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Is on-demand same day package delivery service green?

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ABSTRACT

In light of the rapid development in the e-commerce sector and the increasingly popular demand for same day delivery, this study evaluates the performance of an on-demand same day delivery (SDD) paradigm in terms of its transportation time cost, fuel cost, and emission cost. The performance is further evaluated by comparing among three delivery paradigms: hub-and-spoke, SDD with a commercial fleet, and SDD by crowdsourcing. Among the three service paradigms compared, hub-and-spoke proves to be cost-effective for the traditional distribution service provided by commercial carriers but ill-suited for providing same day delivery service. Commercial carriers are facing tremendous pressure in the era when same-day delivery service is increasingly expected. Crowdsourcing is a promising solution to providing low cost same day delivery service. Lastly, regardless of the delivery paradigm, the total cost goes down as the economy of scale increases; and SDD by crowdsourcing would become even more competitive when the demand ratio is very high; however, its fuel consumption and emissions tend to go up due to the additional vehicle detours to accommodate real time demand.

1. Motivation and significance

Traditional truck delivery services are typically categorized, based on the distribution paradigm between suppliers and customers, as direct shipment, hub-and-spoke and some hybrid form of hub-and-spoke. A hub-and-spoke distribution paradigm is characterized by an organizational structure in which the spokes cover an area with a specific collection of delivery points, and are connected by at least one transshipment center, or hub (Zäpfel and Wasner, 2002). Coordination of logistic flows is achieved by transferring the shipments from one spoke to another through the transshipment center. Different from the hub-and-spoke paradigm, in a direct shipment paradigm each supplier operates independently with its own fleet delivering goods to customers, without the need of going through a central hub (Liu et al., 2003). A hybrid hub-and-spoke can be viewed as a hub-and spoke system that allows some orders to be directly shipped whenever beneficial without going through the hub. In the hybrid system, different delivery modes may be used for different shipments depending on the quantity to be shipped and geographical locations of the supplier and the customer.

Direct shipment has the advantage of short delivery distance and quick service response, but risks losing economies of scale when the origin-destination cargo flow does not sustain the truck load capacity. That translates into high operation cost, and a high risk of partial loss of goods values (Chen et al., 2012; Lin et al., 2016). Overcoming the above disadvantages, the hub-and-spoke paradigm takes advantage of the economies of scale in vehicle utilization. Suppliers can provide a high

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frequency of delivery (and thus improved service quality) by combining the demands or orders of many customers (Elhedhli and Hu, 2005), compared to the direct shipment paradigm. However, the fact that cargos must pass through the hub before reaching the destinations incurs higher vehicle miles traveled (VMT), longer delay, and slower service than that in direct shipment. Furthermore, the total cargo capacity of the network is limited by the hub's capacity.

The rise of e-commerce is rapidly changing the landscape of retail business as well as package delivery service. By 2017, online sales will account for more than 10% of the $4.5 trillion industry, according to a 2014 U.S. Census Bureau report (USCB, 2014). As consumers get used to the notion of "delivery" as an integral part of the shopping experience and service, retailers are under enormous pressure to meet this expectation in order to stay competitive. Large asset-based carriers (e.g., UPS and FedEx) are not particularly well suited for express local deliveries in an urban setting, primarily because their "hub-and-spoke" distribution networks are designed to transport through hubs rather than directly between shippers and receivers (Pohl, 2013). This inherent inefficiency is worsened by mounting demand for same-day delivery – widely considered the Holy Grail for e-commerce at present – that requires more frequent dispatch and in turn increases transportation cost. Recent arrival of tech giants such as Amazon (Bensinger and Dulaney, 2014), Google (Womack, 2014) and Uber (Milian, 2014) in this battlefield attests to the tremendous opportunities and challenges in the urban delivery industry.

In recent years rapid advances in wireless communication and ubiquitous mobile computing (e.g., Bensinger and Dulaney, 2014; Womack, 2014), are enabling better match of demand and supply in freight and making more efficient use of the otherwise unutilized or underutilized vehicle capacities in delivery services, much like what Uber has accomplished for passenger travel. Moreover, the advances in information technology may facilitate fast, flexible online services to real-time customer demand, making pickup and delivery services cheaper, faster, and more convenient to customers. Examples are Amazon's Prime same-day delivery, Amazon's PrimeNow one-hour delivery, and expedited delivery through crowdsourcing (e.g., Instacart, Postmates, Deliv, Roadie, and Sidecar). E-commerce giants Amazon and Alibaba are experimenting delivery with drone (Lapowsky, 2015; Riley, 2015). All of these new delivery services aim at providing expedited service to meet customers' expectation and needs.

In particular, crowdsourcing (Howe, 2006) has been seen as a promising solution to the increasing on-demand urban delivery service (Chen and Pan, 2015; Paloheimo et al., 2015). Crowdsourcing is a concept coined around the notion that a business can outsource certain functions to the crowd (Howe, 2006). Crowdsourced delivery utilizes personal vehicles to deliver packages to residents and/or business. It provides an effective way of matching demand (orders) and supply (vehicle capacity) and thus improving transportation efficiency (Bocken et al., 2014). Crowdsourcing also has the potential to make expedited delivery service cheaper and faster for its flexibility and low cost.

To this end, this study focuses on the same-day urban delivery service for small to medium size packages and attempts to achieve the following objectives. First, the study formulates and solves for an optimal on-demand same-day delivery (SDD) strategy that minimizes the sum of transportation time cost, fuel cost, and emissions cost. Second, the proposed on-demand SDD paradigm is compared with the traditional hub-and-spoke paradigm. This study will further differentiate two types of SDD, i.e., SDD with a commercial fleet (in other words the SDD service is provided by a commercial carrier), and SDD by crowdsourcing.

The performance metrics considered in this study consist of transportation time cost, fuel cost, and vehicular emission cost. In particular, we consider the joint effect of vehicle speed and load on energy consumption and emissions. Vehicle load is in turn affected by the customer demand (quantity and type – delivery or pickup) and the visiting order (Chen and Lin, 2014; Zhou et al., 2015). Vehicle speed in this study is time-dependent and varies over the course of vehicle daily operation. To our best knowledge, this is the first cost evaluation study of on-demand SDD.

The rest of the paper is structured as follows. Section 2 describes the research methodology and a proposed cost model for an on-demand SDD. Section 3 has two parts: the first part evaluates the relative importance of fuel and emission costs in the overall cost performance of the proposed SDD strategy; the second part consists of a performance comparison among hub-and-spoke, SDD with a commercial fleet, and SDD by crowdsourcing. Further discussion on the implications of SDD and crowdsourcing to the local economy, transportation network performance, and the environment is presented in Section 4. Lastly, conclusions and future research are given in Section 5.

2. Methodology

2.1. Problem definition

This study is set out to quantify and compare the service performance of three urban delivery paradigms – hub-and-spoke, SDD with a commercial fleet, and SDD by crowdsourcing. Service performance metrics considered in this study are transportation time cost, energy cost, and emission cost.

First, this study considers an on-demand delivery service setting (i.e., demand scenario). It is described as follows.

2.1.1. Demand scenario

This study considers a demand scenario that consists of two types of demand: (1) a base customer demand set **R** that is static and constant with known quantities, pickup and delivery location, and customer preference (e.g., time window, same-day delivery) in advance, and thus their services (pickup and/or delivery) are pre-scheduled, and (2) a floating demand set **R'**

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