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Designing logistics systems for home delivery in densely populated urban areas

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ABSTRACT

To deliver to customers in densely populated urban areas, companies often employ a two-echelon logistics system. In a two-echelon logistics system, the starting point for goods to be delivered in the urban area is a fulfillment center or city distribution center. From there, the goods are first transported to a satellite, from where they are delivered to their final destinations. To simplify operations, companies, in practice, often restrict the route choices at one or both of the echelons. We study the impact on the delivery cost of such restrictions and conclude that when the number of orders to be delivered is large and the location density of delivery addresses is high, the impact is likely to be small, and the operational benefits probably outweigh the cost increases. To more easily accommodate delivery volume growth and to more effectively handle day-to-day delivery volume variations, we introduce a simple aggregation concept, which leads to quality improvements without affecting operational simplicity. We provide further insight by means of a worst-case analysis for specific geographic topologies.

1. Introduction

In the United Nations report “World Urbanization Prospects – The 2014 Revision” (https://esa.un.org/unpd/wup/), it is observed that, at the time of writing the report, 54% of the world’s population is living in urban areas and that that proportion will continue to increase. The authors of the report also predict the continuing growth in the number of megacities, i.e., cities with a population of more than 10 million, from 28 in 2014 to 41 in 2030. Most future megacities are expected to develop in emerging economies with high population densities (Blanco and Fransoo, 2013). As a consequence, there is an increasing interest and focus on transportation and logistics problems in urban areas and megacities (e.g., Mahmoudi and Zhou, 2016; Franceschetti et al., 2017; Li et al., 2018).

At the same time, business-to-consumer (B2C) e-commerce is rapidly expanding worldwide. The B2C transaction volume in China, for example, has grown from 0.2 trillion RMB in 2011 to 2.6 trillion RMB in 2016 (iResearch, 2017), and e-commerce packages accounted for over 60% of the total express delivery volume in 2016 (State Post Bureau of P. R. China, 2017a). Daily, an average of 327.2 and 1124.5 packages per square kilometer were delivered to customers in Beijing and Shanghai, respectively, in 2016 (State Post Bureau of P. R. China, 2017b).

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Furthermore, to satisfy customers' desire for instant gratification, major B2C e-commerce companies compete on delivery speed. For example, JD.com guarantees that orders placed by 11 a.m. will be delivered the same day, and orders placed by 11 p.m. will be delivered by 3 p.m. the next day.

To efficiently deliver to customers living in densely populated urban areas, companies often employ a two-echelon logistics system. In a two-echelon logistics system, the starting point for goods to be delivered in the urban area is a fulfillment center or city distribution center (CDC). From there, the goods are transported to a satellite, from where they are delivered to their final destination. Typically, large vehicles are used for the transportation of goods from a CDC to a satellite, and small vehicles are used for the transportation of goods from a satellite to customers. More and more, the vehicles used to make last-mile deliveries are environmentally friendly, such as electric cars or electric tricycles. Such two-echelon logistics systems control inventory holding costs through pooling and transportation costs through consolidation (at the first echelon).

The academic community has started to study two-echelon delivery systems as well, which has resulted in a growing, but at the moment still small, body of literature on the so-called two-echelon vehicle routing problem (2E-VRP), e.g., Crainic et al. (2009) and Hemmelmayr et al. (2012), with a focus on developing effective and efficient algorithms. Unfortunately, the size of the instances that can be handled by these algorithms is orders of magnitudes smaller than the sizes encountered in real-life settings, in terms of the number of orders that needs to be delivered (recall that more than 1000 packages per square kilometer have to be delivered in Shanghai every day). Furthermore, due to the aggressive service levels offered, companies have little time to decide on delivery routes.

Our focus, therefore, is different. We explore the positives and negatives of employing a two-echelon logistics system in which the route choices at the second echelon are restricted. The advantage of restricting route choices is that it results in operational simplicity. The potential disadvantage is that it results in an increase in costs. Our study is inspired by the two-echelon logistics system employed by companies providing home delivery services in urban areas in China (e.g., Amazon China, JD.com, SF Express). More specifically, the two-echelon logistics system investigated has a single CDC, divides the coverage area into regions, each with a satellite, and divides each region into cells, each served by a single driver. The drivers themselves decide the (single) route that they will use to deliver the orders in their cell. A similar system of dividing a large delivery area into regions has recently been introduced in German cities (e.g., Hamburg, Frankfurt, and Nuremberg) by UPS and DPD using so-called *micro-depots*, where each micro-depot serves a designated region (DPD, 2016).

Fig. 1 illustrates parts of the region and cell design in Beijing and regions in Hamburg. Note that the design of regions and cells is typically governed by physical practical constraints, e.g., geographical barriers (rivers, roads), administrative boundaries, and residential communities.

We observe that once the regions and the cells have been defined, managing the delivery system is straightforward. All that needs to be done is determining how to supply the satellites, which corresponds to solving a small – since the number of satellites is usually small – split delivery vehicle routing problem. When the packages to be delivered arrive at a satellite, they are simply handed to the drivers responsible for the cell that contains delivery location of a package. This operational simplicity has significant advantages in practice, and, we will show, does not have to result in a huge increase in costs, especially when the number of orders that needs to be delivered is large and the location density of the delivery addresses is high.

Recognizing that operational simplicity in a two-echelon logistics system can be realized in different ways, it is important to investigate and analyze the various design choices. We take initial steps in that direction. We focus on rethinking and expanding the concept of cells, as it only involves operational changes. Increasing the number of regions, for example, necessitates increasing the number of satellites, which may not be easy in densely populated urban areas where space is limited and expensive. (Changing region boundaries, on the other hand, would only involve operational changes.) Our focus on rethinking and expanding the concept of cells is also motivated by the need to handle daily variations, i.e., day-to-day variations in the number of deliveries in a cell, and the desire to be able to accommodate growth, i.e., an increase in the number of daily deliveries.

We extend the concept of a cell by introducing the concept of a *block*. A block is a group of cells to be served by a small set of drivers. The introduction of blocks adds very little operational complexity as all that needs to be done is dividing the deliveries in a block over the drivers assigned to the block, which can be done, for example, by a simple geographic partition of the area that balances the workload of the drivers assigned to the block.

In summary, our research contributes to the existing literature in the following ways:

- We analyze the performance of urban delivery systems designed for operational simplicity, numerically and analytically, in order to demonstrate that such systems are not only practical, i.e., can easily handle the large numbers of delivery orders encountered in real-life settings, but also highly effective and therefore an excellent choice for home delivery in densely populated urban areas. We conduct an extensive computational study that demonstrates that urban delivery systems designed for operational simplicity have excellent performance when the number of orders that needs to be delivered is sufficiently large and the location density of the delivery addresses is sufficiently high.
- We show that the introduction of blocks in an urban delivery system designed for operational simplicity allows such a system to cost-effectively handle day-to-day variations in delivery volumes and to accommodating (moderate) growth thereby avoiding the need to redesign the system too often.
- We show that urban delivery systems designed for operational simplicity can have other fortuitous benefits, e.g., they can automatically provide workload balance.