



# A conceptual framework for agent-based modelling of logistics services

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## ABSTRACT

This paper presents an agent-based microsimulation framework that represents the diversity of roles and functions of actors in the freight system, how they interact through markets and how interactions between actors are established in markets through contracts. The framework provides sensitivity to technology trends, business trends, and policy scenarios. Logistics costs, outsourcing of logistics services to third party logistics firms, growth or retraction of various industry sectors, and the impact of new supply channels are explicitly represented. Data sources available in Toronto, Canada and new data collection efforts required for model estimation are described.

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## 1. Introduction

Over the past few decades, freight transportation modelling has been approached from a variety of perspectives. Supply chain management and operations research approaches have been developed with the purpose of improving the efficiency of the business operations for single firms or groups of firms (see Meixell and Gargeya, 2005; Crainic and Laporte, 1997 for good reviews). Models for public sector decision making have been developed in order to assess infrastructure improvements, land use alternatives, and other transportation policies such as road pricing (see TRB (2008) for a recent review of the current state of practice and future directions). Conventional approaches include three, or four stage modelling approaches (e.g. Pendyala et al., 2000; Cambridge Systematics, 1996) and commodity based approaches (e.g. Cambridge Systematics, 1998; Fischer et al., 2000). These approaches have, to a large degree, been modelled upon methods developed for passenger travel demand forecasting, even though there are fundamental differences between passenger travel and freight travel.

More recently, a small number of hybrid models have been developed to attempt to incorporate behavioural elements of supply chain management and logistics chains into public sector decision making models (Hunt and Stefan, 2007; Fischer et al., 2005; Boerkamps et al., 2000; Wisetjindawat et al., 2007; de Jong and Ben-Akiva, 2007; Wang and Holguin-Veras, 2008; Yin et al., 2005; Tavasszy et al., 1998; Liedtke, 2006; Bovenkerk, 2005). Hybrid models can recognize that:

First, *there are diverse actors* involved in the production and distribution of goods, none of which may have full control or even knowledge of all decisions made throughout the supply chain. A single actor within the supply chain may be specialized in one component of the supply chain (e.g. a small carrier may only provide direct transportation services), may provide a suite of logistics services (e.g. consolidation, warehousing, transportation, distribution, inventory management), or may play roles in both production and distribution (e.g. a manufacturing firm with a private delivery fleet).

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Second, *the interactions between firms are diverse*. Successful supply chains increasingly involve long-term alliances between suppliers, manufacturers, retailers, carriers and 3rd party logistics firms. Other companies operate through spot markets for transportation services. The prices and the level of service vary depending on the type of relationship that is maintained between these business establishments.

Third, *business models are changing over time*, including shifts in business operation towards lower levels of inventory, just in time delivery, and a business environment that is increasingly driven by customer orders (pull logistics). For many commodities order sizes are decreasing to accommodate customer demands for fast delivery. Globalization of trade has also increased, driven by reductions in the cost of transportation and geographical differences in resources, wage rates and production costs.

Understanding and representing the roles that each actor plays in the freight transportation system, the interactions between those actors, and changes in the actors and their interactions over time are of fundamental importance in the development of more behavioural public sector models of the freight system.

This paper presents an agent-based microsimulation framework that explicitly represents the diversity of roles and functions that business establishments play, how they interact through markets and how both long and short term interactions between business establishments are established in the market through contracts. The paper provides a framework only, and no specific application of the framework is presented.

The framework is developed with the intention of providing a consistent modelling philosophy and a consistent degree of granularity with the ILUTE (Integrated Land Use Transportation Environment) modelling framework developed for the Toronto Area (Miller and Salvini, 2001; Salvini and Miller, 2005). The ILUTE model is an agent-based microsimulation model of passenger activities and travel, which represents individual households, families, persons, and jobs, dwellings, etc. Designing compatible modelling systems from the outset will facilitate the eventual development of a fully integrated urban model of both passenger and freight activities and transportation (i.e. jobs modelled in the passenger system are consistent with labour requirements in the freight production system, commercial vehicle travel times are consistent with passenger vehicle flows, shopping trips are consistent with retail business establishment shipments, etc.).

This paper is organized as follows. First, a literature review of other attempts to model the freight logistics system is provided. The conceptual framework is then presented, beginning with a definition of the actors (decision-makers), their attributes, functions and relationships. Following that, the other key model components are defined/formulated, including contracts, shipments, markets and logistics chains. The model's temporal resolution is then presented with consideration given to the variety of decisions that are made over various time frames. The paper provides a plan for implementation, including potential data sources for estimation, and then concludes with a discussion of the potential for this modelling framework to address specific policy questions.

## 2. Literature review

There is growing recognition that freight demand models need to better represent logistics and supply chains and to estimate changes in the economy resulting from the implementation of different policies (Hensher and Figliozzi, 2007). In the realm of household travel modelling, it has been recognized for some time that microsimulation approaches are appropriate to explicitly model various aspects of choice behaviour, to provide explicit representation of tours, and to include specific constraints acting at the individual level (e.g. Arentze and Timmermans, 2005; Bhat et al., 2004; Davidson et al., 2007; Miller and Roorda, 2003). Only more recently have a small number of freight microsimulation models been developed, with applications in urban areas (Boerkamps et al., 2000; Wisetjindawat et al., 2007; Hunt and Stefan, 2007; Wang and Holguin-Veras, 2008; Liedtke, 2006) and in regional/national areas (de Jong and Ben-Akiva, 2007; Ming et al., 2007).

The first attempt to incorporate logistics decisions using a disaggregated approach occurred during the 1970s and early 1980s with inventory-based (otherwise called inventory theoretic) models (Winston, 1983). These models try to incorporate variables related to production, such as shipment size and frequency of shipment, using a profit function that can represent inventory costs. McFadden and Winston (1985) presented another early model that tried to identify the shipment size, mode, and shipping interval that maximize the present discounted value of profit subject to the inventory behaviour.

More recently, Boerkamps et al. (2000) present a conceptual framework, called the GoodTrip model, consisting of actors, markets, and supply chain elements of urban freight movement. This conceptual framework models components of freight movement that are intraconnected by four markets (commodity, transport services, traffic services, and infrastructure markets). Actors are classified in three roles: shipper, transporter and receiver. The origins/destinations of goods flows are estimated first, based on the location of end user (consumer) demand, the average consumer expenditure on each commodity, the location of commodity production companies and the logistical chain. Goods flows are then combined according to the type of commodity, using groupage probabilities, and assigned to vehicle tours. The tours per mode are then assigned to their infrastructure networks. This model is applied for the city of Groningen, Netherlands.

Wisetjindawat et al. (2007) present a microsimulation model for the Tokyo Metropolitan Area. The model is composed of four main stages: (1) commodity generation (production and consumption); (2) commodity distribution; (3) conversion of commodity flows to truck flows; and (4) traffic assignment. The model generates the attributes of each individual firm using Monte Carlo simulation. The four stages are developed using the following procedures:

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