OPTIMIZATION OF LESS-THAN-TRUCKLOAD REQUEST PRICING AND SELECTION FOR CARRIER IN PHYSICAL INTERNET

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ABSTRACT

This paper investigates a less-than-truckload (LTL) request pricing and selection problem to optimize carrier's revenue in Physical Internet (PI). PI can be considered as a global interconnection logistic system that connects logistic networks together via open logistic hubs. In a hub, many types of LTL requests with different volume and route arrive continually and are allocated to carriers frequently. LTL carriers can bid for these requests through participating several auctions. Being faced with many different requests, carrier needs to select one (or several) type of requests of interest to bid and meanwhile decides the bidding price to maximize his profit. Two scenarios are investigated, i.e. carrier with full capacity, or carrier with loads with known destination. For each scenario, an integer programming model based on a multi-legs dynamic pricing model is proposed to solve the request selection problem and pricing problem simultaneously. A computational study is conducted to demonstrate the feasibility of the models.

Keywords: Less-than-truckload, Physical Internet, Request selection, Dynamic pricing, Freight transport

1 INTRODUCTION

From the point of view of carriers in freight transport, the request selection problem consists of selecting the most profitable requests (demands of transport service) at the original depot, for long-haul direct routes or for multiple pickup and delivery routes. They sometime also need to determine the price to bid for the requests, namly the pricing problem. The request selection plays vital role to optimize carrier's revenue. It is particularly obvious considering the fierce competition in transport market, according to the fact that the top 10 third party logistics providers (3PLs) in Europe can only have a market share of 5% (AECOM [1]). In cabotage market for example, more and more new Member States step in the market and saw increased performance. This shows growing competition in the important and newly opened market area[†]. Especially in the LTL industry, during the past decades, the LTL segment has been faced with increased competition and shrinking market, proven by the fact

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[†]http://ec.europa.eu/eurostat/statisticsexplained/index.php/Archive:Competitiveness_in_EU_road_freight_transport#Increasing_competition_in_the_cabotage_market

that the total revenue in LTL industry segment plunged 21% between 2008 and 2009 in U.S. (Prokop [15]). Considering the importance, it is essential for logistics providers to pay more attention on their revenue management in current competitive environment. The problem is thus of significance to investigate.

This paper introduces and investigates a transport request selection problem for less-than-truckload (LTL) carriers based on dynamic pricing in Physical Internet. PI is a global interconnection logistic system that connects logistic networks together via open logistic hubs, i.e. PI-hubs where carriers can gain transport requests or exchange in-hand requests for the sake of economies of scope and scale (Montreuil [13]; Montreuil et al. [14]). In PI-hubs, shippers and carriers can offer transport requests encapsulated in modular and standard PI-containers. The requests are mostly LTL requests with different destination and volume (or quantity) arrive over time (Ballot et al. [4]; Qiao et al. [16]; Sarraj et al. [17]). Carriers propose price to win the requests and then the requests will be allocated to carriers optimally (to the lowest price for example). Auction mechanism is one of the most efficient solution to allocate the requests in PI-hub (Huang & Xu [8]; Kuyzu et al. [10]; Xu & Huang [19]). Moreover, the allocation process in PI-hub is very dynamic and stochastic. As a result, carrier should propose different, or dynamic prices to different requests to maximize his profit.

Request selection problem mainly appears in the areas of collaborative transportation. For example (Berger & Bierwirth [5]) and (Xu et al. [20]), both papers discussed how to select their requests in hand to exchange. Antoher two related references are (Liu et al. [12]) and (Li et al. [11]), who studied the request selection problem in the truckload collaboration area. The former aims to minimize carrier's total costs via combining different requests in a route. The later aims to maximize carrier's profit after outsourcing or sourcing some requests, based on a fixed but not dynamic pricing strategy. Indeed, the literature has rarely paid attention to LTL request selection problem, especially considering dynamic pricing.

