Optimal design of building materials logistics transportation scheme in Beijing based on “outside gathering and inside distribution”

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Abstract: Under the national strategy of vigorously promoting transport restructuring and winning “the battle of blue sky protection”, it is of great significance to promote the railway freight to undertake the distribution of goods and materials in big cities, which can alleviate the traffic congestion on urban roads and optimize the quality of urban environment. This paper puts forward the concept and mode of green logistics of "outside gathering and inside distribution" according to the flow characteristics of production and living materials in cities. It analyzes the market relationship between the production and use of building materials in Beijing, building the optimization model of freight transport scheme based on railway transport, and the logistics transportation scheme of building materials in Beijing is optimized and designed. This paper provides a scientific method for the transportation organization of production and living materials in big cities.

1. The concept of green logistics of “outside gathering and inside distribution” in metropolises

In recent years, with the expansion of the city scale and the adjustment of the spatial layout planning, the urban railway logistics base was gradually relocated. Currently, the existing railway freight yards in some urban areas are idled for a certain period of time, and their functions cannot be effectively used. At the same time, the problems of land utilization, traffic congestion and environmental pollution in big cities have to become prominent. It is imperative to reduce road freight vehicles in cities and accelerate the construction of urban green logistics systems. From the development experience of developed countries, “outside gathering and inside distribution” has become one of the important trends in the development of green logistics systems in large cities. In the 1960s, The Japanese government has begun to separate the large-scale logistics distribution function from the city center, the government has unified planning and fund-raising to construct four modern circulation bases in Kasai, Heiwajima, Itabashi and Zuli in the southeast and northwest of Tokyo, as A large “outside gathering” junction for the gathering and distribution of urban logistics in Tokyo.

China’s 2018 Central Economic Work Conference clearly requires the government work to focus on improving the quality of the ecological environment, adjusting the transportation structure, deepening the reform of the railway industry, and reducing the cost of social logistics\(^1\). The adjustment of the national transport structure, the implementation of the strategy of pollution prevention and control, and the introduction of a series of policies have created favorable opportunities for the railway to utilize the city’s freight yard resources and meet the needs of urban production and living materials circulation.

In this context, for the typical problems of the current mismatch between the function positioning of
the city’s internal railway freight yard and the city’s development, the experience and advanced practices of the “outside gathering and inside distribution” logistics system in Tokyo, we will be used to fully integrate the actual domestic railway yard construction and operation, and the need for transformation and upgrading[2]. It is important to study the construction plan of the “outside gathering and inside distribution” green logistics system of Beijing’s building materials to increase railway traffic, reduce atmospheric environmental pollution, improve urban traffic congestion, and help win the “the battle of blue sky protection”.

1.1 Definition of “outside gathering and inside distribution” the green logistics in metropolises
In big cities, The green logistics of “outside gathering and inside distribution” modes refers to: satisfying by the supply of urban production and living materials, relying on the railway freight yard and mainline transportation resources in the urban area, and to realize the transportation of materials from the railway to the city, then to the end of the new energy vehicles common distributes, to build a highway-rail combined transportation, green urban logistics supply chain.

1.2 The green logistics mode of “outside gathering and inside distribution” in cities
According to the differences between logistics nodes and transportation organizations, the cities “outside gathering and inside distribution” the green logistics can be divided into three modes:

Mode 1: The city supplies materials could arrange direct trains from the place of origin to the logistics bases (outside gathering points) with rail transportation functions outside the city. In logistics bases the materials realize accumulation, storage, processing, packaging, etc. and then through the city’s internal railway freight yard (Internal distribution point), the small-running trains in operation realize the circulation and distribution of materials within the city, and finally realize the common distribution of materials from the railway freight yard to the end of the sales place through new energy vehicles.

Mode 2: The city supplies the goods directly from the place of origin to the urban railway freight yard and through goods train. The new energy vehicles are used to realize the common distribution of the materials from the railway freight yard to the end of the sales place.

Mode 3: The city supplies materials from the place of origin to the logistics bases with rail transportation function outside the city, and through goods trains are provided. The new energy vehicles are used to realize the joint distribution of the materials from the bases of railway logistics outside the city to the end of the market.

