Transportation Research Part E 79 (2015) 83–101

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

An inventory-based simulation model for annual-to-daily temporal freight assignment

Miyuan Zhao [a,*], Joseph Y.J. Chow [b], Stephen G. Ritchie [c]

[a] Google Shopping Express, Google Inc., Mountain View, CA 94043, USA
[b] Department of Civil Engineering, Ryerson University, Toronto, ON M5B 2K3, Canada
[c] Department of Civil & Environmental Engineering and Institute of Transportation Studies, University of California, Irvine, CA 92697, USA

ARTICLE INFO

Article history:
Received 7 October 2014
Received in revised form 9 March 2015
Accepted 6 April 2015
Available online 17 May 2015

Keywords:
Freight forecasting
Demand model
Temporal assignment
Firm simulation
Economic order quantity
Supply chain networks

ABSTRACT

In the aggregate freight demand modeling literature, temporal assignment (annual to daily flows) is often oversimplified or neglected altogether. Unlike passenger flows, freight flows over the course of a year are not uniform and can vary significantly as the result of trade-offs between inventory and transportation cost management. We introduce the first temporal assignment model that explicitly considers these trade-offs for aggregate freight forecasting. A two-stage model is proposed that first decomposes aggregate annual zonal flows to firm group annual flows using a supply chain network model, which are then temporally assigned by simulating purchase order transactions throughout supply chains. Lot sizes are estimated with an Economic Order Quantity (EOQ) model and calibrated with monthly inventory data. The result is an aggregate-disaggregate-aggregate model that fits into aggregate freight forecasting models but makes use of more disaggregate logistical data. The model is illustrated with a simple replicable example, followed by a case study conducted with California statewide data to break out the distributed zonal flows into average daily volumes for network assignment. Calibration results using 2007 IMPLAN data showed a median percentage difference of simulated annual flows from FAF^3 data of 2.38%, and a median percentage difference of simulated inventories from IMPLAN data of 4.85%, which suggests an excellent fit. Empirical validation results showed the model outperforms fixed factor approaches in mean value accuracy by 15–31%.

1. Introduction

Public freight infrastructure planning poses a number of challenges that differ from logistics planning by individual firms, or public infrastructure planning for travelers and commuters, which are discussed in Chow et al. (2010) and a number of other studies cited therein. Liedtke and Friedrich (2012) discuss this issue as one of logistics network planning belonging to the decision-objects of a firm, while the physical transport networks belong in the domain of the public authorities. The consequence is that data tends to be limited and aggregate, which in turn leads to forecasting models in practice (NCHRP 606, 2008) that do not adequately capture the logistical trade-offs made by individual firms. Hesse and Rodrigue (2004) give an excellent overview of the relationship between logistics decisions and the interactions with the public domain. To be clear, there are many freight forecasting models that cover different aspects, from commodity flows to

* Corresponding author.
E-mail address: zhaomiyuan@gmail.com (M. Zhao).

http://dx.doi.org/10.1016/j.tre.2015.04.001
1366-5545/

transshipment activities and mode choice with shipper and carrier interactions. We are interested primarily in models directly related to forecasts of vehicle flows from commodity flows for the purpose of infrastructure planning and related policies.

The lack of logistical sensitivity appears to be addressable by incorporating the logistics decisions of individual firms into the freight forecasting models. Attempts have been made to model the individual choices of firms (e.g. Wisetjindawat, 2006; de Jong and Ben-Akiva, 2007; Donnelly, 2009; Samimi, 2011) or the interactions between them (e.g. Friedrich, 2010; Gong and Guo, 2011; Holmgren et al., 2012; Schroeder et al., 2012). These studies apply hybrids of commodity-based models and vehicle-based models at the firm level using proprietary collected survey data. These studies have been reviewed in several survey papers (Chow et al., 2010; Tavasszy et al., 2012; Liedtke and Friedrich, 2012). However, most practitioners in the US have not embraced these models due to data unavailability.