This paper aims to study how to select request for LTL carriers in a PI-hub based on dynamic pricing. The dynamic pricing in PI has been studied in (Qiao et al. [16]), in which dynamic pricing decision for one-leg and single-sized LTL requests in a hub was investigated. The objective is to optimize carriers' price and to maximize their global profits in a PI-hub. In this paper, we extend the one-leg situation to multi-legs. At a given PI-hub, carrier faces many requests with different destination. To maximize the profit, we assume that carrier would take into account the (predicted) situation of the next hubs (the destination of the requests) when selecting and pricing on the requests. Because, once requests are selected, the next destination he will pass is also decided. Backhaul is a typical example. It is called multi-legs decision here. It means we extend the pricing model for one single route to pricing for different routes. Further, based on the dynamic pricing model, we propose two integer programming models for two different scenarios, to select the request to bid and maximize carrier's profit. The first one considers full capacity carrier without destination. The other one considers partially loaded carrier with a determinate destination. By that, this paper also aims to povide decision making models for carriers' request selection decision in PI-hub.

This paper is organised as follows. After the introduction, section 2 presents a brief literature review of the related research in order to identify the research gap and research interest. Section 3 describes the request selection problem in PI, which is formulated in section 4. A computational study with the results is presented in section 5. Finally, section 6 concludes the contributions of this work and identifies some research prospects.

2 LITERATURE REVIEW

In the literature, request selection mostly appears in the area of transport collaboration. For example, (Berger & Bierwirth [5]) studied how to select several requests that carrier got from customers to sub-contract to other carriers. In (Xu et al. [20]), the similar problem was also discussed. There are two references very close to our problem. In reference (Liu et al. [12]), the author presented the task selection and routing problem for truckload carriers in collaboration transportation. The objective of this problem is to minimize the total cost when carrier serves the requests. In this reference, carrier just needs to decide which requests to serve and which to outsourcing to external carriers, but does not need to decide the price for request. In another reference (Li et al. [11]), the author focused on the requests selection and exchange problem between carriers in collaboration transportation. Carriers need to select requests for outsourcing and sourcing with the objective to maximize their profit. And the exchange of requests based on auction with the objective of maximizing the overall profit was also introduced. But neither the methods from these two references are available for us. First, they did not pay much attention on the pricing. They solve the fleet management problem when the request is selected. Second, the environment they researched is static and they did not consider the future situation after the request selection. While the environment is very dynamic and stochastic, carriers need to forecast the future requests' information.

Another problem which is relative to request selection in freight transport is traveling salesman problem with profits (TSPP). As stated in (Feillet et al. [6]), TSPP is a generalization of the traveling salesman problem (TSP) and each vertex is associated with a profit. There are two objectives in this problem, optimize the collected profit and the travel cost meanwhile. According to the way the two objectives are addressed, TSPP can be divided into three categories: profit tour problems (PTP), orienteering problems (OP), and prize collecting TSPs (PCTSP). In (Balas [3]), the third category problem was studied. This reference solved a routing problem. This problem is still not the same with our problem. The profit in TSPP is related to vertex, while in PI, the profit is related to a request, i.e. the route.

Several research related to vehicle routing problem (VRP) with profit are also related. In (Figliozzi et al. [7]), the TSPP was generalized to a dynamic environment. The author studied the pricing problem for truckload carrier using auction mechanism. In this reference, there is no request selection, but a vehicle routing problem considering maximize carrier's profit. In reference (Aras et al. [2]), the author studied the reverse logistics problem. The problem discussed in this reference can also be seen as an extension of TSPP, except that vehicles need to pay the customers when visit them. Reference (Ichoua et al. [9]) studied how to exploit information about future events to improve the fleet management of vehicles. The objective is to minimize the total cost to serve the possible requests. It solved the problem that if to accept or how to allocate the new arriving requests to the vehicles the firm owns. This is not a request selection problem actually. The reference (Thomas & White Iii [18]) studied the similar fleet management problem when facing possible requests, but this reference considered the revenue to serve the request.

Overall, the literature is very limited to the request selection problem for LTL carriers in a dynamic environment like PI. Here, we conclude the characteristics of LTL request selection problem in PI. First, when carrier selects the request, he needs to look one-step ahead, i.e. considering the request information in the next hub. Because in PI, requests in different hubs are different in quantity and route. This can affect the carrier's future profit. Second, according to our previous work, each kind of request is associated with a profit. This profit is related to the route and the quantity of requests. It means carrier might gain different profit when he goes to the same hub from different hubs. Third, requests information (quantity, route) should be forecasted in each hub, but not the whole network. Therefore, the similar research is hard to find and to study the request selection problem for LTL carriers in PI is essential.

