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Traffic pollution in low carbon environment

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ABSTRACT

Water pollution can be transferred either through natural water bodies or, indirectly, through economic activities. The former is a physical transfer, which has been extensively investigated and just used for controlling pollution of transboundary river basin. The latter is a virtual transfer. Trade and economic globalization increased the needs of transportation, it leaded to energy consumption increasing, so that environmental pollution is worsening in China, in this paper, we analyzed the path of multimodal transport, built a multimodal transport mode on low-carbon goals and cost-selection goals in low-carbon environment, then using genetic algorithms and math methods to solve the modal, we got the conclusion that transportation take a very important role in reducing carbon emissions and costs; although the cost and carbon emissions is a contradiction, but in multimodal transport, through rational optimization, enterprises can meet the economic interests, at the same time, also realize low-carbon transport.

Keywords: Inter modal; Low-carbon transport; Carbon dioxide

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1. Research background

Water pollution can be transferred either through natural water bodies or, indirectly, through economic activities. The former is a physical transfer, which has been extensively investigated and just used for controlling pollution of transboundary river basin. The latter is a virtual transfer, as shown by some studies, where it is demonstrated that the quantity of pollutants embodied in economic activities is much larger and worthy attention [1]. However, understanding the mechanisms of virtual water pollution transfer through economic activities and relating them to domestic water resources remains a challenge. In emerging and developing economies, the rapid convergence of people on cities supplies human resources which contribute to potential economic growth but also intensifies the strain on already vulnerable resources such as land, water, housing and other infrastructure such as transport. The impacts of motorized transport in cities can be seen in congestion, accidents, community severance and pollution.

The adverse effects of transportation on the environment have emerged as a subject of major concern in Chain. Increased urbanization, with over 51% of the population now living in cities and the associated growth in car ownership, is largely responsible for the impact of transportation on the environment. In the past few years, there has also been an increasing amount of analysis looking at the crossover effects of policies in transportation and energy fields and measuring their effects on environmental conditions. These studies recognize and describe the complexity of the problem, which can be explained.

This growth is especially pronounced for China that has one of the most rapidly growing economies and is the second largest energy consumer, just behind US. Its annual gross

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domestic product (GDP) grew at about 10% per annul during the last two decades and its energy consumption in 2000 was about 1,300 Mtce, equivalent to 20% of Organization for Economic Cooperation and Development nations use and a tenth of world consumption. As the second largest CO_2 emitter in the world, China is under pressure to mitigate emissions. Increased urbanization, with over 70% –75% of the population are now living in cities and the associated growth in car ownership in China. The adverse effects of transportation on the environment have emerged as a subject of major concern.

Transport plays a fundamental role in post-industrial society. Despite the benefits to human well-fare that a well-developed transport network can provide, there is a growing awareness of the potential inconveniences that can be attributed to its considerable growth in recent years. Many argue that the transport sector places a burden on the environment that far exceeds its carrying capacity, and the risk exists that ecological sustainability is seriously endangered by economic development. The social costs of road transport have been estimated by Organization for Economic Co-operation and Development studies to amount to approximately 5% of GDP in most developed countries; these costs are largely due to air and noise pollution caused by vehicles and accidents on the road network. Traffic congestion is rapidly becoming one of the most serious problems affecting urban areas. China's carbon emissions are mainly concentrated in large cities. The ranks of Carbon emissions from urban are industrial, building and traffic. Since China's rapid economic growth, private car gradually enter family, CO_2 emissions from private car was upward trend in the proportion of traffic emissions.

Global oil consumption in the urban transport sector is expected to get doubled by 2050. Majority of the increase is expected to come from developing countries where rising urbanization and incomes result in a rapid rise in private motorized transport [2,3].

The environmental performance of transport has been the subject of many recent studies. In general, the focus has tended to be on the impact of transport on various aspects of the environment [4–6]. Comparative studies of transport modes based on environmental criteria are mainly focused on energy use (and emissions) associated with the use of vehicles (direct energy use) [7–9]. Although life-cycle analyses (LCAs) have been used to compare alternative activities from an environmental perspective, such analyses are comparatively rare in the field of transport. Their focus in transportation has mainly been on comparing various materials used in vehicle construction [10,11]. LCAs constitute a suitable means to analyse environmental impacts. However where sustainable development is concerned, there are other issues apart from environmental impact that are important. Sustainable development can be defined as a transformation process, which takes into account environmental, as well as social, and economic objectives [12]. LCAs can be extended to incorporate such sustainable development objectives by integrating social and economic variables in the analysis.

