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Research on Optimizing the Carbon Footprint of Products Based on Identifier Resolution

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Abstract: This article takes a certain refrigerator of Haier Company as the research object and conducts an in-depth discussion on its carbon footprint throughout the full lifecycle. To achieve accurate tracking and calculation of the carbon footprint of the refrigerator's full lifecycle, this article adopts Handle and Ecode identification and resolution technologies. It establishes corresponding identification coding rules for key points throughout the lifecycle of refrigerator production, transportation, usage, and recycling, and designs a set of identification coding schemes for each stage of the refrigerator from raw material acquisition to recycling. Based on this identification coding scheme, this article calculates in detail the carbon footprint of the refrigerator at each stage of its full lifecycle. Based on the calculated carbon footprint data, it gains a deep understanding of the distribution of the carbon footprint of the refrigerator product and proposes a series of targeted optimization strategies. This research provides a powerful reference for the green development of the home appliance industry and promotes its development towards a more environmentally friendly and sustainable direction.

Keywords: Handle Identification Parsing, Ecode Identification Parsing, Carbon Footprint Calculation, Optimization Strategies

1. Introduction

The global manufacturing industry is undergoing profound changes and has become the focus of industrial competition among countries. Industrial Internet is regarded as a key path and methodology for the digital transformation of manufacturing. Similar to the domain name resolution mechanism of the Internet, the industrial Internet identification and resolution system assigns a unique identity to objects through methods such as barcodes, QR codes, and wireless radio frequency identification, enabling precise scheduling and management of resources such as equipment, items, and systems [1]. Such an identification and resolution system can be considered as the "identity card" of objects, recording critical information such as production, usage, and maintenance. By analyzing the product identification, enterprises can track the entire production process of the product and make the product information more transparent, thereby enhancing their competitiveness.

The carbon footprint of a product refers to the total amount of greenhouse gas emissions associated with the product throughout its life cycle. The calculation and evaluation of this footprint are more difficult due to the complex supply chain and production process. Traditional methods rely on

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enterprise data, which may be inaccurate and incomplete. Using identification resolution technology can accurately and comprehensively obtain product carbon emission information, providing a scientific basis for developing emission reduction strategies. This technology not only improves the accuracy of carbon footprint evaluation, but also provides new methods for optimizing carbon footprint, helping enterprises reduce carbon emissions. Therefore, research on carbon footprint optimization based on identification resolution is of innovative significance.

2. Identification parsing technology and identification coding scheme design

The identification coding technology of the Industrial Internet assigns unique identifiers to physical and virtual resources, serving as the "identity cards" for these resources [2]. It ensures that resources can be accurately identified, located, and managed in the cyber world. Therefore, using identification resolution technology to assign unique identifiers to each stage of the product's full life cycle can help to link the carbon footprint data of each stage.

2.1. Identification parsing technology

The Handle identification and resolution technology proposed and invented by Dr. Robert Kahn is a technique used to generate, allocate, and resolve globally unique identifiers [3]. The Handle identifier comprises a prefix and a suffix. The prefix, assigned by the Handle.net system to various institutions and organizations, serves as a globally unique identifier that distinguishes different namespaces, ensuring the uniqueness of each Handle identifier worldwide. This global uniqueness enables the Handle prefix to facilitate more accurate and efficient information flow and interaction across different systems. The suffix, on the other hand, is allocated and managed by the administrators of each namespace based on specific needs. It can incorporate various combinations of numbers, letters, symbols, and other characters, exhibiting a high level of flexibility and customizability.

Ecode, as an independently developed IoT coding scheme in China, has dual significance. Firstly, it represents a unified item coding standard in the IoT. Secondly, Ecode also represents a complete IoT identification system, including key aspects such as coding, data identification, middleware, parsing system, information query, security mechanism and application mode [4].Ecode encoding usually consists of three segments, including version V, encoding system identification NSI, and main code MD[5]. Version V is used to distinguish different data structures of Ecode, ensuring compatibility and scalability of the encoding. Encoding system identification NSI is used to indicate the code of a certain identification system, that is, to identify the specific encoding system to which the Ecode belongs. The main code MD is the core part of the Ecode encoding, used to represent standardized codes in a certain industry or application system.

