# An Iterative Request Exchange Mechanism for Carrier Collaboration in Less than Truckload Transportation

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Abstract: In carrier collaboration, multiple carriers form an alliance and exchange some of their transportation requests to improve the overall profit of the alliance and the individual profit of each carrier. In this paper, we propose a mechanism for the request exchange with limited information sharing among the carriers. In each round of the mechanism, each carrier first outsources multiple bundles of requests with the corresponding transfer payments and then insources bundles of requests from other carriers. The auctioneer reassigns bundles of requests among carriers based on the outsourcing bundles and insourcing bundles of requests. The auction mechanism iterates until a certain criterion is met. Numerical experiments on randomly generated instances show that our iterative request exchange mechanism can provide high quality solutions.

## 1 INTRODUCTION

Road freight transportation is a backbone of trade and commerce. Trucks and vans move more than 14 billion tonnes of goods per year, delivering 75% of all goods carried over land in Europe (ACEA, 2016). However, according to statistics from the Department for Transport in UK (2017), the average empty running of trucks in 2015 in the UK reached 28.6%. Similarly, the vehicle utilization rate was 64% in 2015 in the UK. To reduce transportation costs by eliminating empty back-hauls and raising vehicle utilization rates, shippers and carriers can form an alliance to optimize their transportation operations by consolidating or exchanging their transportation requests to minimize their transportation costs or to maximize their profits.

In this paper, we focus on carrier collaboration, in which an alliance with multiple carriers who provide similar transportation services is formed to exchange transportation requests among them to increase profit and to optimize the utilization of transportation resources. In carrier collaboration, before request exchange (reassignment), carriers offer transportation requests to other carriers that cannot be integrated efficiently into their routing plans and acquire requests from other carriers that are complementary to their existing requests (Krajewska and Kopfer, 2006; Bolduc et al., 2008; Krajewska and Kopfer, 2009; Liu et al., 2010; Dai and Chen, 2011; Defryn et al., 2015; Li, Rong, and Feng, 2015; Li, Chen, and Prins, 2016; Gansterer and Hartl, 2016). In the literature, there are two planning approaches for collaborative transportation problem: centralized planning approach and decentralized planning approach. In a centralized planning approach, a centralized decision maker with complete information about all carriers determines the optimal reassignment of requests among those players to minimize the total transportation cost or to maximize the total profit. In the literature adopting a centralized planning approach, different kinds of multi-depot vehicle routing problem need to be solved to reassign requests among carriers ( Dai and Chen, 2009; Audy et al., 2011; Sprenger and Monch, 2012; Yilmaz and Savasaneril, 2012; Lyu et al., 2018). In a decentralized planning approach, request exchange among carriers is usually realized by an auction with limited information sharing among them. In auction-based mechanisms, many researches focus on



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combinatorial auction (Berger and Bierwirth, 2010; Dai et al., 2014; Wang and Kopfer, 2014a, 2014b; Li, Rong, and Feng, 2015; Chen et al., 2009; Lai et al., 2017; Chen, 2016). Combinatorial auctions take advantage of complementarities, in which requests are not traded individually but are combined to bundles. Except for combinatorial auction, a double-auction mechanism (Özener, Ergun, and Savelsbergh, 2011; Xu et al., 2016) and a combinatorial clock-proxy exchange mechanism (Chen, 2016) are also proposed to solve carrier collaboration problem. As carriers are not willing to share their confidential cost information, we adopt a decentralized collaborative transportation planning approach to solve the carrier collaboration problem.

In this study, we focus on the design of an auction mechanism to solve the carrier collaboration problem in less-than truckload transportation with pickup and delivery requests. An iterative request exchange mechanism with limited sharing of transportation cost information is proposed. In each iteration, each carrier as a seller first provides multiple bundles of requests to offer and determines their corresponding transfer payments. This decision problem is referred to as outsourcing bundles selection problem. Each carrier as a buyer then determines which bundles of requests to acquire from one or multiple carriers. This problem is called insourcing bundles selection problem. Here, a carrier outsources a bundle of requests means that it offers this bundle to other carriers and a carrier insources a bundle of requests means that it acquires this bundle from other carriers. Based on the offers and demands submitted by all carriers, the mechanism reassigns (exchanges) some bundles of requests among carriers by solving a winner determination problem. The request exchange process iterates until a certain criterion is met. In each iteration, each carrier updates its outsourcing bundles of requests based on the feedback from previous iterations. Numerical experiments show that this iterative request exchange mechanism significantly outperforms a combinatorial auction mechanism in the literature.