The transition to sustainable transport futures demands an integrated approach to transport policy development and implementation. This includes lowering carbon dioxide (CO_2) emissions in transport, and achieving progress against wider economic, social and local environmental policy objectives.

The most of urban mobile CO_2 emissions in the world is the United States, China, Russia, and India, and Japan, whose emissions accounted for more than half of the total global fossil-fuel combustion emissions, United States and China's emissions exceed one-third of the world. Since 2000, two-thirds increase in global CO_2 emissions from China. The report of the Garnaut (Garnaut Climate Change Review) notes (published in September 30, 2008, Australia): since 2000, with the booming economies of developing countries, including China, global CO_2 emissions from fossil fuel sources to 3% annual growth rate [13]. Around one-quarter of the carbon dioxide (CO_2) emissions of the European Union (EU) are caused by the transportation sector. While total greenhouse gas emissions in the EU decreased between 1995 and 2005 by around 1.4%, emissions caused by transportation rose 17.3% during the same period [14]. This trend of transport emissions, which is mainly caused by private road transport, is expected to continue further.

The ranks of components urban carbon emission sources were industry, residential, and transport. United States New York, for example, in 2007 greenhouse gas emissions generated by energy consumption, building 51% (including indirect emissions from power consumption), transportation 37.5%, while industry accounted for only 11.5%. Total greenhouse gas emissions in 2006, London, United Kingdom, building 71%, surface transportation 22%, industries accounted for only 7% [15]. Due to the industrial structure is unreasonable in China, industry consumes a lot of energy, industrial emissions ranks first, such as in Shanghai the total CO_2 emissions, industrial absolute proportion, followed by transportation and construction, from 2000 to 2007, transportation upward trend in the proportion of carbon emissions in Shanghai, increased about 8%. This was mainly caused by the private car which was rapidly increased in recent years in China. An average annual growth rate of 22.15%, the annual growth rate higher than the civilian cars in which of 14.2%. CO_2 emissions from private car transport in the share of commercial transport were increased from 23.89% in 2000 to 38.22% in 2007 [16].

According to Relevant statistics, the energy consumption of the transportation industry is relatively large, the vehicle fuel consumption level of china has been 22% higher than Europe and 39% higher than Japan. In Copenhagen, the Chinese government made a commitment to the world that the unit carbon emissions of GDP will be controlled between 40% and 45%. This shows that low-carbon economy will become the main direction of future development in China, further shows that China will focus on the development of low-carbon transport in future.

As a resource-occupying and energy-consuming industrial sector, the transportation industry is an important field to promote energy conservation and emission reduction. The statistics show that with the rapid development of China's economy, the transportation industry is becoming the fastest growing energy consumption industries [17]. At present, China's transportation industry energy consumption accounts for about 10%–15% of China's total energy consumption and the oil consumption accounts for about 40% of the national oil consumption. The traffic conveyance consumes about 95% gasoline, 60% diesel and 80% kerosene. According to the relevant data analysis, the external dependence degree of oil has been close to 50% and it will get to 60% in 2020. The carbon emissions of transportation and storage have accounted for 19% of the national carbon emissions [18]. Therefore, the Carbon dioxide emission reduction has become a hot topic for sustainable development research in various countries.

A study from the United States survey shows that between 1998 and 2008, the world's carbon emissions increased by 13%, while the emissions generated by transport growth rate as high as 25%. Therefore, it is necessary to reduce the carbon emissions of society as a whole and focus on the low carbon road. Low-carbon transport is a mode of transport that carrying the goods by low carbon transport mode, which biggest feature is the energy consumption can be achieved under the high efficiency and low carbon emissions. In addition, through the use of advanced technology to improve energy use structure, the Low-carbon transport can reduce the high energy consumption and high pollution in the transportation system [19]. At present, the extensive transportation mode not only wastes the resources, but also greatly increases the carbon emissions. Thus, to study how to reduce carbon emissions by efficient and reasonable transportation has become an urgent problem to be solved by transportation enterprises.

