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Carbon footprint inventory route planning and selection of hot spot suppliers

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ABSTRACT

In order to achieve the data accuracy on carbon emission from the suppliers, a complete carbon footprint inventory must be compiled at each supplier's site. Generally speaking, to collect the carbon emission inventory, data from various sources must be obtained, resulting in consumption of many resources from enterprises and suppliers. Therefore, to perform the compilation efficiently, a more systematic method for visiting suppliers is required. The carbon footprint inventory routing problem, based the vehicle routing problem (VRP), explores the selection of appropriate suppliers for inventory compilation after the carbon emission reaches a certain accuracy level and determination of the efficient carbon emission inventory route. In this study, the VRP is modified for the selection of the suppliers. Furthermore, by applying the sensitivity analysis, this study discusses the replacement of primary data by secondary data and development of the decision method that can be used to evaluate the route optimization, efficiency maximization, and cost minimization for carbon footprint inventory routing planning.

1. Introduction

In recent years, many enterprises have voluntarily disclosed the data on carbon emission during the manufacturing of their products or services. Using the data, corporate carbon footprint can be determined based on the amount of direct and indirect carbon dioxide equivalent emission during the entire life cycle of its manufacturing processes or products.

Most enterprises follow the guidelines of ISO 14064-1 (2006), ISO14064-2 (2006), and PAS 2050 (BSI, 2008) for calculating the carbon footprint of a product or service. A life cycle analysis (LCA) method, based on (ISO 14040 series) (ISO 2006a,b), is also adopted in evaluation of the environmental impact of raw materials use, manufacturing, distribution, and disposal of their products and waste to develop suitable carbon reduction plans, which would help in creation of eco-friendly products. The life cycle concept and inventory method were first proposed in the late 1960s to evaluate the environmental impact of products, services, and treatment from an environmental perspective. The data collected from various phases of product manufacturing are used to compile a life cycle inventory (LCI), an accounting of carbon gas releases incurred throughout the life cycle of a product (SETAC, 1991).

Although the life cycle analysis is the widely accepted practice, it is still regarded as a specialized research field as the analysis involves a considerable data collection and examination from many sectors, including the suppliers of raw material, manufacturers, logistics providers, and waste treatment facilities. Therefore, it has not been used extensively by enterprises.

Recently, because of the increasing public awareness on environment issues, enterprises have attempted to collect information of their own carbon emission during production. Although enterprises' suppliers are willing to contribute to the life cycle inventory based on the relevant data, it is not an easy task as the globalized modern enterprises rely on operations from their functional divisions and suppliers scattered around the world. This creates difficulties in collecting the carbon footprint data from factories throughout the entire product life cycle. Other issues interfering with an accurate data collection include: (1) the geographical separation and language barrier of global suppliers around the world; (2) qualification of employees and suppliers to collect the accurate inventory data; and (3) diverse methods applied by the suppliers to calculate their own carbon emissions for different components and at various stages of the manufacturing processes.

For a complete and accurate life cycle inventory, an on-site data compilation must be conducted for each supplier to obtain

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the primary data. An on-site inventory activity includes collection of various data on the consumption of resources, such as labor, materials, cost, and time, by enterprises and suppliers. Traditionally, the suppliers contributing to the life cycle inventory compilation are selected arbitrarily; systematic selection of parts suppliers does not exist. In order to reduce some workloads associated with the inventory compilation, some enterprises may define the accuracy of carbon emission inventory in advance, then subjectively selects certain suppliers and replaces first-hand information collected from the supplier with secondary data source obtained from published studies. Although this kind of method reduces costs associated with carbon emission inventory compilation, the data accuracy is compromised.

When selecting suppliers for direct data collection, the selection of "hot spot" suppliers—those with high level of carbon dioxide emission, the determination of the efficient route for visiting suppliers for data collection, the reduction of costs, and accuracy of life cycle inventory are critical issues for modern enterprises to consider. In the past, there is no research that is directly related to route planning for carbon emission inventory compilation. Taking a cue from the fields of transportation, distribution and logistics (Kopfer and Kopfer, 2013; Ubeda et al., 2011), the researchers determine an efficient route for visiting suppliers in regards to compiling life cycle inventory by modeling after the vehicle routing problem (VRP). However, the main difference between the VRP and the present problem is that this problem on the LCI involves finding the appropriate suppliers for data collection after their carbon emission reaches a defined percentage of accuracy value. To conduct a life cycle inventory compilation, the company must assess the inventory cost, route, time needed for compilation, and other unanticipated problems.

