Study on Carbon Emission of Highway Repair and Maintenance Projects

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Abstract. Highway maintenance and repair require the consumption of large amounts of materials and the use of high-energy-consuming construction machinery and transportation equipment, resulting in a large amount of carbon emissions, so it is necessary to quantitatively study the carbon emissions of highway maintenance and repair activities. This article takes the Jinlu Line (Jiyun Canal Bridge Binyu Line) project as an example, and uses a combination of quota method and emission factor method to quantitatively analyze the carbon emissions during the construction process of material transportation, on-site construction, and material production. The results indicate that the carbon emissions of the project during the repair and maintenance process have a certain regularity, which can provide basic data support and emission reduction strategy reference for subsequent highway maintenance projects.

Keywords: Highway; Repair and Maintenance; Carbon Emission; Quota Method; Emission Factor Method

1 Introduction

As the core infrastructure for the development of transportation, highways are under increasing pressure as the demand for transportation grows. However, the dual effects of long-term operation and natural environment have led to the gradual emergence of diseases in highway structures, and the amount of highway maintenance work is increasing year by year. In the process of maintenance and repair, a large amount of materials are also required, and high-energy construction machinery and transportation equipment are used, resulting in a large amount of carbon emissions. Therefore, it is necessary to quantify the carbon emissions of highway maintenance and repair activities and take targeted emission reduction measures, which is of great significance to promote the green development of highway transportation.

From the current research progress, it can be seen that certain achievements have been made in the study of carbon emissions during road maintenance and construction stages. Li Di proposed 7 highway maintenance plans and 2 preventive maintenance plans based on the different locations of urban road maintenance and disease incidence. He constructed a universal econometric model based on LCA and analyzed the energy input and carbon emissions of key links [1]. Zhang and Pan Meiping et al.

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established the IRI index and S-shaped decay prediction models, respectively, analyzed the lifecycle carbon emissions of asphalt roads under different maintenance schemes [2][3]. It can be seen that existing research mostly compares the lifecycle carbon emissions of asphalt roads under different maintenance strategies, or compares the carbon emissions of preventive maintenance and large-scale maintenance, mostly qualitative analysis, lacking quantitative calculation and overall evaluation of an actual road maintenance activity.

This article will take the repair and maintenance of the Tianjin Jinlu Line (Jiyun Canal Bridge-Binyu Line) project as an example, and combine the quota method and the emission factor method to construct a carbon emission assessment model. This model will focus on quantitative analysis of carbon emissions in key links such as material transportation, on-site construction, and material production, and comprehensively evaluate the overall carbon emissions of the maintenance activities of the project. This not only helps to have a deeper understanding of the carbon emission characteristics of maintenance projects, but also provides data support for the maintenance and construction of similar projects in the future, promoting the development of highway structure repair and maintenance towards a greener and lower carbon direction.

2 Carbon Emission Assessment Methods and Model Construction

2.1 Methods for Obtaining Basic Carbon Emission Data

In highway maintenance projects, to accurately calculate construction carbon emissions, it is first necessary to clarify the consumption of road construction materials and terminal energy. Currently, there are three main methods for calculating these consumption amounts: actual measurement method, theoretical method, and quota method.

Table 1. Comparison of Material Consumption Calculation Methods.

Obtaining methods	Applicability,Advantage and Disadvantage
Actual measurement method	1. Measurement of the energy consumption of production equipment in actual use. 2. Accurately reflecting the actual situation of different production facilities, manufacturers, equipment operation, etc., to ensure the accuracy of carbon emission quantification results. 3. Requires large investment in equipment and personnel, long measurement period.
Theoretical method	1. Applicable to the case of missing data, using industry averages for quantitative calculation of energy consumption. 2. Considering the general situation of the industry, representative and adaptable

	3. Possible overestimation or underestimation errors, high demand for basic data, and difficulty in operation.
Quota method	1. Applicable to the calculation of energy consumption of materials, machinery, and equipment specified in the quota. 2. An authoritative and effective quantitative system established using modern management technology 3. Applicable only to situations specified by quota.

As shown in Table 1, taking into account the advantages, disadvantages, and applicability of the above three methods, while ensuring the accuracy and authority of the data, the quota method is chosen as the main method for obtaining basic data to meet the actual situation of different projects and the characteristics of project locations.

2.2 Carbon Emission Measurement Algorithm during Construction Process

The carbon emissions calculation is carried out using a combination of quota method and carbon emission factors. The quota method determines the material consumption of maintenance projects in material production, mechanical construction, and material transportation stages, as well as the fuel consumption of transportation vehicles. Based on the carbon emission factors of materials and energy, the total carbon emissions of the unit project are calculated according to the current highway engineering budget quota and current budget standards. After summing up, the carbon emissions of various materials and energy are obtained.