The main contribution of this paper is in three aspects: (1) To increase collaboration potentials, each carrier can outsource multiple bundles of requests to other carriers and each carrier can insource (acquire) more than one bundles of requests from multiple other carriers in our exchange mechanism. (2) In the mechanism, each carrier updates the outsourcing price of each request based on the feedback from previous iterations and thus selects different bundles of requests to outsource in each iteration. (3) Numerical experiments show that our mechanism significantly outperforms the combinatorial auction proposed in Berger and Bierwirth (2010).

The rest of the paper is organized as follows. Problem description and the iterative request exchange mechanism are described in Section 2. In Section 3, we describe decision problems appeared in the mechanism. In Section 4, numerical experiments to evaluate the mechanism are reported with the analysis of computational results. Section 5 concludes this paper with remarks for future research directions.

## 2 PROBLEM DESCRIPTION AND MECHANISM DESIGN

In this paper, we consider a carrier collaboration problem in less-than truckload transportation. Multiple carriers participate in a collaborative transportation network. Each carrier has a set (fleet) of homogeneous vehicles. Before collaboration, each carrier has a set of pickup and delivery requests provided by shippers. Each request is specified by a pair of pickup and delivery locations, a pickup/delivery quantity, and two time windows for pickup and delivery respectively. Serving each request will generate a revenue paid by a shipper. With collaboration, each carrier can outsource part of its own requests to other carriers and acquire some requests from other carriers in order to increase its individual profit.

We design an iterative request exchange mechanism for LTL carrier collaboration. The general structure of our mechanism is sketched in Algorithm 1. In this mechanism, each carrier sequentially decides the requests to outsource (sell) as a seller and the requests to insource (buy) as a buyer. The mechanism then matches the offers and the demands of all carriers and reassigns some bundles of requests among them by solving a winner determination problem (WDP) with limited information sharing. The iterative request exchange mechanism terminates when a certain stopping criterion is satisfied.

Note that each carrier updates its outsourcing bundles of requests based on the feedback from previous iterations.

To well explore the collaboration potential, the selection of outsourcing requests plays an important role in our iterative mechanism. To increase collaboration possibilities by allowing carriers to have more flexibility to select requests to outsource, we adopt the minimum profit margin, to influence whether a request is selected as an outsourcing request. According to Dai and Chen (2011), the min-

Algorithm 1: Procedure of the request exchange mechanism.

```
1  Do
2      Each carrier determines bundles of outsourcing requests
3      Each carrier determines bundles of insourcing requests
4      The auctioneer solves the WDP problem to reassign bundles of requests among carriers
5      If the offers of all carriers match the demands of all carriers
6          Update the individual profit and request set of each carrier
7      Else
8          Update the bundles of outsourcing requests by each carrier, and go to Step2
9  While (the stopping criterion is not satisfied)
```

imum profit margin for a carrier represents its profitability expectation for each request in percentage of the request's price provided by a supplier.

Each carrier prefers to outsource the requests whose marginal cost is higher than the price paid by a shipper (Berger and Bierwirth, 2010; Li, Rong, and Feng, 2015; Gansterer and Hartl, 2016). In order to make the requests with high marginal costs attractable to other carriers, each carrier can set the initial value of the minimum profit margin to a small value, which represents a low profitability expectation of his requests. Each carrier adjusts the value of the minimum profit margin based on the matching results of offers and demands determined by the auction mechanism. If there is no demand from other carriers for the outsourcing requests offered by a carrier and the carrier does not acquire any request from other carriers, the carrier increases the value of its minimum profit margin. Otherwise, the same value of the minimum profit margin is preserved for the next iteration.

In this iterative request exchange mechanism, the transfer payment for a bundle of requests is the money collected by the auctioneer from the outsourcing carrier and then paid to the insourcing carrier of this bundle after the exchange of this bundle between the two carriers. A rule for determining the transfer payment is specified before the auction.

In order to make a bundle of requests more attractive to other carriers, we introduce a profit sharing mechanism which allows a carrier to share part of the profit it can gain from outsourcing a bundle of requests with another carrier who insources this bundle, in the determination of the transfer payment of this bundle. This profit sharing can make carriers able to identify more profitable request exchanges (Özener, Ergun, and Savelsbergh, 2011). This makes our determination of transfer payment different from that of Dai and Chen (2010).

