Optimization for Time-limited Intermodal Transportation Route Selection Considering Carbon Emission Costs

Yu Nan[1, a], Zhang Zhehui[1, b*] and Zhang Shuhui[1, c]

[1] Logistics Engineering Center, China Waterborne Transport Research Institute, Beijing 100088, China.

[a]yunan@wti.ac.cn, [b]zhangzhehui@wti.ac.cn, [c]zhsh@wti.ac.cn

Abstract: This study considers an optimization problem of intermodal transportation route selection that takes carbon emissions and intermodal transfers into account. An integer linear programming model is built to formulate the problem. The activity-based approach is adopted to estimate the carbon emissions. We present a numerical case with 6 nodes in the intermodal network and then utilize Lingo 11 to generate the best route. We also analyze the results by comparing different time limitation and unit carbon emission cost.

Keywords: Intermodal Transportation Route, Optimization, Caron Emission Costs, Time Limitation.

1. Introduction

With mass emissions of greenhouse gases (GHG) due to the increasing energy consumption in the petrochemical industry, air pollution becomes more and more serious. Transportation industry accounts for 19% of global energy use, and emissions from transportation are expected to grow by 50% by 2030 and by 100% by 2050 from 2007 levels [1]. However, the demand for freight transport has grown rapidly over the past three decades at a rate of 8.4% per year. In this case, how to ensure the efficient and reliable delivery of the commodities with an environment-friendly way leads to new models and technologies.

Intermodal transport refers to the movement of goods in the same single loading unit or road vehicle that successively uses two or more modes of transport, without the goods being handled in a change of transport mode [2]. Intermodal transportation, in that regard, allows for the combination of different modes in order to exploit their individual advantages. Intermodal transportation networks offer flexible, robust and environmentally friendly alternatives to transport high volumes of goods over long distances.

Traditional logistics models have concentrated on minimizing operational transportation costs. With the aim of minimizing transportation cost, Reddy and Kasilingam [3] constructed a mathematical programming model to solve the multimodal transportation routing problem. Chang [4] treated the international multimodal transportation routing problem as a multi-objective, multi-mode and multi-commodity problem with time windows and concave costs (MMMFP). He focused on the study of how to choose the best route through the multimodal transport network. Janic [5] proposed a model for calculating the full costs of an intermodal and road transport network. The formulation of the cost fully considered the impact of the networks on society and the environment. Sadegheih [6] considered the change of the carbon tax and the punishment cost due to the emissions of GHG. Xiong [7] integrated the carbon emissions and the time window into the

optimization model, but did not consider the carbon emissions generated in the transfer process, and also did not convert carbon emissions into money. Qian [8] minimized the cost and carbon emissions in the model with considering the carbon emissions in the process of transportation and transferring, but also did not convert carbon emissions into economic costs. Chen [9] optimized the multimodal transport routes with minimizing the cost of shipping cost and carbon emissions cost without considering the time limitation.

As early as 1990, Holland formally began to levy a carbon tax, while Sweden introduced a carbon tax in the overall tax reform in 1991. Although China is not suitable for the collection of carbon tax, the future of carbon tax is imperative when the growing global greenhouse effect is considered. From the point of view of the multimodal transport carrier, carbon tax will certainly increase the total operational cost. There are a few studies take account into the carbon emissions in a perspective of carrier which do not consider all of the factors.

The key contributions of this paper can be summarized as follows: We present a model to explicitly include transportation cost, intermodal transfer cost, carbon cost which is converted to monetary unit, and time-limited when modeling a green intermodal transportation system.

2. Problem Description and Mathematical Modeling

2.1 Estimating Emissions

There are several ways to estimate GHG emissions, including an energy based approach and an activity based approach. Sun [10] calculates carbon emissions based on fuel consumption and emission factors. Wen [11] assigned the carbon emission statistics of various modes of transport to the unit turnover to calculate the amount of carbon emissions per unit volume. For our modeling approach which is at a more strategic tactical level of planning, we have opted to use an activity-based function by Sun and Lang [12] to estimate CO_2 emissions in intermodal transportation. This approach has also been used elsewhere, e.g., Treitl et al. used it to estimate the total transport emissions in a petrochemical distribution network in Europe, and Park et al. used it to calculate CO_2 emissions in a road network for trucks and railway in an intermodal freight transportation network in Korea [13].