This study will therefore model the optimization problem after the VRP, through the application of linear programming, and develop a decision-making model for supplier selection and efficient carbon emission inventory route planning. Further, with the sensitivity analysis, this study will discuss the use of secondary data by enterprises in replacement of primary data and aim at finding a decision method that can evaluate route optimization, maximize efficiency, and minimize cost for carbon footprint inventory routing, to conduct an efficient carbon footprint compilation. Finally, a case study is implemented to illustrate the research model.

2. Literature review

This section presents information in selected literatures on the carbon footprint inventory problem and VRP.

2.1. Carbon footprint inventory problem

Calculating greenhouse gas (GHG) emissions involves the use of three types of data: (1) the statistics of national or regional energy combustion and emission; (2) emissions from enterprises or organizations; and (3) emissions of GHGs produced during the life cycle of an individual product, i.e., the carbon footprint. The carbon footprint is a measure of the exclusive global amount of CO_2 and other GHGs emitted by human activity or accumulated over the full life cycle of a product or service (Wiedmann and Minx, 2008). A carbon footprint inventory contains the amount of GHG emitted from the exploitation and manufacturing of raw materials, as well as manufacturing, assembly, use, discard, or recovery of products. Previous studies on carbon footprint (Wiedmann and Minx, 2008; Lee, 2011; Fleten et al., 2010) have attempted to urge enterprises to be concerned about CO_2 emissions, and have proposed improvement strategies. For example, a British study found that the carbon footprint of a croissant is 1140 g (BSI, 2008). The five steps involved in ascertaining the carbon footprint are summarized as: (1) product analysis, (2) mapping of supply chain process, (3) setting of boundary system for assessment, (4) identification and collection of data, and (5) assessment of product carbon footprint (Rugrungruang et al., 2009).

2.2. Vehicle routing problem

The VRP, based on the traveling salesman problem (TSP), is proposed by Dantzig and Ramser (1959), who used the linear programming to solve this type of problem. The difference between the VRP and TSP is that the VRP considers more than one vehicle and the capacity limit of the carrier, and it aims at determining the cargo distribution path that satisfies customer needs with consideration of the minimum path cost. The basic VRP model is discussed in Kulkarni and Bhave (1985), who considered the limitation of the carrier's maximum capacity as well as the minimum time or distance. More complicated VRP variants involves time windows and heterogeneous vehicle fleet with different capacities (Kritikos and Ioannou, 2013), VRP12 (VRP with distances one and two) (Ceranoglu and Duman, 2013), and the integrated problems of VRP and delivery scheduling (Yu and Dong, 2013) and VRP and inventory management (Guerrero et al., 2013). For the complete description of other VRP variants, please see Table 1.

3. Research methods

To calculate the carbon footprint, product data are collected at different stages of the life cycle, including stages of raw material input, product manufacture, transportation, product use, and end of life. However, only some suppliers can provide the necessary data. Thus, it is important not only to track the components that generate high amounts of green gases but also to determine the suppliers' ability to provide the primary data. With reference to PAS 2050, an industry specification that provides a method for assessing the life cycle greenhouse gas, both primary and secondary data are required to calculate the product's
carbon footprint. Generally, the secondary data is used to obtain: (1) emission factors, which convert the primary activity data (material/energy/process inputs and outputs) into GHG emissions (CO_2 per kg); (2) information that fill gaps in the primary activity data; (3) information used to calculate the impact of the "downstream" life cycle stages, including the use and end-of-life stages. Generally, the allocation rules for the usage of materials and energy as well as for the emission of waste (air, waste, or water) are developed using the primary data. The LCI of the carbon footprint mainly considers the inventory scope and accuracy of data. According to the CO_2 emissions of primary data specified by the trade association, the accuracy of the inventory of carbon emission data must exceed $V\%$:

$$V\% = \frac{CO_2 \text{ primary data}}{CO_2 \text{ primary data} + CO_2 \text{ secondary data of total components}} \quad (1)$$

An enterprise whose CO_2 emission is greater than 10% should be investigated $((CO_2 \text{of} \text{a} \text{component}/CO_2 \text{of} \text{total} \text{components})/ \geq 10\%)$. The optimization of various costs, paths, and inventory times is taken into account, given the premise that the standard value of