2. Energy consumption analysis of multimodal transport

This paper mainly studies the carbon emissions of diesel fuel as fuel in the three modes of transportation by road, railway and waterway transportation. The energy consumption coefficient of diesel fuel for each transportation mode can be get as Table1.

2.1. Energy consumption coefficient of highway transportation

In China's road transport, the average load of diesel vehicles is 25 tons or 2 TEU. According to the Special Investigation Report on National Highway and Waterway Transportation Volume, this paper takes the energy consumption index of diesel vehicles with loading capacity of 20 tons or more as the energy consumption index of road transportation. In general, trucks consume 0.33 L of diesel per kilometer and heavy-duty trucks consume 0.35 L of diesel per kilometer. By calculating, we can get the energy consumption coefficient is 0.0165L/ton-km.

2.2. Energy consumption coefficient of railway transportation

In general, the traction mode of railway transportation mainly includes electric traction and internal combustion traction. Electric locomotives are mainly used for passenger transport. Diesel locomotives are mainly used for freight transport; whose fuel is diesel oil. Therefore, this paper takes the diesel locomotives as the as the main research object when we analyses the rail freight energy consumption. According to the China's statistical yearbook in 2012, the energy consumption per million tons of kilometer consumption of diesel locomotives is 26.4 kg. Through the conversion, the energy consumption coefficient of railway freight transportation is 0.00264 kg/ton-km.

2.3. Energy consumption coefficient of waterway transportation

In the waterway transportation, we mainly select the transportation energy consumption of ship whose fuel is diesel oil, as the research index. According to the water resources index in public water data bulletin, the energy consumption of ship which the transportation distance is 1 km is 5.44 kg. Through the conversion, the energy consumption coefficient of waterway freight transportation is 0.00544 kg/ton-km.

Comparing the energy consumption of the three modes of transport, we can be found that the fuel consumption of road transportation is the highest and the railway is the lowest [20]. Through the calculation, it is found that the energy consumption per ton-km of highway transportation is 5.25 times the railway transportation and 2.5 times the waterway transportation. What is more, the energy consumption per ton-km of railway transportation is 2 times of that in waterway transportation.

From the above analysis, the railway transportation is the most energy-saving mode of transport, followed by waterway transportation. Therefore, we should focus on the development of railway transportation and waterway transportation in the multimodal transport; this will help promote the process of transport of low-carbon.

3. Multimodal transport path model in low-carbon environment

The establishment of the model is from the environmental and economic point of view, which based on the consideration of environmental issues and business interests. This paper establishes a dual objective function model which with the least carbon emission and the least transportation cost. The model is shown below:

The objective function:

$$\begin{aligned} Z_3 &= \min \sum_{i\in v}\sum_{j\in v}\sum_{k\in K} S_{ijk}\cdot d_{ij}\cdot x_{ijk}\cdot m + \sum_{i\in v}\sum_{j\in v}\sum_{k\in K} s_{ikl}\cdot y_{ikl}\cdot m \\ Z_4 &= \min \sum_{i\in v}\sum_{j\in v}\sum_{k\in K} C_{ijk}\cdot d_{ijk}\cdot x_{ijk}\cdot m + \sum_{i\in v}\sum_{j\in v}\sum_{k\in K} c_{ikl}\cdot y_{ikl}\cdot m \end{aligned} \tag{1}$$

The constraint conditions:

$$\sum_{k\in K} x_{ijk} = 1 \quad i,j = 1,2,\cdots n \tag{2}$$

$$\sum_{k\in K}\sum_{l\in K} y_{ikl} \le 1 \qquad i,j = 1,2,\cdots n \tag{3}$$

$$\sum_{i\in v}\sum_{j\in v}\sum_{k\in K} T_{ijk}\cdot x_{ijk} + \sum_{i\in v}\sum_{j\in v}\sum_{k\in K} t_{ikl}\cdot y_{ikl} \le T_0 \tag{4}$$

$$x_{ijk}\cdot x_{jkl} = y_{jkl} \quad i,j = 1,2,\cdots n \quad k\in K \tag{5}$$

$$m \le m_{ijk} \quad i,j = 1,2,\cdots n \quad k\in K \tag{6}$$

$$x_{ijk,} y_{ikl} \in \{0,1\} \tag{7}$$

- Means that it is only possible to choose one transportation mode between v_i and v_j;
- Means that the transformation of the transportation mode can only be carried out once at node v_i;

