Bidding-Based Hyperconnected Service Network Design

Simon Kwon[a,*], Benoit Montreuil[a,b], and Mathieu Dahan[a]

[a] Physical Internet Center, Supply Chain & Logistics Institute, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA
[b] Coca-Cola Chair in Material Handling and Distribution
skwon82@gatech.edu, benoit.montreuil@isye.gatech.edu, mathieu.dahan@isye.gatech.edu
* Corresponding author

Keywords: Hyperconnected Logistics, Physical Internet, Service Network Design, Parcel Logistics

1 INTRODUCTION

The Physical Internet (PI) is a hyperconnected global logistics system enabling seamless open asset sharing and flow consolidation through standardized encapsulation, modularization, protocols, and interfaces (Kim *et al.*, 2021). PI enables a Logistic Web interconnecting multi-plane and multi-party meshed logistic networks (Montreuil *et al.*, 2018) serving the multi-tier logistic space as illustrated in Figure 1. Such networks comprise multi-tiers of logistics hubs and clusters adapted to each plane, including unit zones at the lowest tier, local cells as groups of adjacent unit zones, areas as groups of local cells, regions as groups of areas, blocks as groups of regions, with the world being a group of blocks (Montreuil *et al.*, 2018). Examples of unit zones include a suburban neighborhood, an urban community, a high-rise building or a campus (Montreuil *et al.*, 2018). Several logistics service providers use the concept of unit zones within their organization, assigning a single courier or a small set of couriers taking charge of all their pickups and deliveries within the zone (Montreuil *et al.*, 2018). This Logistic Web allows parcels to flow through each meshed plane through operations characterized by openly shared access to logistics resources and service outsourcing, increased cooperation and coordination, and information exchange.

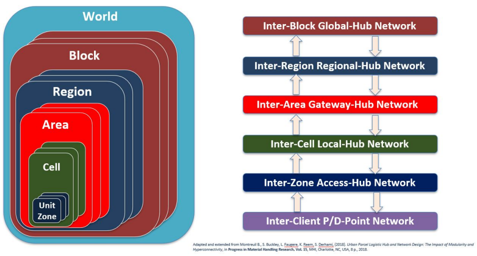

Figure 1 – *Multi-Plane Logistics Web Serving the Multi-Tier Logistic Space*

Provided with a multi-tier set of interconnected logistic networks, this work introduces a methodology and optimization-simulation models to design a service network by leveraging outsourcing to third-party logistic (3PLs) service providers, accounting for customers' expectations to receive accurate, fast and convenient service. Most of the service network design research is focused on first-party service network design. Literature focused on designing a service network leveraging 3PLs is scarce. As a similar spirit to this work, Pan *et al.* (2014) introduces the use of Mechanism Design theory to make a business model of the logistics service providers where every transport service is auctioned and develops a simulation framework for auction-based transport service allocation process in PI. Such service network design must cooperatively leverage the core competencies of various service providers to create a service network that is highly responsive and flexible at responding to customer demands. One of the key issues in developing such a network is the selection of service providers as the performance of the network depends on every single organization involved (Cakravastia *et al.*, 2002).

The key contributions of this work are (1) introducing the design of hyperconnected service networks where each network hub and each transport activity is outsourced to 3PL service providers; (2) introducing a decision-making framework enabling to select the service providers and to set service level expectations and agreements for each service hub and transport activity; (3) proposing a bidding scheme engaging multiple service providers and accounting for price-time trade-offs in such logistic service network design (in the spirit of D'Amours *et al.* (1997)); (4) introducing a simulation-optimization model supporting this bidding based design approach.

