cost mainly means construction cost and maintenance cost of intermodal transport routes and nodes. Manage cost means the cost caused by management, monitoring and coordination of participant enterprises in intermodal transport during the operation process. Implementation cost mainly means the cost of human resource, material resource and financial resource consumed by participant enterprises in intermodal transport. Random cost has great randomicity and uncontrollability. It mainly means the cost caused by environment, policy, climate and other reasons.

4. The Model and Method of Intermodal Transport Cost Computing

4.1. The Forming Mechanism of Intermodal Transport Cost

The Intermodal transport is mainly operated according to the specific task in a contract. With the task carrying out, a lot of operations should be done one by one. During the operation many resources have been used by joint transport enterprises. The intermodal transport will bring the need of the operations, and the operations will bring the use of resources, and the resources used by joint transport enterprises form the cost of intermodal transport (Fig. 1).

4.2. The Calculation Model of Implementation Cost of Intermodal Transport

Assume that the departure and the destination freight stations of the intermodal transport is A and B respectively, the departure region is s, the destination region is

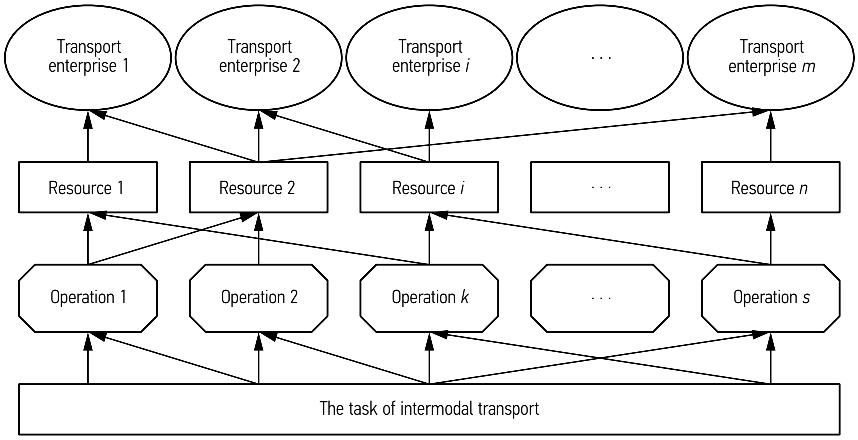

Fig. 1. The formation forming mechanism of intermodal transport cost

u, the freight volume of intermodal transport is Q, the freight is transported m times except the collecting and distributing of two endpoints of the intermodal transport. The service radius of freight station A at region s is r^s, the service radius of freight station B at region u is r^u, the transport distance of section i is $l^i (i = 1, 2, ..., m)$ (Fig. 2).

Assume that the average transfer cost of per time per ton of freight is c_z^i in m times transport, in the region s, A and B the transport frequency is λ^s, λ^i and λ^u respectively, the transport cost of unit transport turnover is c_y^s, c_y^i and c_y^u respectively, the average transport speed of freight is v^s, v^i and v^u respectively, and the rated loading capacity of conveyance is q_0^s, q_0^i and q_0^u respectively, the utilization efficiency of conveyance' capacity is $\alpha^s, \alpha^i$and α^u respectively, the utilization efficiency of mileage is β^s, β^i and β^u respectively, the waiting time is t_w^s, t_w^i and t_w^u respectively, and the time value cost of unit freight is τ, then:

$$\lambda^s = \frac{q}{q_0^s \alpha^s}; \ \lambda^i = \frac{q}{q_0^i \alpha^i}; \ \lambda^u = \frac{q}{q_0^u \alpha^u}.$$

The cost of intermodal transport between freight station A and B is:

$$C_{ly}^{AB}(q,l,t) = \sum_{i=1}^{m+1} \lambda^i q_0^i \alpha^i c_z^i + \sum_{i=1}^{m} \lambda^i q_0^i \alpha^i l^i c_y^i + \sum_{i=1}^{m} \lambda^i q_0^i \alpha^i \left(\frac{l^i}{v^i} + t_w^i \right) \tau = Q \left(\sum_{i=1}^{m+1} c_z^i + \sum_{i=1}^{m} l^i c_y^i + \sum_{i=1}^{m} \left(\frac{l^i}{v^i} + t_w^i \right) \tau \right). \quad (2)$$

