Proceedings of the 8th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/103/20242495

Design and Site Selection of Reverse Logistics Network for Iron and Steel Enterprises from the Perspective of Green Supply Chain

Yuhang Du[1,a,*]

[1]*University of Science and Technology Beijing, Beijing, China*
a. dyh2002@xs.ustb.edu.cn
**corresponding author*

Abstract: The iron and steel industry is not only one of the most important components of China's national economy, but also a typical resource-and-energy-intensive industry. Under the background of "Carbon Peaking and Carbon Neutrality Goals", it is of great significance for the iron and steel industry to improve the green closed-loop supply chain and develop circular economy. From the perspective of green supply chain, this paper puts forward the three-level network structure of waste steel reverse logistics based on the present situation of waste steel recycling in China, and uses k-means clustering algorithm and accurate center of gravity method to select locations for the primary and secondary nodes. The purpose of this paper is to provide a basis for iron and steel enterprises to carry out network optimization of reverse logistics.

Keywords: reverse logistics, iron and steel enterprises, k-means clustering algorithm, accurate center of gravity method

1. Introduction

Xi Jinping, the President of China, announced that China's carbon dioxide emissions will reach a peak by 2030 and strive to achieve carbon neutrality by 2060 at the 75th session of the United Nations General Assembly on September 22, 2020. As an important cornerstone of the construction of China's modern industrial system, the iron and steel industry is facing increasingly heavy pressure on resources and environment. Steel enterprises must transform and upgrade their products, develop a circular economy, extend low-carbon concepts to downstream industrial chains, enhance their risk resistance and sustainable development capabilities, and also contribute to achieving carbon peak and carbon neutrality for the whole society [1].

2. Green Supply Chain and Reverse Logistics

2.1. Definition of Green Supply Chain

Green supply chain, also known as environmental awareness supply chain or environmental supply chain, was first proposed by Michigan State University in 1996. It is a modern management model that comprehensively considers environmental impact and resource efficiency in the whole supply chain [2].

DOI: 10.54254/2754-1169/103/20242495

The ultimate goal of a green supply chain is to save resources, protect the environment, improve efficiency, and reduce costs throughout the entire lifecycle of goods, ultimately achieving green and sustainable development of the social environment, which requires enterprises to adopt an environmentally friendly and sustainable modern operation and management mode in the whole supply chain.

2.2. Definition of Reverse Logistics

According to the definition of Council of Logistics Management (CLM), reverse logistics refers to the process of planning, managing and controlling the efficient and cost-effective flow of raw materials, WIP inventory, finished goods and related information from the place of consumption to the place of origin for recycling or reasonable disposal of waste materials. It redirects the product, material, or component back into the supply chain from the end user or consumer. This process is usually for the enterprise to deal with return, recycling, reuse, remanufacturing and waste disposal, and finally achieve the goal of returning the products that were originally in the consumption link to the production link and regaining their use value.

2.3. The Importance of Reverse Logistics in Iron and Steel Enterprises

Reverse logistics is an important concept of green supply chain and an important component of closed-loop supply chain as well.

From the perspective of social benefits for steel enterprises, implementing reverse logistics can reduce the burden on the environment, which is a powerful practice of the concept of sustainable development and an important measure to establish a good corporate image and improve social influence.

From the perspective of economic benefits for steel enterprises, implementing reverse logistics can reduce the idle and waste of materials in traditional logistics models, can assist enterprises in timely discovering product quality issues that arise during the production process, can encourage enterprises to explore new business models and expanding the sources of corporate income.

To sum up, for the iron and steel industry, reverse logistics is not only a behavior with significant social benefits, but also an effective means for enterprises to achieve significant economic benefits[3].

3. Reverse Logistics Network Design of Waste Steel and Site Selection of Recycling Network

3.1. Network Design of Reverse Logistics of Waste Iron and Steel

According to the different participants in reverse logistics recycling, the organizational models of reverse logistics in iron and steel enterprises can be roughly divided into: enterprise self-management recovery model, enterprise joint venture recycling model, and third-party reverse logistics outsourcing model [4]. Regardless of the reverse logistics model adopted, it is necessary to start layer by layer recycling of waste steel from the end consumers or private recycling stations. At present, the infrastructure of the domestic waste steel recycling network is not yet perfect, with a large number and scattered distribution of private recycling sites, making it difficult for large recycling sites of iron and steel enterprises or third-party enterprises to directly connect. Therefore, it is necessary to set up multi-level recycling sites for indirect recycling.

