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Locating manufacturing industries by flow-capturing location model – Case of Chinese steel industry

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ABSTRACT

The location behaviors of manufacturing industries are analyzed in the context of the economic globalization, and a programming model that integrates the flow-capturing location model with the traffic assignment model is built to optimize the location of manufacturing industries based on the world-wide transport multi-mode network. The flow-capturing location model is used to determine the location scheme, and the traffic assignment model is used to calculate the corresponding attributes of the freight flows in the transport network. A genetic algorithm is designed to solve the model and the Chinese steel industry is used as the case study. The result shows that the proposed method could help decision makers to effectively make location decisions for manufacturing industries.

1. Introduction

Economic globalization alters the previous pattern in which many activities (e.g., production, consumption) are performed in a country or a region, and promotes the mobility and allocation of resources world-wide, which significantly changes the external environment for industries. As a result, many industries no longer depend entirely on domestic local resources and markets; instead, they extend their supply chain world-wide and become actively involved in global sourcing and marketing. Because of this trend, the derived demand for the transport of raw materials and products are served using a global multi-mode transport system. Hence, considerable progress has been made for the transport infrastructure in the economic globalization process, particularly for ports, which are important nodes among the international trade network. The well-developed transport system in turn facilitates the mobility and allocation of the resources world-wide further.

The free environment for resource flow and the well-developed transport system significantly affect the spatial distribution of manufacturing industries. Currently, the industrial locational choice is less sensitive to the distance from the sites of the plants to the origins of the raw materials and the markets of the products. In some cases, the industries are located far away from both the materials and markets. For example, the Japanese textile industry opens new plants in mainland China even though the raw materials and products still originate from and are sold to Japan. In addition, manufacturing industries have converted their mode of production and sale from “local” to “global”, which results in a dispersed pattern throughout the world; this dispersed pattern is particularly apparent in the automobile and electronic manufacturing industries.

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In the context of greater resource mobility, manufacturing industries' location behavior and distributional features, which can significantly increase the benefits and facilitate the formulation of efficient industrial policies, should be studied soundly. The study on the theory of location and distribution formally started with Weber (1909) and was renewed with the subsequent publication of Hakimi (1964). Over the last few decades, the theory of location and distribution has become an important research topic in the field of operations research and management science (e.g. Daskin, 1995; Drezner and Hamacher, 2002; Eiselt and Sandblom, 2004; Klose and Drexl, 2005). During this period, many studies have been performed and have mainly focused on the facility location problems in both the public sectors (e.g., hospitals, post stations) and the private sectors (e.g., plants, retail stores, banks) (e.g. Drezner, 1995; Batta, 2014; Bellettini and Kempf, 2013; Roig-Tierno et al., 2013; Hammad et al., 2017; Karatas, 2017). Although the location problems vary, the components that describe these problems are highly similar and include the customers, who are assumed to be located at the nodes or on the paths (i.e., the demand), the facilities that must be located (i.e., the supply), a space where the customers and facilities are located and the spatial impedance between the customers and facilities (typically indicated by the travel time or cost) (ReVelle and Eiselt, 2005).

Both qualitative and quantitative methods are used to solve the location problems (Chen et al., 2014). Qualitative methods mainly depend on the weighted scoring to determine the optimal location and include the steps of: determining the key location factors, assigning the weight for each factor, scoring each factor for each location, computing the weighted scores for each location and finding the best one (Erkut and Moran, 1991). These methods are relatively easy to use, and sometimes show good performance especially when faced with a limited number of location alternatives and scoring by enumeration seems feasible. However, as the number of location alternatives becomes large and scoring by enumeration seems intractable, the benefit of quantitative methods (e.g., gravity approach, mathematical programming approach) begins to manifest itself. Among the quantitative methods available, facility location modeling is one of the most frequently used approaches. There are various facility location models, and these models are typically classified by the decision maker's objectives and the features of the space. In the work of ReVelle et al. (2008), facility location models are divided into four categories: analytic models, continuous models, network models and discrete models. Most facility location models are formulated to solve the location issues of facilities whose demands are located at the nodes of the network (e.g., the covering problem, the p-center problem, and the p-median problem) (Owen and Daskin, 1998; An et al., 2014). Many studies refer to such demand as "node-based demand" (Hodgson, 1990; Khakbaz and Nookabadi, 2013). In other words, the customers who reside at the network nodes travel to facilities to obtain goods or service; alternatively, the suppliers travel to the customer locations to provide goods or service as requested.

However, there is another type of demand besides the node-based demand, termed as "flow-based demand" (Hodgson, 1990). This demand corresponds to the customer flow along the planned path, not those located at the network nodes. The customers obtain goods or services at the facilities, which can be encountered during their journeys, e.g., park-and-ride services, refueling services, and highway rest services (Zeng et al., 2010; Yang, 2009). In this paper, the location problem of manufacturing industries is regarded as a facility location problem, which is related to the flow-based demand. This problem is based on the consideration that the customers of the products can be considered as a type of substance flows whose initial and final forms are the raw materials and products, respectively, and the makers' activity can be regarded as the process where the industries provide service for the flows, which are destined for the product market, from the origin of raw materials.

The facility location problem for the flow-based demand was first proposed by Hodgson (1990). One of his main findings was the flow-capturing location model. The model has been continually improved since then and applied to location problems in multiple fields. For example, Horner and Groves (2007) proposed an improved flow-capturing location model to locate park-and-ride facilities. The model maximized the likelihood of removing the users from the network (denoted by the vehicle miles traveled) under a given number of facilities. Khakbaz and Nookabadi (2013) extended the work of Horner and Groves (2007) by relaxing the assumption of only one central business district zone and adapting the model objective to the maximum vehicle hours that were removed from the network. Zeng et al. (2009) overcame the shortcoming of the previous flow-capturing location models, namely, the consideration of both the network flow structure and proximity to the preferred locations of the customers. They attained the trade-off between the network flow structure and importance of proximity to the preferred locations using a utility function. Upchurch et al. (2009) established the flow-refueling location model, which considers the limit of capacity to locate refueling stations based on the traditional flow-capturing location models. Lim and Kuby (2010) adapted the flow-refueling location model by adding the constraint that more than one station is required to refuel the round-trip travel of vehicles. Kim and Kuby (2012) continued the study of Berman et al. (1995) and contributed on the flow-refueling location model by considering the deviations that drivers are likely to make from their shortest paths and developing the penalty function that describes the decrease in demand with increasing deviation. Riemann et al. (2015) proposed a flow-capturing model to locate the wireless charging facilities for electric vehicles. They contributed to the field in considering the influences of the congestion and charging facility availability on the routings of electric vehicles and considering the interactions between the charging facility location and the equilibrium traffic flows. Wu and Sioshansi (2017) developed a stochastic flow-capturing model to optimize the location of fast-charging stations with uncertain electric vehicle flows.

The flow-capturing location model can be summarized as an optimization model used to maximize the flow for a given demand, planned paths and number of facilities. The flow-capturing location model is similar to the maximal covering model, which is used for the node-based demand. The flow-capturing location model has been widely applied to the location problems of facilities, such as park-and-ride facilities, refueling stations, fast-food restaurants, and billboards. However, there have been few applications of this model to the location of manufacturing industries.

This paper aims to analyze the location behaviors and the distributional features of manufacturing industries and develop the method to locate the manufacturing industries by considering the widely distributed raw materials supply site and product market, and considering the transport costs in the global multi-mode transport network. Here, we intend to propose an adapted flow-