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Calculation and Analysis of Carbon Emissions from Road Maintenance Projects ——Taking the Tianjin Avenue Restoration and Maintenance Project as an Example

Liping Guo*, Xiaodong Zhu, Tingting You, Kai Niu, Xingyu Zhang

China Municipal Engineering North China Design and Research Institute Co., Ltd, Tianjin 300074, China

Abstract: In response to the phenomenon that road maintenance construction activities may have a certain impact on passing vehicles and generate additional carbon emissions, based on the Tianjin Avenue Restoration and Maintenance Project, a recommended list of carbon emission factors is proposed. A traffic impact carbon emission calculation model is used to calculate the traffic impact carbon emissions of the supporting project, analyze the characteristics of traffic impact carbon emissions composition, and explore the hot spots of traffic impact carbon emissions of maintenance projects, propose emission reduction strategies for road maintenance engineering traffic organization.

1 Introduction

With the proposal of China's goal of achieving carbon peak and carbon neutrality, various industries are vigorously conducting research on carbon emissions calculation and emission reduction strategies. The transportation industry is an important source of carbon emissions, accounting for 24% of global total carbon emissions. In recent years, road construction has shifted from an incremental market to a stock market, with road maintenance accounting for 99.9% of the total road mileage[1]. The carbon emissions from road maintenance projects cannot be underestimated.In addition to certain carbon emissions caused by construction during road maintenance, the impact on transportation also generates additional carbon emissions. Therefore, this study focuses on calculating the carbon emissions affected by transportation, analyzing the hotspots of carbon emissions, and proposing a recommended plan for optimizing the emission reduction of maintenance engineering traffic organization.

The biggest difference between carbon emissions during road maintenance construction and during the construction phase is the need to consider the additional carbon emissions caused by traffic impacts. In recent years, experts and scholars have conducted relevant research, such as Huang et al. using life cycle assessment methods and VISSIM simulation models to calculate the additional carbon emissions of vehicles caused by road maintenance and construction fences in the UK[2]; However, these studies place more emphasis on using microsimulation software such as VISSIM and AIMSUN to simulate the operation status of vehicles during road maintenance construction[3][4][5]. Through software, the instantaneous operation status of vehicles can be relatively accurately obtained. However, due to the high professionalism of the software, it is difficult for engineering personnel to proficiently operate it in a short period of time, so its promotion is not strong.Chinese scholar Liu Yuanyuan has constructed a carbon emission calculation model for the traffic impact of road maintenance construction[6], which has certain significance for the calculation of carbon emissions. Based on this model, this article proposes a recommended list of carbon emission factors applicable to the Tianjin Avenue Restoration and Maintenance Project. Using the above model, the traffic impact carbon emissions of the supporting project are calculated, the characteristics of the traffic impact carbon emissions are analyzed, the hot spots of carbon emissions in maintenance projects are explored, and a recommended plan for optimizing traffic organization and emission reduction in road maintenance projects is proposed.

2 Relationship between maintenance and construction activities, traffic impact, and carbon emissions

The selection of road maintenance plans is influenced by the location and type of diseases in maintenance and construction activities. The different road maintenance plans determine the location, quantity, and length of closed lanes, while the location of the disease and the degree of

*Liping Guo: 409093646@qq.com

damage determine the construction process. Therefore, it is necessary to analyze the relationship between various environmental factors based on the characteristics of the road and maintenance construction area, as well as the correlation between micro and macro perspectives, And summarize the relationship between maintenance construction engineering, traffic impact, and carbon emissions.

3 Carbon emission factors

Due to the complex road environment, there are differences in the performance of operating vehicles, and the operating states are different. The carbon emission factor list presented here is a recommended carbon emission factor list that combines the characteristics of Tianjin Avenue and the structural characteristics of operating vehicles, and combines the research results of experts and scholars. It is suitable for calculating the carbon emission impact of Tianjin Avenue maintenance and construction traffic. The list is divided into two parts, A list of carbon emission factors for various vehicle types under different speed states is provided in Table 2; The other part is a list of carbon emission factors during the speed change process of different vehicle types, as shown in Table 3; For the convenience of subsequent discussions, first define the code for the vehicle type, as shown in Table 1.

