Research on the Decision-making of Processing method of Scrap Iron and Steel on Case-Based Reasoning

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Abstract: Recycling of scrap iron and steel is the key steps to realize the sustainable development of iron and steel industry. Considering the existing processing methods of scrap iron and steel are extensive, and the processing depends on the experience of the staff or manual measurement, which is easy to cause resource waste and secondary pollution. Aiming at the difficulty of the processing decision-making of scrap iron and steel, a method of scrap iron and steel processing technology decision-making based on case reasoning is proposed. After analysing the sources and classification of the scrap iron and steel, and combining with the main processing methods, the modular case base is founded. Extracting the key features of scrap iron and steel, and using the entropy weight method and analytic hierarchy process (AHP) to calculate the weight of each characteristic element, the comprehensive similarity of the index of case is calculated to obtain the processing method. The feasibility and effectiveness of the decision method are verified by taking the scrap iron and steel processing of a metal resource company as an example.

1. Introduction

Steel scrap is a strategic resource in China. Compared with iron ore, scrap iron and steel is more in line with the needs of green and sustainable development and the requirements of low-carbon emission policy of iron and steel industry. In the future, the importance of scrap iron and steel resources in the development of iron and steel industry will be constantly increasing. In recent years, with the increase of China's iron and steel accumulation, the output of steel scrap has been increasing since 2018. Although the utilization scale of scrap steel has increased in China, the utilization rate of scrap steel in China is only 20.2% in 2019, which is far lower than the world average of 36%[1].

A large part of iron and steel scrap comes from the society, mainly from the end of the service life of automobile, mechanical equipment and other products. Social scrap iron and steel which is difficult to recover accounts for more than 60% of the total amount of scrap. The classification of the scrap iron and steel is not fine, and the processing method is extensive, which mostly depends on the experience of processing personnel[2]. It is easy to lead to high energy consumption in the process of scrap steel, aggravation of environmental pollution, and increasing the cost of scrap steel processing.

Recently the academic research on the reverse supply chain of scrap iron and steel, which mainly contains the analysis and discussion of recycling system construction[3,4], reverse logistics planning[5] and logistics network[6,7], and few researches on the decision-making of the processing of scrap iron
and steel. With the transformation from traditional manufacturing industry to service-oriented manufacturing industry, more intangible services are added to the transaction of tangible products among manufacturing clusters [8]. Advanced management methods need to be applied to the recycling process of scrap iron and steel, so as to adapt to the trend of service-oriented, systematic, modular and intelligent development.

A decision-making method of scrap steel processing service process based on the case reasoning is proposed in this paper, on the basis of the service system of scrap steel reverse supply chain [9]. In the decision-making model of scrap processing route scheme, the appearance size, type and weight of scrap are quantified. The decision-making of scrap steel processing technology is one of the service activities of scrap steel reverse supply chain, which provides support for the subsequent service module matching and service scheme decision-making, and can help the scrap steel industry successfully realize the green transformation and upgrading.

2. Classification and main processing methods of scrap iron and steel

2.1 Classification of scrap iron and steel
The source, type, quantity and recycling time of iron and steel scrap are highly uncertain. From the perspective of sources, scrap steel mainly comes from self-produced scrap steel, produced scrap steel and social scrap steel. According to the size and weight, scrap iron and steel contains medium scrap, small scrap, unified scrap and light scrap. From the view of chemical composition, it contains scrap iron, ordinary scrap steel and alloy scrap steel. According to alloy elements, alloy scrap can be divided into manganese steel, silicon steel and so on. Before reusing, the scrap iron and steel should be classified, detected, cleaned, disassembled, cut and other processing procedures according to the destination.

2.2 Main processing methods of scrap iron and steel
There are different kinds of processing methods of scrap steel, because of the different size, weight of and destinations, which can determine the processing routes. The processing methods mainly include cutting, crushing, magnetic separation, shearing, packaging and so on. Such as the cutting method, there are oxygen cutting gun, shearing machine and other equipment for processing. The appearance size and weight of scrap steel are different, and the processing equipment may be different. For example, structural scrap and various specifications of plate steel can be cut by oxygen, which has low cost and easy operation, but high risk and environmental pollution. Some large and thick scrap steel, the shearing machine is used for processing with high efficiency, small loss and low pollution. Therefore, it is necessary to select the appropriate process route of scrap iron and steel.