Assume that the load and unload cost of freight per time per ton in region s and u is c_{zx}^s and c_{zx}^u respectively, then the intermodal transport cost of freight at gathering region s is:

$$C_{ly}^s(q,l,t) = \lambda^s \left(\int_0^{q_0^s} \int_0^{r^s} \alpha^s \beta^s c_y^s dq dl + q_0^s \alpha^s c_{zx}^s + q_0^s \alpha^s \left(t_w^s + \frac{r^s}{v^s} \right) \tau \right) = Q \left(\beta^s r^s c_y^s + c_{zx}^s + \left(t_w^s + \frac{r^s}{v^s} \right) \tau \right). \quad (3)$$

Similarly, we can calculate the distributing cost in region u:

$$C_{ly}^u(q,l,t) = Q \left(\beta^u r^u c_y^u + c_{zx}^u + \left(t_w^u + \frac{r^u}{v^u} \right) \tau \right). \quad (4)$$

According to formula (2), (3) and (4), we can calculate the implementation cost of intermodal transport:

$$C_{ss}(q,l,t) = C_{ly}^s(q,l,t) + C_{ly}^{AB}(q,l,t) + C_{ly}^u(q,l,t). \quad (5)$$

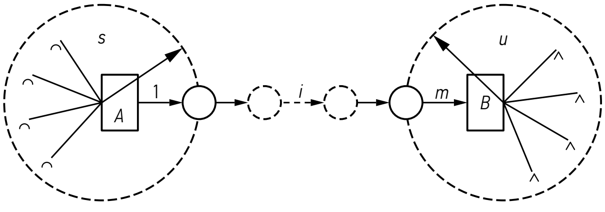

Fig. 2. The constructed figure of intermodal

4.3. The Cost Computing the Model of Intermodal Transport Network

The network usage cost of intermodal transport belongs to the public spending in nature, so we can allocate it according to the actual using frequency.

Assume that the usage rate of intermodal transport network is f^s, $f^i (i = 1,2,\cdots,m)$ and f^u respectively, then the network usage cost of intermodal transport is:

$$C_{wl}(q) = \lambda^s f^s + \sum_{i=1}^{m} \lambda^i f^i + \lambda^u f^u. \quad (6)$$

4.4. The Calculation of Intermodal Transport Cost

Assume that: $C_{ly}(0) = C_{sj} + C_{xt} + C_{zs} + C_{fx}$, then we can obtain the calculation formula of intermodal transport cost:

$$C_{ly}(q,l,t) = \left(\frac{f^s}{q_0^s \alpha^s} + \sum_{i=1}^{m} \frac{f^i}{q_0^i \alpha^i} + \frac{f^u}{q_0^u \alpha^u} + \beta^s r^s c_y^s + c_{zx}^s + c_{zx}^u + \left(t_w^s + t_w^u + \frac{r^s}{v^s} + \frac{r^u}{v^u} \right) \tau \right) q + \left(\sum_{i=1}^{m+1} c_z^i + \sum_{i=1}^{m} l^i c_y^i + \sum_{i=1}^{m} \left(\frac{l^i}{v^i} + t_w^i \right) \tau \right) q + C_{ly}(0). \quad (7)$$

4.5. The Selection of Intermodal Transport Path

Let:

$$\delta=\left(\frac{f^s}{q_0^s\alpha^s}+\sum_{i=1}^{m}\frac{f^i}{q_0^i\alpha^i}+\frac{f^u}{q_0^u\alpha^u}+\beta^s r^s c_y^s+\beta^u r^u c_y^u+c_{zx}^s+c_{zx}^u+\left(t_w^s+t_w^u+\frac{r^s}{v^s}+\frac{r^u}{v^u}\right)\tau\right)+\left(\sum_{i=1}^{m+1}c_z^i+\sum_{i=1}^{m}l^i c_y^i+\sum_{i=1}^{m}\left(\frac{l^i}{v^i}+t_w^i\right)\tau\right). \quad (8)$$

