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Location selection of intra-city distribution hubs in the metro-integrated logistics system

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ABSTRACT

Logistics in cities depends largely on ground transportation and causes problems such as traffic congestion, environmental impact and delivery delays. Taking advantage of a metro system's underutilized capacity to transport same-day delivery items within a city during off-peak periods is not only innovative, but can mitigate the abovementioned urban transportation problems. In this paper, we locate the distribution hubs and construct a metro-integrated logistics system. First, we propose a segmentation method for the urban metro network. Second, based on the resulting sub-networks, indices for evaluating the importance of each metro station are selected by complex network theory and the weight of each evaluation index is calculated by AHP method. Moreover, the importance of each metro station is evaluated using the TOPSIS model and the candidate metro distribution hubs for location model are determined. Then, with the consideration of logistics demand, a location model is formulated to determine the final metro distribution hubs from the candidate metro distribution hubs. Finally, we choose the metro system of Shanghai as a case study and provide strategic planning for location selection of metro distribution hubs.

1. Introduction

With the surging growth of e-commerce and home deliveries in recent decades, city logistics, which focuses on the efficient and effective transportation of goods in urban areas, has become critical in improving the quality of life in cities. At present, city logistics mainly employs ground transportation vehicles such as motorcycles and small pickup trucks to transport goods. However, with the increasing concentration of populations and goods in limited urban areas, ground transportation creates traffic congestion, air and noise pollution, and environmental deterioration. In addition, various factors like rush-hour congestion, road restrictions, and bad weather hamper the timely delivery service provided by ground transportation. To address the above problems and ensure more efficient and effective implementation of city logistics, many initiatives and conceptual solutions have been proposed and tested. Underground logistics system (ULS) is an appealing and innovative solution for reducing the negative impacts of ground transportation. As a result, ULS has been considered by local governments and successfully applied in some cities.

Since the first ULS was started for transporting telegrams and postal mail from the center to the branch office in London in 1853, similar systems have been applied in other European cities, including Berlin, Paris, and Amsterdam (Arends and de Boer, 2001; Taniguchi and Thompson, 2002). ULS has proven to be a very effective method for solving the problems of city logistics. In recent years, urban underground space in China has been increasing rapidly and playing a vital role in the process of urbanization and modernization. Underground space development such as metro and underground complexes are under widespread construction (Qian, 2016; Chen et al., 2018). The metro system is a very common underground system for transporting passengers in most large cities, characterized by punctuality, accessibility, and large capacity. However, the metro system often has considerable underutilized capacity during off-peak periods. Same-day couriers can take advantage of the underutilized capacity to transport documents, small parcels, small machine parts, medical supplies, and other time-sensitive goods among companies and other organizations

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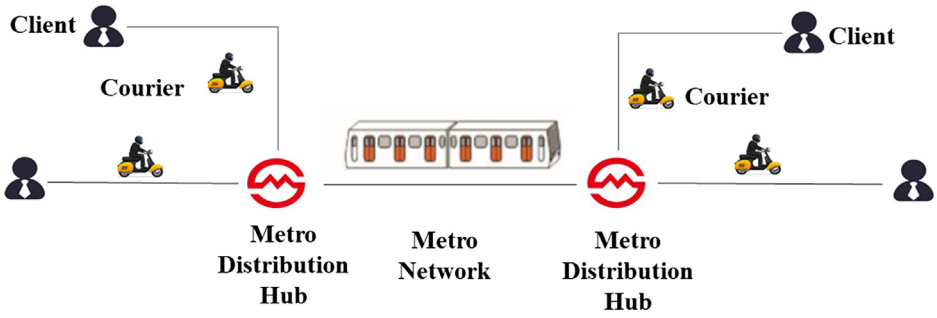

Fig. 1. Conceptual image of the metro-integrated logistics system.

with maximum speed and security. Couriers can also benefit by having lower transport costs and more frequent and reliable deliveries. Residents can benefit by experiencing less congestion as well as reduced emissions and noise from fewer trucks travelling on urban road networks.