3. Construction of Process Decision-making Service Model Based on Case Reasoning

3.1 Model of Process Decision-making Service of Scrap iron and steel
Referring to the method of case-based reasoning system [10,11], the modular case base of scrap steel processing technology can be constructed in scrap steel reverse supply chain service system. The processing technology of scrap steel can be designed by the appearance size and weight of scrap steel which can be obtained by the method of sampling measurement and 3D scanning. The specific algorithm is used to match the index information of the corresponding case set in the case base, and calculate its similarity. According to the given threshold value $\beta$, all the cases whose similarity value are greater than $\beta$ are selected to form a new sequence. According to the process technology of relevant scrap processing service providers, the best scheme is selected. And the processing scheme may be modified or directly applied to the scrap steel to be processed. If the similarity is less than $\beta$, the case with the highest similarity will be referred for modification. If the new processing scheme can solve the problem better, the case will be stored in the case base. The decision-making model of scrap steel processing technology based on case reasoning is shown in Figure 1.
3.2 Construction of Modular Case Library for Steel Scrap Processing

Modular technology is widely used in product design, system planning and organization, and few used in case-based reasoning system. In order to improve the retrieval efficiency and accuracy, a modular case base can be built in case-based reasoning system. According to the attribute of the scrap steel, such as the chemical composition, weight, thickness, width, length, height, source and supply status, the case base can be divided into several modules, and its structure is shown in Figure 2. Through the case index information of scrap iron and steel, the solutions of related cases can be obtained. The case index is the primary key in the case base. The solution of each case includes the process route and other information.

3.3 Computation of Feature Similarity of an Instance

3.3.1 Local similarity calculation

Case similarity calculation in case-based reasoning system is based on the appearance size and weight of scrap steel processing service process plan. Because the attributes and descriptions of each feature element are different, the attributes can be numeric, string, enumeration, etc.

1. Numerical type: 

\[ Sim_{k}(i,j) = \frac{\min(k_{i}^{k},k_{j}^{k})}{\max(k_{i}^{k},k_{j}^{k})} \]  

2. String type: 

\[ Sim_{k}(i,j) = \begin{cases} \mu_{k} = \mu_{j}^{k} & 0 \mu_{k}^{k} \neq \mu_{j}^{k} \\ 1 & \end{cases} \]  

3. Enumerative type: 

\[ Sim_{k}(i,j) = 1 - \frac{|\mu_{k}^{k} - \mu_{j}^{k}|}{M} \]
Simk(i,j) is the local similarity of the characteristic attribute k between the scrap steel processing technology i and the case j in the case base; μi^k is the k attribute value of the scrap steel processing technology i, and μj^k is the k attribute value of the case j in the case base, and M is the maximum attribute value of enumeration type.

3.3.2 Weight determination and total similarity calculation

Analytic hierarchy process (AHP) is often used to determine the weight. But AHP is based on the knowledge and experience of experts, which is more subjective and arbitrary. Entropy weight method can fully tap the information hidden in the original data, which has strong objectivity [13]. In order to overcome the subjective randomness of AHP and improve the accuracy of the weight of each feature element, the entropy weight method and AHP are combined to determine the weight value of each feature element.

Assuming that n feature elements are measured by m levels, a new judgment matrix \( A = [r_{ij}]_{n \times m} \) can be constructed. \( r_{ij} \) means the proportion of the number of people whose i factor is rated as j, which is obtained by interviewing several experts through survey, and \( r_{ij} \) meets \( \sum_{j=1}^{m} r_{ij} = 1 \). Assuming that \( H_i \) is the entropy of the i feature element, then:

\[
H_i = -\frac{1}{\ln m} \sum_{j=1}^{m} r_{ij} \ln r_{ij}
\]

\( m \) is the number of rating, when \( r_{ij} = 0 \), \( r_{ij} \ln r_{ij} = 0 \). And entropy weight \( \omega_{ls} \):

\[
\omega_{ls} = \frac{1-H_i}{\sum_{i=1}^{n}(1-H_i)}
\]

