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A time-dependent freight tour synthesis model

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ABSTRACT

This paper introduces a model of urban freight demand that seeks to estimate tour flows from secondary data sources e.g., traffic counts, to bypass the need for expensive surveys. The model discussed in this paper, referred as Freight Tour Synthesis (FTS), enhances current techniques by incorporating the time-dependent tour-based behavior of freight vehicles, and the decision maker's (e.g., metropolitan planning agency planner) preferences for different sources of information. The model, based on entropy maximization theory, estimates the most likely set of tour flows, given a set of freight trip generation estimates, a set of traffic counts per time interval, and total freight transportation cost in the network. The type of inputs used allows the assessment of changes in infrastructure, policy and land use. The ability of the model to replicate actual values is assessed using the Denver Region (CO) as a case study.

1. Introduction

Due to the globalization process that has defined the world economy in the last several decades, most of the goods consumed in urban areas are produced miles from where they are consumed. The proliferation of commercial transactions between regions has allowed communities with some resource shortage to obtain it through exchange relationships with some other communities that have a surplus of this resource. These exchange relationships have enhanced economic development because, when two such communities are joined by trade, scarcities that were local to one or the other no longer have to be limiting (Catton, 1982). This "scope-enlargement" explains why freight transportation is intrinsic to economic development. In essence, vibrant economies require good transportation systems. The freight traffic observed in urban areas is a complex mix of different layers of economic interactions: flows of products from producing regions outside the urban area; local distribution of supplies; cargo flows between the manufacturers located in the metropolitan area; and the cargo that comes through, and is distributed from, international gateways such as ports and airports. Analyzing such an intricate web of goods movements is made more complicated by the fact that the goods are not transported directly from the primary source to retail stores, as there are intermediary processes to consider. For instance, goods can be produced in manufacturing districts, or transported to distribution centers, stored in warehouses, or transported elsewhere for further processing. Although the dynamics driving freight demand are not fully understood, planning agencies use models to replicate the distribution processes to identify infrastructure needs, manage travel demand, and formulate policies aimed at improving distribution efficiency.

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One of the most important input data in transportation planning are Origin–Destination (OD) matrices, as they capture travel patterns, such as origin and destination of cargo and/or freight trips, their geographical distribution and their linkages to travel impedance. Traditionally, these matrices are obtained through primary data collection efforts such as surveys, and then used to calibrate trip distribution models. Although the large costs associated with primary data collection—$10 million for a city like New York (Holguín-Veras et al., 2010)—have deterred transportation agencies from conducting large scale data collection efforts, the rise of technology in the last decades has brought to the scene ready-to-use data from secondary sources, such as traffic counts, and with it a new generation of models often referred as Origin Destination Synthesis (ODS).

The fundamental objective of ODS models is to produce trip matrices using secondary data such as traffic counts as the key input. The ODS problem is, mathematically, underspecified because the number of independent traffic counts is generally smaller than the number of OD pairs which are the unknowns. The problem can be solved using two main approaches: structured approaches and unstructured approaches (Willumsen, 1978; Ortúzar and Willumsen, 2011). Structured approaches restrict the feasible space by imposing a model structure, such as a gravity model, on the OD flows, and estimate the best parameters subject to traffic counts constraints. The main limitation of this approach is that by imposing a model structure, some information contained in the traffic counts is lost (Van Zuylen and Willumsen, 1980). In contrast, unstructured approaches seek to find a unique solution based on the traffic counts by introducing the minimum external information. The most common techniques are maximum likelihood, information minimization and entropy maximization.

Freight ODS models are called to play an important role in the development of urban freight demand models, as they have a great potential to model urban freight flows while complying with the budget restrictions of freight planning. The experience with passenger ODS models suggests their potential to identify critical infrastructure needs, evaluate performance measures, assess freight related policies, cross-check and/or update old OD matrices, and develop urban freight demand models, among others (Willumsen, 1978; Ortúzar and Willumsen, 2011). However, the vast majority of the freight ODS tend to replicate the efforts made on the passenger side without considering the particularities of goods movements' patterns. The main goal of this paper is to help address this situation.

This paper focuses on a more general version of the traditional freight ODS problem. Here, instead of simply estimating the freight vehicle flows from an origin to a destination, the model estimates the freight vehicle flows that traverse a sequence of pick-up and delivery stops. The model is referred to as Freight Tour Synthesis (FTS) model. It is important to distinguish FTS from freight ODS because they are not equivalent. While the output of freight ODS can be conveniently mapped into a two dimensional matrix, the output of FTS cannot. Essentially, it is incorrect to refer to FTS as a case of freight ODS. In fact, freight ODS is a particular case of FTS when all tours only have one stop. The model discussed in this paper follows similar principles to ODS but incorporates two key aspects of urban goods distribution: the temporality of flows and the tour-based behavior of freight vehicles.

Temporal effects are an important aspect of freight activity. The dynamic nature of urban freight transportation involves variations according to the season, the day of the week, and the hours within the day. The latter is of great importance to this paper. The fluctuation of demand over the day, as opposed to the static nature of supply, is the source of inefficiencies in transportation systems. In general, infrastructure systems are underutilized most of the day and overwhelmed during the peak hours. Variations of demand and the corresponding traffic impacts throughout the day are, therefore, key information for efficient infrastructure decision-making and demand management strategies. This temporal aspect introduces both challenges and opportunities for modeling, as considering temporal effects leads to complex models that require larger amounts of data, though the more realistic models could lead to better forecasts.

In urban areas, the distribution of goods requires complex delivery/pick-up tours that could have dozens of stops, as in the case of parcel deliveries. This reflects the fact that it is generally inefficient for suppliers to assign one vehicle to each delivery; using delivery tours is preferable when shipment sizes are small in relation to the capacity of the truck. Not surprisingly, the available data indicate that more than 80% of urban deliveries are made as part of tours with multiple stops that, depending on the city, could average from 1.80 stops/tour (Schiedam, The Netherlands) (Vleugel and Janic, 2004) to 15.70 stops/tour (New York City, USA) (Holguín-Veras et al., 2006). The large number of stops of urban freight vehicles has important modeling implications. Modeling urban freight demand with the assumption that the individual trips in a tour are independent will inevitably produce major errors, and increase the risk of erroneous investment and policy decisions. First, the behavioral determinants that drive the tour formation process are ultimately related to routing efficiency considerations. Decomposing tours into individual trips destroys any possibility of capturing these effects. Second, assuming separate trips unavoidably forces the model to assume that the trip's explanatory variables are related to the trip's origin and destination. This is erroneous because, in reality, the physical origins and destinations of the individual trips are the result of a logistical decision that is unrelated to the generation of the flow of the cargo.

In order to help fill this void, this paper proposes an urban FTS model that explicitly considers freight vehicle tours and time-dependent effects. The paper is organized in six sections in addition to the introduction: Section 2 reviews the literature related to tour models and freight ODS models. Section 3 describes the methodology and the mathematical derivations; while Section 4 presents the application of multi-attribute value functions to the Time-Dependent Freight Tour Synthesis (TD-FTS) model. Section 5 describes the application of the model, and Section 6 presents the results obtained from the application of the FTS model to the Denver Region. Section 7 summarizes the conclusions of the paper.