In this paper, we propose an intra-city logistics system by integrating the city's existing metro network with the "first and last-mile" delivery service operated by logistics firms in China. The metro-integrated logistics system is based on the use of the passenger subway system, which is composed of a metro distribution hub, metro network, and client and courier, as shown in Fig. 1. The first and last components of the metro-integrated logistics system are realized in the usual way, i.e. couriers use motorcycles or small trucks to pick up or deliver goods to clients. The central component of the system uses the metro network to transport goods from departure stations to destination stations by manpower. Goods are thus collected from different clients by couriers and loaded at metro distribution hubs, then transported by existing subways and unloaded at metro stations, and finally delivered to end clients by couriers. The metro distribution hub of the logistics system should be built near the metro station or just in the metro station hall, so that the goods can be easily transferred. Though several intra-city logistics companies in China have used urban metro network to deliver small parcels, they usually locate the distribution hubs of the metro-integrated logistics systems based on their own experience. This approach lacks a scientific basis and may lead to delivery delays.

We primarily locate the intra-city distribution hubs of the metro-integrated logistics system to secure the timely delivery of small parcels among clients in this paper. The remainder of the paper is organized as follows. In Section 2 we briefly review the research on city logistics, ULS, and previous methods of locating distribution hubs. In Section 3 we describe the materials and research methods used in this paper. First, we present the structural features of a well-developed metro network and then propose a method to segment the metro network into several sub-networks. Second, we use the indices from complex network theory to evaluate the importance of nodes in the metro network, and employ the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method to select candidate distribution hubs from stations of the metro network for the metro-integrated logistics system. Third, we formulate a mathematical model to locate metro distribution hubs from the candidate distribution hubs with minimizing the total distance travelled by couriers. In Section 4 we describe an empirical study of metro-integrated logistics system for Shanghai, and present the results of locating intra-city distribution hubs, as well as make some further discussions about the results and management insights. In Section 5 we summarize the conclusions and suggest the directions of future research.

2. Literature review

There is a rapidly expanding body of literature addressing the issue of city logistics, which provides efficient and effective solutions for distributing goods in congested urban areas. To frame our study against a broader background, we first review the literature on city logistics. Then we focus on the issue of ULS, especially systems that use local metro system to transport goods, to identify gaps in the current research. Finally, we review the quantitative methods that are commonly used in traffic system research, and aim to apply these methods to construct a metro-integrated logistics system in urban areas.

City logistics is finding efficient and effective approaches to transport goods in urban areas while considering the negative effects of goods distribution in urban areas on congestion, safety, and the environment. Since the population in urban areas continues to increase, city logistics impacts a growing number of people. If not done well, it will cause unnecessary congestion and greenhouse gas emissions, negatively affecting quality of life (Savelsbergh and Van Woensel, 2016). Therefore, it is necessary to consider the effects of city logistics in urban transport planning that includes passengers and freight. Cui et al. (2015) present a broad discussion of the links between urban freight transport and urban planning through an overview of the literature in the field. Fatnassi et al. (2015) investigate the potential of integrating a shared goods and passengers on-demand rapid transit system in urban areas. They take advantage of the combination of personal rapid transit and freight rapid transit, and propose an emergent and efficient transportation solution in order to enhance the sustainability of city logistics. Masson et al. (2017) investigate the management of urban transportation flows making joint use of transport resources between passengers and goods. They propose a mathematical model and solve a two-tiered transportation problem to design a city logistics transportation system with mixed passengers and goods. Another solution to mitigate the negative effect of city logistics on urban environments is using ULS to transport goods. ULS is considered a radical and innovative approach to solve the problem of ground transportation as the ground space of cities becomes increasingly limited. Gordijn (1999) investigates a ULS in the Netherlands and offers a sustainable and efficient transport system by designing two types of underground freight transport. Pielage (2001) presents the development of a ULS in the Netherlands and investigates a pilot project for ULS, then discusses the transport technology aspects of an automated underground freight transportation system. Stein and Schoesser (2003) devise a ULS called the "CargoCap" system that can be set up quickly and coordinates well with the traditional transportation system in Germany. Liu (2004) discusses the technical and economic feasibility of using pneumatic capsule pipelines for underground transportation of freight in New York City.

Currently, metro system are considered the most convenient and economical systems of passenger transport. Moreover, they are stable, fast, and offer wide coverage in the city, enabling passengers to rapidly reach their destination. Since these characteristics meet the needs of an ideal city logistics system, extending the metro system's freight function could be a useful approach to city logistics. Pielage and Rijsenbrij (2002) discuss the available transport capacity of metro system and their potential to carry freight. He et al. (2008) design a conceptual urban logistics system based on metro network, which is composed of a management information center, cargo center, metro system, and workers. Liu et al. (2008) propose several critical problems in planning,