Table 1 Vehicle Type Code Definition Table

TYPE	code
Small and medium-sized passenger cars (fuel)	C1
Small and medium-sized passenger cars (hybrid)	C2
Small and medium-sized passenger cars (electric)	C3
Bus (fuel)	B1
Bus (electric)	B2
Van	T1
Medium truck	T2
Large truck	T3
Extra large truck	T4

Table 2 List of Carbon Emission Factors for Various Vehicle Types under Different Speed States (Unit: g/km/veh)

speed(km/h)	C1	C2	C3	B1	B2	T1	T2	T3	T4
10	261	114	18	424	30	316	472	553	799
20	254	111	17	389	28	308	431	455	630
30	239	105	16	367	27	289	406	444	592
40	233	102	16	354	25	282	394	425	571
50	224	97	15	333	23	276	373	410	546
60	221	92	14	320	21	278	360	399	536
70	217	85	13	354	25	295	396	439	576
80	214	78	12	392	29	316	435	478	622

Table 3 List of carbon emission factors during speed changes of different vehicle types (unit: g/s/veh)

Speed changes (km/h)	C1	C2	C3	B1	B2	T1	T2	T3	T4
80 to 40	1	1	0	35	4	5	38	55	69
40 to 80	9	5	1	225	24	57	275	325	424
40 to 0	1	1	0	35	4	5	38	55	69
0 to 40	12	6	1	253	28	62	264	375	477

4 Calculation model

Using the carbon emission calculation model of road maintenance construction traffic impact constructed by scholar Liu Yuanyuan, based on the characteristics of Tianjin Avenue communication and considering the complex and variable traffic impact factors of the road under construction, the vehicle operation status is divided into five categories, and carbon emissions are calculated and summarized separately. The overall modeling idea is shown in Figure 1.

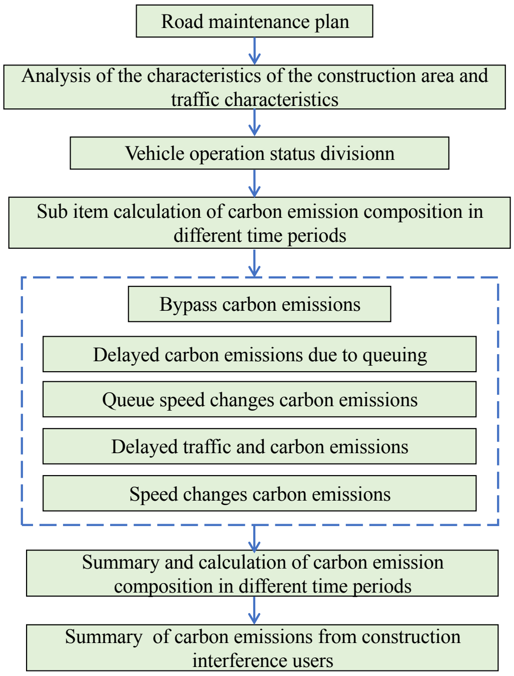

Fig. 1. Calculation ideas for traffic impact carbon emissions during road maintenance construction

5 Calculation and analysis of carbon emissions based on engineering

5.1 Overview of Tianjin Avenue Restoration and Maintenance Project

Tianjin Avenue (S125) starts from the Jingu Interchange on the Outer Ring Road and ends at the Central Avenue in Binhai New Area, with a total length of 36.5 kilometers. The project relies on the maintenance engineering scope of the K28+000 Yingbin Avenue (K34+900) section downstream (from Binhai to the urban area) and the Yingbin Avenue Central Avenue (K36+500) section two-way lanes, with a total length of 8.5 kilometers for the construction section.

The roadbed and pavement engineering is divided into three construction sections. The first section is the K28+000 to Daguhua Railway Qiaoxi Qiaotou (K31+267) section, with a length of 3.267 kilometers; The second section is from the eastern bridgehead of Daguhua

Railway Bridge (K31+785) to Yingbin Avenue, with a length of 3.115 kilometers; The third section is from Yingbin Avenue to Zhongyang Avenue, with a length of 1.6 kilometers. In addition, it also includes drainage and other projects, bridge engineering, traffic and security facilities engineering.