The adaptation scenarios of the above three “outside gathering and inside distribution” logistics modes are shown in Table 1.

| Table 1 Adaptation scenarios of three modes |
|--------------------------------------------|
| **category** | **logistics mode** | **Adaptation scenarios** |
| Mode 1 | Tains | Origin | Logistics bases outside the city | Railway freight yard inside the city | New energy vehicles | Destination |
| | | District transfer train | | | | The materials are sold within the city, and the demand for each land is smaller. It needs to be temporarily stored in the outside collection point, and the small-scale trains can realize the allocation of the sales in the urban area. Such as vegetables, rice noodles and other living supplies. |
1.3 The category analysis of urban supply materials.
In the process of urban planning and development in China, part of the production functions are gradually stripped from the inner city. For example, large factories with serious environmental pollution are moved out of the city. Therefore, the city supplies few bulk goods such as coal, oil and coke. Generally, urban supplies can be divided into two categories: production supplies and living supplies. The specific main categories are shown in table 2.

| Type          | Subdivided category                                      |
|---------------|----------------------------------------------------------|
| Production    | Metal products, textile leather, agricultural machinery,  |
|               | industrial machinery, LTL, electrical and electronic     |
|               | machinery, containers, mineral building materials        |
| Life supplies | Medicine, food and tobacco, fresh goods, cultural and    |
|               | educational paper, agricultural and sideline products    |

2. Transportation demand and supply of building materials in Beijing
With the advancement of urbanization, the construction sand and stone aggregate gap in Beijing has been increasing year by year, with an annual gap of about 100 million tons, which is basically transported by diesel trucks from the sand and stone mining areas to 148 mixing plants in the administrative areas of Beijing. In order to reduce the interference of building materials trucks into Beijing for disturbing urban traffic, Beijing realize to reduce cost and increase efficiency in the logistics process, it is necessary to study the green logistics system construction scheme of “outside gathering and inside distribution” for the transportation of building materials [3].

2.1 Distribution of goods sources of construction materials in Beijing
(1) Distribution of goods sources on the Beijing-Harbin Railway Line
a. Luan County area
The main source of production in the Luan County area is the Wushan mining area and the Sijiaying iron mine, with an annual output of 30 million tons. In 2018, the Tangshan area carried out environmental protection treatment. The 287 private sand and aggregate production plants were shut down in early June. It is currently away from the Luan County East Station. There are three gravel factories within a short distance of 10 kilometers. They are Wushan Mining Group, with an annual output of 2 million tons; Luan County JingCao Building Materials Co., Ltd., with an annual output of 10 million tons; Tangshan Xingye Building Materials Co., Ltd., with an annual output of 3 million Tons.
b. Qianan area
   The main source of origin in Qianan is the Shougang Mining industry’s Malanzhuang No.2 Mine, with an annual output of 3 million tons. It is about 20 kilometers away from Shaheyizhen Station. It can be loaded through the Shougang subway or transported to Shaheyi China Railway Joint Logistics (Qianan) Co., Ltd., by short road shuttle Special railway line loading.

   Railway loading point can choose Luanxian East Station, Shaheyizhen Station and Qianan Station.

2) Distribution of goods sources on the Beijing-Tongliao Railway Line

Chengde District all have tailings mining enterprises in the Jingoutun Town, Hushiha Town, and Hongqi Town of Luanping County. Such as Xinglong Mining industry, Baotong Mining industry, Yuantong Mining industry, etc. With an annual output of more than one million tons, and sand reserves stone aggregate is nearly 100 million tons; the annual output of sand and stone production enterprises near Xinglong County Station is about 1 million tons.

   Railway loading point can choose Longhua Station, Jingoutun Station and Yaoshang Station.

3) Distribution of goods sources on the Beijing-Chengde Railway Line

Chengde County of Chengde area has rich limestone mining reserves, such as Liuhe Mining industry and Xinman Mining industry, which are near Shangbancheng Station and Xiaobancheng Station, with a natural mountain rock mining area of nearly 9,800 square kilometers. The annual output is more than 3 million tons.

   The railway loading point can choose Shangbancheng Station and Lower Bancheng Station.

4) Distribution of goods sources on the Beijing-Yuanping Railway Line

The goods sources of the Beijing-Yuanping Railway Line are mainly distributed in the Yima and Laiyuan County Juma River basins. Taking Yi County as an example, the annual output is 7 million tons, of which more than 3 million tons of construction materials are transported to Beijing by road and other construction materials are transported to Hebei. The surrounding area of the province. Nanchengsi Station and Qifengta Station are adjacent to Juma River, and within 20 kilometers from the building material production area (such as many production plants in upper ash kiln and lower ash kiln), and the annual output is more than 1 million tons.

   Railway loading point can choose Laiyuan County Station.