- Means that the goods must arrive within the specified time. The whole time includes the transportation time and transshippingion time between nodes. T_0 represents the time limit for the transportation of goods;
- Means that the continuity of transportation mode between adjacent nodes;
- Means that the freight volume cannot exceed the maximum amount of which take the transportation mode of *k*;
- Means that it represents a 0–1 variable.

4. Model solving

4.1. Example description

A logistics company decide to transport a group of goods and the goods will be transported from city S to city D by multimodal transport. The freight volume for this transportation is 60 tons and the transportation modes include highway, railway and waterway [21]. Considering the complexity of transport routes and transshipping stations between nodes, in order to facilitate the calculation, we choose the hub city which with relatively developed traffic as the transshipping city in multimodal transport. The transportation network can be shown in Fig. 1.

As shown in Fig. 1, we select three major urban nodes and city A has expanded into three node cities. Similarly, the city B has expanded into two node cities and city C has expanded into three node cities [22]. The modes of transportation between city extended nodes can be shown in Fig. 1.

4.2. Data statistics

In this paper, we define the transportation cost formula as: transportation cost = (transportation unit price) × (transport distance) × (transport weight). This paper mainly takes the container transportation, the distance unit is km and the time unit is hour. The transport distance between urban nodes can be shown in Table 2 and the transport time can be shown in Table 3.

In the actual multimodal transport process there are differences in infrastructure construction between urban nodes, which lead to the difference of transshipping costs and transshipping time. In addition, the difference of regional economic level also leads to the difference of transshipping costs and transshipping time [23]. In order to facilitate the calculation, this paper assumes that the transshipping process occurring is under ideal conditions.

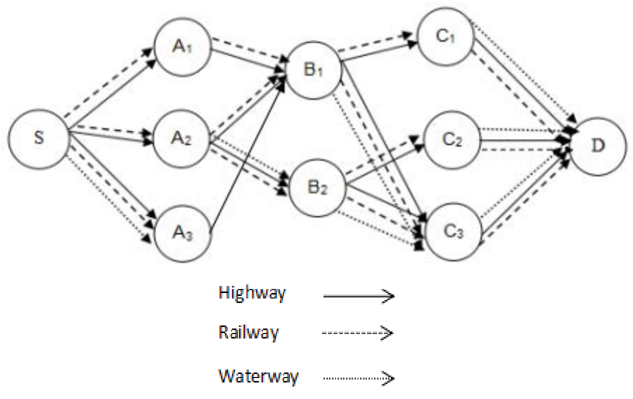

Fig. 1. Transportation network.

If there is no transshipping process between the city nodes, transshipping costs and transshipping time are 0. The transshipping costs between the urban nodes can be

Table 1
Energy consumption indicators

Mode of transport	Coefficient of energy consumption
Highway	0.0165 L/ton-km
Railway	0.00264 kg/ton-km
Waterway	0.00544 kg/ton-km

Table 2
Transportation distance between nodes

Serial number	Urban nodes	Transportation distance (km)		
		Highway	Railway	Waterway
1	S→A1	230	280	
2	S→A2	315	350	
3	S→A3	290	260	275
4	A1→B1	530	495	
5	A2→B1	400	520	
6	A3→B1	505		
7	A2→B2	600	710	730
8	B1→C1	430	400	
9	B1→C3	380	400	390
10	B2→C2	260	290	
11	B2→C3	380	430	460
12	C1→D	550	650	600
13	C2→D	450	470	400
14	C3→D	360	350	380

Table 3
Transportation time between nodes

Serial number	Urban nodes	Transportation time (hour)		
		Highway	Railway	Waterway
1	S→A1	4.5	5	
2	S→A2	6.5	6	
3	S→A3	5	6	10
4	A1→B1	9	11	
5	A2→B1	8	11.5	
6	A3→B1	10		
7	A2→B2	14	12	18
8	B1→C1	8	9	
9	B1→C3	7	8	15
10	B2→C2	6	4.5	
11	B2→C3	8	7.5	18
12	C1→D	10	11	19
13	C2→D	8.5	8	14
14	C3→D	6.5	7	12.5

shown in Table 4 and transshipping time can be shown in Table 5.