5.2 Roadbed and Pavement Engineering - Calculation of Carbon Emission Composition from Yingbin Avenue to Zhongyang Avenue Section

Due to the relatively complex traffic organization and complete carbon emission composition of the section from Yingbin Avenue to Central Avenue, this section is selected for a detailed discussion on the calculation of traffic impact carbon emissions. The carbon emissions calculation results of its transportation impact are shown in Table 4.

Table 4 Carbon Emission Calculation of Traffic Impact from Yingbin Avenue to Central Avenue Section (Unit: g)

Carbon emission composition	Carbon emission (kg/d)	Carbon emission(t/Duration)	Total carbon emissions(t)
Speed changes carbon emissions	369.44	11.08	26.21
Delayed traffic and carbon emissions	44.06	1.32	
Queue speed changes carbon emissions	35.20	1.06	
Delayed carbon emissions due to queuing	36.50	1.09	
Bypass carbon emissions	388.32	11.65	

The traffic impact carbon emissions of this construction section include: speed change carbon emissions, traffic delay carbon emissions, queue speed change carbon emissions, queue delay carbon emissions, and detour carbon emissions. The second column shows the different carbon emissions caused by construction from 9 to 17 hours a day; The third column shows the different carbon emissions formed during the construction period of 30 days; The last column shows the total carbon emissions from the Yingbin Avenue to Central Avenue section of the roadbed and pavement engineering, which is 26.21 tons. It can be seen that the carbon emissions from detours and speed changes account for the highest proportion, reaching 44.5% and 42.3% respectively. The high carbon emissions from detours are due to the fact that the detour path is generally longer than the original path; The carbon emissions from speed change are mainly composed of carbon emissions from vehicle deceleration and carbon emissions from vehicle acceleration, with vehicle acceleration accounting for a larger proportion of carbon emissions.

5.3 Calculation and analysis of carbon emissions from individual projects

According to the classification of individual projects, the above calculation data can be divided into roadbed and pavement engineering, bridge engineering, traffic and security facility engineering. Due to the fact that only hard shoulders are occupied during the construction process of the drainage project, which has little impact on passing vehicles, the traffic impact and carbon emissions caused are zero, so they are not listed here.

Table 5 Carbon Emission Calculation of Each Single Project (g)

Special engineering	Construction section	Carbon emission (t)	Sum(t)	Proportion (%)
Roadbed and pavement engineering	The first construction section	47.55	75.22	68%
	The second construction section	3.22		
	The third construction section	24.45		
Bridge engineering	Daguhua Railway Bridge	15.21	24.66	22%
	Henan Road and Bridge	9.44		
Traffic and security facilities engineering	——	11.53	11.53	10%
sum	——	111.41		100%

From Table 5, it can be seen that the traffic impact carbon emissions of roadbed and pavement engineering are 75.22t, accounting for 68%, with the highest proportion; The traffic impact of bridge engineering on carbon emissions is 24.65 tons, accounting for 22%; The traffic and security facilities project has a carbon emission impact of 11.53 tons, accounting for 10%.The roadbed and pavement engineering has the characteristics of long construction period and long closed road sections, resulting in the highest carbon emissions.

5.4 Comparative analysis of different carbon emission components

Classify the above calculation data according to the carbon emission composition of the established calculation model, and calculate carbon emissions separately.

Table 6 Calculation of Carbon Emissions from Different Constituents (g)

Carbon emission composition	Carbon emissions (t)	Proportion (%)
Speed changes carbon emissions	67.10	59.21

Delayed traffic and carbon emissions	32.28	28.49
Queue speed changes carbon emissions	1.18	1.04
Delayed carbon emissions due to queuing	1.12	0.99
Bypass carbon emissions	11.65	10.28

From Table 6 , it can be seen that due to the influence of speed restrictions, vehicles generate the most carbon emissions during the speed change process, reaching 67t, accounting for 59.21%; Secondly, due to speed restrictions, the carbon emissions of traffic delays caused by vehicles traveling at low speeds are 32.28 tons, accounting for 28.49%; Next is the traffic congestion in the construction section, resulting in a detour carbon emission of 11.65 tons, accounting for 10.28%; The queuing here is mainly controlled by traffic lights, causing less additional carbon emissions. The carbon emissions due to changes in queuing speed and delayed queuing are both around 1 ton, accounting for about 1%.