5) Distribution of goods sources on Fengtai-Shacheng Railway Line

Xuanhua area is rich in basalt and limestone reserves. The main mining companies such as Xinxing Mining, Xinhua Mining, Open Source Mining, Pengsheng Mining, etc. have an annual output of more than 6 million tons. Construction of high-speed railway and G7 expressway.

   Railway loading point can choose Guoleizhuang Station and Shalingzi Station.

6) Distribution of goods sources on Beijing-Guangzhou Line

Dingzhou city, Wangdu County has a large number of limestone reserves, Dingzhou Mengjiazhuang, brick Road Town, Wangdu county Gaoling Township as the main production areas, the region sand aggregate output in more than 20,000 tons, and the annual output of more than 7 million tons.

   Railway loading point can choose Wangdu Station and Zhengding Station.

2.2 Demand distribution of building materials market in Beijing

According to the market data of Beijing’s construction industry, Beijing needs a total of about 100 million tons of building materials (sandstones) every year. At present, the buyers of building materials (sand and gravel) are mainly concrete mixing companies. At present, there are 148 major concrete mixing plants and asphalt plants in Beijing, mainly distributed outside Beijing’s Third Ring Road, including: 4 factories from the third ring to the fourth ring Road, 36 factories in the fourth ring to fifth ring Road, 59 factories from Fifth Ring to Sixth Ring Road, and 6 Ring Road, 49 factories outside the sixth ring road. The annual production capacity of Beijing’s major state-owned asphalt plants and mixing plant plants is 60 million tons, of which, Jinyu Group’s annual output is 17 million tons, Beijing Construction Engineering Group’s annual output is 13 million tons, Beijing Zhugong Group’s annual output is 10 million tons, and Beijing Urban Construction The annual output of the group is 10 million tons, and the annual output of Beijing Luqiao Group is 10 million tons.
Figure 1 Distribution of concrete mixing stations and asphalt plants in Beijing

With the implementation of Beijing’s《Urban Construction Master Plan》, it is expected that the annual demand for sand and gravel in Beijing will increase by about 3-5% year-on-year in the next few years. At present, the self-supplied sand and gravel in Beijing can only meet 10% of the market demand, and the gap is entirely transferred from Qianan, Luan County, Chengde city, Yi County, Hebei Province and other places[6]. With the influence of policies such as environmental governance, highway over travel, and restrictions on the passage of large vehicles in recent years, road transportation of sand and gravel materials into Beijing has been restricted, and the demand for "public turn to railway" is extremely urgent[7].

3. Optimization of logistics scheme of building materials “outside gathering and inside distribution” in Beijing

3.1 Basic requirements of building material logistics transportation

By analyzing the distribution of the origin and sales of building materials in Beijing, it is found that the distance between the origin and Beijing is more than 200 kilometers, and the sales are concentrated in the area within the sixth ring of Beijing (accounting for 67% of the total), and the demand is large. It can meet the whole line of loading and unloading, so the building materials in Beijing are suitable for the second “outside distribution and internal distribution” green logistics model, that is, from the origin to the urban railway freight yard directly to the train, through the new energy vehicles to achieve materials from the railway freight yard to the land The end of the joint distribution. For the transportation of building materials with railway as the skeleton, railway transportation should meet the following requirements:

(1) Passenger bus train schedules provide stable capacity support

Since October 2017, Beijing has completely stopped sand and gravel mining and closed all gravel yards in the Beijing area. Therefore, once the transportation of construction materials into Beijing is disturbed, it will cause an imbalance between engineering construction and gravel supply, which will seriously affect Beijing The normal operation of the construction market. Therefore, compared with
ordinary bulk cargo transportation, urban building materials have higher requirements on the timeliness and stability of the transportation organization. The railway needs to have a fixed number of trains and operation lines between the fixed departure and arrival stations, and a clear opening cycle and operation. At the moment, according to the “passenger car” model to organize the construction materials into the Beijing trains.

(2) Based on the demand side, reducing the inventory of goods in the railway freight yard in the city

According to the design concept of the city’s “outside gathering and inside distribution” green logistics system, the internal distribution points in the city are derived from the upgrading of the city’s internal railway freight yard. Due to the city’s existing planning constraints, the scale is difficult to expand and the storage capacity is relatively limited. Therefore, in the process of designing the plan for the origin to the urban railway freight yard, we should proceed from the demand side to implement the "zero inventory" of the urban railway freight yard as the goal to develop freight transportation products that meet the needs of urban internal enterprises for building materials.