2.3 Carbon Emission Measurement Model for Maintenance and Construction Activities

Highway repair and maintenance projects mainly cover roadbed, pavement, bridge culvert, tunnel, three-dimensional intersection, traffic safety facilities and greening and environmental protection and other unit projects. When constructing the carbon emission measurement model of maintenance and construction activities, carbon emissions are considered in each unit project in stages, including material production, mechanical construction and material transportation [4]. In the material production stage, carbon emissions mainly originate from the production process of building materials. The building materials for each unit project are numbered and the corresponding carbon emission factors are determined in order to accurately calculate the carbon emissions in this stage.

$$E_I = \sum_j \sum_i m_{ij} \times f_{ij} \tag{1}$$

E_I indicates the carbon emission of material production process, mij indicates the number of building materials in each unit project, f_{ij} indicates the carbon emission factor of building materials in the unit project.

The carbon emissions in the mechanical construction stage mainly come from the use of various construction machinery. The carbon emissions of this stage are calculated based on the number of machinery shifts required by various machinery in the course of repair and maintenance construction, combined with the carbon emission factor per unit shift of each machinery.

$$E_2 = \sum_l \sum_k n_{kl} \times p_{kl} \tag{2}$$

E_2 indicates the carbon emission in the process of machinery construction, n_{kl} indicates the number of various required machinery shifts in the process of repair and maintenance construction, p_{kl} indicates the carbon emission factor of each unit shift of machinery.

Finally, the carbon emission of the material transportation stage is closely related to the transportation distance of the building materials and the carbon emission of the unit turnover of the transportation machinery. Based on the number of building materials in the unit project, combined with the transportation distance and the carbon emission data of the transportation machinery, the carbon emission in this stage is estimated.

$$E_3 = \sum_j \sum_i m_{ij} \times p_{ij} \times q_{ij} \tag{3}$$

E_3 indicates the carbon emissions of the material transportation process, m_{ij} indicates the number of construction materials in each unit of work, q_{ij} indicates the distance of construction materials in each unit of work, p_{ij} indicates the carbon emissions of the unit turnover of transportation machinery.

The carbon emission measurement model of maintenance and construction activities is as follows:

$$E = E_1 + E_2 + E_3 \tag{4}$$

E indicates total carbon emissions from repair and maintenance works.

In summary, the carbon emission measurement model for maintenance and construction activities provides a comprehensive and accurate assessment framework for the carbon emission measurement of subsequent maintenance projects by comprehensively considering the carbon emissions of the three phases of material production, machinery construction and material transportation.

3 Case Analysis

Jinlu Line (Jiyun Canal Bridge - Binyu Line) repair and maintenance project is a major road connecting Ninghe District and Dongli District, Tianjin City. The total length of maintenance is 7.098km, with a design speed of 60km/h. It has six lanes in both directions, and a total width of 42m. At present, there are transverse and longitudinal cracks, severe cracking, and local diseases such as settlement, potholes, and frost heave on the road surface. After testing and on-site investigation, maintenance and upkeep will be carried out on the project, covering road surface disease repair, improvement of traffic facilities, restoration of markings, and restoration of green areas in the median strip.

3.1 Analysis of Carbon Emission Characteris- Tics in Material Production Process

The construction materials for highway repair and maintenance projects are simpler than those for new construction projects, mainly including asphalt mixture materials for surface layer repair, lime fly ash crushed stone materials for base layer repair, traffic sign steel materials for traffic improvement facilities, cement materials for curb and sidewalk repair, etc. According to the emissions and engineering consumption, the materials used in the project were classified, converted into units, and ranked. Calculated by formula (1), the material categories that accounted for the top 93% of the cumulative total emissions and consumption of materials are shown in Table 2.

Table 2. Calculation of Carbon Emissions from Consumption of Main Engineering Materials.