Based on the above characteristics, the three-level network structure of reverse logistics of waste steel is designed (figure 1):

（1） The primary recycling network responsible for recycling waste from the scattered civil recycling sites at the end;

DOI: 10.54254/2754-1169/103/20242495

（2） The secondary recycling network responsible for recovering waste from each primary recycling network;

（3） The processing and recovery center (tertiary recovery network) responsible for collecting waste from secondary recovery sites and carrying out pre-treatment work such as classification, inspection, cleaning, disassembly and waste disposal;

（4） Finally, the third-level recovery network is responsible for transporting treated iron and steel materials to iron and steel enterprises. The number of outlets is decreasing step by step, which is conducive to the docking of superior outlets to subordinate outlets, thus improving the efficiency of recovery.

3.2. Problem Description

In the waste steel reverse logistics network, the primary and secondary recycling network has the important connecting function of "connecting link between the preceding and the next", and it is also one of the core business links of reverse logistics. Its quantity and layout have an important impact on the efficiency of the whole reverse logistics system. Therefore, the location and optimization of primary and secondary recovery network is an important problem, and the solutions are as follows:

（1） Location optimization of primary recovery network based on k-means clustering algorithm;

（2） Location optimization of secondary recovery network based on accurate center of gravity method.

3.3. Construction of Location Model of Primary Recovery Network Based on K-means Algorithm

3.3.1. K-means clustering algorithm

K-means clustering algorithm is an unsupervised learning algorithm that classifies and reorganizes data sets according to a specific index. The basic principle is to divide the data into different clusters according to the similarity of the data. Through iterative optimization, the data similarity in the same cluster is as large as possible, while the data similarity between different clusters is as small as possible, and finally achieve the goal of local optimization.

3.3.2. The Rationality of K-means Clustering Algorithm to Solve the Location Problem of Primary Recovery Network

The first-level recycling network is mainly for the end of the folk recycling station to carry out recycling business. As mentioned earlier, folk recycling sites have the characteristics of large quantity and scattered distribution. According to the incomplete statistics of Baidu map, there are more than 1000 private waste recycling stations in Beijing alone, so when selecting the site of the first-level recycling network, the primary consideration is how to reduce the transportation distance and improve the recovery efficiency. The k-means clustering algorithm has good clustering performance and efficiency for large-scale data sets [5], and this method takes distance as the similarity criterion, and after repeated iterations, the sum of the distances between the scattered folk recovery stations in the cluster and the first-level recovery network where the cluster center is located is minimized, which fully meets the location requirements of the first-level network. It is reasonable to choose k-means clustering algorithm.

DOI: 10.54254/2754-1169/103/20242495

3.3.3. Model Construction

First of all, the optimal clustering number is determined by the "elbow rule" of k-means clustering algorithm. The so-called "elbow rule" means that with the increase of the simulated clustering number k, the sum of the square of the error decreases rapidly at the beginning, and slows down after reaching an "elbow" point. The simulated clustering number k of this "elbow" point is the best clustering number of the data set.

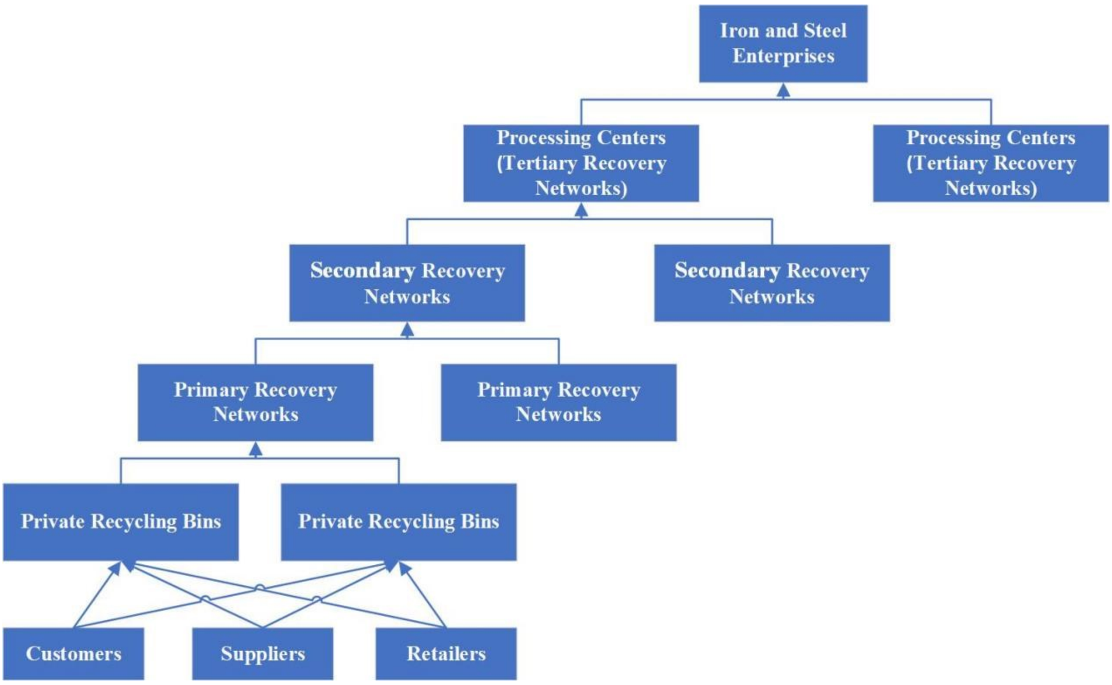

Figure 1: Three-Level Network Structure of Reverse Logistics of Waste Iron and Steel.

