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Zone pricing for time-definite LTL freight transportation with elastic demand

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ABSTRACT

Because shipments to a pair of administrative divisions are typically delivered with the same time-in-transit service level, shippers expect that they should be charged the same price. Thus, the carrier clusters operation centers located in the same administrative division into a tier-1 zone. These zones are subsequently aggregated into a set of hierarchical zones for which the carrier defines and publishes a zone tariff chart. Zone pricing is a tactical decision that simultaneously determines the zone prices and an operational plan to use its operating capacity to maximize carrier's profit while meeting the expected service level and operational requirements. We modeled this integral-constrained concave program using link formulation and proposed an implicit enumeration embedded with Lagrangian relaxation upper bounds to determine the optimal prices and operations plan. To meet the shippers' expectation, we proved our model mathematically and demonstrated computationally, using Taiwan's largest time-definite LTL freight carrier, that zone pricing has a negative impact on carrier profit in the process of aggregation.

1. Introduction

Network industries provide point-to-point services to customers. Providers of network industries are called *carriers* who provide respective services to shippers and users. The ground [10] and air less-than-truckload (LTL) parcel delivery industries [2] handle small parcels, whereas postal services [8] provide mail services for shipper-to-consignee deliveries. In contrast, telecommunications [18] provide caller-to-receiver message communication.

Carriers in the time-definite less-than-truckload (LTL) freight delivery industry, such as UPS, FedEx, DHL, and postal services, are among the network industries that publish tariffs (a list of prices) and deliver small shipments door-to-door with various service levels all with guaranteed delivery times for the shippers. These common carriers must provide service indiscriminately for anyone who pays the published tariff. The design and execution of the most cost-effective operation is one of the core competencies in this industry. Thus, the carriers construct a hub-and-spoke operations network that consists of two types of facilities: hubs and centers. Centers are many in number and dispatch package cars to deliver shipments to consignees while picking up new shipments from shippers. Each center is assigned to serve a non-overlapping geographic area spanning over a/several zip code(s). Hubs, in contrast, consolidate shipments, are few in number and are located remotely from concentrated population areas. Such a network configuration reduces partial loads and thus achieves a lower overall operating cost. However, cost consciousness is but one of several success factors. Carriers may tactically integrate prices with the most cost-effective operations to maximize their profits [13] because profit may not be unilaterally achieved via a cost minimization strategy.

Each shipment is the freight from the shipper's address to the consignee's address. The *zip-code tariff* prices a shipment based on the zip code pair of the shipper and the consignee. Each zip-code is assigned to and served by an exclusive center; thus, the distance of their assigned origin (shipment pickup) and destination (shipment delivery) centers plays a key factor in the determination of a shipment's price. The practice is that carriers first determine a *flat* rate, a single fee per unit of distance (in kilometer/mile). The flat rate is subsequently applied to the distance between the origin-destination center pair. The price of a shipment is determined by its respective assigned centers.

However, without full information on how the carriers design and/or execute their delivery operations, the rationale of customer expectation is driven by the following facts. First, short-haul shipments are less expensive than long-haul shipments. Second, the same delivery conditions should incur an equal price. The delivery conditions may include geographic and temporal conditions. Geographically, shipments between a pair of administrative divisions should be charged the same price because the shipments are typically delivered under the same time-in-transit service level. An

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administrative division is a geographic entity that oversees a relatively small geographic area usually assigned to a given governmental authority. As an example, suppose that two residents with different addresses in New York City ship parcels of equal weight class to Philadelphia; both customers should be charged the same price. To meet the shippers' expectations in practice, in recent years, time-definite less-than-truckload carriers abandon zip-code pricing in favor of *zone pricing*. They designate an administrative division as a *single* or subdivide it into a few *tier-1 zones* if covering a vast geographic area. Each tier-1 zone may contain several operation centers spanning a set of zip codes. None of the zip codes can be divided or contained by more than one tier-1 zone. Tier-1 zones are gradually aggregated into a set of *hierarchical* zones to determine zone prices (Fig. 1). To determine the zone price of a shipment, again, carriers determine zone distances by measuring the geographical centroids of all tier-1 zones to the centroid of all other tier-1 zones. The flat rate, a single fee per unit of distance, is applied to the distances with the result of the shipments' zone prices.

Both zip code and zone flat rate pricing are *distance-based* schemes. They are biased and inappropriate because in addition to long-haul transportation, one of the characteristics of the LTL industry is that all of the shipments must be rehandled at hubs. The rehandling cost is not a function of distance. Furthermore, the limited handling and transportation capacities may prohibit some of the origin-destination centers from being shipped on their respective shortest paths, i.e., straight line distances. To properly determine *zip code* pricing, [13] argued that carriers must implicitly determine the paths and the associated operating costs of their assigned origin-destination centers (OD pairs) in capacitated networks. The demand function is then applied to equate the operating costs to determine the optimal prices with the result of the zip code prices. This pricing scheme is *OD pricing* that integrates the elastic demand with operating costs.