5.5 Calculation and Analysis of Carbon Emissions from Different Vehicle Models

For the above calculation data, classify according to vehicle type and separately calculate carbon emissions.

Table 7 Carbon Emission Calculation for Different Vehicle Models (g)

Vehicle model	**C1**	**C2**	**C3**	**B1**	**B2**	**T1**	**T2**	**T3**	**T4**	**Sum**
Number of vehicles	19937	1692	2537	187	348	7	2	33	40	24782
Vehicle proportion (%)	80.45	6.83	10.24	0.76	1.40	0.03	0.01	0.13	0.16	100
	97.51			2.16		0.33				
Carbon emissions (t)	85.38	5.65	1.36	9.94	1.96	0.08	0.10	2.68	4.24	111.41
subtotal	92.40			11.90		7.11				
Carbon emission proportion (%)	76.64	5.07	1.22	8.93	1.76	0.07	0.09	2.41	3.81	100
	82.94			10.68		6.38				

From Table 7, it can be seen that the proportion of small and medium-sized passenger cars reaches the highest of 98%, while the proportion of trucks is the lowest, less than 1%; The carbon emissions of small buses are 92.40t, accounting for 83%; The carbon emissions of large buses are 11.90t, accounting for 6%; The carbon emissions of trucks are 7.11 tons, accounting for 6%. The number of vehicles is basically positively correlated with carbon emissions, but it is evident that the carbon emissions of a single truck are greater.

From the above table, it can also be seen that the proportion of fuel powered small and medium-sized buses, hybrid small and medium-sized buses, and electric small and medium-sized buses is 82%, 7%, and 11%, respectively. The carbon emission rate of fuel powered small and medium-sized buses reaches 92%, exceeding the proportion of vehicles; The proportion of carbon emissions from hybrid small and medium-sized buses is close to the proportion of vehicles, at 6%; Electric small and medium-sized buses account for the least carbon emissions, only 2%. Therefore, vigorously promoting the use of electric small and medium-sized vehicles is of great significance in reducing vehicle carbon emissions.

5.6 Analysis of Traffic Impact on Maintenance Construction

To further analyze the impact of Tianjin Avenue maintenance construction on traffic, assuming normal traffic, we obtained relevant traffic parameters through simulation software and calculated the carbon emissions without maintenance construction impact to be 394.35 tons. As previously estimated, the carbon emissions from transportation impact were 111.41 tons, and the carbon emissions from transportation impact accounted for 28.25% of the carbon emissions from non transportation impact, indicating that maintenance construction increased traffic carbon emissions by 28.25%.

Calculate the carbon emissions from maintenance and construction operations, including the production, transportation, and on-site construction of raw materials. The total carbon emissions are 1560 tons, and the total carbon emissions from maintenance and transportation are 1671 tons. The carbon emissions from transportation account for 6.67% of the total carbon emissions.

6. Maintenance and construction traffic organization and emission reduction strategies

6.1 HotSpots

6.1.1 Detour

In the roadbed and pavement engineering - Yingbin Avenue to Central Avenue section, the proportion of carbon emissions from detours is the highest, reaching 44.5%. Therefore, detours are one of the hotspots of carbon emissions. However, the overall path of Tianjin Avenue has a certain degree of closure, so there is no reasonable detour plan for other construction sections except for the reasonable detour path available for this construction section. Therefore, the proportion of detour carbon emissions in the total traffic impact of the project is only 10.3%.

6.1.2 Speed limit setting

From the above analysis data, it can be seen that the process of changing vehicle speed due to speed restrictions produces the largest carbon emissions, accounting for 59.21%. Therefore, speed restrictions are the main sensitive point of carbon emissions. However, speed restrictions are influenced by industry standards and other factors, and there are certain restrictions on the flexibility of setting them. The operability of construction organization designers is not high.

6.1.3 Traffic organization mode

Reasonable traffic organization is an important means to reduce traffic delays and carbon emissions. Tianjin Avenue is a two-way eight lane road. Considering that Tianjin Avenue is an important transportation channel connecting the urban area of Tianjin and the Binhai New Area, the interruption of traffic due to construction will inevitably have a huge impact on traffic and negative effects on urban economic development. Therefore, appropriate construction traffic organization methods should be selected to minimize the impact of maintenance construction on road traffic, which has important social and economic significance.