According to Sun and Lang [12], the total cost of CO_2 emissions of a vehicle carrying a load of l (in tonnes) over a distance of d (in km) calculated by Eq. 1 below,

$$l \times d \times e \tag{1}$$

where e is the average CO_2 emission factor (g/tonne-km). Because China has not started to levy carbon tax, in order to convert CO_2 emissions into monetary units, we adopt the figures provided by the World Bank [14]. Particularly, we use \$100 per tonne (= ¥690.4 per tonne). The reason for adopting this CO_2 emission calculation method is its ease of use.

2.2 Problem Description

We suppose that a company has a batch of goods to transport from origin point O to destination point D through several cities. There are three transportation modes which are roads, waterways and airways can be chosen between two arbitrary adjacent cities. Each node is a transit hub for different transportation modes. when we transfer the goods from one transportation mode to another one with emissions of CO_2, we need to spend some time and cost. The total transportation time must be within the scope of a time window. We aim to deliver the goods in the least cost way by choosing the proper transportation modes during the agreed period.

2.3 Making the Assumption

(1) We have known and fixed all the relevant constants;
(2) There is one transportation mode existent at least on any section of known delivery path;

(3) The speed of the same mode of transport is fixed and only depends on the mode;

(4) Each vehicle of the same mode of transport incurs the same fixed unit cost and emission of CO2;

(5) The transfer cost and emission of CO2 only depend on the volume of freight and modes;

(6) The same batch of goods cannot be separated during the transport process;

(7) The volume of freight does not over the carrying capacity of the route.

2.4 Description of the Model Parameters

We defined the model parameters in Table 1.

Table 1 model parameters and the explanation in our model

Parameter	Explanation
$G=(N,A)$	Transportation network, where N corresponds to the set of nodes and A represents the set of arcs
M	The set of modes
O	The origin of goods
D	The destination of goods
h,i,j	Indexes of the nodes in the intermodal transportation network
H	Conversion coefficient of converting CO2 emissions into monetary units
W	The volume of freight
k_{ij}^x	Transportation mode on arc(i,j) $\in$ A. If we select x transportation mode on arc(i,j), k_{ij}^x=1; otherwise, k_{ij}^x=0
C_{ij}^x	Unit cost for shipping goods on arc(i,j)$\in$A by mode x$\in$M
d_{ij}^x	Distance of arc(i,j)$\in$A by mode x$\in$M
t_{ij}^x	Time for shipping goods on arc(i,j)$\in$A by mode x$\in$M
tt_i^{xy}	Transfer time from the transportation mode x to y in the node i
v^x	Speed of the transportation mode x
ω_i^{xy}	Indicates whether the transport mode x transfer to y in node i; If the goods is transferred from transportation mode x to transportation mode y in the node i, ω_i^{xy}=1; otherwise, ω_i^{xy}=0
p^x	Unit emission of CO2 for mode x
r^{xy}	Unit transfer emission of CO2 from mode x to y
S^{xy}	Unit transfer cost from mode x to y
T_{OD}	Time from origin to destination
[ET,LT]	Time-limited

2.5 Mathematical Modeling

Using the parameters in Table 1, a mathematical model for the problem can be written as follows:

Objective

$$\sum_{x\in M}\sum_{(i,j)\in A}W\cdot C_{ij}^x\cdot d_{ij}^x\cdot k_{ij}^x+\sum_{x,y\in M}\sum_{i\in N}W\cdot s^{xy}\cdot\omega_i^{xy}$$

$$+H(\sum_{x\in M}\sum_{(i,j)\in A}W\cdot p^x\cdot d_{ij}^x\cdot k_{ij}^x+\sum_{x,y\in M}\sum_{i\in N}W\cdot r^{xy}\cdot\omega_i^{xy}) \qquad (2)$$

Subject to

(1) We can only choose one transportation mode between two nodes. Consider

$$\sum_{x \in M} k_{ij}^x \leq 1 \quad \forall\, (i,j) \in A \tag{3}$$

(2) To ensure that transfer times at a node will not exceed once. Consider

$$\sum_{x \in M} \sum_{y \in M} \omega_i^{xy} \leq 1 \ \forall\, i \in N \tag{4}$$