With the minimum profit margin and profit sharing, the transfer payment for each bundle of requests includes two parts. The first part consists of the maximum profit margin of each outsourcing request that a carrier is willing to offer to another carrier for serving it. The second part is the percentage of profit gain that each carrier is willing to share with another carrier when outsourcing a bundle of requests.

In the next section, we will present the decision problem for the selection of outsourcing bundles of requests (Section 3.1) and the decision problem for the selection of insourcing bundles of requests (Section 3.2), for each carrier in each iteration of the auction and the winner determination problem (Section 3.3) for the auctioneer.

# 3 DECISION PROBLEMS IN REQUEST EXCHANGE

In this section, we present the outsourcing bundles selection problem, the insourcing bundles selection problem, and the winner determination problem (WDP). The first two problems are solved by each carrier and the WDP is solved by the auctioneer in each iteration of the request exchange mechanism.

## 3.1 Outsourcing Bundles Selection

In this stage, each carrier needs to select multiple requests to outsource to other carriers from its current request set. We adopt the idea of minimum profit margin in Dai and Chen (2011) to select outsourcing requests. Dai and Chen (2011) defined the minimum profit margin of a carrier as the carrier's profitability expectation. This problem of selecting requests to outsource is a pickup and delivery problem with selective requests, time windows, and profits, which can be modeled as a mixed integer programming problem.

After selecting the requests to outsource, each carrier composes multiple outsourcing bundles of requests to exploit synergies between requests. The set of outsourcing requests for each carrier is constructed by the requests which each carrier decides to outsource. Each outsourcing bundle of requests is composed by a number of different requests in the set of outsourcing requests.

Each carrier calculates its profit gain for outsourcing each bundle of requests composed. The profit gain is computed by the difference of the total profit required to serve all the requests including and excluding this bundle of requests. Each carrier selects a bundle of requests with the positive profit gain to outsource to make sure that after outsourcing this bundle of requests, its profit will not be decreased. The transfer payment for each outsourcing bundle of requests is computed as described in Section 2.

Different from Berger and Bierwirth (2010), Dai and Chen (2011) and Gansterer and Hartl (2016), we propose multiple bundles of requests to outsource in order to increase collaboration possibilities. However, from a practical point of view, offering all possible bundles is not manageable, since the number of outsourcing bundles of requests grows exponentially with the number of outsourcing requests. When the number of outsourcing requests in the outsourcing set is large, we limit the number of outsourcing bundles of requests. We rank the outsourcing bundles of requests based on the profit gain and select the first number of *NR* bundles.

## 3.2 Insourcing Bundles Selection

Before determining the bundles of requests to insource by each carrier, the auctioneer reveals all information about outsourcing bundles of requests and their transfer payments to all carriers in the alliance. Each carrier insources bundles of requests that complement to their current set of requests. Once a bundle of requests is insourced by the carrier, the transfer payment of this bundle is paid to this carrier.

Each carrier selects multiple bundles of requests to acquire (insource) from one or multiple carriers. This decision problem is modeled as a mixed integer programming problem. The following assumptions are made for this decision problem:

1) In each round of the auction, each outsourcing bundle of requests can only be insourced (acquired) by one carrier.
2) Once each carrier decides to insource one bundle of requests, it must serve all of the requests in this bundle by its own vehicles.
3) In each round of the auction, each carrier can insource at most one bundle of requests from any other carrier.

The insourcing bundles selection problem can also be formulated as a mixed integer programming problem.

After solving the insourcing bundles selection problem, each carrier constructs its set of insourcing bundles of requests. This set is composed of one or multiple outsourcing bundles of other carriers. The profit gain for this set of insourcing bundles of requests is the difference between the total profits obtained by serving the requests including and excluding all the requests in the set of insourcing bundles respectively.

## 3.3 Winner Determination

In our request exchange mechanism, there is an auctioneer (coordinator) who solves a WDP to reassign (exchange) some bundles of requests among carriers to improve their overall operational efficiency. Because carriers may be competitors, they are not willing to share their confidential information, such as the profit gain or transportation cost after outsourcing or insourcing a bundle of requests. Because of this, when the auctioneer determines winning carriers and winning bids in the stage of requests reassignment, the only information available is the outsourcing bundles of requests and the insourcing bundles submitted by each carrier.