2.2. Design of Identification Coding Scheme

This article takes a Haier refrigerator as an example, divides its full life cycle into five stages: raw material acquisition, product manufacturing, product distribution, product use, and product recycling, and designs a labeling and coding scheme for each stage. This scheme combines the coding principles of Handle and Ecode to innovatively form a new coding scheme.

2.2.1. Identification Prefix

At each stage of the product's lifecycle, a prefix code is designed for each stage of identification, referencing the design concept of the Handle coding prefix. First is the country code, which occupies 2 digits and uses numeric data format. Next is the industry code, which consists of 3 characters and uses character data type, which accurately represents different industry categories. Finally, the enterprise code, which has a length of no more than 20 characters, also uses character data type, which represents different enterprise nodes. This design enhances the autonomy of enterprises.

2.2.2. Identification Suffix

The identification suffix code for each stage uses the core part of the Ecode encoding, namely the main code MD. The main components of the suffix code include the national economic industry classification, product specifications and models, system boundaries, and stage sequence numbers. Among them, the national economic industry classification accounts for 5 bits, and the data type is character type, indicating the industry category of the product. This study selects product specification and model codes with ≤18 bits as an important component of the suffix code, as the carbon footprint of a product is closely related to its specifications, such as product volume and sales method. Taking the specification and model BCD-465WGHTDE9S9 of a refrigerator from Haier as an example, this specification and model contains key element information about the product, such as BCD representing refrigerator, 465 representing the total volume of the refrigerator, and G representing global sales. The system boundary of a product's carbon footprint is also a key element in identifying the suffix code, which clarifies the scope of accounting for greenhouse gas emissions generated by the product throughout its life cycle. This study uses 0 or 1 to identify different system boundaries, which occupies 1 bit in the suffix code and is represented by numeric data type in the identification code. Where 0 represents "cradle to grave" and 1 represents "cradle to gate". The stage sequence number is the last part of the suffix code and is used to identify different stages in the life cycle of a product. This study uses 01-05 to represent different stage sequence numbers, with 00 representing the entire life cycle of the product. For the manufacturing stage of the product, it is further represented by 20 for energy resource consumption sub-stage and 21 for three wastes resource consumption sub-stage. The stage sequence number occupies 2 bits and is represented by numeric data type.

2.2.3. Identification code and analysis

The identification code for each stage of the product's full life cycle consists of an identification prefix and a suffix, as shown in Figure 1. The prefix code and the suffix code are separated by a "/" character. The identification prefix for this identification scheme is 88.XXX.XXX. The identification suffix is composed of the national economic industry classification code, the product specification and model, the system boundary, and the stage sequence number. According to the research, the national economic industry classification code for home appliances is C3815. The system boundary is selected from cradle to grave. Taking the specification and model BCD-465WGHTDE9S9 of a refrigerator from Haier as an example, the identification of this refrigerator in the raw material acquisition stage is 88.178.600690/C3851. BCD-465WGHTDE9S9.001.

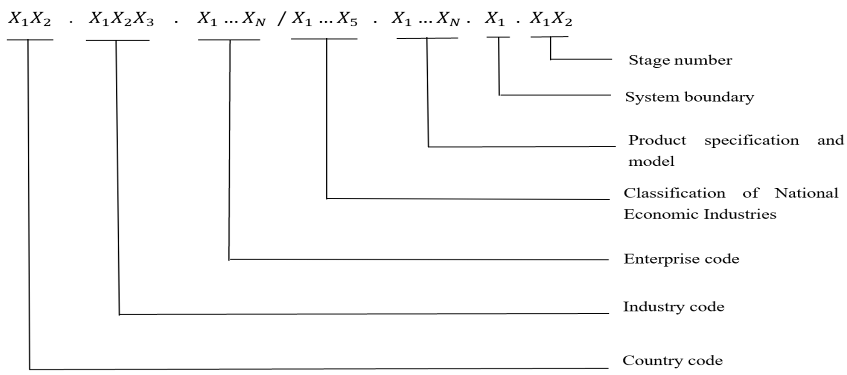

Figure 1: Identification coding scheme.