The formula of the sum of squares of the error is as follows, and the parameters of the model are described in Table 1.

$$H = \sum_{p=1}^{k} \sum_{\alpha \in c_p} \left| d - m_p \right|^2 \quad (1)$$

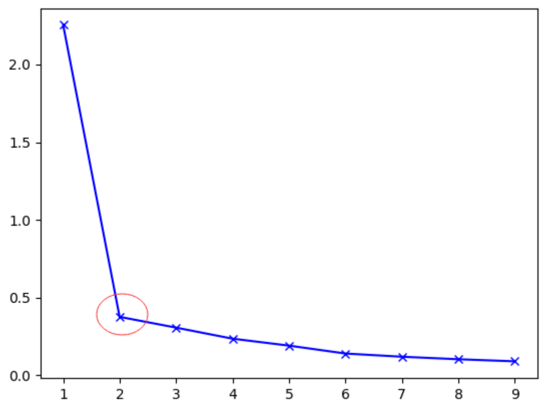

Figure 2: Schematic Diagram of Determining the Optimal Number of Clusters by "Elbow Rule".

Secondly, standardize the original data t_{pq}:

DOI: 10.54254/2754-1169/103/20242495

$$t'_{pq} = \frac{t_{pq} - \overline{t_q}}{s_q}, \text{(p=1,2,…,a;j=1,2,…,b)} \quad (2)$$

The arithmetic mean of the q element is:

$$\overline{t_q} = \frac{\sum_{p=1}^{a} t_{pq}}{a} \quad (3)$$

The standard deviation of the q element is:

$$s_q = \sqrt{\frac{\sum_{p=1}^{a} (t_{pq} - \overline{t_q})^2}{a}} \quad (4)$$

After standardization, the arithmetic mean value of each element ($\overline{t_q}'$) is equal to 0 and the standard deviation (s_q') is equal to 1.

Then, the k initial clustering centers are determined according to the optimal clustering number, and the samples are assigned to the nearest cluster according to the principle of shortest Euclidean distance. If the coordinate of the initial clustering center is G and the coordinate of the p-th clustering object is Tp, the Euclidean distance Q from the clustering object p to the initial clustering center is:

$$Q = \sqrt{\sum_{p=1}^{a} (T_p - G)^2} \quad (5)$$

Finally, take the average value of the samples in each cluster as the new clustering center, and repeat the above steps until the clustering center no longer changes, and finally form the best clustering result to complete the clustering of the first-level recovery network.

The above k-means clustering algorithm process can be realized by SPSS software. According to the relevant data of local folk recycling stations or small recycling points, the number and longitude and latitude coordinates of the first-level network can be obtained.

Table 1: Reference table for model parameters and decision variables of k-means clustering algorithm.

Parameters or decision variables	Meanings
H	Sum of squares of error
k	Simulated number of clusters
c_p	The p-th cluster
d	Sample point of c_p
m_p	The center of mass of c_p
t_{pq}'	Standardized data for the q-th element of the p-th cluster
t_{pq}	The original data of the q-th element of the p-th cluster
$\overline{t_q}$	The arithmetic mean of the q-th element
s_q	The standard deviation of the q-th element

DOI: 10.54254/2754-1169/103/20242495

3.4. Construction of Location Model of Secondary Recovery Network Based on Improved Center of Gravity Method

3.4.1. The Concept of Gravity Method

The center of gravity method is a mathematical method used to determine the location of new facilities, which determines the best location scheme of distribution center by considering resource points, locations to be sought, transport volume and transport rates, so as to achieve the purpose of minimizing the total cost. The resource point is defined as each first-level recovery network and the third-level recovery network, the demand point is defined as each secondary recovery network, and the appropriate location of the secondary network is determined by solving the model. Because it is stored in multiple secondary nodes in the recovery network, the multi-center method is adopted to solve the problem.

3.4.2. The Rationality of the Barycenter Method to Solve the Location Problem of Secondary Recovery Network

There is a difference in the location between the primary recovery network and the secondary recovery network. The first-class network mainly faces a large number of scattered end consumers or private recycling bins, so the shortest transportation distance should be taken as the primary consideration. On the other hand, the second-level network mainly carries out business for the first-level network, while the number of first-level outlets has been greatly reduced compared with the end consumers or private recycling bins, and the location has been optimized, so the minimum recovery cost should be taken as the primary consideration. Different from the k-means clustering algorithm, which takes the minimum distance between the data points in the cluster and the center of the cluster as the location criterion, the center of gravity method takes the minimum transportation cost as the location criterion, which fully meets the location requirements of the secondary network, so the center of gravity method is more reasonable in the secondary network location.