In our iterative request exchange mechanism, the exchange rules are defined as follows:

1) In each round of the auction, each carrier can only be a seller or a buyer, but not both.
2) Each carrier can insource only one bundle of requests from any other carrier.
3) The goal of the auction is to maximize the number of bundles of requests to be exchanged among carriers in each round.

Let $M$ be the set of carriers involved in the auction. Each carrier $l \in M$ submits a set of outsourcing bundles of requests $B_l$ and a set of insourcing bundles of requests $I_l$ to the auctioneer in a round. $O_l \in B_l$ is an outsourcing bundle of requests in the set $B_l$ for each carrier $l \in M$ .

Based on the information provided by all carriers, the mechanism reassigns (exchanges) some bundles of requests among them by solving a winner determination problem. The WDP model with incomplete information is formulated as follows:

**Notations**

| | |
|---|---|
| $M$ | The set of carriers in the alliance |
| $B_l$ | The set of outsourcing bundles of requests for each carrier $l \in M$ |
| $O_l$ | Each outsourcing bundle of requests for each carrier $l \in M, O_l \in B_l$ |
| $R_o$ | The set of outsourcing requests by all the carriers |

$I_l$ The set of insourcing bundles of requests for each carrier $l \in M$

$\theta_{i,R}$ The binary parameter indicating whether request $i$ is included in the set of requests $R \subseteq R_0$

**Decision Variables**

$w_{O_l}$ Binary variable which equals to 1 if andonly if carrier $l \in M$ is assigned to be aseller and a bundle of requests $O_l \in B_l$ isoutsourced by the carrier $l \in M$

$w_{I_l}$ Binary variable which equals to 1 if andonly if carrier $l \in M$ is assigned to be abuyer and carrier $l \in M$ insources the setof bundles of requests $I_l$ .

$$\max\left(\sum_{l\in M}\sum_{O_l\in B_l} w^{-}_{O_l} + \sum_{l\in M} w^{+}_{I_l}\right) \tag{1}$$

Subject to:

$$\sum_{l\in M}\sum_{O_l\in B_l} w^{-}_{O_l}\cdot\theta_{r,O_l} = \sum_{l\in M}\sum_{m\in M, m\neq l}\sum_{O_m\in I_l} w^{+}_{I_l}\cdot\theta_{r,O_m} \quad \forall r\in R_o \tag{2}$$

$$\sum_{l\in M}\sum_{O_l\in B_l} w^{-}_{O_l}\cdot\theta_{r,O_l} \le 1 \tag{3}$$

$$\sum_{l\in M}\sum_{m\in M, m\neq l}\sum_{O_m\in I_l} w^{+}_{I_l}\cdot\theta_{r,O_m} \le 1 \tag{4}$$

$$w^{-}_{O_l} + w^{+}_{I_l} \le 1 \qquad \forall O_l\in B_l, l\in M \tag{5}$$

$$w^{-}_{O_l} \in \{0,1\} \qquad \forall O_l\in B_l, l\in M \tag{6}$$

$$w^{+}_{I_l} \in \{0,1\} \qquad \forall l\in M \tag{7}$$

The objective function (1) maximizes the total number of bundles of requests to be exchanged in each round of auction. Constraints (2) mean that if a request is outsourced, this request must be insourced by other carriers. Constraints (3) and (4) ensure that each request can only be outsourced by at most one bundle and insourced by at most one carrier. Constraints (5) ensure that each carrier cannot be a seller or a buyer in the same time. Constraints (6) and (7) define the variables.

Based on the offers and demands of bundles of requests submitted by all carriers, the auctioneer reassigns (exchanges) some bundles of requests among carriers by solving the WDP. After solving the WDP, carriers exchange some bundles of requests based on the decision making of the auctioneer. Based on the results of WDP, each carrier updates its outsourcing bundles of requests in the same way as described in Section 2.

# 4 COMPUTATIONAL STUDY

In this section, we evaluate the performance of the proposed iterative request exchange mechanism. The proposed approach was coded in C++. Numerical experiments were carried out on a computer with an Intel Core i5-3210M CPU and 4.0 GB of RAM under the Microsoft Windows 7 operating system.

