Study on Carbon Emission of In-plant Transportation in the Components’ Production Stage of Prefabricated Building

Chunzhen Qiao¹, Peihao Hu², Jianling Gao³
School of Civil Engineering, North China University of Technology, Beijing, 100144, China
¹joecz1221@sina.com
²hupeihao888@126.com
³Gaojlnct@126.com

Abstract. Prefabricated buildings are at a stage of rapid development in China. However, there is an absence of detailed scientific research or case studies of this field. This paper is concerned with the in-plant transportation’s carbon emissions of prefabricated building components at the production stage. The discussion is largely guided by the qualitative analysis and the basic information of the plant, measuring equipment and points, data accounting and analysis combined with actual measurement data. The qualitative analysis consists of three interrelated parts: stage division, determination of carbon emission calculation boundary, calculation and release method. Through the discussion and the analysis, this paper concludes the influencing factors affecting the carbon emissions of in-plant transportation.

1. Introduction
According to the survey of the United Nations Intergovernmental Panel on climate change (IPCC), buildings consume 40% global energy and emit 36% global CO₂[1]. Building carbon emissions have a large proportion in carbon emissions of all industries.

With the acceleration of urbanization and the improvement of people's living standards, carbon emissions will keep increasing rapidly. Transportation industry is one of the high carbon emissions industries in China. Therefore, it is very urgent to reduce the carbon emission of transportation and build a low carbon transportation system.

Industrial enterprises have an irreplaceable role of the rapid development of modern society. In-plant transportation is an essential part of industrial enterprises. At present, the research on the carbon emission of industrial enterprises from the angle of carbon emission is still in the primary stage, and even the research on the transportation of fabricated buildings in the production plant is rare.

The purpose of the research here is to study the carbon emissions of prefabricated building components in the production process. And the article is analyzed from the following three aspects: stage division, accounting boundary determination, and accounting method. Through the above analysis combined with actual measurement data, the factors can be obtained, which influence the carbon emission of in-plant transportation.

2. In-plant transportation carbon emission accounting

2.1 Phase division
To identify the source of carbon emission, this requires the stage division of the whole life cycle\cite{2}. Therefore, the inventory analysis of the carbon emission is applied to achieve this goal\cite{3}. This method lists the processes of producing carbon emissions from in-plant transportation and calculates the amount of carbon dioxide emitted to the external environment based on the consumption of resources and energy in the whole life cycle of in-plant transportation.

![Division of in-plant transportation](image)

**Figure 1. Division of in-plant transportation**

2.1.1 *Design stage.* The design stage is not included in the calculation of the carbon emissions in the life cycle, because there is no carbon dioxide emission produced during this stage. However, the design stage has a significant influence on the carbon emissions in the later stage, such as construction and operation. Moreover, the rationality of the general layout and the mode of transportation within the plant also have a great impact on the carbon emissions of the plant\cite{4}. Therefore, it is necessary to make the general layout conform to the process flow and satisfy the transportation requirements.

2.1.2 *Construction stage.* Carbon emissions of construction stage account for a large proportion in in-plant transportation. The carbon emissions come from three parts in the construction process: the production of materials, the process of material transportation and the construction process. The construction of the plant infrastructure consumes plenty of construction materials which need a great amount of energy to produce. In the stage of construction, using construction equipment will also inevitably consume energy and produce carbon emission.

2.1.3 *Operation stage.* The carbon emissions in the operation stage are mainly caused by the energy consumption of transportation equipment. Although electrical energy is converted from primary energy, it’s difficult to analyse the whole process of carbon emission because the carbon emission coefficient varies according to the sources of electrical energy. If it is clean energy, there will be no carbon emission and the carbon emission coefficient will be zero\cite{5}.

2.1.4 *Recovery stage.* In the recycling stage, the removal and disposal of some infrastructure require the use of mechanical equipment which can produce a certain amount of carbon emissions. However, recycling and reuse of removed material will mitigate the impact of the carbon emission problem.

2.2 *Boundary determination*

According to the life cycle theory, in-plant transportation life cycle carbon emissions refers to the total amount of carbon dioxide emitted to the external environment produced by energy and resources consumption during the life cycle of each transportation mode\cite{6}. However, the main research object of this paper is the in-plant transportation carbon emission during the operation phase of the fabricated building. Therefore, to calculate the carbon emissions at this phase, it is necessary to determine the boundary in the in-plant transportation operation phase.
2.3 Accounting Method

There are three types of carbon emission accounting methods: Emission-Factor Approach, Mass balance method, and Measurement method. This paper uses the Emission-Factor Approach for carbon emission accounting in the operation phase[7].

In the operation stage, carbon emissions are mainly derived from two parts: the first part is transportation equipment; the second part is other sources (fuel, etc.) of energy. Both can be calculated using Equation 1.

\[
Car = \sum W_i \cdot T_i \cdot \alpha_i
\]  

(1)

In the formula, Car is carbon emissions from transportation equipment, \(W_i\) is the power of the \(i\)-th transport equipment, \(T_i\) is run time of the \(i\)-th transport equipment, and \(\alpha_i\) is carbon emission factor for energy used in the \(i\)-th transport equipment.