2 PROPOSED METHODOLOGY

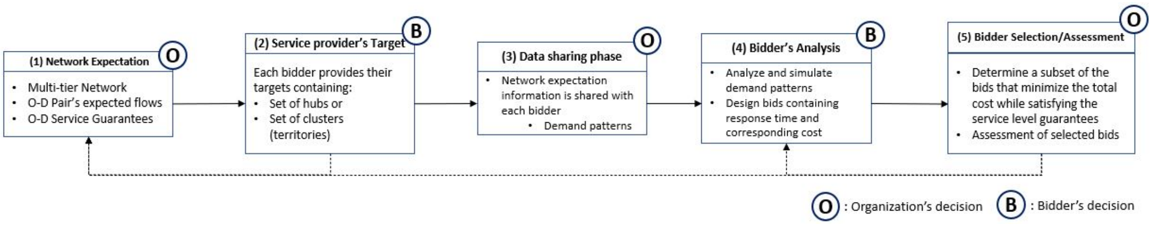

Figure 2 – *Multi-Phase Design of Hyperconnected Service Networks*

We consider an urban authority, a logistics company or set of such organizations desiring to design a hyperconnected service network leveraging service providers to transport commodities between a set of predetermined Origin-Destination (O-D) pairs in a time-sensitive manner. We assume that the O-D pairs are grouped into three types of shipments: (1) Within-Local cell (LC) shipments, (2) Within-Urban area (UA) shipments (moving across LCs within the same UA), and (3) Within-Region shipments (moving across UAs within the same Region) and each type of shipments is associated with target service guarantees (e.g., 6-hour delivery). We also assume that there are a set of service providers interested in offering hub processing services and/or cluster transport services. Hub processing services refer to a set of operations that take place in a hub to handle inbound parcels/containers to be ready for outbound shipment. Cluster transport services refer to the practice of transporting parcels/containers within a specified cluster.

As shown in Figure 2, a hyperconnected service network planning is designed in multi phases. In Phase 1, the organizations collect information and expectations on their multi-tier network including O-D demand flows and service guarantees offered in each O-D pair. Such guarantees can be estimated through simulation with historical data or by benchmarking competitors' service offers. The process of estimating service guarantees is important to the organizations as the service guarantees impact their overall business and service costs outsourcing service providers. In Phase 2, service providers share the service activities on which they desire to bid to provide services and such information is shared with the organizations. In Phase 3, the organizations provide the service providers with network expectations required for their desired services. In Phase 4, based on the provided network expectations, each service provider conducts analyses to create their service bids containing which activity to bid on, corresponding service agreement such as robust hub processing times at hubs/robust transport times within a specified cluster, and corresponding cost. In Phase 5, collecting all bids submitted, the organizations choose a subset of the service bids to set service level expectations and agreements for each service hub and transport activity that meet the service guarantees offered in O-D pairs while minimizing the total outsourcing cost and assess the performance of the selected bids. Throughout the planning, there can be multiple rounds of bidding with organizations' feedback shown as dashed lines in Figure 2, which will drive different bidding behavior and bid outcomes. For example, after Phase 2, if there are service activities that are not liked by any service providers, organizations can revisit Phase 1 to amend their network expectations to attract service providers. After Phase 5, should the assessment of the selected bids turn out to be dissatisfying (e.g., failing to meet service guarantees), organizations could revisit Phase 4 to negotiate with the associated service providers their bids or revisit Phase 1 to amend their network expectations.

We model the multi-phased design of a hyperconnected service network using a simulation-based optimization approach. For Phase 1, demand patterns for hubs and clusters depend on the hub and cluster transport services offered to the network and thus they can vary depending on the services provided. Hub service processing times can also depend on many factors including volume of in-bound flows and flows' next destinations which could require different hub processing times, and are also impacted by the transport services provided to the clusters associated with the hubs. Cluster transport services also depend on the services provided to the hubs associated with the clusters as those impact vehicle planning. We suppose that such fluctuating demand patterns and mutual dependency in the services can be modeled using a representative finite set of service level expectation scenarios Ω^H and Ω^C for hub and cluster transport services, respectively in each of which service expectations of each logistic activity are approximately estimated. We model Phase 4 using simulation to generate service bidders for hub and cluster transport services and corresponding service bids. Each service bidder (provider) designs their bids, considering the service level expectation scenarios provided for the other side of the logistics activities. For example, hub service bidders generate their bids considering the service expectations provided for the cluster transport services and vice versa for cluster transport service bidders. Each service bidder uses different strategies to provide services. For hub processing services, one can offer advanced technologies and practices of processing operations that cost high yet provide high-speed performance while others may offer mode manual operations that may be less expensive yet of slower-speed. For cluster transport services, one can impose constraints on number of stops vehicle can make per route and dwell times up to which vehicles can wait at hubs, which will impact parcel's total transport time and their service capabilities. Such various capability options and constraints are considered in the simulation in generating bids.

We model Phase 5 using an assignment-oriented mixed-integer program formulation. Key is to ensure solvability of the optimization model in large-scale networks with multiple service expectation scenarios and multiple bids per service provider. We rely on a predetermined set of service expectation levels for each hub and cluster transport service to generate service expectation scenarios. For example, for each hub and cluster transport service, we consider three levels of service expectations including fast, medium, and slow and the expected service time range is assigned to each level. The expected time range for each level differs across hubs and clusters. After a set of bids is generated, each bid is mapped to corresponding service expectation level. We then feed such input to the optimization model to choose a subset of the service bids that leads to achieving time-sensitive transports between O-D pairs in a cost minimization manner.

3 EMPIRICAL CASE STUDY

We apply the developed decision-making framework to design a hyperconnected urban parcel logistic service network for a network topology for a Chinese megacity to demonstrate how the proposed framework can be used for large-scale cases and to investigate the performance achieved by using the approach under representative sets of assumptions.