## 4.1 Test Instances

Firstly, two sets of 10 small instances were randomly generated. Each instance has three carriers and each carrier with two vehicles at its own vehicle depot has 3 or 5 requests. The capacity of each vehicle is 20 units. The coordinates of all nodes in the transportation network of each instance are generated in the same way as in Chen (2016). The distance between any two nodes is their Euclidean distance and it is assumed that the traveling time between any two nodes coincides with their distance. The profit of each request is set to $2\times[pnode, dnode]$, which depends on the distance from the pickup location to the delivery location of the request (Chen 2016). For easy reference, each instance is named with the format *SerialNumber—NumberOfRequest*. For example, the instance 0-9 has the serial number 0 and 9 requests in the carrier alliance.

## 4.2 Evaluation of the Request Exchange Mechanism

We use the two sets of instances introduced in Section 4.1 to evaluate the performance of our request exchange mechanism by comparing it with a centralized planning approach. In the centralized planning approach, a decision-maker with complete information of all carriers determines the optimal reassignment of requests among carriers with the objective of maximizing the total profit. Moreover, we compare our iterative exchange mechanism with the single request auction and the combinatorial auction of Berger and Bierwirth (2010) on benchmark instances.

All mixed integer programming models involved in individual planning, centralized planning and our iterative request exchange mechanism were solved by calling the MIP solver of CPLEX 12.6.

The parameters used in our iterative request exchange mechanism include the initial value of the minimum profit margin, the percentage of profit sharing, the step size for the increase of the minimum profit margin in each round of the auction and the maximum number of outsourcing bundles for each carrier in each round. For simplicity, the values of these parameters are set the same for each carrier, which are 0, 0.5, 0.1, and 100, respectively.

The comparison results of our iterative request exchange mechanism with the centralized planning approach on the randomly generated instances are given in Table 1, where $p_{IRE}$ and $p_{CP}$ denotes the total profit of all carriers generated by our iterative request exchange mechanism (IRE) and the centralized planning approach (CP) respectively, *CPU* is the computation time in seconds and *Gap* denotes the relative gap between the profits obtained by IRE and CP. *Gap* is defined as follows:

$$Gap = (p_{CP} - p_{IRE}) / p_{CP} *100\% \qquad (8)$$

Table 1: Comparison results on randomly generated instances.

| Instance No. | IRE | | CP | | *Gap* |
|---|---|---|---|---|---|
| | $P_{IRE}$ | CPU | $P_{CP}$ | CPU | |
| 1-9 | **271.28** | 91.18 | 271.28 | 0.95 | 0.00 |
| 2-9 | **281.62** | 8.48 | 281.62 | 0.25 | 0.00 |
| 3-9 | **256.20** | 16.45 | 256.20 | 1.64 | 0.00 |
| 4-9 | **350.06** | 69.65 | 350.06 | 1.45 | 0.00 |
| 5-9 | **179.71** | 11.74 | 179.71 | 0.44 | 0.00 |
| 6-9 | **320.59** | 121.60 | 320.59 | 1.89 | 0.00 |
| 7-9 | **274.52** | 18.18 | 274.52 | 0.38 | 0.00 |
| 8-9 | **216.28** | 9.91 | 216.28 | 0.48 | 0.00 |
| 9-9 | **239.59** | 12.30 | 239.59 | 0.97 | 0.00 |
| 10-9 | **427.61** | 81.34 | 427.61 | 0.56 | 0.00 |
| 1-15 | 257.27 | 410.21 | 274.27 | 294.89 | 6.20 |
| 2-15 | **213.73** | 414.18 | 213.73 | 213.69 | 0.00 |
| 3-15 | **206.03** | 592.55 | 206.03 | 563.33 | 0.00 |
| 4-15 | 254.15 | 1304.23 | 256.93 | 1727.36 | 1.08 |
| 5-15 | 202.09 | 85.46 | 211.36 | 220.09 | 4.39 |
| 6-15 | **523.50** | 503.25 | 523.50 | 3682.44 | 0.00 |
| 7-15 | **226.87** | 568.22 | 226.87 | 340.66 | 0.00 |
| 8-15 | 322.30 | 113.46 | 340.28 | 164.78 | 5.28 |
| 9-15 | 358.77 | 962.8 | 366.31 | 763.91 | 2.06 |
| 10-15 | **232.29** | 347.63 | 232.29 | 271.83 | 0.00 |

From Table 1, we find that our iterative request exchange mechanism can find an optimal solution for most instances except for the instances 1-15, 4-15, 5-15, 8-15 and 9-15.