As a consequence, aggregate freight demand models have become the most common one used by practitioners. Their classic structure is based on the principles of traditional four-step passenger transport modeling. Freight demand models in practice (Tavasszy, 2006; Beagan et al., 2007; NCHRP 606, 2008) feature trip generation, trip distribution, mode choice, and assignment model components. The assignment component includes two dimensions: a temporal assignment where annual commodity OD flows are converted to daily and peak period truck trips, and a spatial assignment that determines the truck routes in the physical transportation network. Most states and metropolitan planning organizations in the U.S. that have freight forecast models make use of these practical approaches (Ranaiefar et al., 2014).

Like passenger forecasting models, freight forecasting models tend to focus more on spatial assignment than on temporal assignment or allocation. Fixed temporal factors are common in passenger transportation planning; for example, design hour volumes may be proportioned from annual average daily traffic (AADT) volumes. In passenger models, peak commuter travel patterns are repetitive across different days in the year and fall within relatively well-defined and short spatial ranges. Long haul freight, however, involves decisions that affect much broader geographies and temporal landscapes. There is much more consideration of trade-offs made in time or seasonal effects. For example, Burns et al. (1985) illustrates the holistic view that firms need to adopt in managing their costs; transportation costs can be decreased by making fewer trips (movement of goods over space), but it may come at the expense of increases in inventory costs (storage of goods over time). This fundamental trade-off between space (transportation) and time (inventory) is central to freight decision-making. However, few aggregate models have considered the temporal assignment component (see discussion by Holguín-Veras et al., 2011) despite the increasing realization that decisions of firms depend on temporal and seasonal variations (Beagan et al., 2007). Such space–time tradeoffs can aid in quantifying policy impacts such as different land uses on monthly truck distributions or the impact of rising fuel costs on shipment frequency and warehousing needs. To the best of our knowledge, no research has been conducted on policy sensitive *temporal assignment* methods for aggregate commodity-based freight models.

We propose a novel temporal freight assignment model (from annual flows to daily flows) that is grounded in the central trade-offs between transportation and inventory costs present in firm logistics. This is accomplished by first assigning the annual flows to individual firms or groups of homogeneous firms (for cases where computational tractability is an issue) under an assumption of a supply chain network optimum. The resulting firm-level flows are then allocated temporally under a simulation framework based on randomly arriving purchase orders throughout the year and an optimal production quantity policy held by each firm or firm group. Calibration and validation are conducted with public data on monthly inventories held. The freight temporal assignment model is thus in line with the aggregate-disaggregate-aggregate (ADA) concept proposed by Ben-Akiva and de Jong (2008), where disaggregate methods are used to assign aggregate annual flows to aggregate daily flows. Unlike other existing firm-based microsimulation models (e.g. Donnelly, 2009; Samimi, 2011) that seek to replace the whole freight forecasting process, the proposed model only requires disaggregate data for temporal assignment and can work alongside aggregate models in practice as an add-on. As such, it has a much lower data burden than holistic firm microsimulation models, and can be easily integrated into existing aggregate models to consider inventory-transportation trade-offs.

The paper is organized as follows. Section 2 presents a literature review of supply chain and spatial network equilibria, economic order quantities, and firm-based microsimulation. Section 3 introduces the proposed model. Section 4 includes a validation of the model with data from California. Section 5 discusses potential use cases of our model in goods movement analysis.

2. Literature review

State-of-the-practice models typically use fixed factors for temporal assignment. The NCHRP 606 (2008) suggests using a factor of 1/306 to derive weekday traffic. This fixed factor approach cannot represent the temporal variability of commodity flows nor their dependence on logistical factors. For example, decreased fuel cost will likely increase the annual flows by a certain amount. At the same time, the decreased fuel cost will change firms' daily cost functions and their logistics decisions regarding supplier, shipment size, inventory quantities, etc.