In general, the transportation cost includes the box fee and the transportation base price. In the transportation cost calculation, this paper only considers the transportation base price and the box fee is not included.

According to the data, this paper assumes the transportation base price of highway is 0.5 yuan/ton-km, railway is 0.3 yuan/ton-km and waterway is 0.02 yuan/ton-km. From the above assumptions, we can see that the transportation cost of highway is the highest and the waterway is lowest under the same freight volume and transportation distance [24,25]. Through calculation, the transportation costs of different transportation modes between nodes can be shown in Table 6.

4.3. Calculation of carbon emissions

In multimodal transportation, there are two main sources of carbon emissions that one is the carbon emissions generated during transportation process; another is the carbon emissions generated during transshipping [25–27]. In addition, the transshipping carbon emission coefficient reference Aaron Falzarano [28]. According to the relevant information, the carbon emission formula can be described as follows:

Carbon emissions = (carbon emissions per unit) × (transportation distance) × (freight volume).

Transshipping carbon emissions = (transshipping carbon emission coefficient) × (freight volume).

The specific carbon emission data can be shown in Table 7.

From Table 8, we can find the carbon emission that the highway transportation converts to railway transportation is lower than waterway transportation converts to two other ways. In addition, because of the railway hub station is not in the same place as the port that lead to the goods need to be transported by highway transportation to the transshipping station. Therefore, the carbon emission that the waterway transportation converts to railway transportation is highest.

Table 4
Transshipping costs

Mode of transport	Transshipping costs (yuan/box)		
	Highway	Railway	Waterway
Highway	0	30	30
Railway	30	0	50
Waterway	30	50	0

Table 5
Transshipping time

Mode of transport	Transshipping time (hour)		
	Highway	Railway	Waterway
Highway	0	1.5	1.5
Railway	1.5	0	3
Waterway	1.5	3	0

5. Solving and analyzing

Depending on the number of transportation modes, each city node can be expanded into three virtual nodes that 1 represents highway, 2 represents railway and 3 represents

Table 6
Transportation costs of different transportation modes

Serial number	Urban nodes	Transportation costs (yuan)		
		Highway	Railway	Waterway
1	S→A1	6,900	5,040	
2	S→A2	9,450	6,300	
3	S→A3	8,700	4,680	396
4	A1→B1	15,900	8,910	
5	A2→B1	12,000	9,360	
6	A3→B1	15,150		
7	A2→B2	18,000	12,780	876
8	B1→C1	12,900	7,200	
9	B1→C3	11,400	7,200	468
10	B2→C2	7,800	5,220	
11	B2→C3	11,400	7,740	552
12	C1→D	16,500	11,700	720
13	C2→D	13,500	8,460	480
14	C3→D	10,800	6,300	456

Table 7
Transshipping carbon emission coefficient

Transshipping	Carbon emissions (g/kg)
Highway to railway	32.4
Waterway to highway	42.8
Waterway to railway	42.34

Table 8
Carbon dioxide emissions of different transportation modes between nodes

Serial number	Urban nodes	Carbon dioxide emissions (kg)		
		Highway	Railway	Waterway
1	S→A1	621.69	158.76	
2	S→A2	851.45	198.45	
3	S→A3	783.87	147.42	285.95
4	A1→B1	1,432.59	280.67	
5	A2→B1	1,081.2	294.84	
6	A3→B1	1,365.015		
7	A2→B2	1,621.8	402.57	759.05
8	B1→C1	1,162.29	226.8	
9	B1→C3	1,027.14	226.8	405.52
10	B2→C2	702.78	164.43	
11	B2→C3	1,027.14	243.81	478.31
12	C1→D	1,486.65	368.55	623.88
13	C2→D	1,216.35	266.49	415.92
14	C3→D	973.08	240.45	395.12