3.4.3. Model Construction

First of all, make the following assumptions: (1) the demand is concentrated at a certain point (2) the construction and operating costs of the recycling network in each region are the same (3) the transportation cost increases in proportion to the transportation distance (4) the transportation route is a spatial straight line distance (5) the number and location of the first class network can be obtained from the modeling solution of Chapter 3.3.3. The third-level network uses the processing centers set up by iron and steel enterprises (the number and location are known).

Assuming that the number of secondary nodes to be proposed is m, the accurate center of gravity method location model in spherical coordinate system is as follows, and the parameters and decision variables of the model are described in Table 2.

$$minTC = \sum_{i=1}^{m}\sum_{j=1}^{n} V_i R_{ij} D_{ij} Z_{ij} \tag{6}$$

$$d_{ij} = \sqrt{\left(\overline{x_i} - x_j\right)^2 + \left(\overline{y_i} - y_j\right)^2 + \left(\overline{z_i} - z_j\right)^2} \tag{7}$$

$$\mathrm{D_{ij}} = \beta \mathrm{d_{ij}} \tag{8}$$

$$x_j = R\cos\theta_j \cos\varphi_j \tag{9}$$

DOI: 10.54254/2754-1169/103/20242495

$$y_j = R\cos\theta_j \sin\varphi_j \tag{10}$$

$$z_j = R\sin\theta_j \tag{11}$$

Brought the formula (7) ~ (11) into (6), and the partial derivative of the variable is calculated respectively, so that the partial derivative is 0, and the coordinate values of the second-order nodes can be obtained. The formula is transformed by spherical coordinates:

$$\overline{\theta_i} = \cos^{-1}(\frac{\bar{z}}{R}) \tag{12}$$

$$\overline{\varphi_i} = \tan^{-1}(\frac{\bar{y}}{\bar{x}}) \tag{13}$$

As a result, the longitude and latitude coordinates $(\bar{\theta}, \bar{\varphi})$ of second-order nodes can be obtained.

The process of the center of gravity method can be realized by Lingo software. According to the relevant data of the first-level network obtained above, the number and longitude and latitude coordinates of the second-level network can be obtained.

Table 2: Reference table of model parameters and decision variables of gravity method.

Parameters or decision variables	Meanings
TC	Total transportation cost
Z_{ij}	0 or 1
V_i	Traffic volume of secondary nodes
R_{ij}	Unit freight from secondary nodes to node i
D_{ij}	Transportation distance from secondary nodes to node i
d_{ij}	The linear distance from the secondary nodes to node i
β	Correction factor
$\overline{x_i}$、$\overline{y_i}$、$\overline{z_i}$	Spatial horizontal, vertical, and vertical coordinates of secondary node i
x_j、y_j、z_j	Spatial horizontal, vertical, and vertical coordinates of primary or tertiary node j
$\overline{\theta_i}$、$\overline{\varphi_i}$	Latitude and Longitude of secondary node i
θ_j、φ_j	Latitude and Longitude of primary or tertiary node j
R	Radius of the earth

4. Conclusion

Based on the current market order and infrastructure construction of waste steel recycling network in China, the three-level network structure of reverse logistics for iron and steel enterprises is designed, and the location of primary and secondary network is optimized in this paper by using k-means clustering algorithm and accurate center of gravity method. This paper focuses on the theoretical knowledge, methods and strategies, so there is no detailed introduction to the specific data of the enterprise, and the enterprise case can be verified in the follow-up research.

The deficiency of this paper is that k-means clustering algorithm and centroid method have their own limitations, but the two methods are simple, convenient and efficient in site selection, and have high practicability for enterprises to make preliminary decisions.

References

[1] *Exploration and Innovation of Low Carbon and Green Development Management Model in Large Steel Enterprises [J]. Metallurgical Management, 2023 (22): 52-58.*

[2] *Linjie Lu. How to promote green supply chain management in China [J]. Foreign Investment in China, 2023, (18): 79-81.*

[3] *Zujun Ma, Ying Dai, Dianye Zhang. Reverse logistics network structure and design [J]. Logistics Technology, 2004, (04): 12-14.*

[4] *Peng Xing, Tianjun Hu. Research on the organization mode of enterprise reverse logistics [J]. Logistics Technology, 2012 331 (17): 357-360.*

[5] *Mengmeng Ni, Chunshu Li, Yin Liu. Research on the Location Selection Method of Express Delivery Network Based on Particle Swarm Optimization K-means Clustering Algorithm [J]. Ningxia Engineering Technology, 2023,22 (02): 181-186+192.*