3 PROBLEM DEFINITION

The network of Physical Internet consists of plenty of PI-hubs. In each hub, there are shippers that offer transport requests encapsulated in containers. Carriers, providers of transport services, participate in a sequence of auctions to win these requests, by taking into account their constraint of capacity (capacity-finite) and, eventually, time to depart (time-finite). We assume that auction mechanism is employed here to allocate the *n* requests to the *m* carriers. The transport requests have different quantity and route, which represents these requests have different travel cost and expected profit. In this context, this paper studies the problem how to select the request to bid and how to decide the bidding price meanwhile to maximize carrier's total profit. This is the request selection problem based on dynamic pricing in PI.

In this paper, to simplify the problem, we assume carrier just take one type of request, i.e. requests with one same route. This means we do not consider requests in bundles and carrier bids for requests one by one. Besides, we study the requests selection problem in two scenarios.

Scenario 1: Full capacity carrier without determinate destination

In this scenario, we study the request selection for full capacity carrier who has no request in hand and has a full capacity. Full capacity carrier has no determinate destinations which depend on the requests carrier wins.

A full capacity carrier arrives at a PI-hub, where there are several types of requests with different quantity and routes. Carrier needs to decide just one type of request to bid and meanwhile decides the bidding price to maximize his expected profit. When making the decision, carrier should consider the requests information (quantity, route) in the hub which the bidding requests lead him to. Without losing generality, we just consider the hub one-step ahead, i.e. the hub that carrier will go next and stop considering the hub carrier might go after the next hub. In the network in Figure 1, a full capacity carrier located at hub 1. There three types of requests (hub1->hub2, hub1->hub3, hub1->hub4) with different quantity in hub 1, carrier needs to select one type to bid. When he makes the decision, he should consider the request in the next hub, for example, if carrier selects request going to hub 2, he should consider if the request in hub 2 can give him a better profit.

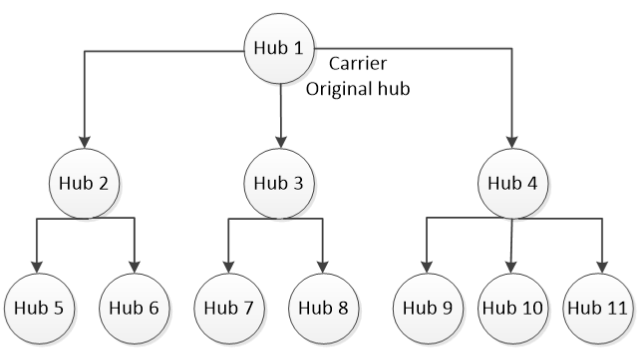

Figure 1: example for scenario 1

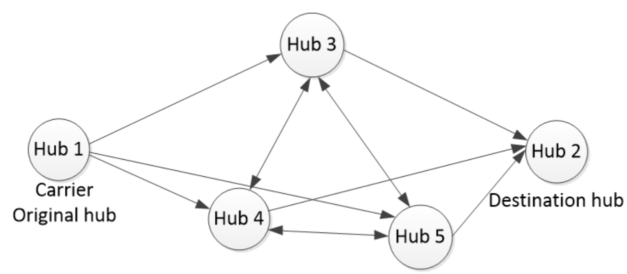

Figure 2: example for scenario 2

Scenario 2: Loaded carrier with determinate destination

Contrary to full capacity carrier, loaded carrier already acquired some requests and thus has a determinate destination (a PI-hub) to go to deliver the requests in hand. If these requests cannot fill carrier's whole capacity, carrier could travel to other hubs to collect some requests on the way to the destination hub passingly, with the objective to maximize the fill rate and profit.

Some hubs, where there are also different requests with different quantity to other hubs, located around the carrier's way to the destination hub. Carrier needs to decide which hubs to pass and which type of requests to bid in each hub. The requests carrier bids will decide the sequence to pass the middle hubs, i.e. the route of carrier. Meanwhile, like scenario 1, carrier also needs to decide the bidding price when selecting the bidding requests. In the network of Figure 2, carrier staying at hub 1 already got some requests going to hub 2. To maximize his fill rate and profit, he could travel to several middle hubs (hub3, hub4, hub5) to collect more requests. The routes of requests in each hub are shown in the figure. Carrier should select the hubs to travel to and also the sequence to pass.

4 MODELLING

4.1 Notions

Parameters:

r: requests remaining in the auction period. We assume that a vehicle can bid n times at most if there are n requests during the auction period, so r = n, n-1, ⋯, 1.

