Joint Parcel Routing and Containerized Consolidation

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1. Introduction

The high-velocity flow of small-size goods from many origins to many destinations inherent to last-mile logistics encourages hub-based network structures for better consolidation and economies of scale. However, sorting large number of parcels at hubs can require considerable investment in real estate, human and machine resources. It can also add significant waiting and processing time to the time a parcel spends in the system. As such, unlike long-haul transportation, travel time is often not the dominant part of the time a parcel spends in a last-mile delivery. In fact, waiting and processing times at hubs can prevent faster service offerings. Therefore, finding ways for parcels to bypass the sorting process at hubs is expected to result in significant time and cost savings. Containerization is one such way.

In this study, we investigate the potential of joint parcel routing and containerized consolidation for reducing sorting requirements at hubs and for reducing the time parcels spend in the last mile logistic network. We refer to parcels with a common origin hub, destination hub, and service promise as a commodity, where service promise refers to the maximum time a parcel is allowed to spend in the system. Parcel routing and containerization decisions have to be considered simultaneously. On the one hand, the path of a commodity through the network impacts the potential level of consolidation. On the other hand, seeking a desired level of consolidation may require adjusting the routing decisions. Therefore, we investigate the joint planning of parcel routing and containerized consolidation and its potential savings in terms of transportation, and sorting and crossdocking time in last-mile logistics systems.

2. Literature Review

Assignment of shipping items to paths and consolidating them into containers (potentially of varying sizes and costs) is referred as Freight Consolidation and Containerization Problem (FCCP) in the literature. This problem was first addressed in 2004 by Chayanupatkul and Hall in a project for USC METRANS transportation center. They studied package routing for long haul flight shipments while accounting for containerization, aimed at minimizing transportation and sorting costs (Chayanupatkul, Hall, and Epstein (2004)).

To the best of authors knowledge, there was no further research on this problem until 2014, when Qin et al. studied the FCCP faced by a 3PL company shipping textiles from a warehouse in China to different retail stores in the US. Their goal was to minimize the total container transportation and parcel delivery costs in the underlying hub-and-spoke logistic network (Qin et al. (2014)). Their work initiated further research on scalability of the FCCP through breaking solution symmetry or exploiting heuristic approaches (Melo and Ribeiro (2015), Hanbazazah et al. (2019a,b)).

This study is differentiated from the existing literature in several ways. First, all previous research in FCCP literature concern long-haul transportation logistics. Most long-haul transportation shipments rely on sparse hub-and-spoke network structures with few inter-nodal links. Such a structure offers few alternative paths for shipping origin-destination flows. In this work, we focus on last-mile logistics whose relatively shorter origin-destination distances encourage denser network setups and a larger set of possible shipping paths per commodity. Second, we address multi-stop vehicle routes which are common practice in last-mile delivery. This feature, which has not received enough attention in the literature, has significant impact when it comes to transportation capacity limits. Finally, we explore the impact of containerized consolidation on different network setups with different levels of vertical and horizontal inter-nodal connectivity.

3. Methodology and Preliminary Results

Our goal is to determine an origin-destination path for each commodity, so that the total time commodities spend in the system is minimized, including travel, sorting, and crossdocking times. The paths have to respect the service promises as well as the sorting and crossdocking capacities at the hubs. We assume that commodities are indivisible, i.e., we seek a single origin-destination path for each commodity.

A path-based integer program (IP) formulation is developed to model the parcel routing and containerized consolidation problem. The set of feasible paths for each commodity is generated in a pre-processing stage and fed to the model. Generated paths are limited in terms of the number of intermediate hubs and maximum deviation from the shortest (time) path. In order to capture containerization potential when making routing decisions, we consider a network with two types

of arcs: (1) *physical arcs* and (2) *container arcs*. A physical arc represents a connection (road) along which a commodity can be transported from one hub to another. A container arc represents a sequence of physical arcs along which a commodity can be transported without sorting at intermediate hubs, i.e., the commodity is assumed to travel in a container that is crossdocked at intermediate facilities (sorting only takes place at the first and the last hub).