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This identification coding scheme ensures uniqueness and identifiability through structural prefix and suffix design. The prefix combines country, industry, and enterprise codes to accurately define the source and field of the product. The suffix covers industry classification, product specifications, system boundaries, and stage sequence numbers to deepen product understanding. The scheme is flexible and scalable, adapts to industry development and corporate changes, meets the needs of analysis at different stages, and provides strong support for product carbon footprint accounting.

3. Product carbon footprint calculation and optimization

This section uses a refrigerator with the model number BCD-465WGHTDE9S9 from Haier as the research object, and uses PAS2050 as the carbon footprint calculation standard to calculate the carbon footprint of a refrigerator in one year [6]. According to the General Principles for Carbon Footprint Accounting of Household Appliances, the system boundary is determined to be from cradle to grave, including the stages of raw material, product manufacturing, product distribution, product use, and product recycling [7]. Next, we will introduce the calculation model of product carbon footprint and the optimization strategy for carbon footprint [8].

3.1. Calculation of product carbon footprint

1) In the raw material acquisition stage, indirect and direct emissions of greenhouse gases caused by energy loss during the production process of raw materials are mainly considered, without considering the transportation emissions of raw materials. The calculation formula for this stage is:

$$G_m = \sum_{i=1}^{n}(M_i * \alpha_{i1}) \tag{1}$$

Where, G_m represents the carbon emissions in the raw material acquisition stage. The unit is $kgCO_2e$. M_i represents the physical quantity of the i-th type of material consumed in the production process, with the unit of kg. α_{i1} represents the carbon emission factor of the i-th type of material, with the unit of $kgCO_2e/kg$.

2)In the product manufacturing stage, the carbon footprint of the product mainly comes from energy resource consumption. The carbon footprint calculation formula for this stage is as follows:

$$G_p = \sum_{j=1}^{m} E_j * \alpha_{j2} \tag{2}$$

Where, G_p represents the carbon emissions in the product manufacturing stage, with the unit of $kgCO_2e$. E_j represents the physical quantity of the j-th type of energy consumed during the manufacturing process, with the unit of kg. α_{j2} represents the carbon emission factor of the j-th type of energy, with the unit of $kgCO_2e/kg$.

3) In the product distribution stage, the carbon footprint of a product mainly considers the carbon emissions generated during the transportation of the product from the production site to the sales site, and only considers the distance between the product manufacturer and the primary distributor, ignoring multi-level distribution. The key factors to consider are load and transportation distance[9]. Therefore, the carbon footprint calculation formula for this stage is as follows:

$$G_d = M * D * T \tag{3}$$

Where, G_d represents the carbon emissions during this stage; M represents the transported mass of a single product in tons; D represents the transportation distance, in kilometers (km); T represents the carbon emission factor per unit weight and transportation distance, with the unit of $kgCO_2e/(t * km)$.

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4) During the use stage, the primary consideration is the carbon emissions generated by the electrical energy consumption during the operation of the product. The calculation formula is:

$$G_u = p * UT * \alpha_{s4} \quad (4)$$

Where, G_u represents the carbon emissions during the product use stage, with the unit of $kgCO_2e$; p represents the comprehensive power consumption during the product use process, with the unit of $kWh/24h$; UT represents the product use duration, with the unit of days; α_{s4} represents the power carbon emission factor of the grid in s region, with the unit of $kgCO_2e/kWh$.