Assume that λ^s, λ^i, λ^u, c_z^i, c_y^s, c_y^i, c_y^u, v^s, v^i, v^u, q_0^s, q_0^i, q_0^u, α^s, α^i, α^u, β^s, β^i, β^u, t_w^s, t_w^i, t_w^u and τ all are the constants, then:

$$C_{ly}(q)=\delta q+C_{ly}(0). \quad (9)$$

According to formula (9), intermodal transport cost is linear function of freight volume q, and its graphic is a straight line. Assume that there are two or more paths of intermodal transport; the cost of intermodal transport can be calculated. According to the cost of intermodal transport an economic intermodal transport path can be selected (Fig. 3). The calculation formula (9) can provide out a basis for selecting the intermodal transport path:

$$Min\left(C_{ly}^{\mathrm{I}}(q),C_{ly}^{\mathrm{II}}(q),C_{ly}^{\mathrm{III}}(q)\right)=\begin{cases}C_{ly}^{\mathrm{III}}(q) & (0<q\le q_1)\\ C_{ly}^{\mathrm{II}}(q) & (q_1<q\le q_2).\\ C_{ly}^{\mathrm{I}}(q) & (q_2<q<\infty)\end{cases} \quad (10)$$

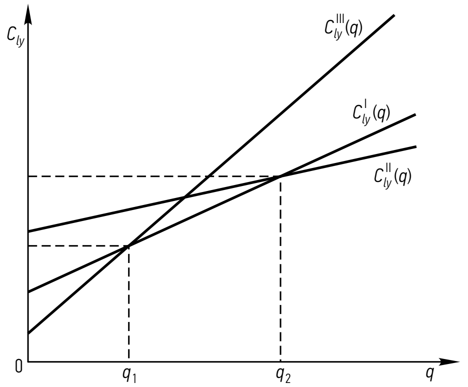

Fig. 3. The relation between the cost and the quantity of intermodal

5. Example

There are four transport enterprises participating the transport of 800 tons freight, there are two intermodal transport programs. Program I consists of four parts: firstly, the freight is transported from shipper to Changsha North railway freight station A in trucks by the first transport company; secondly, the freight is transferred from trucks at railway freight station A to the train and taken over by the second transport company; thirdly, at the Yueyang intermodal freight station C, than the freight is transferred from the train to sea craft and taken over by the third transport company; finally, at the Shanghai intermodal freight port B, the fright is transferred from sea craft to trucks and delivered to the consignee in trucks by the fourth transport company (Fig. 4). In the intermodal transport, the special fixed cost is 6000 yuan, the design cost is 3000 yuan, the manage cost is 4000 yuan, the risk cost is 7000 yuan; Program II consists of four parts: firstly, the freight is transported to Xiani port D in Changsha through road transport by the first transport company, secondly, the freight is transported from Xiani port D in Changsha to transfer Wuhan port E by the second transport company; thirdly, the freight is transported from Wuhan port E (intermodal station) to Shanghai intermodal station B by train by the third transport company; finally, the freight is distributed from Shanghai intermodal port B to every consignee by the fourth transport company. In the intermodal transport, the fixed cost is 3000 yuan, the design cost is 3000 yuan, the manage cost is 2500 yuan, and the risk cost is 3000 yuan. Assume that coefficient of time value is 0.2 (yuan/t.h).

The service radius of freight station A is showed in Table 1. The distance between station A and C is 600 km, the distance between station C and B is 800 km. The distance between station D and E is 1000 km, the distance between station E and B is 400 km. The using rate of facilities in intermodal transport is calculated according to using times, the efficiency index refers to Table 2, the using rate of transport network refers to Table 3. Try to calculate the cost of programs and select an economy program with a lower cost.