However, under carriers' zoning plans, a zone consists of several zip codes that may be assigned and served by a number of centers in the zone. Thus, in this research, we extend the OD pricing resulting in zip code prices [13] to price a shipment by zone, resulting in zone prices. By capturing the characteristics of the LTL industry, this requires first determining the paths of all OD pairs and then calculating their respective associated operating costs. The zone demand function must then be applied to determine a *single* optimal zone price considering the *different* operating costs of the OD pairs contained in the zone. Such a pricing scheme is called *zone pricing*. Thus, to effectively leverage the operating capacity, the objective of zone pricing planning for a carrier is to simultaneously determine the zone prices and develop the most cost-effective operations plan to maximize profit while meeting the expected service level and operational requirements.

The contributions of this research are described as follows. First, most of the previous research has studied the cost effective carrier operation to minimize its operating cost [1,4,10]. Price planning may be incorporated into the overall marketing strategy by the time-definite LTL freight delivery industry to achieve and realize the type of profit that cost effectiveness cannot unilaterally achieve. Second, in this research, we study the pricing issue for carriers. Studies of pricing strategies in a capacitated network have been carried out for perishable asset industries, such as airlines [5,7,15,16,17], cruises [14] and liner shipping industries [19]. These studies determined the *discriminating* prices for the same product and simultaneously allocated available capacity to maximize the profits. The pricing scheme is implemented through booking and limited overbooking. As a prime example, airline passengers may pay different prices, depending on the purchase time for an identical product, economy seats on a flight. Such an approach cannot be applied to common carriers in the LTL industry, which must charge an equal price to and must provide service indiscriminately for anyone whose shipments are from the same origin zone to the same destination zone. The *indiscriminating* pricing for the LTL industry is a different stream of research and that previous research in discriminating pricing cannot be directly applied. Third, certain research works have studied the integration of pricing and operations under a set of demands/requests [6,3]. This approach implicitly assumes that the demand is price *inelastic*, i.e., the alteration of prices will not change the demands. In this research, we relax this assumption and assume that the demand is price dependent. Our contribution is to extend the previous inelastic demand to elastic demand. Fourth, zone prices make the tariff chart simpler than zip-code prices and are more intuitive for shippers. The aggregation of unequal operating costs and setting an identical price, as in zone pricing, may have a negative impact on carrier profits. This study allows us to study the monetary penalty that carriers must pay to meet customer expectations.

The structure of this paper is described as follows. In Section 2, we give a brief overview of a carrier's line-haul operations in a pure hub-and-spoke network and review three streams of related literature: cost minimization operations, revenue under inelastic demand for freight and elastic demand. In Section 3, we represent the carrier pricing planning problem as a capacitated directed network for mathematical formulation and algorithmic design. The mathematical model in the link formulation is formulated in Section 4, resulting in an integer concave program. In Section 5, we propose an exact algorithm, which consists of implicit enumeration of paths with an embedded concave programming sub-problem to determine the optimal zone prices for the carrier. The sub-problem is solved using the Frank–Wolfe algorithm. The Lagrangian Relaxation (LR) upper bounds are implemented to improve the computational efficiency via relaxation of the capacity constraints. The algorithmic scheme maintains feasibility while searching for optimality. In Section 6, we select a small pure hub-and-spoke network from the largest time-definite LTL freight delivery carrier in Taiwan for numerical testing. The computational results are presented, analyzed and discussed. We provide conclusions for our research in the field of pricing in the last section.

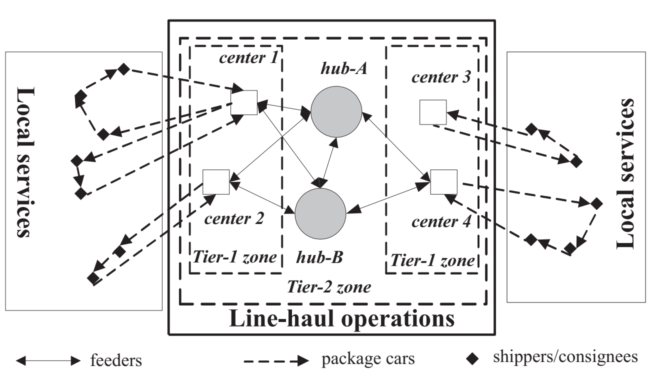

Fig. 1. An illustration of the time-definite LTL operations network.

2. Literature review

The time-definite less-than-truckload (LTL) freight delivery common carriers publish tariffs and deliver small shipments door-to-door with various service levels all with guaranteed delivery times for the shippers [10]. To run an efficient operation, carriers typically design a hub-and-spoke line-haul operations network, illustrated in Fig. 1, which consists of *facilities* and *lines* connecting pairs of facilities. There are two types of facilities: the *centers* are many in number and serve an exclusive geographic area spanning a/several zip code(s) to deliver shipments to consignees and subsequently pick up new shipments from shippers using a fleet of package cars. The centers serve as the interface points between the *local pickup/delivery service* and the