3.2 The Optimal model of building material logistics transportation scheme based on railway

3.2.1 Basic assumptions
(1) The unit transportation price and distance from the loading point to the urban railway freight yard, from the urban railway freight yard to the mixing station (building material demand point) are known;
(2) The loading and unloading capacity of the urban railway freight yard is known;
(3) The demand of the mixing plant is known;
(4) The building materials are homogeneous, and the mixing station has no special requirements for building materials;
(5) Direct trains are used in the railway transportation process.

3.2.2 Problem model

Suppose there are \( I \) building material loading points that transport building materials such as sand and gravel to \( J \) urban railway freight yards. Each loading point \( i \) can provide building materials of \( S_i \) from the neighboring production area. The maximum loading and unloading capacity is \( A_i \). At the same time, \( J \) urban railway freight yards deliver building materials to \( K \) mixing stations. The loading and unloading capacity of each railway freight yard \( j \) is \( B_j \), and the demand for each mixing station \( k \) is \( C_k \). The entire transportation process is shown in Figure 2.

![Figure 2 The transportation process of building materials](image_url)

The parameters are defined as in Table 3.
Table 3 Definition of model parameters

| Parameter | Definition |
|-----------|------------|
| $i$       | Building materials loading point outside Beijing, $i \in \{1, 2, \ldots, I\}$ |
| $j$       | Alternative railway freight yard in Beijing, $j \in \{1, 2, \ldots, J\}$ |
| $k$       | Mixing plant, $k \in \{1, 2, \ldots, K\}$ |
| $S_i$     | Loading point $i$, The maximum supply that can be provided by the nearby origin. Unit: tons; |
| $A_i$     | Loading point $i$ maximum loading and unloading capacity. Unit: tons; |
| $B_j$     | Railway cargo yard $j$ maximum loading and unloading capacity. Unit: tons; |
| $C_k$     | Total demand of mixing plant. Unit: tons; |
| $R_{i,j}$ | The railway freight between the loading point $i$ and the railway freight yard $j$ is proportional to the transportation distance. Unit: Yuan/ton; |
| $T_{j,k}$ | The road freight between the railway freight yard $j$ and the mixing station $k$ is proportional to the transportation distance. Unit: Yuan/ton; |
| $x_{i,j}$ | The decision variable represents the quantity of material supplied by the loading point $i$ to the railway freight yard $j$. Unit: tons; |
| $y_{j,k}$ | The decision variable represents the quantity of materials supplied by the railway freight yard $j$ to the mixing station $k$. Unit: tons; |
| $z_j$     | $0, 1$ variable; if the alternative railway freight yard $j$ is selected, $z_j = 1$. Otherwise 0 |

Based on RDC location analysis, the logistics transportation optimization model is established, the objective function can be described as formula (1), the constraint conditions are shown in formula (2)-(9).

$$\begin{align*}
\min Z &= \sum_{i=1}^{I} \sum_{j=1}^{J} R_{i,j} x_{i,j} z_j + \sum_{i=1}^{I} \sum_{k=1}^{K} T_{j,k} y_{j,k} z_j \\
\sum_{i=1}^{I} x_{i,j} &\leq S_j \quad i = 1, 2, \ldots, I \tag{2} \\
\sum_{j=1}^{J} x_{i,j} &\leq A_i \quad i = 1, 2, \ldots, I \tag{3} \\
\sum_{j=1}^{J} x_{i,j} &\leq B_j \quad j = 1, 2, \ldots, J \tag{4} \\
\sum_{j=1}^{J} y_{j,k} &\geq C_k \quad k = 1, 2, \ldots, K \tag{5} \\
\sum_{j=1}^{J} x_{i,j} &= \sum_{k=1}^{K} y_{j,k} \tag{6} \\
z_j &= \begin{cases} 
0 & \text{Otherwise} \\
1 & \text{Alternative railway freight yard $j$ is selected} 
\end{cases} \tag{7} \\
x_{i,j} &\geq 0 \tag{8} \\
y_{j,k} &\geq 0 \tag{9}
\end{align*}$$

Equation (1) is the objective function, which represents the minimum total cost of the railway transportation section and the highway transportation section; Equations (2) to (5) are supply and demand constraints, and (2) indicates that the loading volume at the loading point is less than the loading point. The maximum loading and unloading capacity, (3) indicates that the loading volume at the loading point is less than the output of the production site near the loading point, and (4) indicates that the loading point is that the amount of materials transported by the urban railway freight station is less than the loading capacity of the urban railway freight station (5) indicates that the supply volume of the urban railway freight yard to the mixing station is greater than the demand of the mixing station; (6) is a zero inventory constraint, indicating that the total amount of materials transferred from the urban railway yard is equal to the total amount of materials transferred; It is a 0, 1 variable constraint. If the alternative
railway freight yard is selected, it is 1; otherwise, 0; Equations (8) to (9) are non-negative constraints on decision variables.