Material type	Carbon emissi-ons (t)	Proporti-on of carbon emission	Consu-mption (t)	proportion of consumpt-ion
Asphalt mixture	4646.94	56.44%	62013.2	52.24%
Steel	1614.18	19.61%	435.9	0.37%
Lime fly ash crushed stone	695.25	8.44%	51047.2	43.00%
cement	678.70	8.24%	1001.5	0.84%
Crushed stones and sand	8.35	0.10%	4175.1	3.52%
Other materials	589.28	7.16%	44.67	0.04%

As shown in Table 3 and Figure 1, the materials with higher total emissions are mainly asphalt and steel, accounting for 56.44% and 19.61% of the total material emissions, respectively, with a total proportion exceeding 76%; The materials with high consumption are mainly asphalt mixtures and lime fly ash crushed stones, accounting for a total of 95% of the month; However, comparing the emissions and consumption of various materials, it can be seen that the proportion of high consumption lime fly ash crushed stone and crushed stone emissions is extremely small, with a total of no more than 9%; However, materials with low consumption, such as steel and cement, account for a large proportion of carbon emissions, while their emissions account for nearly 28%.

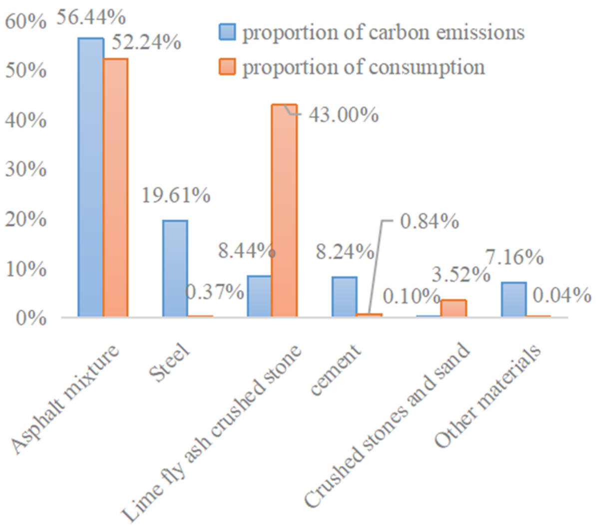

Fig. 1. Comparison of carbon emissions and consumption in material production.

The emissions from material production are not only closely related to consumption, but also influenced by the size of carbon emission factors. The specific values of carbon emission factors are shown in Table 3.

Table 3. Collection of Carbon Emission Factors for Main Engineering Materials

Material type	The main set of values for carbon emission factors (kgCO_2/t)
Asphalt mixture	{45.2， 47.6， 69.5， 76.5}
Lime fly ash crushed stone	{13.6}
Steel [5]	{3551， 3589， 4339}
Cement	{678}
Crushed stones and sand	{1.93， 2， 2.43}

By comparing the emission factors of different materials, it was found that under the same consumption, materials with higher carbon emission factors have higher carbon emissions during the material production process. The carbon emissions of steel are the highest, followed by cement and asphalt mixtures, while the carbon emissions of lime fly ash crushed stone, crushed stone, and sand are relatively low. Other emission characteristics of materials not mentioned can be analyzed based on these typical materials.

3.2 Analysis of Carbon Emission Characteris- Tics during on-Site Construction Process

Based on the data of mechanical emissions and unit shift consumption, the machinery and transportation equipment used in the project were classified, and the unit shift energy consumption was queried and ranked. Calculated by formula (2), the total emissions and total consumption of the mechanical part were sorted into mechanical categories, which are detailed in Table 4.

Table 4. Carbon emission calculation results during on-site construction process.

Specificati-on Name	Total Quanti-ty (Unit Shift)	Unit Shift Ratio	Total Emissi-ons (t)	Carbon Emissio-ns Ratio
Loader	104.82	2.81%	76.08	7.39%
Roller	769.59	20.66%	135.57	13.18%
Mixing equipment	3.31	0.09%	148.14	14.40%
Road milling machine	339.84	9.12%	203.89	19.82%
Dump truck	1769.92	47.51%	325.87	31.67%
Sprinkler truck	232.69	6.25%	33.42	3.25%
Paver	119.88	3.22%	30.47	2.96%
Asphalt distributor truck	13.17	0.35%	2.05	0.20%
Synchrono-us gravel sealing vehicle	56.23	1.51%	23.1	2.25%
Regenerati-on machine	19.26	0.52%	18.64	1.81%
air compressor	34.73	0.93%	7.73	0.75%
Other machinery	261.73	7.03%	23.87	2.32%

It can be clearly seen from Table 4 that there is a significant positive correlation between the emissions of on-site mechanical equipment and the number of shifts. Among them, dump trucks, road milling machines, mixing equipment, and road rollers account for a relatively large proportion of carbon emissions, totaling about 79%. It is worth noting that the size of mechanical carbon emissions is not only affected by the number of shifts, but also closely related to energy consumption and emission factors. In this analysis, carbon emission factors from the IPCC database and various journal papers were used as references.