Similarly, the corresponding entropy weight of other feature elements can be obtained, then the weight of each feature element based on entropy weight method can be obtained: \( W_s = (\omega_{ls}, \omega_{ls}, \cdots, \omega_{ls}) \). The judgment matrix is established after comparing each characteristic element through the 9-th percentile scale method and the consistency test. The weight of each feature element can be obtained by the analytic hierarchy process (AHP): \( W_e = (\omega_{le}, \omega_{le}, \cdots, \omega_{le}) \). A set of \( (X_1, X_2, \cdots, X_n) \) is formed by n feature elements. Based on the combination of entropy weight method and AHP, the comprehensive weight of the i feature element can be expressed as follows:

\[
\omega_i = \frac{\omega_{ls} \omega_{le}}{\sum_{i=1}^{n} \omega_{ls} \omega_{le}}
\]

Combined with the calculation of local similarity, the global similarity between the i process of scrap iron and steel waiting to process and the j process case is as follows:

\[
Sim(i,j) = \sum_{k=1}^{n} Simk(i,j) \times \omega_k
\]

\( Sim(i,j) \) is the global similarity between i process of scrap iron and steel waiting to process and j process instance; \( \omega_k \) is the comprehensive weight of k attribute of process instance, \( \omega_k \in [0,1] \).

4. Cases

An iron and steel scrap metal resource company has purchased about 1.8 million tons of scrap annually. The purchased scrap is recycled and processed and then distributed to four major steel mills as required. According to the shape, scrap can be classified into five categories which are the primary modules in Figure 2. The main characteristic elements of scrap steel are the secondary modules in Figure 2. The main processing technologies include oxygen blowing cutting, drop hammer processing, bundling processing and shearing processing, forming the process scheme of scrap steel processing, which constitutes the example set in Figure 2.

The values of characteristic elements of scrap steel to be processed are as follows: {'X70'', 5, 50, 10, 10, 'Pipeline', 60, 'self-produced'} . According to the three levels of slight importance, obvious importance and special importance, the weight of each feature element is...
calculated, and the above eight feature elements are evaluated. The judgment matrix \( A^T \) is
\[
\begin{bmatrix}
0.10 & 0 & 0.15 & 0.10 & 0.25 & 0.35 & 0.35 & 0.55 \\
0.75 & 0.65 & 0.50 & 0.65 & 0.55 & 0.55 & 0.50 & 0.45 \\
0.15 & 0.35 & 0.35 & 0.25 & 0.20 & 0.10 & 0.15 & 0
\end{bmatrix},
\]
and the entropy weight \( W_s = (0.189, 0.232, 0.052, 0.052, 0.089, 0.51, 0.211) \). Three examples of scrap iron and steel processed in the past are selected to build the case set. \( P_i \) means the past scrap process example \( i \), including characteristic elements, process route, and processing scheme. The attribute values of case \( P_1, P_2, P_3 \) are as follows:
\[
\begin{align*}
\text{'Q235',} &\quad 11, 50, 10, \text{'Massive',} 100, \text{'Outsourcing'} \}
\cup
\{ 'X70', 6, 60, 10, 'Pipeline', 70, 'Self-produced' \}.
\end{align*}
\]
After calculation, the similarity of \( P_1, P_2, P_3 \) is 0.623, 0.974 and 0.938. If \( \beta = 0.85 \), the similarity between the scrap steel to be processed and \( P_2, P_3 \) is greater than \( \beta \). A new case can be formed for designers to select, and \( P_2 \) is finally determined as the best case. The scrap process can be slightly modified and applied to the current scrap to be processed.

5. Conclusions

It is an effective way to reasonably recycle scrap iron and steel by making decision on the processing method, which has good economic benefits, resource and environmental benefits. Considering the problems of wide sources, complex classification and extensive processing methods of scrap steel, a case-based reasoning method for scrap steel processing technology decision-making was proposed. It can effectively avoid increasing cost and wasting resource caused by improper selection of the processing technology, and improve the global efficiency of scrap iron and steel processing service. Finally, the method is validated by a case study of scrap steel processing in a metal resource company.

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