D: the capacity of a vehicle.

(i,j): the route of one type of request.

Dis_{ij}: the distance from hub i to hub j.

C_u: unit cost, i.e. the cost to deliver a request with unit weight in unit distance, here C_u=1€.

C_{ij}: the cost of fulfilling a request in route (i,j), i.e. $C_{ij}=C_u*Dis_{ij}$.

N_{ij}: request quantity from hub i to hub j.

(d_r,n,c): the vehicle status, defined according to the remaining capacity d_r when bidding for r requests, the total requests quantity n to bid and the travel cost c.

p(x): the probability of winning with a given bid price x at an auction. Based on(Qiao et al. [16]), we have $p(x) = e^{-(\frac{x}{\lambda})^k}$. We assume that the average price $\lambda = 2 * c$, and k=5.

$V_r(d_r,n,c)$: the expected maximum profit for one type of request with the status (d_r,n,c).

$V_{ij}(D)$: the maximum expected profit for carrier to bid request with route (i,j).

A: the set of routes of requests, (i,j) ∈A. (O,D) represents the original hub and the destination hub.

X: the set of bid prices, i.e. range of prices to be tested in the model, and X = [C_{ij}, 3*C_{ij}] here.

Variable:

x: bid price given by the carrier for a request during each auction period. In particular, the optimal bid price determined by the model is noted as x* and x*∈X.

x_{ij}: the binary variable, set to one if carrier select request from hub i to hub j, and i ≠ j.

4.2 Dynamic pricing model

We extend the one-leg pricing model in reference (Qiao et al. [16]) to multi-legs. The main difference is the different travel cost associated with the route is considered in the model. The multi-legs dynamic pricing model is presented blow:

$$V_r(d_r,n,c) = \max_{x\in X}\left[p(x) * [x - c + V_{r+1}(d_r - 1,n,c)] + \left(1 - p(x)\right) * V_{r+1}(d_r,n,c)\right], r = 1,\dots,n \quad (1)$$

$$V_r(d_r,n,c) = 0, if\ d_r \leq 0\ OR\ r > n \quad (2)$$

$$x^* = arg\max_{x \in X}\left[p(x) * [x - c + V_{r+1}(d_r - 1, n, c)] + \left(1 - p(x)\right) * V_{r+1}(d_r, n, c)\right],\ r = 1,2, \dots n-1, n \quad (3)$$

$$V_{ij}(D) = V_1\left(D, N_{ij}, c_{ij}\right) \quad (4)$$

Function (1) is a recursive function to calculate the carrier's maximum expected profit when they bid for r requests using price x with a remaining capacity of d_r and travel cost c. When the carrier wins a request its capacity will be minus 1, otherwise the capacity will not change. Function (2) is the boundary condition represents that the expected profit will be 0 when the capacity is sold out or no more requests to bid. Functions (3) presents the optimal bidding price x*. At last, function (4) is used to calculate the maximum expected profit V_{ij} to bid the request on the route (i,j).

4.3 Request selection model for scenario 1

Based on the dynamic pricing model above, an integer programming (IP) model to select request for carrier is given as (5)-(8). This model is constructed according to the idea of maximum expected profit:

Objective:

$$Max \sum_{(i,j)\epsilon A} V_{ij}(D) * x_{ij} \quad (5)$$

Constraints:

$$x_{ij} - \sum_{(j,k)\epsilon A} x_{jk} \geq 0, (i,j) \in A \quad (6)$$

$$\sum_{(i,j)\epsilon A} x_{ij} \leq 1,\ i \in N \quad (7)$$

$$x_{ij} \in \{0,1\}, (i,j) \in A \quad (8)$$

The objective function (5) maximize the carrier's total expected profit after selecting one type of request to bid. Constraint (6) ensures that the requests information of the next hub will be considered only if the request going to this hub was selected. Constraint (7) ensures only one type of request can be selected in one hub.