The comparison results of our iterative request exchange mechanism (IRE) with the two auction mechanisms proposed in Berger and Bierwirth (2010) on the thirty benchmark instances are given in Table 2, where $p_{SRA}$, $p_{CA}$ and $p_{IRE}$ denotes the total profit of all carriers generated by the single request auction (SRA), the combinatorial auction (CA) and our iterative request exchange mechanism (IRE) respectively. *Imp* denotes the improvement of our iterative request exchange mechanism with respect to one of two auctions of Berger and Bierwirth (2010). $Imp_{I-S}$ and $Imp_{I-C}$ are defined as follows:

$$Imp_{I-S} = (p_{IRE} - p_{SRA}) / p_{IRE} *100\% \qquad (9)$$

$$Imp_{I-C} = (p_{IRE} - p_{CA}) / p_{IRE} *100\% \qquad (10)$$

Table 2: Comparison results on instances in Berger and Bierwirth (2010).

| Instance No. | $P_{SRA}$ | $P_{CA}$ | $P_{IRE}$ | $Imp_{I-S}$ | $Imp_{I-C}$ |
|---|---|---|---|---|---|
| A1 | 21 | 21 | **25** | 16.00 | 16.00 |
| A2 | 164 | 164 | **216** | 24.07 | 24.07 |
| A3 | 210 | 210 | **253** | 17.00 | 17.00 |
| A4 | 187 | 187 | **187** | 0.00 | 0.00 |
| A5 | 149 | 149 | **149** | 0.00 | 0.00 |
| A6 | 190 | 190 | **209** | 9.09 | 9.09 |
| A7 | 237 | 237 | **300** | 21.00 | 21.00 |
| A8 | 218 | 218 | **229** | 4.80 | 4.80 |
| A9 | 142 | 142 | **159** | 10.69 | 10.69 |
| A10 | 230 | 230 | **289** | 20.42 | 20.42 |
| O1 | 273 | 273 | **328** | 16.77 | 16.77 |
| O2 | 187 | 187 | **236** | 20.76 | 20.76 |
| O3 | 164 | 164 | **231** | 29.00 | 29.00 |
| O4 | 247 | 294 | **303** | 18.48 | 2.97 |
| O5 | 226 | 231 | **282** | 19.86 | 18.09 |
| O6 | 198 | 198 | **280** | 29.29 | 29.29 |
| O7 | 176 | 176 | **240** | 26.67 | 26.67 |
| O8 | 213 | 213 | **340** | 37.35 | 37.35 |
| O9 | 137 | 169 | **183** | 25.14 | 7.65 |
| O10 | 184 | 184 | **286** | 35.66 | 35.66 |
| I1 | 268 | 320 | **320** | 16.25 | 0.00 |
| I2 | 272 | 187 | **373** | 27.08 | 49.87 |
| I3 | 265 | 265 | **367** | 27.79 | 27.79 |
| I4 | 158 | 158 | **227** | 30.40 | 30.40 |
| I5 | 189 | 189 | **403** | 53.10 | 53.10 |
| I6 | 307 | 378 | **439** | 30.07 | 13.90 |
| I7 | 283 | 283 | **491** | 42.36 | 42.36 |
| I8 | 288 | 417 | **483** | 40.37 | 13.66 |
| I9 | 259 | 258 | **355** | 27.04 | 27.32 |
| I10 | 314 | 237 | **398** | 21.11 | 40.45 |
| Avg | | | | 23.25 | 21.54 |

From Table 2, we find that our iterative request exchange mechanism can achieve better solutions than the two auctions in Berger and Bierwirth (2010) with the average improvement of 23.25% and 21.54% respectively. This shows our mechanism significantly outperforms those of Berger and Bierwirth (2010).

## 5 CONCLUSIONS

We have proposed an iterative request exchange mechanism for carrier collaboration with pickup and delivery requests in less-than truckload transportation. Numerical experiments show that our mechanism can obtain high quality solutions and outperforms the combinatorial auction proposed by Berger and Bierwirth (2010). Future research may focus on developing efficient and effective algorithms to solve the outsourcing requests selection and the insourcing requests selection problems to improve the effectiveness of our mechanism. Moreover, we may consider new characteristics in carrier collaboration in less than truckload transportation, such as the dynamic arrival of requests in the carrier alliance.

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