A Calculation Method of Carbon Emissions in Highway Construction by Bid and Unit Engineering

Yanan Qi[1], Qinping Mao[2], Jiugen Tu[2], Gang Xiao[2], Wanjun Deng[2], Wei Jiang[2], and Zhaoming Wang[1](✉)

[1] Research Institute of Highway Ministry of Transport, Beijing 100088, China
zm.wang@rioh.cn
[2] Jiangxi Communications Investment Group Co., LTD., Nanchang 330200, China

Abstract. Transportation is among the most promising, but also most challenging areas for carbon emission reduction, in which highway transportation is the major part of carbon emissions. This study aims to provide an in-depth understanding of the characteristics of carbon emissions from highway construction, and to provide a reference for carbon emissions calculation. This study presents how to calculate carbon emissions of highway construction by bid and unit engineering, and provides examples of table designs. The results show the statistical method benefits in clear boundary and simple division of responsibility. Furtherly, this method is highly generalizable and has practical benefits for the investigation of carbon background in highway transportation.

Keywords: Highway Construction · Carbon Emissions · Calculating Method · Statistical Design

1 Introduction

'Peak carbon dioxide emissions in 2030 and carbon neutrality in 2060' has become an important strategic decision of China and a consensus of social development. In the Notice of the State Council on the Issuance of the Action Plan for Peak Carbon Dioxide Emissions before 2030 ([2021] No. 23) issued by the State Council in 2021, several key points are clarified as follows: peak carbon dioxide emissions and carbon neutrality should be included in the overall situation of economic and social development; the general policy of 'national overall planning, the priority of energy saving, two-wheel drive, internal and external channels of communication to be kept open, and risk prevention' should be adhered to; the task of peak carbon dioxide emissions should be effectively and orderly fulfilled; the objectives and tasks in various regions, fields and industries should also be clarified; the green transformation of production and life style should be accelerated; the economic and social development should be promoted on the basis of efficient utilization of resources and green and low-carbon development so as to ensure that the goal of peak carbon dioxide emissions by 2030 will be achieved on schedule.

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As one of the three major energy consuming industries, transportation has the greatest potential and the highest difficulty in carbon emission reduction [5, 6]. According to IEA data, the compound growth rate of China's transportation carbon emissions from 1990 to 2018 reached 8.3%, which is significantly higher than the growth rate of the world's transportation carbon emissions (2.1%) and China's overall carbon emissions (5.6%). With the growth of per capita GDP, the demand for transportation will continue to grow. In terms of structure, highway ranks first in the list of China's transportation carbon emissions in 2018, accounting for 83.4% of all. The upward pressure of highway carbon emission is significant, besides, the carbon emissions from highway transportation accounts for a high proportion in the total carbon emission, so it is of great difficulty to realize the carbon emission reduction in 2030 [1].

At present, the research on carbon emission calculation of transportation infrastructure at home and abroad mostly focuses on the whole life cycle theory. The studies and standards of carbon emission in the construction industry are relatively mature, while the research on transportation infrastructure starts late. Highway transportation facilities have the nature of both transportation projects and infrastructure construction facilities, which are not only a key area to deal with climate change, but also an important part of new infrastructure in light of the new development concept. The calculation of carbon emission value of the construction of highway transportation facilities is not only an important foundation for the mechanism, method and technology of carbon emissions, but also a vital basis for infrastructure planning and construction. At the same time, it is also the key work for the requirements of "green and low carbon" in *the Program of Building National Strength in Transportation.* Therefore, it is of great significance to reasonably calculate the carbon emissions of highway construction.

2 Characteristics of Carbon Emissions from Highway Construction

2.1 Lots of Emission Programs

Due to the linear characteristics, highway engineering is mobile, some of them are temporary projects, others have narrow and long construction working surface and uneven project distribution. There are not only subgrade earthwork engineering of various types of bridges, tunnels, high filling and deep excavation sections, but also pavement engineering, traffic engineering and greening engineering along the line. There are so many emission programs, and it is not easy to count with the same standard [2].