(3) Ensure continuity during the transportation process [15]. Consider

$$\sum_{h \in N} \sum_{x \in M} k_{hi}^x - \sum_{j \in N} \sum_{y \in M} k_{ij}^y = \begin{cases} 1, i = d \\ 0, \forall\, i, \in N \ and \ i \notin \{o,d\} \\ -1, i = o \end{cases} \tag{5}$$

(4) To indicate the relationship between the two decision variables [16]. Consider

$$\sum_{h \in N} k_{hi}^x = \sum_{y \in M} \omega_i^{xy} \ \forall\, i \in N \ \forall\, x \in M \tag{6}$$

$$\sum_{j \in N} k_{ij}^y = \sum_{x \in M} \omega_i^{xy} \ \forall\, i \in N \ \forall\, y \in M \tag{7}$$

(5) The decision variable is 0 or 1. Consider

$$k_{ij}^x = \begin{cases} 1 \\ 0 \end{cases} \forall\, (i,j) \in A \ \forall\, x \in M \tag{8}$$

$$\omega_i^{xy} = \begin{cases} 1 \\ 0 \end{cases} \forall\, i \in N \ \forall\, x \in M \ \forall\, y \in N \tag{9}$$

(6) Definition of T_{OD} Which is limited. Consider

$$T_{OD} = \sum_{(i,j) \in A} \sum_{x \in M} t_{ij}^x + \sum_{i \in N} \sum_{x,y \in M} tt_i^{xy} \omega_i^{xy} \tag{10}$$

$$t_{ij}^x = \frac{d_{ij}^x k_{ij}^x}{v^x} \tag{11}$$

$$ET \leq T_{OD} \leq LT \tag{12}$$

3. Computational Experiments

3.1 Description of case study

There is a transportation enterprise needs to transport 20 tons of goods from city O to city D with going through four cities (1,2,3,4) one by one. There are three transportation modes can be selected between two arbitrary adjacent cities. Table 2 shows the average speed, unit transportation cost, and unit CO2 emissions about different transportation modes. Table 3 shows the distance between two cities about different transportation. Table 4 shows the unit transfer cost, unit transfer time and unit transfer CO2 emissions. The cargo delivery time interval was [25h, 30h] in the contract.

Table 2 Parameters used in case study

Transportation mode	Average speed (km/h)	Transportation cost (yuan/tonne-km)	CO2 (g/tonne-km)
Road	80	0.26	62
Railway	70	0.12	22
Waterway	36	0.1	16

Table 3 Distance between two cities

Transportation mode	O-1 (km)	1-2 (km)	2-3 (km)	3-4 (km)	4-D (km)
Road	300	160	630	230	320
Railway	310	165	580	240	280
Waterway	260	120	610	210	290

Table 4 Unit Transfer costs (yuan/tonne)/unit transit time (hour)/unit transfer CO_2 emissions (kg/tonne) of different transportation modes.

	Road	Railway	Waterway
Road	0/0/0	5.5/0.03/16.2	6/0.06/21.17
Railway	5.5/0.03/16.2	0/0/0	7.5/0.06/21.4
Waterway	6/0.06/21.17	7.5/0.06/21.4	0/0/0

3.2 Computational Results and Analysis

Based on the data set introduced in Section 3.1, we then used the mathematical programming software Lingo 11 on a Lenovo Laptop with Intel Core i5-5200U 2.20GHz CPU and 8 GB RAM to solve empirical example. The computational results for the example are presented in Table 5.

Table 5 Computational results of Lingo 11 towards the example.

	O-1	1-2	2-3	3-4	4-D
Transportation Select (with delivery time in [25,30] H=0.6904)	Waterway	Waterway	Railway	Railway	Railway
Cost(yuan)	4263.597				
Transportation Select (with delivery time in [20,25] H=0.6904)	Railway	Railway	Railway	Railway	Railway
Cost(yuan)	4258.45				
Transportation Select (with delivery time in [20,25] H=1)	Railway	Railway	Railway	Railway	Railway
Cost(yuan)	4473				

Due to the limitation of the space, we only compare with the results in two different delivery time constraint to demonstrate the feasibility model. The results show that the combination of the transportation modes and the cost are different under different delivery time constrain. The unit carbon emission, unit transportation cost and the distance of route O-1 and 1-2 of waterway are all lower than that of railway, but the coast of routes of waterway- waterway-railway- railway- railway

are higher than the route of railway- railway- railway- railway- railway. Because there is a transfer in node 2 with expensive cost on carbon emission. Due to the limitation of the example, the combination of the transportation modes does not change with the change of carbon emission cost from 0.6904 to 1. The readers can experiment with different data by asking for the code of model from the corresponding author, if you are interested in it.