The IP model chooses a path for each commodity consisting of a sequence of container arcs. Since each container arc is associated with a unique sequence of physical arcs, the chosen path defines not only the path of physical arcs but also the handling occurring at the hubs along the path: (1) unload, sort, and load, (2) unload, crossdock, and load, and (3) leave in the truck. The IP model seeks to select paths that minimize the total time commodities spend in the system while respecting hub sorting and crossdocking capacities, and transport capacities.

We conducted two preliminary experiments using the IP model to assess the benefits of containerization. The first experiment investigates the impact on containerization of the structure of the allowed paths (the number of intermediate hubs and their length) and the ratio of sorting and crossdocking time for a network with 16 hubs, 46 physical arcs, and 50 commodities. Numerical results show that when the ratio of sorting time to crossdocking time increases, the savings through joint routing and consolidation also increases. For some instances, up to 15 percent savings are observed. Moreover, for a given ratio of sorting and crossdocking time, allowing longer paths for commodities only marginally improves the savings.

In the second experiment, we study and compare the savings of containerization for three different types of tiered logistics network structures, including *Tree*, *Network*, and *Web* (Figure 1). With a

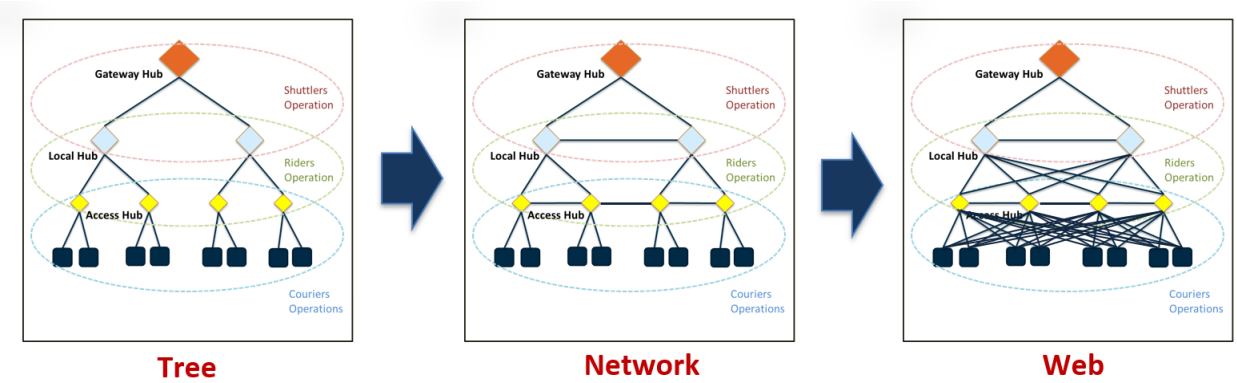


Figure 1 **Transition from Tree structure to Web structure.**

Tree structure, each hub in a given tier is connected to exactly one hub in the next higher tier. With a Network structure, each hub in a tier is connected to exactly one hub in the next higher tier, but also to one or more hubs in the same tier. Finally, with a Web structure, each hub in a

tier is connected to one or more hubs in the next higher tier, as well as one or more hubs in the same tier. The benefits of a hyperconnected logistic web over more traditional delivery practices are discussed in Montreuil et al. (2018). Numerical results show that without containerization, the use of network and web structures rather than a tree structure reduces shipping times by about 26 and 33 percent, respectively. Moreover, with containerization, reductions in shipping time of 25, 42, and 47 percent are observed for tree, network, and web structures compared to the tree structure without containerization.

We are currently developing custom solution approaches for the joint parcel routing and containerized consolidation problem to allow the solution of real-life instances. We will report on these approaches during the conference and will also present more in-depth and comprehensive computational studies.

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