6.1.4 Construction section length

Different lengths of construction sections will have different impacts on traffic. The shorter the construction closed section, the smaller the construction working face, the more scattered the division of construction sections, the slower the construction progress, and the longer the impact of construction on the road may be. The longer the construction closure section, the more traffic delays drivers may experience when driving in the construction area due to the increase in traffic density, the decrease in lane width, and the interference caused by maintenance operations. Drivers will drive cautiously at lower speeds, resulting in increased traffic delays. During this process, the longer the construction section, the more likely it is to have an impact on the traffic of vehicles in the construction area, resulting in queuing and congestion. Therefore, selecting an appropriate length of closed construction section has a positive impact on construction progress and traffic.

6.1.5 Construction period

The impact of road closures on traffic varies at different time periods. The larger the traffic flow, the greater the impact of construction closures, resulting in more additional carbon emissions. Therefore, selecting appropriate construction time periods has certain significance in reducing carbon emissions.

6.1.6 Vehicle composition

Vehicles are the source of carbon emissions, and different power sources generate different carbon emissions. Electric cars generate relatively less carbon emissions. Therefore, promoting the use of electric small and medium-sized vehicles is of great significance in reducing vehicle carbon emissions.

6.2 Emission reduction strategies

6.2.1 Reasonably plan the vehicle guidance path.

In the process of road maintenance, variable information boards and other tools can usually be used to guide the detour path of passing vehicles, reasonably plan the detour path, and determine the appropriate proportion of detour vehicles, which is of great significance for reducing carbon emissions of vehicle detours. Tianjin Avenue is a two-way eight lane road with a certain degree of closure, and in the case of construction occupation, traffic congestion is not obvious. Therefore, there is no need to take traffic guidance measures, allowing passing vehicles to choose whether to detour or not.

6.2.2 Reasonable selection of transportation organization methods.

Tianjin Avenue is a two-way eight lane road with the conditions for construction of a closed part of the lane. To meet the needs of the construction site, it is recommended to choose a traffic organization plan that closes two lanes and passes through two lanes.

6.2.3 Reasonably divide the length of construction sections.

The damage situation of different sections of Tianjin Avenue varies, and the maintenance construction plan is also different. Multiple construction sections are divided according to the pavement disposal plan. For road maintenance and major repair operations, considering the continuity of the construction process, the length of the enclosed area should be $\geqslant$ 2km. Due to the fact that the length of the above construction sections does not meet the standard for dividing them into multiple construction sections, no further division will be carried out according to the above construction plan.

6.2.4 Reasonably select the construction period.

The vehicles passing through the Tianjin Avenue section are mostly passenger and freight flows between the urban area and the Binhai New Area, with obvious tidal characteristics in vehicle travel. From 8 to 9 o'clock in the morning, there are more vehicles from the urban area to the Binhai New Area, and from 17 to 19 o'clock in the evening, there are more vehicles from the Binhai New Area to the urban area. Closed roads should be avoided for maintenance and construction during peak hours in the morning and evening. If there are fewer surrounding residents and the construction content allows, nighttime construction can also be considered.

6.2.5 Optimize vehicle composition.

Measures such as further optimizing policies to support the purchase and use of new energy vehicles, encouraging enterprises to enrich the supply of new energy vehicles, and increasing the configuration of charging facilities can be taken to promote the application of new energy vehicles.

7. Conclusions

(1) Propose a carbon emission list applicable to the traffic impact of Tianjin Avenue maintenance and construction, including a list of carbon emission factors for each vehicle type under different speed states and a list of carbon emission factors for different vehicle types during speed changes.

(2) Using a traffic impact carbon emission calculation model, calculate the traffic impact carbon emissions of supporting projects, and analyze the calculation data from the perspectives of individual projects, different carbon emission components, and different vehicle models.

(3) Explore the hot topics of carbon emissions caused by maintenance engineering traffic impact, and propose targeted emission reduction strategies for road maintenance engineering traffic organization based on the identified hotspots.

(4) The carbon emission factor list proposed in this article is based on the transportation characteristics of Tianjin Avenue, and has a certain regional and engineering significance. In subsequent research, further calculations should be made on the carbon emission factors affected by transportation, and a universal list of carbon emission factors should be proposed.

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