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Transportation Research Procedia 25C (2017) 1144–1150

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

Freight network design with heterogeneous values of time

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Abstract

This paper aims to demonstrate the effect of recognizing heterogeneity in values of time on the design of a hub network for freight transportation. By taking the VOT distribution into account, we emphasize shippers' broader logistical, social and economic situation in the network design, and are not limited to commodity types. The paper employs the single allocation p-hub median problem which minimizes the total generalized transportation cost (time, distance, etc.) with given demands. VOT is assumed to be discretely distributed, and estimated by mean-dispersion model and Latent Class model, based on a Stated Preference survey conducted in China, investigating railway shippers' choice behavior of railway services. A local railway network with 14 nodes and 20 linkages is applied to discuss the effect of VOT distribution on multiple (i.e., 3) hub location strategy. Simulated Annealing (SA) is designed to solve the single allocation p-hub median problems. The numerical results shows that the VOT and its distribution should be taken into account for better simulating railway shippers' heterogeneous valuations of service time versus time.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: freight transport; heterogeneity; VOT distribution; single allocation p-hub median probelm

1. Introduction

The hub network refers to a distribution system in which hubs are located for switching, transshipment and sorting, and non-hub nodes are allocated to one or more hubs, to pursuit the economies of scale for inter-hub transportation, rather than direct services between non-hub nodes. The main issues in hub network studies are, as noted by O'Kelly and Miller (1994), to find the optimal hub locations, to assign non-hub nodes to the hubs, to determine inter-hub

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Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.
10.1016/j.trpro.2017.05.127

linkages and to route demand flows through the network. Besides, a series of hub location and non-hub nodes allocation problems have been widely studied in transportation, logistics, and telecommunication, in last decades. And the main research focuses on hub network are: (1) p-hub median problem, (2) hub location problem with fixed costs, (3) p-hub center problem, and (4) hub covering problems. A comprehensive review on variants of hub network design problem involving with models and solution methods could be found in Alumur and Kara (2008), as well as Campbell and O'Kelly (2012). Since its advantages in multiple flows concentration and redistribution in freight transport, hub network has been adopted by major international logistics companies, like Federal Express and UPS, to organize air and ground transportation and delivery.

As the input of the hub network, demand in hub network design problem are normally assumed to be homogeneous, which can be represented by origin and destination nodes, as well as the hubs connected them. Demands sharing the same link by one transport mode are viewed as a single demand. However, there is considerable heterogeneity in network demand, especially for freight transport. As implied by De Jong (2000), demand heterogeneity in freight transport is more complicated than that in passenger transport, in terms of shipment diversity, like shape, size, value, etc.

As one critical component for measuring demand heterogeneity, the values of time (VOT) distribution and its effects on travelers' route/mode choice has been studied. Yang et al.（2001）studied how the distributions of values of time (VOT) would affect the competition among differentiated bus services in terms of price and quality. The VOT was assumed to distribute continuously across users, and was take as the critical component of generalized trip costs. Results showed that there was a highly significant relationship between VOT distribution and profitability of bus service providers. Then, Yang et al. (2002) investigated the impact of users' heterogeneity on the profitability and welfare gain of a private toll road in a given network, in which users was segmented into a number of distinct groups according to their VOT. Authors suggested that incorporating user heterogeneity in terms of VOT and its distribution were important for stakeholders' choice making on new investment projects. Yang and Huang (2004) examined the network equilibrium and system optimum problem in a network with a discrete distribution of VOT. Besides, Zhao and Kockelman (2006), Cantos-Sánchez et al. (2011) ,Tan and Yang (2012), Qian and Zhang (2013), Wang and Ehrgott (2013), Wang et al. (2014), and Wang et al. (2014) discussed the importance of VOT and its distribution for travelers' route choice decision.

On the other hand, there are a few articles about heterogeneity in freight transport, studies include Kwon, et al. (1998), which proposed a dynamic freight car routing and scheduling model based on railway time-space network, in which the traffic could be classified into several differentiated classes because of heterogeneous service requirement from railway shippers. And Francesco et al. (2006) focused on the empty container reallocation problem of logistic companies, which the empty containers were modeled as heterogeneous fleet with different sizes. However, heterogeneity captured by industrial activities, consignment commodity type or service requirement is often impracticable, as noted by Arunotayanun and Polak (2011), to study freight choice behavior.

Although there is abundant literature on freight network design, there is little work that explicitly takes into account heterogeneous preferences. Especially when it concerns the trade-off between transport time and tariffs, knowledge of this heterogeneity may play an important role in designing the network, increasing its overall performance.

Thus, this paper will study the relationship between VOT distribution and hub network design in freight transport. In detail, we employ the single allocation p-hub median network design model as theoretical basis, and VOT will be incorporated into the unit transport cost formulation, to calculate the generalized transport costs. What's more, VOT is assumed to be distributed discretely, based on a series of estimation by Latent Class (LC) model and the relative Mean-dispersion model.

The outline of this paper is as follows. Section 2 describes the single allocation p-hub median network design model. VOT distribution and formulation are discussed in Section 3. Section 4 presents a numerical analysis based on a local railway network in China. And Section 5 contains our discussions and conclusions.