2.2 Many Undefined Boundary

The amount of highway projects is huge. Generally, the process of construction is divided into several bids. Different stages and programs of the construction are often carried out by different construction companies, and the organization boundary and personnel boundary are not easy to delimit. The whole construction project is uninterrupted in time and discontinuous in space. At the same time, the construction is multithreaded, and the time boundary of construction is not easy to define. In addition, highway engineering involves large engineering fluidity, many temporary projects, uneven distribution of construction operation sites, and thus it is difficult to delimit the physical boundary [3].

2.3 Greatly Affected by Natural Conditions

The carbon emission of highway engineering is greatly affected by natural conditions such as geographical location, topography, geology, hydrology and climate. For example, the power of Beijing's highway project is controlled by North China Power Grid and the carbon emission factor is 1.0416 $kgCO_2$/kwh, while the power of Jiangxi's highway project is controlled by Central China Power Grid and the carbon emission factor is 0.9515 $kgCO_2$/kwh. The carbon emissions are different under the same power consumption. In the other grades, different temperature and humidity lead to different fuel consumption of machinery and carbon emission, too.

3 Feasibility of Statistics of Highway Construction by Bid and Unit Engineering

Considering the above carbon emission characteristics of highway engineering, calculating by unit and division is proposed to be the most efficient statistical method to get the carbon emission of highway engineering.

3.1 Clear Boundary

Generally speaking, the sections of highway engineering are divided according to the geographical position. Each construction company is responsible for one or more sections. The organization supporting facilities of each section are similar. As long as the statistics of each construction company is carried out, the organization boundary and personnel boundary can be well defined in the whole project. On this basis, each bid has clear statistics on the construction time, and the construction time boundary of the whole highway project can be determined. Furthermore, when the project is divided into bids, the unit works of each bid are relatively single, thus the operation difficulty of statistics is lowered.

3.2 Clear Statistical Responsibilities

First, the supplies and materials of each bid are under control. Each bid has its own supplies and account book, what's more, there is a consumption inventory mechanism within a certain period to facilitate the statistics and verification of carbon emissions. Second, the technicians in the construction organization are able to ensure the clear division of statistical power and responsibilities. The following chart shows a common organization in highway construction company. In this structure, the materialmen, budgeters and planning statisticians shall ensure the statistics of construction supplies and materials, while the machinery administrators shall be responsible for the performance and energy consumption statistics of construction machineries; the documenters are conducive to the cross inspection of statistical data. Thus, the structure has clear division of responsibilities as well as feasibility of implementation.

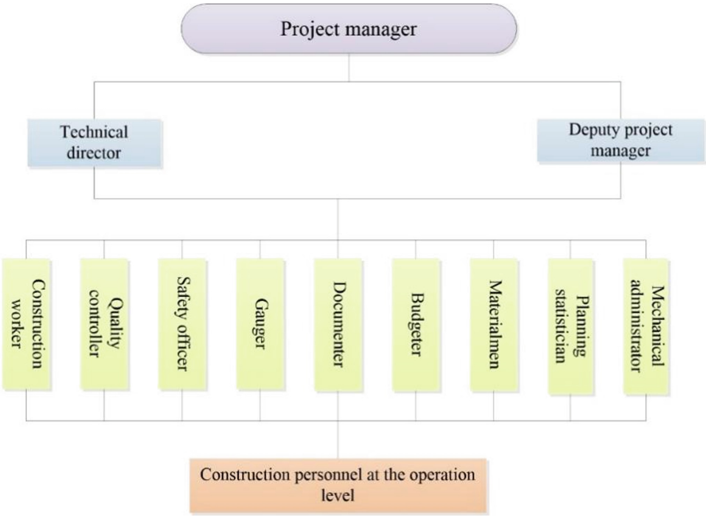

Fig. 1. Structure of Common Construction Organizations.

3.3 High Applicability

The statistical method of sections is in line with the engineering practice, which has organizational guarantee, and the least difficulty in implementation, thus the effective working mechanism formed can be better copied and widely applied. The statistical method of bid and unit engineering is conducive to the comparative analysis of the carbon emission intensity of the same type of unit works, and has a high reference for the carbon emission of similar types of highway construction in the same area.