4. Conclusion

In this study, we explore the intermodal transportation routing problem by taking carbon emission cost and time limitation into account. We established a node-arc-based mixed linear programming model to solve the problem. The computational example suggests that the proposed model can address the intermodal transportation routing problem. This makes it interesting for practical applications.

Although several advances have been made by this study, weaknesses still exist. (1) We use a hard constraint in the time constraint which can be changed into time penalty function in future study. (2) We use a small-scale and simple case study which cannot be on behalf of all of the situations. (3) By changing the value of the fixed costs for the three modes of transport, the tradeoffs between emissions and transfer costs can be analyzed.

5. Acknowledgments

6. References

[1] Anthony J. Craig, Edgar E. Blanco, Yossi Sheffi, Estimating the CO2 intensity of intermodal freight transportation, Transportation Research Part D. 22(2013) 49-53.

[2] ECE (Economic Commission for Europe), Terminology on Combined Transport, United Nations, New York and Geneva, 2001.

[3] Reddy V R, Kasilingam R G. Intermodal transportation considering transfer costs, Proceedings of the 1995 Global Trends Conference of the Academy of business Administration. Aruba, Holland, 1995.

[4] Tsung-Sheng Chang. Best routes selection in international intermodal networks, Computers & Operations Research, 2008,35(9): 2877-2891.

[5] Janic, M.,2007. Modelling the full costs of an intermodal land road freight transport network, Transp.Res. PartD: Transp.Environ.12,33–44.

[6] A. Sadegheih, P. R. Drake, D. Li, S. Sribenjachot. Global supply chain management under the carbon emission trading program using mixed integer programming and genetic algorithm, International journal of engineering, 2011, 24(1): 37-53.

[7] Xiong guiwu. The Optimal Research on Multimodal Transportation with Time Window, Chongqing University, 2014.

[8] Qian Jingjing. The Study of Intermodal Transport Path in Low Carbon Environment, Chongqing Jiaotong University, 2015:1-21.

[9] Chen lei, Lin Boliang, third ed., Optimization model of mode selection for intermodal transportation based on carbon-reduction policy, Journal of Beijing Jiaotong University. 39(2015) 70-75.

[10] Sun Bin, Chen Qiushuang, The Routing Optimization for Multi-modal Transport with Carbon Emission Consideration under Uncertainty, A. China Institute of automation control theory Specialized Committee, Chinese Society for systems engineering, Proceedings of the thirty-second China Control Conference (E), C. 2013:6.

[11] Wen Xuhong, Lin Boliang, third ed., The Optimization Model for Flow Assignment and Routing Plan in Integrated Transportation Based on Carbon Emissions, J. Transactions of Beijing Institute of Technology. 33(2013) 5-8.

[12] Sun Yan, Lang Maoxiang, Modeling the Multicommodity Multimodal Routing Problem with Schedule-Based Services and Carbon Dioxide Emission Costs, Mathematical Problems in Engineering, 2015, 1-21.

[13] Park D, Kim NS, Park H, Kim K (2012) Estimating trade-off among logistics cost, CO2 and time: a case study of container transportation systems in Korea. Int J Urban Sci 16(1):85–98.

[14] Information on http://www.worldbank.org/en/topic/climate finance.

[15] Sun Yan, Lang Maoxiang, Wang Danzhu, Optimization Models and Solution Algorithms for Freight Routing Planning Problem in the Multi-modal Transportation Networks: A Review of the State-of-the-Art, Open Civil Engineering Journal, 2015-9(1):714-723.

[16] Sun Yan, Lang Maoxiang, Bi-objective Optimization for Multi-modal Transportation Routing Planning Problem Based on Pareto Optimality, Journal of Industrial Engineering and Management, 2015, 8(3): 1195-1217.