4.4 Request selection model for scenario 2

Similar to 4.3, an integer programming (IP) model to select request for loaded carrier is constructed below:

Objective:

$$Max \sum_{(i,j)\epsilon A} V_{ij}(D) * x_{ij} - \left(\sum_{(i,j)\epsilon A} Dis_{ij} * x_{ij} - Dis_{OD}\right) * R_{OD} * C_u \quad (9)$$

Constraints:

$$\sum_{(i,j)\epsilon A} x_{ij} - \sum_{(j,k)\epsilon A} x_{jk} = 0, j \in N^- \quad (10)$$

$$\sum_{(i,j)\epsilon A} x_{ij} \leq 1,\ i \in N^- \quad (11)$$

$$\sum_{(O,j)\epsilon A} x_{Oj} = 1 \quad (12)$$

$$\sum_{(i,D)\epsilon A} x_{iD} = 1 \quad (13)$$

$$x_{ij} + x_{ji} \leq 1, i \in N^-, j \in N^- \quad (14)$$

$$x_{ij} \in \{0,1\}, (i,j) \in A \quad (15)$$

Function (9) maximize the expected profit of carrier after selecting the middle hubs to pass. The first term represents the total expected profit gained from passing the middle hubs. The second term calculates the detour cost for loaded requests in hand, R_{OD} is the quantity of loaded requests. Constraint (10) imposes the balance in each hub, i.e. if carrier travel to a hub, he must leave from this hub, except the original and destination hubs. Constraint (11) ensures only one type of requests can be selected in one hub. Constraints (11) and (12) ensure that for original and destination hubs, only one type of request going out and in. At last, constraint (14) avoids the situation that carrier back and force between two hubs.

5 COMPUTATIONAL STUDY

A computational study was proposed to illustrate and evaluate the performance of the models developed. For the two scenarios described in sector 3, two examples were used to test the models separately. All the illustrations were running on Mathematics 10.4 under the environment of Windows 10 on a DELL of Model Inspiron 15 (5000) with 16 GB of RAM.

Scenario 1:

Based on the network in Figure 1, the distance and request quantity on each route is given in Table 1. And the measuring unit are *KM* and *unit* separately.

Table 1: Input Data (distance, request quantity) for scenario 1

Route	Distance	Request Quantity	Route	Distance	Request Quantity
1->2	0.92	171	3->7	0.34	261
1->3	0.75	231	3->8	0.29	161
1->4	0.87	144	4->9	0.85	164
2->5	0.99	255	4->10	0.27	5
2->6	0.31	110	4->11	0.92	71

Based on the input data in Table 1 and the model proposed, the computation result show that carrier should select requests 1->2, 2->5, which means the optimized route is 1->2->5. Accordingly, the maximum expected profit is 49.6879. This decision will maximize carrier's expected profit.

Scenario 2:

Based on the network in Figure 2, the requests quantity on each route is given in Table 2 and the coordinates of each hub is given in Table 3.

Table 2: Input Data (distance, request quantity) for scenario 2

Route	Request Quantity	Route	Request Quantity	Route	Request Quantity
1->3	30	3->4	50	4->5	200
1->4	120	3->5	150	5->2	300
1->5	100	4->2	300	5->3	150
3->2	200	4->3	150	5->4	180

Table 3: Coordinates of PI-hubs

Hub	Hub 1	Hub 2	Hub 3	Hub 4	Hub 5
Coordinate	(0,0)	(0,1)	(0.2,0.1)	(0.3,-0.2)	(0.8,-0.2)

According to the input data in Table 2 and Table 3 and the model proposed, the optimal decision for a carrier is to select the requests 1->4, 4->2, which means the optimized route is 1->4->2. The maximum expected profit is 25.843. The hub 3 and hub 5 is abandoned, because the profit gained from hub 3 and hub 5 cannot afford the cost to travel to them.

6 CONCLUSION

This paper introduces and analyses the LTL request selection problem in PI. First, we extend the one-leg dynamic pricing model in (Qiao et al. [16]) to multi-legs. Second, we propose dynamic pricing-based optimization models for carrier's decision on LTL request selection. And two scenarios considering full capacity carrier and partially loaded carrier are proposed. An illustrative computational study is conducted to demonstrate the models. Comparing the two scenarios, the main difference is how to consider the future requests information. Scenario 1 just considers one-step ahead, i.e. one hub the carrier will go next. While scenario 2 needs consider all hubs around the carrier's way from the original hub to the destination hub.

One main limitation of this work is that the request quantity considered in each PI-hub is static. But in fact, the quantity might change very quickly. Because transportation is a very dynamic and stochastic environment, the allocation of request in PI-hubs is very frequent. In the next, we will study the request selection problem in a dynamic situation, i.e. the request quantity in each hub is not static but stochastic. The request selection problem will be associated with forecasting problem in the network of PI.

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