According to the case, we can solve the problem step by step:

1) Calculate the transport frequency of region:

$$\lambda^s(\mathrm{I})=\frac{q}{q_0^s\alpha^s}=\frac{800}{5\cdot 80\%}=200.$$

Similarly: $\lambda^{AC}(\mathrm{I})=4$, $\lambda^{CB}(\mathrm{I})=4$, $\lambda_B^u(\mathrm{I})=160$.

The transport frequency of interval is listed in Table 4.

2) Calculate the intermodal transport cost of departure region and destination region.

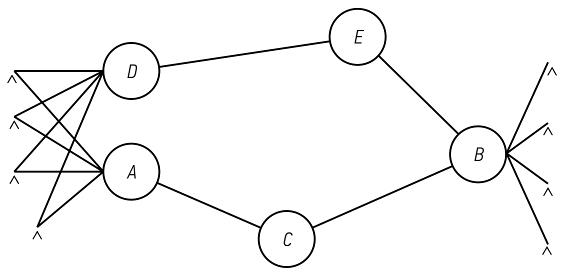

Fig. 4. The process of the road–rail intermodal

Table 1. The cost and radius of the road–rail intermodal

Freight station	A	B	C	D	E
Transfer cost (yuan/t)	0.8	1.0	1.2	1.0	1.2
Radiation radius (km)	100	120	–	90	–

Table 2. The efficiency index of the road–rail intermodal

Interval	S_A	S_D	AB	AC	DE	CB	EB	U_B
Rated tonnage (t)	5	4	25	200	1000	200	200	5
Rate Of tonnage (%)	80	80	90	100	80	100	100	100
Rate of mileage (%)	70	60	100	100	100	100	100	80
Waiting time (h)	6	4	4	1	6	2	1	2
Delivery speed (km/h)	40	30	60	200	40	50	200	40

Table 3. The fee index of the road–rail intermodal

Interval	S_A	S_D	AB	AC	DE	CB	EB	U_B
Ton-kilometer cost (yuan/tkm)	0.8	0.8	0.4	0.3	0.2	0.2	0.3	1.0
Handing cost (yuan/time)	0.5	0.5	–	–	–	–	–	0.5
Using rate of facilities (yuan/time)	10	10	180	100	20	20	100	10

Table 4. The transport frequency rate of interval in the road–rail intermodal transport

Program	λ_A^s	λ_D^s	λ^{AB}	λ^{AC}	λ^{CB}	λ^{DE}	λ^{EB}	λ_B^u
I	200	–	–	4	4	–	–	160
II	–	250	–	–	–	1	4	160

Substitute the relevant date into formula (3) and (4), then

$$C_A^s(\mathrm{I}) = q\left(\beta_A^s r_A^s c_y^s + c_{zx}^s + \left(t_{Aw}^s + \frac{r_A^s}{\upsilon_A^s}\right)\tau\right) = 46560;$$

$$C_B^u(\mathrm{I}) = q\left(\beta_B^u r_B^u c_y^u + c_{zx}^u + \left(t_{Bw}^u + \frac{r_B^u}{\upsilon_B^u}\right)\tau\right) = 78000.$$

3) Calculate the cost of trunk movement in the intermodal transport.

Substitute $m = 2$ and the other relevant date into formula (2), then:

$$C_y^{AB}(\mathrm{I}) = 800 \cdot \left(\sum_{i=1}^{2+1} c_z^i + \sum_{i=1}^{2} l^i c_y^i + \sum_{i=1}^{2}\left(\frac{l^i}{\upsilon^i} + t_w^i\right)\tau\right) = 276160.$$

4) Calculate the cost of intermodal transport network:

$$C_{wl}^{AB}(\mathrm{I}) = \lambda^S f + \sum_{i=1}^{m} \lambda^i f^i + \lambda^u f^u = 4080.$$

The design cost, coordination cost, random cost and dedicated cost is listed respectively:

$C_{sj}(\mathrm{I}) = 3000$, $C_{xt}(\mathrm{I}) = 4000$, $C_{fx}(\mathrm{I}) = 7000$, $C_{zs}(\mathrm{I}) = 6000$.