5) During the product recycling stage, the main considerations are the transportation of the product for recycling, waste disposal, and emissions from product disassembly. Assuming that after the user discards the product, the recycling location is the nearest waste product processing facility to the distributor's collection address, and the distance between the two is estimated as the transportation distance for recycling. The power consumption during the disassembly process is the only factor considered for the disassembly process. The carbon footprint calculation formula for this stage is:

$$G_r = R * K * \alpha_{r5} + \sum_{f=1}^{p} Q_f * \alpha_{f5} + P * \alpha_{s5} \quad (5)$$

Where, R represents the weight of the recycled transport, in tons (t); K represents the transportation distance of the recycled transport, in kilometers (km); α_{r5} (in $kgCO_2e/kg$) represents the carbon emission factor for the transportation vehicle in recycling; Q_f (in kilograms, kg) represents the weight of the fth type of waste; α_{f5} (in $kgCO_2e/kg$) represents the carbon emission factor for processing the fth type of waste; P (in kWh) represents the power consumption during product disassembly; and α_{s5} (in $kgCO_2e/kWh$) represents the power grid carbon emission factor in region s.

3.2. Optimization of product carbon footprint

3.2.1. Distribution of Carbon Footprint of Products

Using the aforementioned carbon footprint calculation method, the carbon footprint of each stage in the full lifecycle of Haier's refrigerator model BCD-465WGHTDE9S9 has been obtained. The carbon footprint of one refrigerator in the raw material acquisition stage is 229.3749$kgCO_2e$, 12.4537$kgCO_2e$ in the product manufacturing stage, 27.5721$kgCO_2e$ in the product distribution stage, 156.3488$kgCO_2e$ in the product usage stage, and 70.9447$kgCO_2e$ in the product recycling stage. According to these data, the carbon footprint of a refrigerator accounts for 46% in the raw material acquisition stage, 31% in the product use stage, 14% in the product recycling stage, 6% in the product distribution stage, and 3% in the product manufacturing stage.

3.2.2. Optimization strategies for product carbon footprint

Based on the carbon footprint of refrigerator products throughout their various stages, the raw material acquisition and product usage stages account for a significant proportion. The carbon footprint of these two stages is mainly attributed to material consumption and electricity usage. Optimizing these two stages can effectively reduce the carbon footprint.

In the raw material acquisition stage, suppliers should firstly prioritize the use of low-carbon and environmentally friendly materials to reduce their dependence on fossil fuels. Secondly, they should establish a strict supplier management system to ensure the compliance and environmental protection of raw material sources. In addition, promoting the concept of circular economy and improving the recycling rate of raw materials are also effective ways to reduce carbon footprint.

During the product use stage, manufacturers should focus on improving the energy efficiency ratio of refrigerator products to reduce energy consumption during use. At the same time, companies should promote products with energy-saving features such as smart refrigerators to guide consumers to develop energy-saving habits. In addition, sellers should provide quality after-sales services to extend the life of products and reduce the carbon footprint caused by frequent product replacement.

In addition to the acquisition of raw materials and the use of products, other stages of the product's life cycle can also be optimized to reduce its carbon footprint. For example, in the manufacturing stage, manufacturers can introduce advanced production processes and equipment to reduce energy consumption and emissions during production. In the distribution stage, distributors can optimize logistics and transportation methods, choosing low-carbon and efficient transportation modes. In the product recycling stage, recyclers should establish a sound recycling and disposal mechanism to ensure that products are properly disposed of after they are scrapped, and also improve the recyclability of products to reduce waste pollution to the environment.

4. Conclusion

This article takes a refrigerator from Haier as the research object, and uses identification resolution technology to design an identification coding scheme for each stage of its full life cycle. In the design process of the identification coding scheme, this article fully considers the characteristics of the refrigerator product and the needs of its full life cycle. Through the structural prefix and suffix design, the uniqueness and identifiability of the identification coding are ensured. The prefix part integrates country code, industry code and enterprise code, clearly defining the source and field of the refrigerator; the suffix part records in detail the specifications and models of the refrigerator product, system boundaries, and stage serial numbers, providing a rich and accurate data foundation for carbon footprint accounting. Based on this identification coding scheme, this article accurately calculates the carbon footprint of the refrigerator product. By calculating and analyzing the carbon footprint data at each stage, it can identify high carbon emission links, and propose targeted optimization strategies accordingly. In conclusion, innovative design of identification coding schemes will be further pursued in the future to better achieve the goal of optimizing the carbon footprint of products.

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