4. Design of green logistics distribution scheme of Beijing Building Materials

4.1 Node selection
There are 46 railway freight stations in Beijing, which can be used as an alternative set of urban railway freight yards in the optimization model of building materials railway transportation organization. Using LINGO11 to solve the model, the global optimal solution can be obtained. Finally, 8 loading stations and 8 unloading stations were selected. The results are shown in Table 4.

| Loading station | Service unloading station | Unloading station | Number of mixing stations |
|-----------------|----------------------------|-------------------|--------------------------|
| YaoShang Railway Station | Huairou Railway Station | Shahe Railway Station | 18 |
| Luanxiandong Railway Station | Dahongmen Railway Station | Shijingshannan Railway Station | 21 |
| Shaheyizhen Railway Station | Dahongmen Railway Station | Liangxiang Railway Station | 20 |
| Qianan Railway Station | Dahongmen Railway Station | Liulihe Railway Station | 10 |
| Wangdu Railway Station | Liangxiang Railway Station | Huangcun Railway Station | 12 |
| Zhengding Railway Station | Liangxiang Railway Station | Dahongmen Railway Station | 28 |
| Laiyuan Railway Station | Shijingshannan Railway Station | Huairou Railway Station | 17 |
| Shalingzi Railway Station | Shahe Railway Station | Sanping Railway Station | 27 |

4.2 Logistics distribution scheme based on railway framework
Based on the calculation results of the model, the distribution plan of Beijing building materials logistics can be obtained as shown in Figure 3 and Table 5. Relying on the Beijing-Tongliao Railway Line, Beijing-Harbin Railway Line, Beijing-Guangzhou Railway Line, Beijing-Yuanping Railway Line, and Beijing-Baotou Railway Line, “passengerized” construction materials are opened on 13 channels daily to enter the Beijing train, and the production area and the depot railway freight yard Line), the main railway station to the station, the Beijing railway yard (dedicated line) and the mixing station are all combined with the railway and railway to provide customers with full logistics services.
Table 5 Railway building materials train organization plan

| Railway line | Section | Train operation plan |
|--------------|---------|----------------------|
| Beijing-Tongliao Railway Line | Yaoshang-Huairou | 2 trains per day, marshalling 34 vehicles |
| Beijing-Harbin Railway Line | Luanxiandong-Dahongmen | 1 train per day, marshalling 51 vehicles |
| | Luanxiandong-Sanping | 1 train per day, marshalling 32 vehicles |
| | Shaheyizhen-Dahongmen | 1 train every two days, marshalling 34 vehicles |
| | Shaheyizhen-Sanping | 2 trains per day, marshalling 30 vehicles |
| | Qianan-Dahongmen | 1 train per day, marshalling 42 vehicles |
| | Qianan-Sanping | 1 train every two days, marshalling 36 vehicles |
| Beijing-Guangzhou Railway Line | wangdu-Liangxiang | 2 trains per day, marshalling 351 vehicles |
| | wangdu-Huangeun | 1 train every three days, marshalling 33 vehicles |
| | Zhengding-Liangxiang | 1 train every three days, marshalling 33 vehicles |
| | Zhengding-Lulihe | 2 trains per day, marshalling 35 vehicles |
| Beijing-Yuanping Railway Line | Laiyuanshijingshannan | 2 trains per day, marshalling 41 vehicles |
| Beijing-Baotou Railway Line | Shalingzi-Shahe | 2 trains per day, marshalling 34 vehicles |
5. Conclusion
The construction of a green logistics system for building materials in Beijing has a positive effect on the implementation of the central transportation structure adjustment, winning the “pollution prevention and control battle” and “blue sky defense battle” strategic deployment, boosting railway freight incremental actions, and reducing Beijing’s logistics costs. By constructing the “8+8+13” construction material “outside gathering and inside distribution” railway transportation network, it can strengthen the supply capacity of building materials in Beijing, ensure the construction progress of the capital, and at the same time enhance the operation vitality of the city’s railway freight yard and revitalize the idle freight yard resources, effectively promote the logistics industry to move towards high-quality development.

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