5) Calculate the cost of intermodal transport according to formula (7):

$C(I)$ = 3000 + 4000 + 4080 + 6000 + (46560 + 78000 + 276160) + 7000 = 424800.

Similarly, we can calculate the cost of program II, the result refer to Table 5.

According to the calculation results stated above, we know that the program II can save 30700 yuan than the program I, firstly the gathering cost of saving is 10480 yuan, the distributing cost is identical, the trunk movement cost of saving is 12160 yuan, the usage cost of network exceeds 440 yuan. In addition, in program II, the risk cost of saving is 4000 yuan, the manage cost of saving is 1500 yuan, the special fixed cost of saving is 3000 yuan.

6) Select the program of intermodal transport .

The efficiency index and cost index of two programs refer to Table 6 and Table 7.

According to formula (8), then: $\delta(\mathrm{I}) = 870.5$; $\delta(\mathrm{II}) = 887.6$.

According to formula (9), then:

$$C^{ly}(\mathrm{I}) = 870.5q + C_{ly}^{\mathrm{I}}(0) = 870.5q + 20000.$$

Similarly, then:

$$C^{ly}(\mathrm{II}) = 887.6q + C_{ly}^{\mathrm{II}}(0) = 887.6q + 11500.$$

According to the two equations above, $q \approx 497$ t.

When the distance of intermodal transport is constant, and the freight volume is less than 497 t, the cost of program I is less than the one of program II, we should take program I. When the freight volume is more than 497 t, we should take program II.

Table 5. The index of the road–railway intermodal

Program	C_{sj}	C_{xt}	C_{zs}	C_{fx}	C_{wl}^{AB}	C^s	C_{yl}^{AB}	C_z^{AB}	C_{js}^{AB}	C_{wt}^{AB}	C_B^u	C
I	3000	4000	6000	7000	4080	46560	276160	2400	272000	3520	78000	424800
II	3000	2500	3000	3000	4520	36080	264000	2560	256000	5440	78000	394100

Table 6. The index of the road–railway intermodal

Interval	I(α, β, v, t_w)	II(α, β, v, t_w)
SA	(80%, 70%, 40, 6)	–
SD	–	(80%, 60%, 30, 4)
AC	(100%, 100%, 200, 1)	–
DE	–	(80%, 100%, 40, 6)
CB	(100%, 100%, 50, 2)	–
EB	–	(100%, 100%, 200, 1)
UB	(100%, 80%, 40, 2)	(100%, 80%, 40, 2)

Table 7. The index of the road–railway intermodal

Index	c_y^s	c_y^1	c_y^2	c_y^u	c_{zx}^s	c_{zx}^u	c_z^A	c_z^B	c_z^C	c_z^D	c_z^E
I	0.8	0.3	0.2	1.0	0.5	0.5	0.8	1.0	1.2	–	–
II	0.8	0.2	0.3	1.0	0.5	0.5	–	–	–	1.0	1.2

6. Conclusion

This paper provided a mathematic formula to calculate the shortest path of intermodal transport according to the intermodal transport cost. The design cost, manage cost and random cost are taken into account in the formula, the time cost of goods is computed, the network usage cost of intermodal transport is allocated. This will help operator and custom to select the transport path in order to make it scientifically an intermodal transport program, and at the same time it can lad a foundation for the operator to set the intermodal price.

Compared with the similar methods, the presented method has two advantages:

1. It is simple and easy to get the optimal transport path. Most of the cost can be computed according the statistical data. The design cost, manage cost and random cost can be got in statistical method. The other methods usually are NP problem. They can only get a local optimal value in most of the time.
2. It is reasonable and acceptable to select the transport path based on the intermodal cost. It can figure out systematically and completely to the intermodal cost one by one according to the forming mechanism of intermodal cost. The program mathematic model can be designed as well as they can, but they can not totally represent the true condition. In practice, a case is analyzed and computed. The result shows that the theory and method is scientific and useful.

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