2.4 Case Analysis

2.4.1 Factory introduction. Fabricated building component production factory Longxin is located at Haimen, Jiangsu Province. The PC components produced by the factory include laminated slabs, wallboard, staircases, etc. The production line in the workshop includes automatic production line of the laminated slab, the fixed production line of wallboard and the automatic production line of rebars.

The field transportation in the factory consists of three parts: The first part is to use the brakes to hoist the components that have been cured into the transport vehicle. The second part is that components are transported outside the workshop by the transport vehicle. In the third part, the gantry cranes are used to hoist the components from the transport vehicle to the component stacking place.

2.4.2 Test equipment and measuring point arrangement

The carbon emissions generated by the production components are electrical equipment in the factory. Therefore, the power consumption of the equipment is the purpose of this measurement. In order not to interrupt the normal production of the factory, split-core current transformer is used to measure the current value of each device. And the measuring instruments (Fig.2) which used in this measurement include 9 three-item power recorders(a in Fig.2), 36 different ratio split-core current transformers (b in Fig.2), a hand-held pincer power meter (c in Fig.2) and a multimeter(d in Fig.2).
The measuring points are arranged according to the actual position of the distribution box in the factory (Fig.3). In the figure, 2#, 4#, 8# represent the measuring points of the cranes trolley, transport vehicles and gantry cranes. And above equipment is used for actual measurement.

### 2.4.3 Accounting and analysis.

Carbon emissions of component production are mainly generated by electrical equipment. Therefore, the carbon emissions of all electrical equipment are calculated using equation (2).

\[
\text{Car} = \frac{(I_a + I_b + I_c) \times U \times \cos \omega \times T \times \alpha}{\sqrt{3} \times V}
\]  

(2)

In the formula, Car is carbon emission, \(I_a, I_b, I_c\) is phase current, \(\cos \omega\) is Power factor, \(U\) is line voltage, \(V\) is concrete volume, \(T\) is run time of equipment, and \(\alpha\) is electric carbon emission factor. Phase current and line voltage are measured by split-core current transformers and multimeter. Then the three-item power recorders record the data per second. Run time of equipment and concrete volume are provided by the factory production log. Table 1 shows electric carbon emission factor. The carbon emissions of the two components are calculated in table 2.

| Region       | North China | Northeast | East China | Central China | Northwest |
|--------------|-------------|-----------|------------|---------------|-----------|
| 2011         | 0.8969      | 0.8189    | 0.7129     | 0.5955        | 0.6860    |
| 2012         | 0.8843      | 0.7769    | 0.7035     | 0.5257        | 0.6671    |
Table 2. The carbon emission of Laminated slabs and Wallboard

| Production process          | Laminated slabs (kg/m³) | Wallboard (kg/m³) |
|----------------------------|-------------------------|-------------------|
| Automatic production line   | 5.30                    | \                |
| Concrete                   | 3.31                    | 3.34              |
| Rebars                     | 2.76                    | 1.33              |
| Crane trolley              | 1.18                    | 3.46              |
| Internal transfer vehicle  | 0.02                    | 0.02              |
| Gantry crane               | 0.52                    | 0.72              |

As shown in figures (Fig.4 and Fig.5), in-plant transportation of laminated slabs and hand-made wallboard accounted for 13% and 49% of carbon emissions, respectively. Laminated slabs and wallboard in-plant transport carbon emissions are 13% and 49%. Different production processes make the difference in the carbon emissions of the two components’ in-plant transportation. These cranes trolley are only used to transport the laminated slabs that have been cured on the automatic production line. However, the wallboard is manually produced on a fixed platform, and the cranes trolley are not only to complete the above work but also to hoist the mold and construction materials.

As can be seen from this figure (Fig.6), the carbon emissions of in-plant transportation increase along with the amount of concrete contained by the components. Figure.6 also shows the carbon emissions of the gantry cranes may be different when the amount of contained concrete is similar. This also shows that the transport distance has a great impact on the carbon emissions of gantry cranes.

The effect of transport distance on carbon emissions during gantry crane operation is shown in...
figure (Fig.7). Although the carbon emissions of gantry crane increase with transport distance, it's not a proportional relationship. This also explains that there are other factors that affect the carbon emissions of gantry crane in the actual hoisting process, such as using vertical adjustment process to reach the stacking position and the proficiency difference of worker hoisting. These factors are difficult to quantify.

3. Conclusions
This study divides in-plant transportation into four phases: design phase, construction phase, operation phase, and recovery phase. The carbon emissions in the operation phase are taken as research objects. The sources and the boundaries of carbon emissions at this phase have been identified. And based on this, the carbon emissions in this phase is calculated. Then the article analyses the influencing factors of the operation phase through the actual measurement data.

Component types and production processes have a significant impact on the carbon emissions of in-plant transportation according to the actual measurement data of the factory. The carbon emissions of in-plant transportation increase along with the amount of concrete contained by the components. But they are not linear relation.

The concrete volume and transportation distance of the components also serve as the key factors. It was found to be a nonlinear relationship after analyzing the relationship between carbon emissions and concrete in the plant. So the carbon emissions in the plant are not only related to the amount of concrete and the transport distance of the components, but also related to worker proficiency and transportation adjustment process.

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