We consider a megacity instance with a multi-plane spatial structuring in line with Figure 1 composed of 110 clusters. The megacity logistic networks leverage 4522 hubs to serve a daily demand on the order of 7 million parcels daily across 26,000 origin-destination (O-D) pairs. We consider 162 hub service bidders and 140 cluster transport service bidders and 5 service level expectation scenarios for hub and cluster transport services, respectively. Hub service bids from each bidder are generated through simulation with different capability options aforementioned. Cluster transport service bids for each bidder are generated through Vehicle Routing Problem (VRP) simulation with different options of vehicle sizes and vehicle operations (e.g., on-demand or bus-type operations), and constraints aforementioned. We use the service guarantee offer settings as shown in Table 1 to assess the network's service guarantee's performance.

Table 1 – *O-D Service Guarantee Offer Settings*

Service Offer Settings	**Within LC**	**Within UA**	**Within Region**
1	6 hours	10 hours	12 hours
2	6 hours	10 hours	11 hours
3	6 hours	8 hours	12 hours
4	6 hours	8 hours	11 hours
5	6 hours	8 hours	10 hours
6	4 hours	8 hours	11 hours
7	4 hours	8 hours	10 hours
8	4 hours	6 hours	9 hours
9	4 hours	6 hours	8 hours

We here present a minimal preview of empirical results of our bidding-based optimization-simulation approach. Figures 3 focus on the achieved customer service performance overall (left) and disaggregated by each type of shipments (right), respectively. As the order-to-delivery time requirements of each shipment are challenged, the percentage of service guarantee satisfaction decreases from 100% to 87.52%, with the steepest decrease felt when imposing 8 hours on within-region shipments instead of 12 hours max. The shorter within-local cell and within urban-area service offerings are overall better served. This illustrates the compromises between targeted service offers, service levels, and the reality of the urban geography and the capabilities of the service providers.

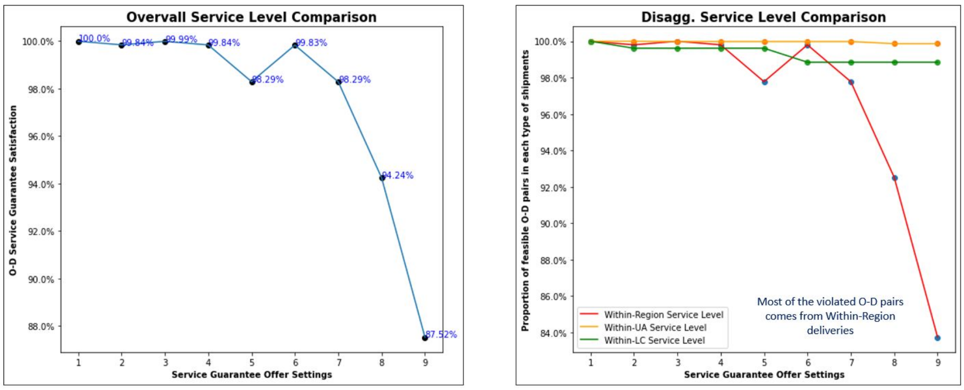

Figure 3 – *Customer Service Performance Measurement: (Left) Proportion of total service guarantee satisfaction. (Right) Proportion of service capability violation in each shipment type*

In the presentation, we plan to study each phase of the developed framework in detail and present more elaborate and completed experiments, enabling to assess the approach in terms of multiple key performance indicators, including service performance, cost analyses, and price-time trade-offs. We will also present further research directions, notably in terms of profit maximization.

References

Cakravastia, Andi, Toha, Isa S, & Nakamura, Nobuto. 2002. A two-stage model for the design of supply chain networks. *International journal of production economics*, **80**(3), 231–248.

D'Amours, Sophie, Montreuil, Benoit, & Soumis, François. 1997. Price-based planning and scheduling of multi-product orders in symbiotic manufacturing networks. *European journal of operational research*, **96**(1), 148–166.

Kim, Nayeon, Montreuil, Benoit, Klibi, Walid, & Kholgade, Nitish. 2021. Hyperconnected urban fulfillment and delivery. *Transportation Research Part E: Logistics and Transportation Review*, **145**, 102104.

Montreuil, Benoit, Buckley, Shannon, Faugere, Louis, Khir, Reem, & Derhami, Shahab. 2018. Urban parcel logistics hub and network design: The impact of modularity and hyperconnectivity.

Pan, Shenle, Xu, Xiaozhou, Ballot, Eric, *et al.* 2014. Auction based transport services allocation in Physical Internet: a simulation framework. *In: 5th international conference on information systems, logistics and supply chain.*