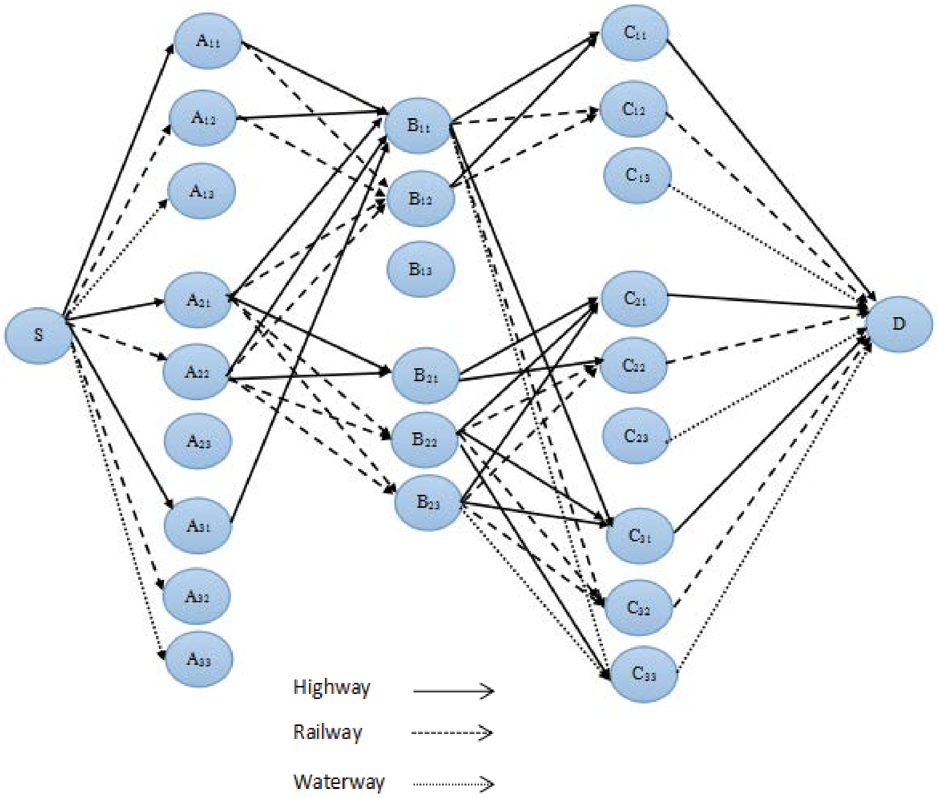

Fig. 2. Virtual transportation network.

waterway. For example, we expand city A_1 into three virtual nodes that A_{11}, A_{12}, A_{13}. From the virtual transportation network, we can see that there are three transportation modes can be selected in the transportation process of city S to A_1 and other nodes also can be expanded according to the method of the city node A_1. What is more, there is no relationship between the three virtual nodes extending from a single city and three virtual nodes cannot be connected. If there is a corresponding transportation mode between city nodes that nodes can be connected by transportation lines. The virtual transportation network can be shown in Fig. 2.

In this paper, we take the genetic algorithm to solve the model. The initial population was set to 1,000, the number of iterations was 700, the initial crossover probability was 0.675, and the mutation probability was 0.08. Through MATLAB 7.0 software programming, we can get the optimal transportation path based on the minimal of carbon emissions and transportation costs. The optimal path is $S \to A_1 \to B_1 \to C_3 \to D$, the carbon emissions are 1,230.65 kg and transportation costs is 20,918 yuan.

6. Conclusion

In recent years, the carbon emission factor is gradually taken account into the traffic path planning. From the above results, the transportation costs and carbon emissions are contradictory. This paper provides a theoretical reference for multimodal transportation path planning in low-carbon background. In multimodal transport, we find that through a reasonable path planning can reduce the carbon emissions on the basis of reducing transportation costs. In the context of environmental protection, the transport companies only take the more environmentally friendly transportation program so that can achieve their long-term development.

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