3.3 Analysis of Carbon Emission Characteris- tics during Material Transportation

After in-depth investigation of engineering material transportation equipment and distance in Tianjin, and comprehensive consideration of carbon emission factors and material transportation volume of different transportation vehicles, calculated by formula (3), the total emissions and proportion of transportation vehicles were obtained.

Table 5. Carbon Emission Calculation for Material Transportation.

Material type	Total Emissi-ons (T)	Carbon Emissi-ons Ratio	Transpo-rtation volume (t)	Transporta-tion volume proportion
Asphalt mixture	136.2	47.22%	62013.2	52.24%
Lime fly ash crushed stone	111.79	38.76%	51047.2	43.00%
Steel	1.53	0.53%	435.9	0.37%
cement	2.19	0.76%	1001.5	0.84%
Crushed stones and sand	30.48	10.57%	4175.1	3.52%
Other materials	6.24	2.16%	44.67	0.04%

According to Table 5, the materials with high total transportation emissions are mainly asphalt and lime fly ash crushed stone, accounting for 47.22% and 38.76% of the total material emissions, respectively, with a total proportion of about 86%; This data indicates that the transportation emissions of these two types of materials are basically proportional to their transportation volume.

3.4 Overall Feature Analysis

Calculated by formula (4), the total carbon emissions from the repair and maintenance project of the Jinlu Line (Jiyun Canal Bridge Binyu Line) are 7509.9 tons, with pavement engineering accounting for the largest total emission value, about 76%. The carbon emissions from other unit projects are relatively low, which is basically consistent with the actual situation of maintenance engineering.

The carbon emissions from material production are 6232.7 tons, the carbon emissions from material transportation are 288.4 tons, and the total carbon emissions from on-site construction machinery are 988.739 tons. The total maintenance length of the Jinlu Line project is 7.098 km, with 6 lanes, resulting in a carbon emission of 1057.8 tons per kilometer and 176.3 tons per lane per kilometer.

4 Emission Reduction Strategies and Measures for Maintenance Projects

Through the analysis of the above cases, it can be found that the carbon emissions of highway repair and maintenance projects are relatively prominent. Therefore, for highway maintenance projects, low-carbon and energy-saving new maintenance methods should be actively advocated and adopted. Specific emission reduction measures can be summarized as follows:

In terms of energy conservation and emission reduction of mechanical equipment, priority should be given to selecting equipment that meets national energy conservation and emission reduction standards, and regular maintenance should be carried out to ensure its efficient operation. At the same time, arrange mechanical operation time reasonably, avoid high-energy consumption during peak hours, and promote the use of electric mechanical equipment to reduce fuel consumption and exhaust emissions.

In the application of green maintenance materials, priority should be given to construction materials with low carbon emission factors, and the use of environmentally friendly materials such as recycled asphalt and recycled cement [6] should be advocated to reduce the exploitation of primary resources. Priority should be given to selecting local materials, reducing energy consumption and emissions during long-distance transportation, and actively exploring and promoting the use of new low-carbon materials.

In the selection of maintenance methods, a scientific maintenance plan should be developed based on road conditions and actual needs to avoid excessive maintenance. Promote preventive maintenance techniques, improve road surface quality, extend road service life, and reduce maintenance frequency. At the same time, green maintenance technologies such as cold regeneration and hot regeneration are adopted to reduce energy consumption and emissions during the maintenance process.

In addition, it is necessary to strengthen supervision and training. Establish a emission reduction supervision system for highway maintenance projects, and conduct real-time monitoring and evaluation of carbon emissions from maintenance projects. Regularly conduct energy-saving and emission reduction training to enhance the environmental awareness and technical ability of maintenance personnel. At the same time, strengthen cooperation with scientific research institutions, introduce advanced emission reduction technologies and equipment, and promote innovative development of emission reduction work in highway maintenance projects.

5 Conclusion and Outlook

This article takes the Tianjin Jinlu Line (Jiyun Canal Bridge Binyu Line) repair and maintenance project as an example, and uses a combination of quota method and carbon emission factors to calculate the carbon emissions of the project's material production, material transportation, and on-site construction processes. After summarizing the total carbon emissions of the entire maintenance project, further calculate the emissions per kilometer per lane. In addition, this article proposes specific emission reduction strategies and measures from multiple dimensions such as energy conservation and emission reduction of mechanical equipment, application of green maintenance materials, selection of maintenance methods, and supervision and training. This study not only provides practical and feasible guidance for carbon emission accounting in future maintenance projects, but also provides useful references and suggestions for reducing carbon emissions in maintenance projects.

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