4 The Design of Statistical Tables

4.1 The Principles

(1) High Quality, Low Cost and Energy
In highway engineering, quality and cost are the two most important controlling variables for both the employer and contractor. At the same time, energy consumption in carbon emissions is also an important determinant. Therefore, quality, cost and energy consumption should also be taken into account in table design. Building materials with cumulative quality accounting for more than 90% of the total quality, building materials with cumulative cost accounting for more than 90% of the total cost, and machinery and equipment with cumulative energy consumption accounting for more than 90% of the total energy consumption are included in the calculation [4].

(2) Calculation Consistency
When designing statistical tables, it is required that the statistical principles and statistical components of each unit project should be consistent to avoid missing the emission units. Carbon emission categories of the same order of magnitude

should be counted to avoid mistakes and omissions. The centralized construction sites such as 'two zones and three plants' shall be calculated separately to avoid repeated inclusion.

(3) Decrease Data Deviation
If a certain emission source is provided by multiple construction units, it is necessary to conduct comparison and statistical analysis on the data, remove the most discrete source, and confirm its rationality through return visit, so as to reduce the deviation of the data.

(4) Traceability Statistics of Mechanical Energy Consumption and Construction Consumables
The carbon emission in construction can be divided into two parts according to the source: one is the carbon emission caused by mechanical energy consumption, and the other is the carbon emission caused by the production and transportation of materials. In the process of highway construction, the types of projects involved are diverse and the types of machineries are complex, besides, the materials are complex and changeable. In recent years, the level of highway management has been further improved, and technological means have been more and more widely used in highway engineering management. The use of materials and energy could be recorded in the account books and the source can be traced, which provides conditions for this study to refine the statistics of mechanical energy and materials.

4.2 An Example of Statistical Tables Design

(1) Project Overview
Jiangxi Province has carried out capacity expansion and reconstruction of an expressway with a total length of 132.716 km and a connecting line of 11.954 km. The design speed is 100 km/h, the subgrade width is 33.5 m, the vehicle load grade is Road-Grade I.

(2) The Example of Statistical Tables Design
The design of the tables is consistent with the statistical principles, the mechanical energy consumption and construction consumables are counted separately. The tables are designed by unit engineering and distributed to each bid to ensure that responsibility is clearly defined and there is no duplication of statistical items Table 1, 2 and 3. The following are some examples of statistical table design:

4.3 Implementation Effect

The statistical tables along with the instructions shall be distributed to the chief engineers of each bid, and a publicity meeting is held. At the meeting, the chief engineer of each bid also raised questions and gave opinions on the actual project, and the tables were got revised. The chief engineer of each bid, together with the main technicians, gaugers, documenters, materialmen, planning statisticians and construction mechanics, filled in the form and returned the statistical results in 5 workdays. The survey received 6,324 data, including 6,302 valid data and 22 invalid data. The data qualification rate was 99.65%, and the data effect was good.

Table 1. Statistics of Mechanical Energy Consumption of Subgrade Engineering.

Equipment name	Machinery type	Rated power /kwh	Rated voltage /V	Number of shifts	Power consumption record /kwh	Gasoline consumption record /L	Diesel consumption record /L	Gas consumption record /m^3	Coal consumption record /t	Water consumption record /m^3
excavator	350	187	-	3570	0	0	385560.00	0	0	0
bulldozer	SD18	140	-	960	0	0	110750.12	0	0	0
loader	ZL50	165	-	2760	0	0	373411.76	0	0	0
land leveler	165	165	-	480	0	0	75783.53	0	0	0
road roller	32	220	-	480	0	0	70588.24	0	0	0
	22	140	-	720	0	0	88941.18	0	0	0
dynamic compactor	FS50	150	-	120	0	0	4658.82	0	0	0
Back compactor	ZL50	165	-	120	0	0	225.88	0	0	0
dump truck	15	103	-	18090	0	0	307219.50	0	0	0
blasting equipment	90	55	-	60	0	0	6480.00	0	0	0
other										

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Table 2. Energy Consumption Statistics of Tunnel Construction Machineries.

Equipment type	Equipment name	Machinery type	Rated power /kwh	Rated voltage/V	Number of shifts	Power consumption record /kwh	Gasoline consumption record /L	Diesel consumption record /L	Gas consumption record /m^3	Coal consumption record /t	Water consumption record /m^3
power supply machinery and equipment	Power supply machineries	-	630	380	0	0	0	0	0	0	0
tunnel construction machinery	intelligent three-wall drilling rig	Boomer XE3C	225	380	125	21990	0	691.53	0	0	0
	multifunctional arch installation trolley	XZGT311	132	380	76	63960	0	1780.89	0	0	0
	wet-spraying trolley	ZTC30	92	380	132	89020	0	856.23	0	0	0
	self-propelled hydraulic inverted arch trestle	48m	45	380	85	550	0	0	0	0	0
	multifunctional waterproof operation trolley	6m	15	380	255	1560	0	0	0	0	0
	secondary lining trolley	12m	7.5	380	515	6916	0	0	0	0	0

(*continued*)

Table 2. (*continued*)

Equipment type	Equipment name	Machinery type	Rated power /kwh	Rated voltage/V	Number of shifts	Power consumption record /kwh	Gasoline consumption record /L	Diesel consumption record /L	Gas consumption record /m^3	Coal consumption record /t	Water consumption record /m^3
	intelligent spray curing trolley	self-made	3.5	380	350	1880	0	0	0	0	0
	cable grooved trolley	12m	30	380	240	30019	0	0	0	0	0
	muck truck	-	120	24	312	0	0	16500.25	0	0	0
	loader	ZL50	162	24	53	0	0	5823.60	0	0	0
	steel frame assembling machine	ZLC50	162	24	49	0	0	5300.18	0	0	0
	jumbolter	J50	162	24	85	0	0	6156.23	0	0	0
	grout injector	S50	162	24	75	0	0	6537.90	0	0	0
	shotcrete machine	220	110	24	195	0	0	15330.00	0	0	0
	concrete pump	400NT	123	24	168	0	0	11800.00	0	0	0
	concrete carrier vehicle	-	7.5	380	195	12100	0		0	0	0
environmental equipment	axial flow fan	SPDZ-P	110	380	497	432900	0	70776.81	0	0	0

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Table 3. Statistics of Raw Materials.

Construction stage	Separate process level	Type	Statistical Unit	Designed consumption	Actual quantity of entering	Transportation distance (km)	
						Outside	Inside
Production stage of highway construction materials	Crushed stone	Crushed stone	m^3	129851.78	132448.81	110	4.6
	Modified asphalt	modified SBS	T	0	0	0	0
	Ordinary asphalt	50#	T	0	0	0	0
		70#	T	0	0	0	0
	cement	42.5	T	47825.48	48009.38	240	4.6
		52.5	T	24062.99	24113.36	240	4.6
	steel	Φ6	T	0	0	0	0
		Φ8	T	201.624	203.45	300	5.4
		Φ10	T	1656.446	1657.55	300	5.1
		Φ12	T	4317.4	4318	300	5.1
		Φ16	T	4243.6	4240	300	5.4
		Φ18	T	0	0	0	0
		Φ20	T	741.01	811.228	300	2.8
		Φ24	T	792.708	828.656	300	5.1
		Φ28	T	3750.4	3941.232	300	4.6
		Φ32	T	661.67	661.665	300	0.6
	diesel oil	0#	T	-	527976	0	0

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5 Conclusions

In recent years, China's total highway mileage and highway density have increased year by year, and the carbon emission generated of it cannot be underestimated. The green and low-carbon upgrading and transformation of the highway transportation industry is urgent. This study provides a clear idea for the scientific method of carbon emission calculation of highway infrastructure, that is, the investigation and calculating by bid and unit engineering, and provides the design method of statistical tables. The results show the statistical method benefits in clear boundary and simple division of responsibility. Furtherly, this method is highly generalizable and has practical benefits for the investigation of carbon background in highway transportation. It also provides the basis for the next key measures and process innovation of carbon emission reduction and offers decision support for the industry management to formulate emission reduction policies, which is of practical benefit to the goal of peak carbon dioxide emissions of the highway transportation industry.

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